Attachment V

Development Licence applications

Part 2 - FSRU Supporting document

Viva Energy Gas Terminal Project

Prepared for
Viva Energy Gas Australia Pty Ltd
ABN: 645 450 059

EPA Development Licence Application APP013874 Supporting Document

Viva Energy Gas Terminal Project

25-Feb-2022
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Client: Viva Energy Gas Australia Pty Ltd

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Acronym List

Term	Description
ACCC	Australian Competition & Consumer Commission
AEMO	Australian Energy Market Operator
AMSA	Australian Maritime Safety Authority
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australia and New Zealand Guidelines for Fresh and Marine Water Quality
BATT	Best available techniques and technologies
BOG	Boil-off gas
CHMP	Cultural Heritage Management Plan
CO	Carbon monoxide
CPO	Chlorine produced oxidants
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DELWP	Department of Environment, Land, Water and Planning
DL	Development Licence
DNV GL	Det Norske Veritas and Germanischer Lloyd
DSDOA	Dredged spoil disposal options assessment
EES	Environment Effects Statement
EPA Victoria	Environment Protection Authority Victoria
ERS	Environment Reference Standard
FSRU	Floating storage and regasification unit
GED	General Environmental Duty
GGPS	Greater Geelong Planning Scheme
GHG	Greenhouse gas
GJ	Gigajoule
GSOO	Gas Statement of Opportunities
HAP	Hazardous air pollutants
HAZID	Hazard identification
HAZOP	Hazard and Operability Analysis
HSSE	Health, Safety, Security & Environment
IMO	International Maritime Organisation
IN2Z	Industrial 2 Zone
ISM	International Safety Management
ISO	International Organisation for Standardisation
km	Kilometre
kW	Kilowatt
LAT	Lowest Astronomical Tide

Term	Description
LNG	Liquefied natural gas
LO	Lube oil
m	Metre
MDO	Marine diesel oil
MHF	Major Hazard Facility
ML	Megalitres
MLA	Marine loading arm
MW	Megawatt
NAGD	National Australian Guidelines for Dredging
NOx	Nitrogen oxides
OCIMF	Oil Companies International Marine Forum
OL	Operating Licence
PBI	Performance Based Inspection
PJ	Petajoule
ppm	Part per million
PZ	Port Zone
QRA	Quantitative Risk Assessment
RAP	Registered Aboriginal Party
SHES	Safety, Health, Environment and Sustainability
SIGTTO	Society of International Gas Tanker and Terminal Operators
SIRE	Ship Inspection Report Program
SOPEP	Shipboard Oil Pollution Emergency Plan
Sox	Oxides of sulfur
STP	Sewage Treatment Plant
STS	Ship to Ship
SWP	South West Pipeline
t CO_2-e	Tonnes of carbon dioxide equivalent
TJ	Terajoule
TRG	Technical Reference Group
Viva AAQMS	Viva Energy Ambient Air Quality Monitoring Station
VOC	Volatile organic compounds
VRCA	Victorian Regional Channels Authority
VTS	Victorian Transmission System

1.0 Primary information

1.1 Introduction

This document is a supporting document to the online submission on behalf of Viva Energy Gas Australia Pty Ltd (Viva Energy) to the Environment Protection Authority Victoria (EPA) for a Development Licence (DL) under Section 44 of the *Environment Protection Act 2017 (Vic)* ('EP Act') for the continuous mooring of a floating storage and regasification unit (FSRU), at Refinery Pier in Corio Bay, Geelong. The FSRU is a component of the Viva Energy Gas Terminal Project ('the project').

The project would introduce a new source of natural gas supply to the south-east Australian gas market where there is a projected supply shortfall in coming years.

The project would be comprised of the following components:

- An extension to the existing Refinery Pier
- A floating gas terminal known as an FSRU continuously moored at Refinery Pier and supplied by visiting liquefied natural gas (LNG) carriers
- A treatment facility located within the Geelong Refinery site
- A 7-kilometre pipeline, comprising a 3-kilometre aboveground section and a 4-kilometre underground section, from the FSRU to the South West Pipeline (SWP) connection point at Lara.

This DL application relates solely to the proposed mooring and operation of the FSRU, and the proposed discharges from the FSRU. In accordance with Section 45 of the EP Act, an EPA Operating Licence (OL) will be required prior to commencing FSRU operations.

EPA Publication 2011: Development licence application guidance (EPA 2021) identifies the information required as follows:

- Primary Information
  - Company legal entity (Section 1.2)
  - Application fee (Section 1.3)
- Land use:
  - Planning and other approvals (Section 3.0)
  - Choice of location for an activity (Section 2.1.1.1)
- Track record (Section 4.0)
- Community and third-party engagement (Section 5.0)
- Evidence supporting compliance with the obligations of the EP Act and Environment Protection Regulations 2021 (Environment Protection Regulations):
  - Demonstrate compliance with the General Environmental Duty (GED) (Section 7.0)
  - Demonstration of reduction of risk(s) to human health and the environment, so far as reasonably practicable (Section 7.0)
  - Demonstrate compliance with the eleven principles of the EP Act (Section 6.1)
  - Best available techniques and technologies (BATT): Demonstrate proposed techniques and technologies are compliant with relevant duties so far as is reasonably practicable (Section 7.0 and Section 8.0)
  - Demonstrate the activity is consistent with the requirements of the EP Act
  - Details of proposed measures to comply with all relevant applicable duties, including waste duties, other than the GED (Section 7.0))
- Prescribed matter(s):

- identify and address any other requirements in the Environment Protection Regulations or subsidiary legislation related to the specified development activity

In addition to a DL for the FSRU, the Geelong Refinery will also require a DL or exemption for prescribed activity A04 (Industrial wastewater treatment), which requires permission for discharging or depositing industrial wastewater generated at another site (the FRSU) exceeding a design or actual flow rate of 5000 litres per day or on any day. Reuse of the FSRU discharge water as refinery cooling water is a modification to the existing prescribed activity at the refinery (which is only for G03 - Oil or gas refining) as this would involve 'discharging or depositing industrial wastewater' generated by the FSRU. The current refinery OL would also need to be modified, subject to issue of a DL, to enable the new prescribed permission activity in the A04 category to occur, however, may not need modification for discharge of the wastewater if the discharge is compliant with current licence conditions. This DL application does not include the DL required for the Geelong Refinery.

An Environment Effects Statement (EES) has been prepared for the project under the *Environment Effects Act 1978 (Vic)*. The EES has been prepared in accordance with the scoping requirements and relevant legislation, policy and guidelines and has been informed by the environmental impact assessments and specialist studies completed for the EES. This DL application has been informed by the EES and the supporting specialist studies prepared for the project.

1.2 Company legal entity

Viva Energy Gas Australia Pty Ltd (Viva Energy) company details are provided in Table 1-1 below.

Table 1-1 Viva Energy Company Details

	Details
Company Name	Viva Energy Gas Australia Pty Ltd (Viva Energy)
ACN	645 450 059
ABN	35 645 450 059
Registered Address	Level 16 720 Bourke St, Docklands VIC 3008
ASIC Extract	Provided in Appendix A
CEO	Scott Wyatt CEO +61 3 8823 4256 scott.a.wyatt@vivaenergy.com.au
Application contact	Robert Mackie Project Manager, Viva Energy Gas Terminal Project +61 433 711 566 robert.makie@vivaenergy.com.au
Email address for billing	energyhub@vivaenergy.com.au

1.3 Application fee

Due to the complexity of the DL application, Viva Energy has advised that the cost of the application fee is likely to be the upper limit fee. This equates to a DL application fee of $67,635.00.

1.4 Need for Development Licence

Under the EP Act to perform prescribed activities that may cause harm, a permission such as a licence, permit or registration must be obtained. A licence is required for a prescribed activity requiring the highest level of regulatory control within the EPA permission scheme. This is due to the potential high risk of harm to human health and the environment. Schedule 1 of the Environment Protection Regulations sets out prescribed permission activities.

The operation of the FSRU, to which this DL application applies, would constitute a new activity under either activity type K01 (Power generation) or L01 (General discharges or emissions to the atmosphere).

A DL is required for the FSRU and therefore the boundary of this DL application will include the infrastructure used by the prescribed activity. This is the FSRU up to the point where water from the FSRU is discharged into the Geelong Refinery seawater intake, and to the connection point of the diffusers located on Refinery Pier (refer to Figure 1-1).

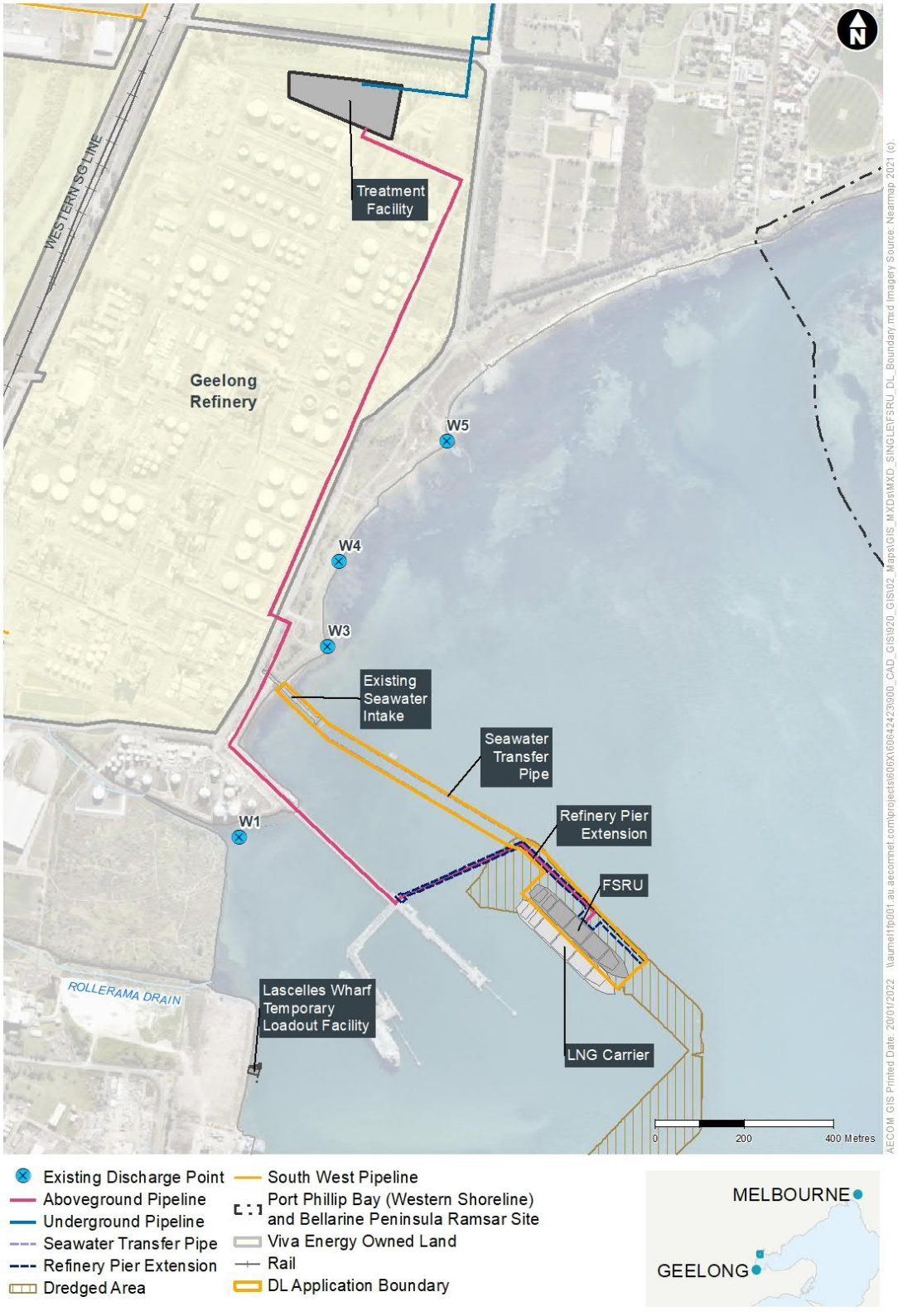


Figure 1-1 FSRU DL application boundary

A separate DL application has been prepared for the Geelong Refinery for activity type A04 (Industrial wastewater treatment) which requires permission for discharging or depositing industrial wastewater generated at another site (the FRSU) exceeding a design or actual flow rate of 5000 litres per day or on any day. Reuse of the FSRU discharge water as refinery cooling water is a modification to the existing prescribed activity at the refinery (which is only for G03 - Oil or gas refining) as this would involve 'discharging or depositing industrial wastewater' generated by the FSRU. The current refinery OL would need to be modified, subject to issue of a DL, to enable the new prescribed permission activity in the A04 category to occur, however, may not need modification for discharge of the wastewater if the discharge is compliant with current licence conditions.

1.4.1 Others: L01 – General Emissions to Air

The FSRU is not included in an industry category as a prescribed permission activity, however, due to the emissions to air from the FSRU, it is a prescribed development activity and a prescribed operating activity as described in *Others: L01 – General discharges or emissions to the atmosphere*.

The prescribed permission activity in the L01 (general discharges or emissions to the atmosphere) category is described as: Activities which discharge or emit to the atmosphere from one or more sources and the discharge or emission from the activity is:

- at least 100 kilograms per day of (i) volatile organic compounds (VOCs); or (ii) particles; or (iii) oxides of sulphur (SOx); or (iv) oxides of nitrogen (NOx); or (v) other acid gases (excluding carbon dioxide); or
- at least 500 kilograms per day of carbon monoxide (CO).

NOx, CO and VOC emissions from the FSRU are predicted to exceed the emission thresholds. Consequently, operation of the FSRU is expected to be a prescribed activity and will require a DL and OL under the EP Act.

This DL application is an application for the continuous mooring of the FSRU at Refinery Pier in Corio Bay, Geelong, having regard to its likely emissions and discharges during operation. Prior to operations commencing, an OL for the FSRU will be required.

1.4.2 Utilities: K01 – Power stations

In addition, the FSRU could be included in industry category *Utilities: K01 – Power generation* as a prescribed development activity and a prescribed operation activity. The prescribed permission activity K01 is described as generating electrical power from the consumption of a fuel at a rated capacity of at least 5 megawatts (MW) of electrical power.

The proposed FSRU would be equipped with four dual-fuel reciprocating engines. The four engines drive gensets that provide electrical power for the equipment onboard the FSRU (e.g., driving pumps, gas compressors etc.) and for propulsion. All the power that is generated would be generated and used onboard the FSRU for ship operations. No power would be exported from the FSRU to the electricity grid.

The generators onboard the FSRU comprise:

- One generator with 5,850 kilowatts (kW) of maximum electrical output
- Three generators with 7,800 kW of maximum electrical output per generator.

This equates to a total of 29.25 MW of electrical power from the four generators onboard the FSRU.

The power required for propulsion of the FSRU would be approximately 20 MW. Although the maximum electrical power of all four engines combined is 29.25 MW, the FSRU would not generate and/or consume this maximum.

The FSRU would also be equipped with an emergency diesel generator set which would provide emergency power in the event that the power from the main generators is lost. The emergency generator set consists of a diesel engine with 1,007 kW of maximum electrical output and an alternator with an output of 750 kW.

The FSRU would be self-sufficient with regard to electricity generation. Connection to the electricity grid would not be required to power any of the electrical facilities on board the FSRU. This removes the requirement for new or augmented electricity infrastructure that would otherwise be required.

2.0 Project overview

This DL application relates solely to the proposed mooring and operation of the FSRU, and the proposed discharges from the FSRU.

The FSRU is an integral component of the Gas Terminal Project ('the project'). The project is described in the following sections, with specific discussion on the FSRU processes (the subject activity of this application) described in Section 2.3.1.

2.1 Project background

In June 2020 Viva Energy announced its vision to transform its Geelong Refinery into an Energy Hub. The Geelong Energy Hub would support both the company's and the Australian economy's energy transition, which is currently underway, while helping to underpin the future viability of the refinery.

Having been part of the Geelong community since 1954, the refinery already supplies approximately half of Victoria's liquid fuel energy needs. The broader Geelong Energy Hub vision could see the facility taking a leading role in supplying liquid fuels and gas as well as supporting the development of other alternative energy solutions. Importantly, diversification of the Geelong Refinery site would protect local jobs, generate new jobs and skills and support economic development for the region.

The Geelong Energy Hub comprises a number of potential projects. The first project to be developed, is the Gas Terminal Project. Other projects that are currently being considered include a solar energy farm, projects to support alternative energies such as renewables and hydrogen, and the development of strategic storage to improve fuel supply security as part of a Government program. It is important to note that the Gas Terminal Project has no inter-relationship with, or reliance on these other projects being considered for the Geelong Energy Hub. Other potential Geelong Energy Hub projects would be subject to different approvals processes in the event that they are progressed by Viva Energy. In addition to potential future Geelong Energy Hub projects, a low sulfur gasoline project is being considered by Viva Energy as part of an upgrade to existing Geelong Refinery operations to meet new fuel standards which come into force in 2024. This project is unrelated to the Gas Terminal Project and would also undergo a separate approvals process.

2.1.1 Project setting

The project would be located in the City of Greater Geelong, 75 kilometres (km) south-west of Melbourne. The project area is situated adjacent to, and on, Viva Energy's Geelong Refinery, within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. The Geelong central business district is located approximately 7 km to the south of the project. The FSRU would be situated in an industrial setting with limited sensitive receptors in the vicinity of the project area. Geelong Grammar School buildings are located approximately 1.7km north of the FSRU.

Corio Bay is the largest internal bay in the south-western corner of Port Phillip and is a sheltered, shallow basin at the western end of the Geelong Arm with an area of 43 square kilometres (km^2). The FSRU is located approximately 1 km to the south-west of the Point Wilson /Limeburners Bay area of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site. The Ramsar site covers 22,650 hectares (ha) and is comprised of 6 distinct areas, including Limeburners Bay and Avalon Coastal Reserve.

The Port of Geelong has been in operation for over 150 years and is the largest industrial bulk cargo port in Victoria with over 600 ship visits annually handling more than 14 million tonnes of product. Geelong's shipping channels extend 18 nautical miles through Corio Bay from Point Richards through to Refinery Pier. Ports Victoria (formerly known as Victorian Regional Channels Authority (VRCA)) manages commercial navigation in the port waters in and around Geelong and is responsible for the safe and efficient movement of shipping, and for maintaining shipping channels and navigation aids. The channels are man-made having been deepened and widened through periodic dredging to support port trade development.

Refinery Pier is the primary location within the Port of Geelong for movement of bulk liquids. Vessels up to 265 metres in length currently utilise the four berths at Refinery Pier which service Viva Energy refinery operations. The majority of ship visits to the port are to Refinery Pier, with Viva Energy

accounting for over half of the trade through the Port of Geelong. Refinery Pier facilitates the import and export of bulk liquid fuels from the Geelong Refinery with over 200 shipping movements per year through the Port of Geelong shipping channel.

Refinery Pier is located on Crown land leased and managed by GeelongPort. The existing pier and associated landside infrastructure, owned by GeelongPort, are zoned Port Zone (PZ) under the Greater Geelong Planning Scheme (GGPS). Onshore of the pier to the east of Shell Parade within the Port Zone, the land is freehold owned by GeelongPort.

The Geelong Refinery has been in operation since 1954 with both the refinery and the co-located Lyondell Basell plant being licensed Major Hazard Facilities (MHF). A range of industrial activities are located in the port environs including wood fibre processing and chemical, fertiliser and cement manufacture.

The Geelong Refinery and undeveloped land immediately to the north, also owned by Viva Energy, is zoned Industrial 2 Zone (IN2Z) under the GGPS.

2.1.1.1 Choice of location for the activity

The FSRU would be located at Refinery Pier No.5, 120 Shell Parade Corio.

The Port of Geelong and Corio Bay area was selected as the preferred location for the FSRU. Three alternate locations were considered for the project, all of which are located close to Geelong with two in Corio Bay inner harbour and one in the outer harbour. The following three options were considered:

- Refinery Pier (either rebuilding existing Refinery Pier No.1 or a new pier extension to create Refinery Pier No.5)
- Lascelles Wharf No. 4
- Point Henry Pier.

The location of each of these options is show in Figure 2-1.

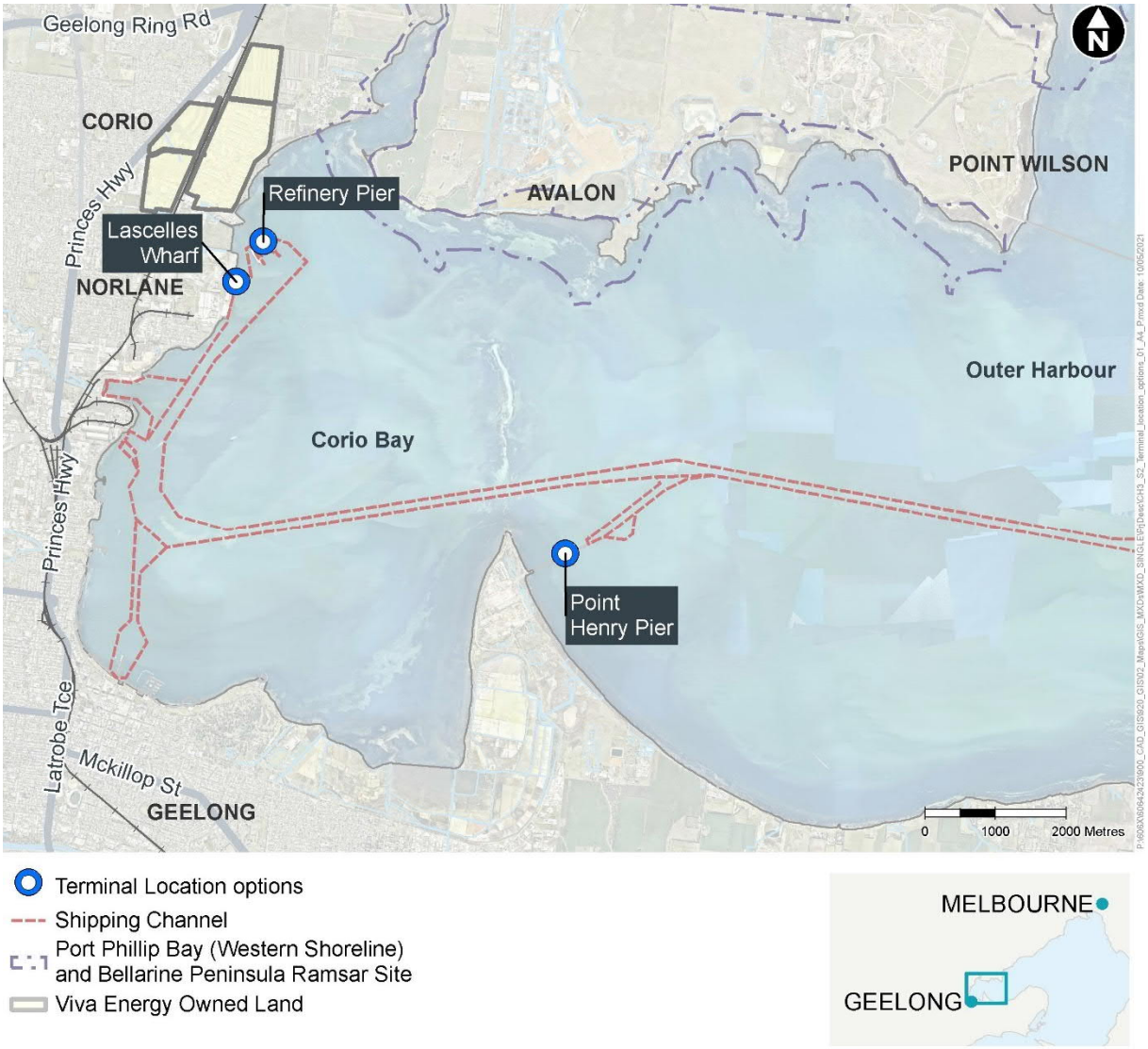


Figure 2-1 FSRU location options

Offshore FSRU location options, particularly along the western shoreline of Port Phillip Bay which is relatively proximal to the Victorian gas network pipeline, were also considered during the project screening stage. These options were not progressed to the next stage of assessment after the initial screening stage for the following reasons:

- Potential locations would be outside of existing port and industrial areas and likely to display more environmental constraints than an existing port setting
- Locations closer to Melbourne would be more problematic due to factors including shipping congestion, potential conflict with recreational boating, visual impact and difficulty obtaining onshore pipeline access for connection to the Victorian gas network
- Subsea pipeline construction is complex with significant infrastructure required
- If located in the western area of Port Phillip Bay, the underwater section of the pipeline required would be greater than 15 km and could pass through a Ramsar site depending on the proposed offshore location
- The location could potentially conflict with the announced Bay West port proposal
- An offshore location does not align with the vision for an Energy Hub at the Geelong Refinery

- Locating the FSRU offshore would not enable synergies to be captured with the Geelong Refinery such as seawater reuse and the potential for boil off gas usage at the refinery.

The assessment concluded that the proposed fixed location at Refinery Pier, proximal to the existing Viva Energy Geelong Refinery has significant benefits when assessed and compared with the alternatives having regard to a range of environmental, social, engineering, operational and economic parameters (refer to Figure 2-2).

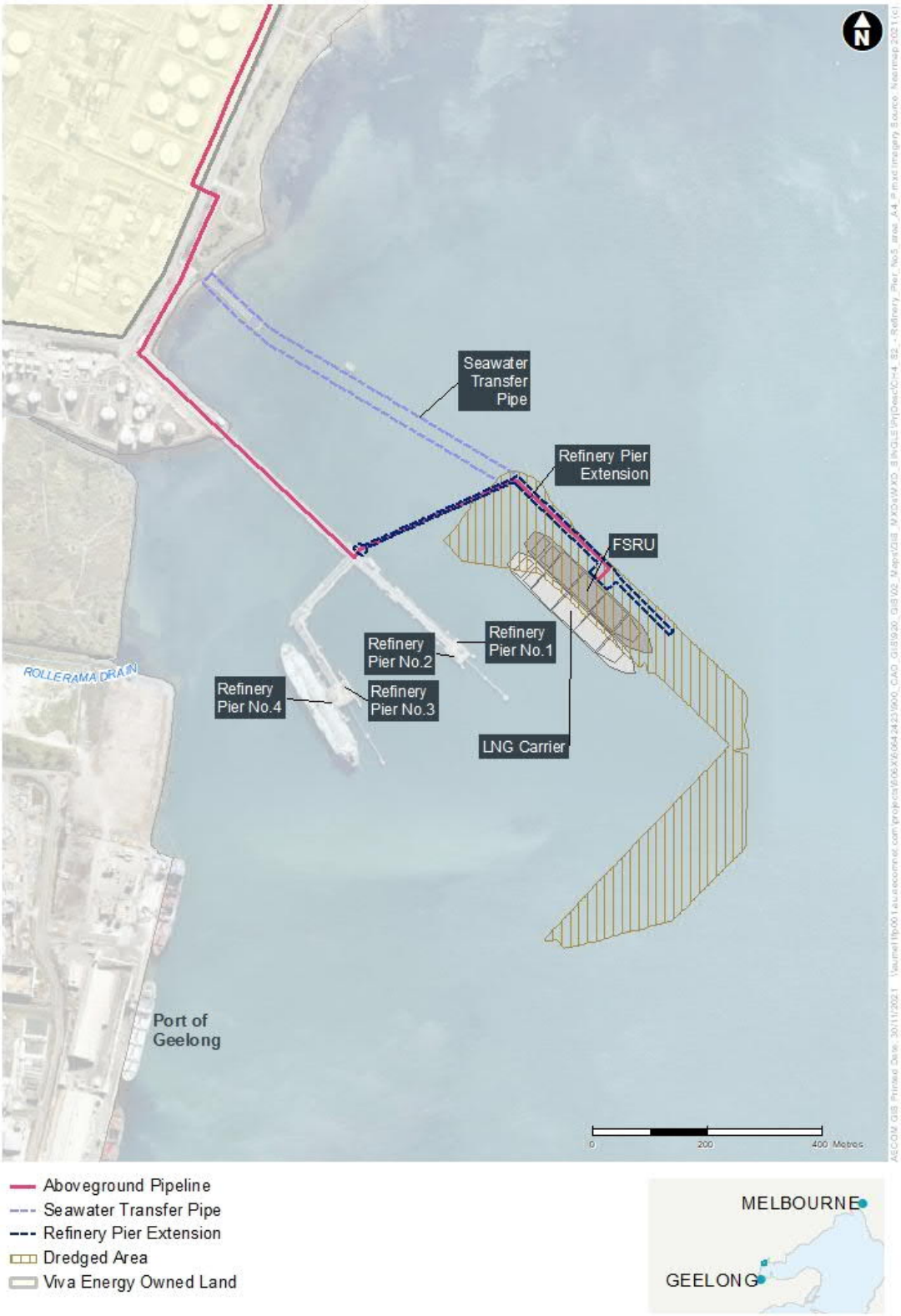


Figure 2-2 Selected FSRU location

Co-locating the FSRU with the existing Geelong Refinery and within the Port of Geelong offers significant opportunity to minimise potential environmental effects and utilise a number of attributes that come with the port and industrial setting. A detailed description of the advantages of the proposed location can be found in Chapter 3: *Project alternatives and development* (refer to Appendix B).

For more than 60 years, the refinery has been using approximately 350 megalitres (ML)/day seawater for cooling purposes and discharging this seawater back into Corio Bay at temperatures approximately 9°C warmer than ambient conditions and containing residual chlorine, through the four EPA licensed discharge outlets. Surveys of the seagrass beds beneath the existing plumes showed that seagrass grows prolifically in close proximity to all refinery discharge points and the marine environment appears to be in a healthy condition. The existing conditions of the project area are discussed extensively in all technical reports developed for the EES.

A key environmental benefit of co-location of the project with the refinery is the proposed reuse of seawater used for the FSRU regasification process in the refinery's cooling water system. This reuse would result in no change to the total volume extracted from Corio Bay, no change to the volume of water discharged from the refinery, no change in residual chlorine levels and an improvement in the temperature of the discharge compared to the existing refinery discharge.

2.1.2 Project rationale

The installation of the FSRU, an LNG terminal, is integral to the project, allowing for the storage and distribution of natural gas. The project would introduce a new source of natural gas supply to the south-east Australian gas market where there is a projected supply shortfall in coming years.

Victorian gas production from legacy fields such as Bass Strait's Gippsland Basin are in decline, meaning Victoria will need to find alternative sources of gas supply. Geographically, the transportation of available gas is highly constrained by the existing network of gas pipelines. The existing pipeline network is not designed to carry gas from the north and west of the country in the volumes needed to satisfy large demand centres in the east and south of the country. Augmenting the existing pipeline system would be costly and time consuming.

The lack of gas reserves and resources in the south-east of Australia combined with inadequate transmission infrastructure is expected to a create a gas shortage for domestic customers in the south-eastern states by the mid-2020s (Australian Energy Market Operator Gas Statement of Opportunities (AEMO GSOO), 2021). Both AEMO and the Australian Competition & Consumer Commission (ACCC) have identified a range of measures to address and mitigate the predicted shortfalls, which includes the development of LNG terminals.

LNG terminals that would import gas from both Australian and international sources have been identified by the ACCC as a way of potentially improving competition within the market. An LNG terminal would offer a more cost-effective supply of gas compared to transporting gas long distances via a pipeline network. Gas, like many commodities, can be transported more cost effectively by ship. In this way, the terminal can be thought of as a 'virtual pipeline' bringing gas from where it is available to where it is needed. LNG terminals are considered by AEMO and a number of respected industry analysts, to be an important measure in avoiding the predicted gas supply shortfalls in the south eastern states.

2.2 Project objectives

The key objectives of the project are to:

- Provide a new secure and flexible source of gas to the south-east Australian domestic gas market
- Ensure forecast annual supply shortfalls in Victoria are avoided
- Contribute to meeting peak seasonal and peak day demand for gas in Victoria
- Support the Geelong Energy Hub vision for the Geelong Refinery, the Geelong economy and Victoria's energy transition.

2.3 Project description

Key components of the project include:

- Extension of the existing Refinery Pier with an approximately 570 metre (m) long angled pier arm, new berth and ancillary pier infrastructure including high pressure gas marine loading arms

(MLAs), a diffuser located under the Refinery Pier extension and a seawater transfer pipe connecting the seawater discharge points on the FSRU to the refinery seawater intake

- Continuous mooring of an FSRU at the new Refinery Pier berth to store and convert LNG into natural gas - LNG carriers would moor alongside the FSRU and unload the LNG
- Construction and operation of approximately 3 kilometres (km) of aboveground gas pipeline on the pier and within the refinery site connecting the FSRU to the new treatment facility
- Construction and operation of a treatment facility on refinery premises including injection of odorant and nitrogen (if required)
- Construction and operation of an underground gas transmission pipeline, approximately 4 km in length, connecting to the SWP at Lara.

This DL application relates to the FSRU component of the project only.

The FSRU would be up to 300m in length, 50m in breadth and 65m in height, with the capacity to store approximately 170,000m^3 of LNG. The FSRU would receive LNG from visiting LNG carriers and store it on board in cryogenic storage tanks at approximately -160°C. Further details on the FSRU (the subject of this DL application) are provided in Section 2.3.1.

The FSRU would receive up to 160 petajoules (PJ) per annum (approximately 45 LNG carriers) depending on demand. The number of LNG carriers would also depend on their storage capacity, which could vary from 125,000 to 180,000m^3.

When gas is needed, the FSRU would convert LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification). The natural gas would then be transferred through the pipeline to the SWP.

Construction and commissioning of the project is estimated to take up to 18 months (including localised dredging, and construction of a temporary loadout facility at Lascelles Wharf, the new pier extension and supporting infrastructure, pipeline and treatment facility). There are no construction activities required for the FSRU component of the project (the subject of this DL application). The vessel would be built, commissioned and all production and safety systems verified prior to being brought to site. The project is anticipated to operate for approximately 20 years.

An overview of the project and its components is shown in Figure 2-3.

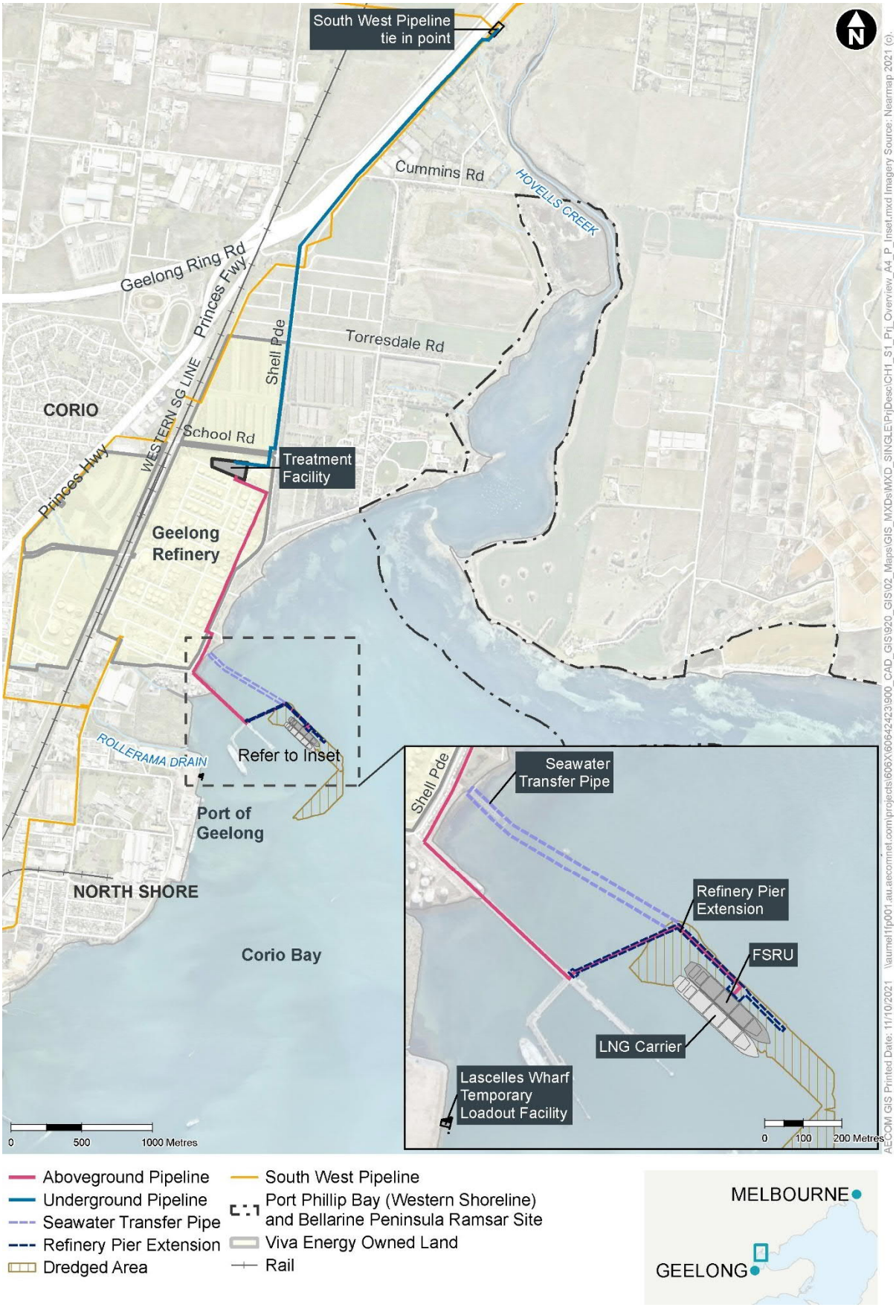


Figure 2-3 Project overview

2.3.1 FSRU description

This DL application relates solely to the proposed mooring and operation of the FSRU, and the proposed discharges from the FSRU. To facilitate the FSRU discharges, two seawater transfer components would be installed under separate approvals. This would include a diffuser located under the Refinery Pier extension and a seawater transfer pipe from the FSRU to the Geelong Refinery via a Planning Scheme Amendment. Reuse of the seawater in the Geelong Refinery is the subject of a separate DL application as a modification to an existing activity.

An FSRU vessel approximately 300m long, 50m in breadth and 65 m in height with a maximum draft of approximately 55 metres (distance from the water level to highest point on the vessel) would be continuously moored at the new berth at Refinery Pier.

The candidate engines and boilers for the FSRU are the Wärtsilä 6L50DF dual-fuel engine, Wärtsilä 8L50DF dual-fuel engine, and Mitsubishi MAC-90BF boiler. The four Wärtsilä 50DF dual-fuel engines are located below deck and would be equipped with silencers installed in the exhaust funnel to limit noise emission levels. The regasification boilers are located on the lower deck. Both the engines and boilers would be run on natural gas with marine diesel oil used only as a pilot fuel and during emergency, maintenance or start-up.

The FSRU contains six control valves in the regasification area, two control valves on the starboard side deck area and six control valves in steam heater skid area.

The FSRU has four key functional elements:

- Receiving LNG from LNG carriers
- Storing LNG
- Converting LNG to high-pressure natural gas
- Injecting gas into the pipeline through marine loading arms.

2.3.1.1 Receiving LNG

Periodically, LNG carriers would arrive at Refinery Pier and berth alongside the FSRU to deliver LNG via a flexible hose connection. Depending on gas demand, LNGCs would visit Refinery Pier approximately every 20 days or every 8 days at maximum demand periods. The LNG carriers would carry between 125,000 and 180,000m^3 of LNG. Up to 45 LNG carriers would arrive each year, depending on the gas demand and their storage capacity.

The LNG carriers would berth next to the FSRU with the assistance of four tugboats for up to 36 hours while LNG is transferred into the cargo tanks of the FSRU. Purpose-built flexible hoses would be used to transfer LNG from visiting LNG carriers to the FSRU. These hoses would be stored on the FSRU.

Once the transfer of LNG is complete, LNG carriers would depart from their berth alongside the FSRU with the assistance of four tugboats and leave the port.

2.3.1.2 Storing LNG on the FSRU

The FSRU would have the capacity to store approximately 170,000m^3 of LNG. The FSRU is a double-hulled ocean-going vessel that would store the LNG in a liquid state at very low temperatures. The cargo tanks on board the FSRU are purpose built to store LNG with primary and secondary barriers further supported by insulation and intervening spaces. These cargo tanks are designed to insulate and keep the LNG cargo at cryogenic temperatures (approximately –160°C) and to prevent leakages and isolate the cargo from the hull structure.

Boil-off gas (BOG) management facilities would also be in place on the FSRU to capture small amounts of natural gas that evaporates from LNG in the cargo tanks. The BOG would be used to fuel the onboard generators for operation of pumps and other equipment used onboard. Excess BOG would potentially be directed into the refinery natural gas system to be used as a fuel at times where BOG production surpasses FSRU generator demand. The need for BOG piping connecting the FSRU to the refinery natural gas system would be determined during detailed design. If required, BOG would be compressed on the FSRU and transferred via a hose connection to piping that would run along the pier structure. This connection would provide an additional source of natural gas for the refinery. The flow of BOG into the refinery natural gas system would be controlled using pressure control and priority would

be given to BOG from the FSRU to reduce refinery gas consumption from the transmission network. The FSRU BOG injection point would be located near the existing fuel gas injection points at the refinery.

2.3.1.3 Converting LNG back to gas on the FSRU

When gas is needed, the FSRU would convert LNG to its gaseous form, via a process called 'regasification'. The regasification unit located on board the FSRU would be typically located near the bow or centre of the vessel. The FSRU would be able to operate in different regasification modes which are described in detail in the following sections. For the project the usual regasification mode is 'open loop mode', where seawater would be continuously drawn in to the FSRU and used as the medium to heat the LNG into a gaseous state. The FSRU would also be able to operate in closed loop regasification mode (where water is continuously recycled within the vessel) and combined loop regasification mode (where a combination of modes may be used to heat seawater if it falls below a specified temperature).

To prevent marine growth in the FSRU heat exchange system, a small portion of the seawater intake would be subject to an electrolysis process. Electrolysis breaks up the naturally occurring salt molecules (sodium chloride) in seawater and produces hypochlorite. The water with hypochlorite is injected into the seawater coming into the FSRU to reduce biofouling of heat exchange equipment. Discharge of seawater from the FSRU would contain some short-lived residual hypochlorite after it has been used for regasification (hypochlorite is generically termed chlorine throughout this application).

Open loop regasification

Open loop regasification on the FSRU would use seawater from Corio Bay to heat the LNG. For this project seawater would be continuously drawn in via intakes, pass once through a heat exchange system and would then be redirected to the refinery for reuse as cooling water via a seawater transfer pipe. In open loop mode, the FSRU would typically discharge the seawater directly back to the sea at 7ºC below ambient seawater temperature. However, the project has identified a synergy between the FSRU and the refinery that would avoid discharging the cooled water directly back into the sea with the exception of the limited times when the refinery requires less cooling water than FSRU production rates due to maintenance activities.

The energy used to pump the seawater through the heat exchanger would consume about 1.5 per cent of the send out gas for power generation.

Open loop is the most commonly used system globally for FSRUs.

The project also allows for open loop operation where all or part of the FSRU cooled water could be discharged via a diffuser located on Refinery Pier. This discharge option would only be required in very limited circumstances as described in Section 7.5.1.

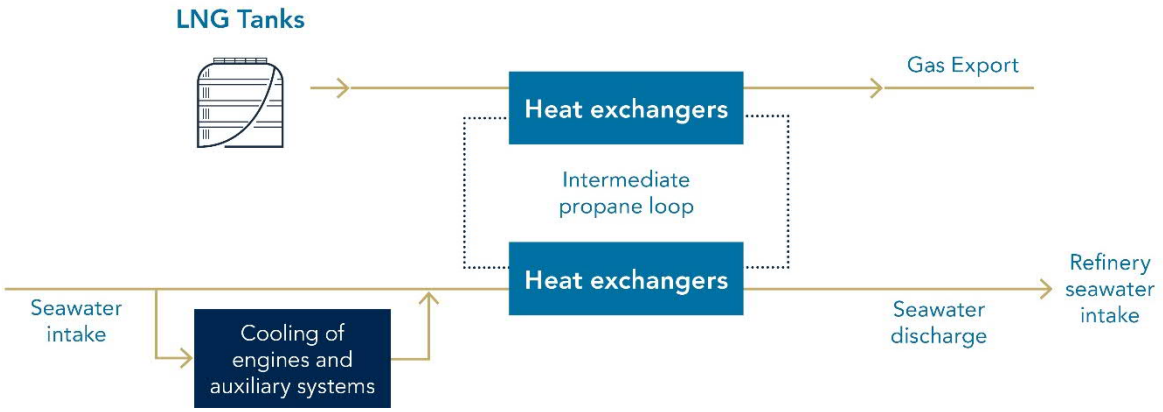


Figure 2-4 Open loop regasification

Closed loop regasification

Closed loop regasification would use gas-fired steam boilers to heat a closed loop of circulating seawater within the FSRU as an intermediate heating medium for heat exchange in the LNG

regasification trains. Around 500m^3 of seawater from Corio Bay would be required to fill the FSRU heat exchange piping. The seawater would then be continually circulated in the heat exchange process instead of being discharged from the FSRU as per open loop mode. Seawater would only be discharged to Corio Bay when the FSRU reverts to open loop (usual) mode or if maintenance is required (anticipated to be annually). Discharged seawater from the closed loop process would be around 5 ºC warmer than the ambient seawater temperature. Figure 2-5 shows a simplified diagram of how the closed loop regasification mode would work.

This mode would use 2.5% of the send out gas to heat the circulating fluid to vaporise the LNG compared to 1.5% for open loop (Songhurst 2017). This contributes to an increase in greenhouse gas emissions when compared to open loop operation and reduces the regasification plant output. Due to the environmental and economic implications as well as the synergy identified between the FSRU and the refinery, closed loop is not the preferred mode of regasification for the project and would only be required in very limited circumstances.

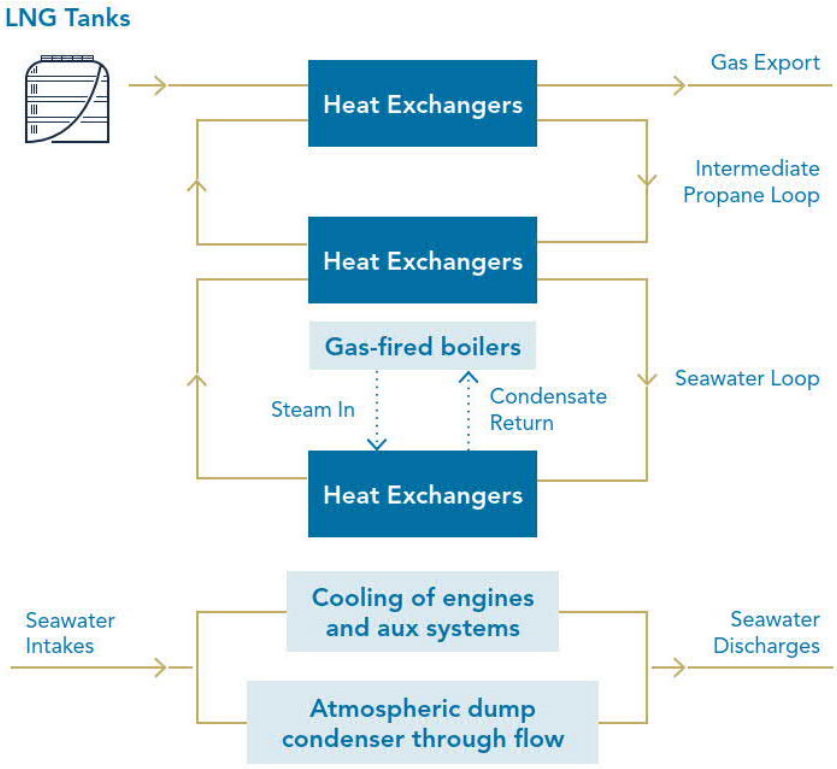


Figure 2-5 Closed loop regasification process

Combined loop regasification

The FSRU would also have the ability to operate in both open and closed loop, which is referred to as 'combined loop'. The combined loop mode would operate similar to open loop mode; however, seawater would be heated via steam from gas-fired boilers prior to reaching the regasification system on the FSRU. The seawater would be continuously drawn into the FSRU through seawater inlets and heated by heat exchange with steam. Seawater use associated with combined loop regasification mode would be the same as seawater use for open loop regasification. This mode would be used when the ambient seawater temperature is below a certain temperature and needs to be heated for effective and efficient regasification.

Proposed mode of regasification

The usual regasification mode of the FSRU would involve open loop operation with the transfer of seawater from the FSRU via a pipe to the refinery intake. For the project, the FSRU discharge would replace all or some of the existing intake requirements of the refinery from Corio Bay with the amount of replacement being determined by the production rate of the FSRU at any given time. For example,

there would be days where seawater discharge from the FSRU is lower than the approximate 350 ML/day intake requirements of the refinery (e.g., when the production rate for the FSRU is low due to reduced gas demand). In this situation, the refinery would simply draw the remaining volume of seawater required for cooling through the existing refinery seawater intake as is done at present.

The project also provides for the direct discharge of some, or all, of the FSRU discharge water into Corio Bay via a diffuser located under the Refinery Pier extension. The diffuser would only be required in the event that the refinery was permanently decommissioned in the future and the option for reuse of the FSRU discharge water in the refinery was no longer available. Consideration was also given to whether there would be any periods where refinery demand for cooling water was lower than the volumes of water being discharged from the FSRU necessitating use of the diffuser for discharge of the surplus water. The only times where there would be potential for this to occur would be during refinery maintenance shutdowns.

The project also makes provision for use of the FSRU in closed loop mode which would be utilised in very limited instances where discharge water may not be able to be transferred to the refinery.

Further detail on the proposed mode of regasification is provided in Section 7.5. The potential impacts of each mode of regasification are discussed in Section 7.5.3. Table below provides a summary of the potential modes of regasification and when they may be used.

Table 2-1 Proposed mode of regasification

Mode	Refinery Operational	Refinery Closed	Summary	Section Discussed
Open loop with reuse of FSRU discharge in the refinery	✓		The usual mode of regasification. FSRU discharge would be reused as cooling water in the refinery	Section 7.5.1.1 DL application no. APP013841 (Section 7.2) Technical Report A: *Marine ecology and water quality impact assessment* (Section 8.5, 8.6, 9.8, 9.9)
Open loop with diffuser discharge	✓	✓	Only required in the event that the refinery is decommissioned or is undergoing maintenance shutdowns, resulting in a surplus of discharge from the FSRU	Section 7.5.1.2 Section 7.5.3.1 Section 7.5.3.2 Technical Report A: *Marine ecology and water quality impact assessment* (Section 8.7, 9.10, 9.11)
Closed loop	✓		Not the preferred mode of regasification, would be utilised in very limited instances where discharge water may not be able to be transferred to the refinery when it is operational.	Section 7.5.1.3 Section 7.5.3.1 Section 7.5.3.2 Technical Report A: *Marine ecology and water quality impact assessment* (Section 8.8, 9.12)

Seawater transfer pipe

Seawater discharged from the FSRU during regasification is proposed to be transferred to the existing refinery via a single pipe. The FSRU seawater discharge would be directed into the existing refinery seawater intake through a submerged high density polyethylene (HDPE) pipe that would sit approximately 2 metres below the seabed to enable the cooled seawater to be effectively delivered and reused within the refinery. The pipe would be directed into the existing refinery seawater intake to prevent any cold seawater discharged from the FSRU escaping into Corio Bay.

The seawater transfer pipe would start at the FSRU and connect to the overboard manifold system located at the front and rear of the vessel. The pipe would then run from the vessel into piping installed on the new pier arm via flexible hoses. The seawater transfer pipe would then transition from the pier down into the seabed and would run towards the refinery seawater intake. A single DN1200 pipe is proposed to minimise the pipeline size and a trenched option to install the pipe beneath the seabed was selected to protect the pipe and ensure the pipe remains submerged during low tide.

Refinery intake

There would be one point of connection between the seawater transfer pipe and the existing refinery intake, and this would be located where the seawater transfer pipe terminates and the cooled seawater discharge from the FSRU is released into the open channel intake structure as show in Figure 1-1. At this point, the cooled FSRU discharge would mix with water in the channel from Corio Bay. This connection point would be located close to the shore to prevent back flow of cooled seawater to the bay. An upstream control valve would control the flow into the refinery, however, as the intake structure is an open channel the level is controlled by the tide. Flow rate and temperature measurements in the refinery cooling water system would assist in control of the cooled FSRU discharge.

As the FSRU discharge would be released into the open water source which terminates within the intake structure, the change in water discharge from the FSRU would not change how the refinery sources or pumps seawater through its system and would not change the ability of the existing refinery intake to draw water from Corio Bay.

Diffuser

In the event that the Geelong Refinery closes and reuse of the FSRU discharge water in the refinery for cooling water is no longer an option, a 300 m long diffuser with 100 small high-velocity ports would need to be installed by divers supported by a small crew vessel alongside the pier structure. The diffuser would need to be positioned under the pier such that it is at least 0.5m below the seawater surface at Lowest Astronomical Tide (LAT).

At present, the diffuser may not be constructed for project commencement. This is primarily because discharge via the diffuser would only be undertaken during a full refinery maintenance shutdown or following permanent closure of the refinery. Both of these scenarios are unlikely to occur before 2028. As such, it is proposed that gas demand and maintenance cooling water demand be monitored for a period post project commencement and prior to the construction of the diffuser taking place. This would confirm whether or not a diffuser is needed as part of the project.

During a period where gas demand and maintenance cooling water demand is being monitored, should refinery maintenance occur resulting in a decrease of cooling water demand, FSRU production would be limited to match the refinery cooling water demand. It is anticipated that during periods of refinery maintenance, a significant volume of cooling water would still be required by the refinery and demand is only likely to drop by 25-35%. Typically, the refinery requires approximately 250 ML/day of cooling water even during major maintenance. Refinery maintenance shutdowns are not conducted during winter which is when gas demand is highest and the FSRU would be generating higher levels of discharge water. Based on projected demand forecasts, it is considered unlikely that the FSRU would be generating gas at sufficient quantities to create a surplus of discharge water during maintenance shutdowns, but it is proposed to monitor this for several years and a decision on the diffuser construction informed by this monitoring.

Despite this, potential impacts from diffuser discharge are discussed in Section 7.5.3.

The seawater transfer pipe and diffuser would be connected to each other to allow for seawater discharged from the FSRU to be redirected into one or the other. Pressure control would be used to manage flow into the refinery intake via the seawater transfer pipe and/or into the diffuser via distributors. The control valve to the refinery intake would provide backpressure control to maintain a constant pressure in the system. There would also be a flowrate demand selector in addition to the back pressure controller to control valves and ensure that the water flowrate does not exceed refinery demand. If pressure in the FSRU discharge water piping at the pier increases due to additional water in excess to refinery demand, the header valves on the distributor would open to lower the pressure and this would allow the remaining flow to be discharged via the diffuser.

As flowrates increase and decrease at the refinery and the FSRU there is a direct impact on the pressure in the system. Using a pressure-based control system allows for a more accurate and smooth control process rather than relying on flow meters or operator intervention.

2.3.1.4 Injecting gas into the pipeline

Following regasification on the FSRU, the natural gas would be transferred into the supporting gas infrastructure on the pier. Two high-pressure gas MLAs located on the pier head would transfer the natural gas to the aboveground pipeline. The natural gas would flow through the 3km aboveground pipeline on Refinery Pier and within the refinery to the treatment facility located at the northern boundary of the refinery.

Note that the MLAs, pipeline and treatment facility are not within the scope of the DL application and this information is provided only for context.

2.3.1.5 Hazardous materials

The FSRU would introduce the bulk storage and distribution of hazardous materials, of sufficient volume to have the potential for off-site consequences. The predominant hazardous materials of interest for the FSRU include liquefied natural gas (LNG) and propane (heat transfer medium). The dangerous goods classification, hazard, location and estimated quantities of materials being introduced are listed in Table 2-2. Further information is provided in Section 5.1.1 of Technical Report N*: Safety, hazard and risk assessment* (Appendix J).

Table 2-2 Hazardous materials

Material	DG Class	HAZCHEM Code	Hazard	Location	Estimated Quantity
LNG (Liquefied Natural Gas)	2.1	2WE	Flammable Cryogenic	FSRU Storage	170,000 m^3
Propane	2.1	2YE	Flammable	FSRU Process	~50 m^3
Acetylene	2.1	2SE	Flammable	FSRU Workshops	0.16 m^3 (4×40l cylinders)
Oxygen	2.2 5.1	2S	Oxidising gas	FSRU Workshops	0.32 m^3 (8×40l cylinders)
Paint Thinner	3	3YE	Flammable	FSRU Stores	~0.5 m^3

Leaks or a loss of containment may occur due to failures of pipe work, flanges, valves and failures of pressure vessels. A release of hydrocarbons can potentially lead to fire and explosion scenarios and constitute a major incident. Additional risks introduced by the project include cryogenic burn risk and asphyxiation risk associated with liquefied gases and electrical risks from contact with exposed live conductors. The prevention of major incidents has been a primary focus of the hazard analysis, risk assessments and safety studies completed by the project. The results of such studies for the FSRU are presented in Section 6 of Technical Report N: *Safety, hazard and risk assessment* (Appendix J).

3.0 Planning and other approvals

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the *Environment Effects Act 1978* (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic and transport as well as visual amenity.

In accordance with the EES scoping requirements, a Technical Reference Group (TRG) was convened and chaired by the Department of Environment, Land, Water, and Planning (DELWP) Impact Assessment Unit on behalf of the Minister for Planning. The TRG included a number of regulatory authorities who provided input throughout the EES process. The regulatory authorities that were part of the TRG included:

- Department of Environment, Land, Water and Planning
  - Pipeline Regulation
  - Barwon South West Region
  - Heritage Victoria
- First Peoples – State Relations
- Environment Protection Authority Victoria
- Energy Safe Victoria
- Worksafe Victoria
- Corangamite Catchment Management Authority
- Ports Victoria
- Wadawurrung Traditional Owners Aboriginal Corporation
- City of Greater Geelong Council.

Viva Energy must obtain a number of statutory approvals for the project (including the FSRU) at the state and Commonwealth levels. A summary of the approvals specific to the activity is provided in Table 3-1.

Table 3-1 Primary State and Commonwealth approvals for the FSRU component of the project

Jurisdiction	Legislation	Regulator	Approval
Commonwealth	*Environment Protection and Biodiversity Conservation Act 1999*	Commonwealth Minister for Environment and Energy	Approval of the Gas Terminal Project as a controlled action
State	*Aboriginal Heritage Act 2006*	First Peoples – State Relations and relevant Registered Aboriginal Party (RAP)	An approved Cultural Heritage Management Plan (CHMP)

Jurisdiction	Legislation	Regulator	Approval
State	*Environment Protection Act 2017*	Environment Protection Authority Victoria (EPA)	Development Licence and Operating Licence for the installation and operation of the FSRU The Geelong Refinery will also require a Development Licence or exemption for A04 (Industrial wastewater treatment) which requires permission for discharging or depositing industrial wastewater generated at another site (the FRSU) exceeding a design or actual flow rate of 5000 litres per day or on any day and modification to the current refinery Operating Licence.
State	*Marine and Coastal Act 2018*	Minister for Energy, Environment and Climate Change	Consent to use, develop and undertake works on marine and coastal Crown land (including the continuous mooring of the FSRU)
State	*Planning and Environment Act 1987*	Minister for Planning	Approval under the Planning and Environment Act will be required for the project via a Planning Scheme Amendment to the Greater Geelong Planning Scheme. It is proposed to apply a Specific Controls Overlay with an Incorporated Document. The Incorporated Document would allow the use and development of land for the project to be undertaken in accordance with specific conditions contained within the Incorporated Document.
State	*Occupational Health and Safety Act 2004* *Occupational Health and Safety Regulations 2017*	WorkSafe Victoria	MHF Licence for the FSRU

4.0 Environmental performance and track record

Viva Energy is committed to protecting the environment and minimising any potential environmental impacts arising from its operations or its products. The Health, Safety, Security & Environment (HSSE) Policy outlines this commitment to operating in an environmentally responsible manner. The environmental aspects of Viva Energy's operations are governed by environmental regulations, and subject to project and site-specific environmental permits and approvals, at both the Commonwealth and State government levels, which are managed in accordance with the HSSE Management System.

Viva Energy has a dedicated and experienced team of in-house environmental professionals and leverages the specialist technical expertise of environmental consultants. Viva Energy has a long history of operating major hazard facilities and executing significant projects in an environmentally responsible manner.

For major facilities, including the Geelong Refinery, environmental licence compliance and performance monitoring results are reported publicly. Recent information on Viva Energy's environmental performance and a summary of environmental performance data is available in the Sustainability Report contained within the 2020 Viva Energy Group Limited Annual Report. This information can be found at the following links respectively:

https://www.vivaenergy.com.au/about-us/environment-and-sustainability – Our Major Facilities

https://www.vivaenergy.com.au/about-us/environment-and-sustainability – Read our 2020 Sustainability Report

https://investor.vivaenergy.com.au/investor-centre/?page=company-reports – 2020 Annual Report

4.1 State of knowledge

The FSRU would be located adjacent to, and on, Viva Energy's Geelong Refinery which has been operational for over 60 years. The co-location of the FSRU would enable Viva Energy to leverage their experience as an existing EPA licence holder and an MHF operator.

As an existing EPA licence holder, Viva Energy is required to ensure that licensed activities are maintained and operated so that risk of harm to human health and the environment is reduced so far as reasonably practicable. In addition, Viva Energy implements a risk management and monitoring program to enable the EPA to determine compliance with the general environmental duty and the requirements of licence conditions. Viva Energy will look to use and build on their experience and consider the use of existing management and monitoring measures for the operation of FSRU.

Viva Energy maintains effective major incident prevention and control measures, an up to date safety case and an ongoing commitment to improving safety as an MHF operator. Viva Energy monitors their safety performance, reviews the effectiveness of safety systems and controls and makes improvements where needed. As part of this continual improvement process, Viva Energy also monitor technical developments and best available techniques or technology in their industry in order to apply learnings to refinery operations. Viva Energy would use their experience as an MHF operator during operation of the FSRU.

As stated in previous sections, while Viva Energy would oversee the operation of the FSRU, Hoegh LNG is likely to be the third party operator of the FSRU, subject to finalisation of the commercial arrangements. Hoegh LNG is an industry leader in the development, ownership, and operation of modern FSRUs globally.

Hoegh LNG commenced operations in 1973 and currently operates a fleet of 2 LNG carriers and 10 FSRUs globally. The global fleet is managed inhouse by Hoegh LNG Fleet Management, a wholly owned subsidiary of Hoegh LNG. The integrated operations between the fleet management and the technical division in the company, facilitates experience exchange and continued optimisation of the vessel operation and design. The experience drawn from operation of FSRUs in different parts of the world with varying operating conditions and requirements is shared in the organisation and these learnings are used to further improve FSRU operational performance and the efficiency.

Hoegh LNG's position as a world leading FSRU provider is based on more than 45 years of operational experience and excellence. The company strives to minimise potential impacts related to its operations

on the environment and other sensitive receptors. There is a focus within the company on energy management and energy efficient operation to minimise environmental impact. Hoegh LNG implements operational key performance indicators on zero pollution incidents across the global fleet.

The Maintenance & Performance Optimisation (M&PO) department within Hoegh LNG Fleet Management monitors the ongoing performance of the FSRUs in operation around the world for continual improvement. This department evaluates and implements measures to optimise operational performance of the various vessels across the fleet based on the monitoring data that is collected. An information management system has been installed onboard all vessels in the fleet, and this system allows for the FSRU performance to monitored by the M&PO department and continually improved.

The safety management system used by Hoegh LNG is certified in accordance with the International Safety Management (ISM) Code by the International Maritime Organisation (IMO) which is an international standard used for the safe management and operation of vessels at sea. The safety management system is also certified under the ISO 9001 (Quality Management System) and 14001 (Environmental Management System).

The operation of FSRUs are governed by internal procedures, guidelines, philosophies and contingency plans which have been developed over the years based on operational experience, industry standards, equipment manufacturer recommendations and applicable guidelines and regulatory authority requirements.

5.0 Community and third-party engagement

This section briefly sets out the key stakeholder engagement and consultation that has been undertaken to support the preparation of the EES and, more broadly, to assist in the development of the project.

An extensive engagement and consultation program was undertaken to ensure that the community and interested stakeholders were informed, involved and able to actively contribute to the development of the project and preparation of the EES.

A Consultation Plan for the Viva Energy Gas Terminal Project (Consultation Plan) was prepared in accordance with the final scoping requirements and the EES Consultation Plan Advisory Note outlining the opportunities and approaches for community engagement during the preparation of the EES and to show how Viva Energy would consult with owners and occupiers of land about the proposed pipeline. The Consultation Plan was published on the DELWP website in April 2021. The Consultation Plan was updated in July 2021 to include an updated project timeline and project approvals schematic, and to provide a separate rolling Consultation Activities Plan for the upcoming months. The Consultation Plan is available at:

https://www.planning.vic.gov.au/environment-assessment/browse-projects/projects/viva-energy-gas-terminal-project

Figure 5-1 below outlines the six phases of engagement activities for the project.



Figure 5-1 The six phases of engagement activities for the project

5.1 Overview of engagement to date

In October 2019, Viva Energy commenced preliminary engagement to introduce the Gas Terminal Project as part of the broader Geelong Energy Hub to individuals and stakeholders that would be directly involved in or impacted if it were to proceed. This initial engagement primarily involved Commonwealth, State and local governments as well as key regulators. Subsequent engagement then expanded to include the refinery's closest neighbours, local Geelong associations and businesses and the broader community primarily through announcements in the media in June and July 2020. Information about the project was made available on the Viva Energy website in November 2020. Table 5-1 below summarises engagement and consultation from January 2020 to December 2021.

Table 5-1 Summary of engagement from January 2020 to December 2021

Activity	Description	Target Audience	Phases
Media and advertising	Advertisements and advertorials in 3 local newspapers and 1 local magazine with a combined readership of at least 123,000 5 letterbox drops of the Refinery Update newsletter to residents and businesses surrounding the project area. Total distribution of 13,300 1,316 media mentions about the Gas Terminal Project. Included coverage in local papers including the Geelong Advertiser and Geelong Independent and national coverage in The Age, Australian Financial Review and The Australian.	Neighbours and local residents Business and industry Community and interest groups Recreational users of Corio Bay	2 & 3
Community information sessions and booths	Included 6 in-person and 2 virtual community information sessions. In-person events at local, accessible venues. There were 2 pop-up style community information booths at shopping centres.	Neighbours and local residents CALD communities Community and interest groups Recreational users of Corio Bay Wider community	2 & 3
E-news updates	8 editions of the E-news update sent to project update subscribers. Total number of emails sent; 1920	Neighbours and local residents Community and interest groups Wider community	2 & 3
Social media	Facebook for sharing project information; there were 163 posts, there are 403 followers and a reach of 36,095 LinkedIn and Twitter for posting key milestones; there were 13 posts	Neighbours and local residents CALD communities Community and interest groups Business and industry Recreational users of Corio Bay Wider community	2 & 3
TRG meetings	10 meetings held	Members of the TRG convened by DELWP on behalf of the Minister for Planning as part of the EES process	2 & 3

Activity	Description	Target Audience	Phases
Meetings	Both in person and virtual, includes visits to landowners and occupiers in the pipeline corridor and briefings to elected government representatives. There have been 186 meetings.	Government Neighbours and local residents Landowners and occupiers Business and industry Community and interest groups Traditional Owners and Indigenous groups	2 & 3
Webpage	Repository of project materials including; - 24 fact sheets and study summaries - 15 videos There have been 12,808 unique views and 17,697 views of the videos	Neighbours and local residents CALD communities Business and industry Community and interest Groups Traditional Owner and Indigenous groups Wider community	2 & 3
Project email address	Less than 25 email enquiries about the project	Neighbours and local residents Community and interest groups Business and industry groups Recreational users of Corio Bay Wider community	2 & 3
Letters and emails	700 letters and emails used to introduce the project, provide updates and for formal communications with landowners and occupiers	Government Neighbours and local residents Landowners and occupiers Business and industry Community and interest groups Recreational users of Corio Bay Traditional Owner and Indigenous groups	2 & 3
Business and industry forums	Presented at 4 events of the Geelong business community, total number of attendees 192	Business and industry	2 & 3
Utility and infrastructure provider workshops	Completion of constructability workshops and pipeline Safety Management Study	Government Business and industry Landowners and occupiers	2 & 3
Employee events	Regular presentations and updates about the project through internal communications channels such as town halls, all-company emails and @workplace	Viva Energy workforce	2 & 3

Further information about the consultation activities undertaken and planned for the project are provided in EES Chapter 6: *Stakeholder and community engagement* (refer to Appendix C).

5.2 Consultation findings and response

Viva Energy has sought to understand and address stakeholder and community feedback received during preparation of the EES and consider, and where possible incorporate, this feedback in the design of the project.

In addition, Viva Energy has sought to provide stakeholders and the community with information about the key areas of concern through targeted communications collateral (displays and presentations) and targeted community meetings.

Table 5-2 provides a summary of issues raised and how these were addressed in the EES and project design.

Table 5-2 Viva Energy responses to stakeholder and community feedback

Issue raised	Response to issue	Location in the EES
Project Rationale		
Questions about how this project in the context of broader climate change policy and use of fossil fuels	• Extensive consultation with community and environmental interest groups – particularly highlighting the gas supply/demand balance, the role that gas plays in the Victorian economy and in the transition to lower carbon energies • Viva Energy's commitment to reducing operational (Scope 1 and 2) emissions to net zero by 2050 and as part of this Viva Energy is committed to medium-term 2030 emissions reduction targets for operational Scope 1 and 2 emissions, from a FY2019 base year: - net zero across Retail, Fuels and Marketing (all non-refining parts of the business) - 10% reduction in emissions intensity at the Geelong Refinery - offsetting Scope 1 and 2 emissions from the construction and operation of the gas terminal • An independent study into the Australian east-coast gas market was commissioned. The report identified a gap in the gas supply/demand balance could emerge as early as 2024. LNG import via a gas terminal is the most flexible and cost effective way to address this shortfall. • Geelong Energy Hub communications channels were created emphasising the role of the project as part of the vision for the Geelong Refinery	Attachment I: *Energy demand and market statement* Chapter 2: *Project rationale*

Issue raised	Response to issue	Location in the EES
Questions around the project's greenhouse gas emissions	• Selection of 'open loop' regasification as the usual operating mode of the FSRU to reduce greenhouse gas emissions by approximately four times that of closed loop operation. • A number of considerations have been adopted to minimise greenhouse gas emissions from the project including: - Material selection - Equipment selection - Prioritisation of locally sourced suppliers - Potential for excess boil off gas from the FSRU to be used in the refinery - Lighting design • Commitment to offset the project's residual Scope 1 and 2 construction and operation emissions • Study Summary prepared summarising the Greenhouse gas impact assessment	Technical Report C: *Greenhouse gas impact assessment* Chapter 9: *Greenhouse gas emissions*
Safety		
General concern around safety of gas terminal operation and transportation of LNG	• Extensive consultation with WorkSafe Victoria, Energy Safe Victoria, DELWP Pipelines Regulation and Ports Victoria • Suite of safety studies conducted including hazard identification (HAZID), Hazard and Operability Analysis (HAZOP), pipeline Safety Management Study and Quantitative Risk Assessment (QRA) • Pipeline design specification exceeds the requirements of Australian standards • Development of varied collateral to assist in responding to the questions that have been raised regarding the safe operations of the gas terminal and LNG transportation. This has included: - LNG safety fact sheet - Safe and secure operations fact sheet - information in Refinery Update newsletters, and - E-news updates This information was shared on communications channels including Facebook, advertorial in local newspapers and the project website • In response to the frequency of the issue being raised a community information session was held in July 2021 to provide safety study results to date – recognising that further work was underway. The session focused on the LNG carriers and FSRU and provided an opportunity to answer questions. This meeting was recorded and made available online. Further follow up occurred after the session to respond to additional areas of concern • A second community information session focused on safety was held in October 2021 • Developed a Study Summary for the safety, hazard and risk assessments technical report	Technical Report N: *Safety, hazard and risk assessment* Chapter 12: *Safety*
Impact on maritime and port operations safety with	• Berthing simulations and modelling of LNG carrier movements undertaken in conjunction with Ports Victoria and pilotage providers	Chapter 12: *Safety*

Issue raised	Response to issue	Location in the EES
increased ship visits to Refinery Pier	• Highlighting that LNG shipping movements will only be a small increase in total shipping visits to the Port of Geelong	
Concern around increased security and terrorism risk	• An independent vulnerability and security risk assessment was completed by an industry risk management specialist with consideration of the presence of the FSRU and LNG carrier • Security content added to safe and secure operations fact sheet • A security expert was present at the community information sessions in July 2021 and October 2021 and answered direct questions about this topic	Chapter 12: *Safety*
Understanding the outcomes of risk assessments (QRA analysis) and relevance to residents	• QRA was used in an iterative process to inform additional design measures to minimise risk based on results and stakeholder feedback • Cumulative QRA risk profiles developed for project and the refinery • Met with stakeholders to discuss the safety, hazard and risk assessment tools, methodology and outputs • Shared current status of risk assessments for FSRU; treatment facility and cumulative impact assessment • Safety information was posted on project website • Community information sessions held in July 2021 and October 2021 focused on the issue of safety. Meeting materials made available on-line	Chapter 12: *Safety*
Potential for major incident / explosion on the FSRU	• The FSRU would be classified as a Major Hazard Facility (MHF) and would require an accepted MHF safety case and licence issued by WorkSafe Victoria. Multiple studies and assessments have been completed to ensure safety in design and operation • Partnered with reputable FSRU provider Hoegh LNG with strong track record around the world • Engaged FSRU specialist consultants to provide input into design and operational requirements including exclusion zones. • Community information session held July 2021 with content showing QRA for FSRU. Meeting materials made available on-line. This was also discussed at the October 2021 community information session • Facilitated a meeting with Worksafe and Geelong Grammar School to ensure stringent regulatory requirements for a MHF were well understood.	Technical Report N: *Safety, hazard and risk assessment* Chapter 12: *Safety*
Marine Environment		

Issue raised	Response to issue	Location in the EES
Concerns about the FSRU seawater discharge changing the temperature of the bay and chlorination of seawater.	• The gas terminal has been designed to enable reuse of seawater transferred from the FSRU into the refinery for use as cooling water which is an environmental enhancement. Discharge from the refinery after reuse of discharge water would be very similar to the current refinery discharge and continue to comply with current EPA licence conditions • Engagement with EPA regarding licensing requirements. Development Licence applications will seek approval from EPA for the FSRU and for discharge of FSRU wastewater from the refinery. • Additional investigations were completed to understand the existing condition of flora and fauna under the current refinery seawater discharge outlets • Diagrams outlining seawater use design were produced and included in communications material including a video of how the gas terminal would work • Created a fact sheet on the topic of the marine environment • In May 2021, a community information session was held focusing on the marine studies conducted in support of the EES process • Stand at November 2021 community information session presented the results of the marine studies conducted in support of the EES. A technical specialist was available to answer questions	Technical Report A: *Marine ecology and water quality impact assessment* Chapter 8: *Marine environment*
Questions around understanding what the impact on seawater discharge would be if the refinery was to stop operations	• Communication on the company's commitment to continue refining until at least mid-2028 as part of the Commonwealth Fuel Security Package • Potential impact of direct discharge of cooled seawater from the FSRU to Corio Bay was modelled and assessed. • Use of a diffuser to distribute the cooled seawater through a number of outlets over a larger distance to enable improved mixing has been provided for in the event this is needed for a future mode of operation.	Technical Report A: *Marine ecology and water quality impact assessment* Chapter 8: *Marine environment*
Concern around the scale of dredging and potential impacts on Corio Bay	• Shipping simulations were completed to minimise the dredge footprint and volume of material removal dredging required. The dredged material volume was reduced from 1,000,000 m^3 to 490,000 m^3. • Extensive consultation with Ports Victoria, EPA and DELWP on technical studies and dredged material disposal options assessment • Extensive marine surveys conducted over a 12 month period to characterise the existing environment of Corio Bay • Sediment dispersion modelling was completed in conjunction with a comprehensive offshore sediment sampling and contaminant analysis in accordance with the National Australian Guidelines for Dredging (NAGD) • A dredging methodology assessment was completed to ensure optimal equipment and methods were recommended • A dredged spoil disposal options assessment (DSDOA) was undertaken	Technical Report A: *Marine ecology and water quality impact assessment* Technical Report B: *Dredged sediment disposal options assessment* Chapter 8: *Marine environment*

Issue raised	Response to issue	Location in the EES
	• Marine and Coastal Act consent required for dredging • Communications developed on Refinery Pier works and localised dredging • Stand at November 2021 community information session focused on localised dredging and dredged material disposal. Technical specialist was available to answer questions • Study Summary prepared to summarise the findings of the marine ecology and water quality impact assessment technical report	
Concerns about potential impacts on Ramsar wetlands in Corio Bay	• Proactively engaged with wildlife and bird conservation groups, and the Ramsar Coordinating Committee • Entrainment and discharge/turbidity plume modelling was undertaken to ensure any potential for direct or indirect impacts to the site were mitigated • Light spill assessment conducted. Potential impacts of pier lighting are to be minimised through selection of wildlife sensitive lighting design as per the National Light Pollution Guidelines for Wildlife • A community information session on marine studies to support the EES impact assessment incorporating Corio Bay and the Ramsar site was held in May 2021 • Created a fact sheet with information on the Ramsar site • Developed an informational video on the assessments incorporating Corio Bay and the Ramsar site • November 2021 advertorial focused on marine ecology and referenced Ramsar wetlands	Technical Report A: *Marine ecology and water quality impact assessment* Technical Report J: *Landscape and visual impact assessment* (Appendix A: Light spill impact assessment) Chapter 8: *Marine environment*
Other themes		
Interest in job creation and local and Indigenous content in procurement	• Information on the economic benefits including job creation was made available in Facebook posts, through a project benefits poster and highlighted in meetings and briefings • Indigenous and local content to be implemented as part of the procurement policy for goods and services	Technical Report L: *Social and business impact assessment* Chapter 11: *Amenity and environmental quality*
Questions around effective tools for local community engagement	• Created 8 factsheets and 3 videos for CALD communities • Utilised multiple avenues of communication including pop-up shopping centre booths, face-to-face meetings, community information sessions, letter-box drops and local newspaper adverts • Targeted website and Facebook content	Chapter 5: *Stakeholder Consultation*

Issue raised	Response to issue	Location in the EES
Concern around cumulative noise with the refinery	• A noise impact assessment was conducted by specialists in support of the EES process to assess potential noise impacts and identify management measures to reduce impacts on sensitive receptors, including recommendation to minimise 'out-of-hours' construction works • Noise measurements were conducted to establish the baseline noise levels • Community information session via webinar covered noise in August 2021. The recording was made available online after the meeting. • Short video with information about the noise impact assessment was made available on the website and Facebook • Study Summary on the noise and vibration impact assessment technical report published online	Technical Report I: *Noise and vibration impact assessment* Chapter 11: *Amenity and environmental quality*
Concern around increased traffic using the local roads.	• Consultation occurred with Department of Transport and GeelongPort • Liquid nitrogen delivery to the treatment facility would occur via Refinery Rd consistent with current heavy vehicle movements to the refinery • A transport impact assessment was conducted in support of the EES. Cumulative impacts were assessed with consideration of future Spirit of Tasmania ferry passenger traffic and any overlap with other future projects • A community information session via webinar was held in August 2021 to present the findings of the transport impact assessment. The recording was made available on the project website after the meeting. • Study Summary published summarising the transport impact assessment • Short video with information on the transport impact assessment was created and made available on the project website and social media	Technical Report K: *Transport impact assessment* Chapter 11: *Amenity and environmental quality*
Concern expressed around the size (and consequent visual impact) of the FSRU	• The landscape and visual impact assessment was extended beyond the Theoretical Zone of Visibility to include a viewpoint from the Geelong Waterfront precinct given its high use and significance within the local area • Selection of most appropriate Geelong Grammar School viewpoint for inclusion in the impact assessment was determined in consultation with the School • Photomontages of the FSRU moored at Refinery Pier were created from key viewpoint locations across Geelong – Eastern Beach; Cunningham Pier; North Shore; Geelong Grammar School, demonstrating the visual appearance within what is an existing port and industrial area. These images were displayed at community meetings, on the project website and on Facebook • Comparative height/dimension chart of project infrastructure and LNG carriers was created and displayed via communications channels	Technical Report J: *Landscape and visual impact assessment* Chapter 11: *Amenity and environmental quality*

Issue raised	Response to issue	Location in the EES
	• Visual impacts were assessed as part of the landscape and visual impact assessment conducted to support the EES • Study Summary published summarising the Landscape and visual impact assessment	
Request for information regarding future restricted access for recreational users of Corio Bay	• Maps showing the current and proposed exclusion zones were published on the project website • Proactive engagement with VRFish on the project	Chapter 11: *Amenity and environmental quality* Chapter 12: *Safety*

Further information about the key consultation findings and the manner in which they have been responded to during the EES process are provided in EES Chapter 6: *Stakeholder and community engagement* (refer to Appendix C).

6.0 Obligations of the EP Act

6.1 Principles of the EP Act

EPA has eleven principles of environment protection ('principles') as listed in Part 2.3 of the EP Act on which they must operate. The applicant must demonstrate that their proposal incorporates technologies, practices and other measures are capable of meeting each of these principles. The principles are listed below with responses for the Viva Energy Gas Terminal Project:

Principle	Principle description	Summary of project response	Sections in this report that principle is addressed
Integration of environmental, social and economic considerations	Environmental, social and economic considerations should be effectively integrated	The EES provides a clear, objective and well-integrated analysis of the potential environmental, social and economic considerations of the proposed project.	Section 7.0
Proportionality	A decision, action or thing directed towards minimising harm or a risk of harm to human health or the environment should be proportionate to the harm or risk of harm that is being addressed	An environmental, social and economic issues risk screening tool was used to prioritise and focus the proposed investigations, assessments and approaches to avoiding, minimising or managing potential impacts. The issue screening process involved an evaluation of the potential issues associated with the project to determine the level of assessment required for the EES commensurate with their potential impact. Detailed technical work was undertaken to confirm the extent and severity of potential impacts and to propose mitigation measures proportionate to the risk of harm to human health or the environment.	Section 7.0
Primacy of prevention	Prevention of harm to human health and the environment is preferred to remedial or mitigation measures	The project has applied the mitigation hierarchy to identify measures to primarily avoid impacts. Key measures to prevent harm to human health and the environment includes the siting of the FSRU at Refinery Pier and the reuse of FSRU discharge water in the Geelong Refinery cooling process.	Section 7.0
Responsibility shared by all levels of Government and industry, business, communities and the people of Victoria		The EES process enables input on the project and proposed mitigation measures from the technical reference group (TRG) of state government agencies and City of Greater Geelong, in addition to the public and affected stakeholders. The consultation	Section 5.0

Principle	Principle description	Summary of project response	Sections in this report that principle is addressed
		conducted for the project included various stakeholder groups, including local residents, business and industry, community and interest groups and Traditional Owners and indigenous groups. This wide engagement has allowed for Viva Energy to share details on the proposal to provide transparency on the project and Viva Energy's environmental responsibilities.	
Polluter pays	Persons who generate pollution and waste should bear the cost of containment, avoidance and abatement	Viva Energy will address and manage pollution and waste generated by the project. Contingency measures are proposed in the event of a pollution incident.	Section 7.7
Waste management hierarchy	Waste should be managed in accordance with the following order of preference, so far as reasonably practicable: a. avoidance b. reuse c. recycling d. recovery of energy e. containment f. waste disposal.	The waste hierarchy has been applied for the minimisation and management of industrial wastes generated as a result of operation of the FSRU. With the exception of seawater used for regasification, all waste generated on board the FSRU will be treated and/or stored and pumped to deck for off-site disposal by a licensed contractor, in accordance with the relevant Commonwealth and State regulations, and the IMO regulations. Seawater used for regasification will be reused in the Geelong Refinery. This means that the amount of water being taken from the bay and discharged to the bay would not be greater than the existing refinery usage.	Section 7.7
Evidence-based decision making	Actions or decisions under this Act should be based on the best available evidence in the circumstances that is relevant and reliable	The EES has assessed the proposal using the best available evidence of FSRU processes and emissions in the context of	Section 7.0

Principle	Principle description	Summary of project response	Sections in this report that principle is addressed
		Corio Bay and the wider environment. A key element to the decision making was based on the empirical evidence from field studies conducted for the marine assessment, which did not identify evidence of negative impacts on marine life under the existing refinery discharge plumes that have occurred over the last 60 years. As such, it was concluded that there would be no adverse impacts on the marine environment from the additional operation of the FSRU.	
Precautionary	If there exist threats of serious or irreversible harm to human health or the environment, lack of full scientific certainty should not be used as a reason for postponing measures to prevent or minimise those threats	For all specialist studies, where information was not available, a pre-cautionary or 'worst-case' scenario was used in lieu of final operational data. Furthermore, the refinery has a long history of operation by Viva Energy, providing a catalogue of historic environmental data. Models and assumptions have been validated based on empirical evidence associated with refinery operations.	Section 7.0
Equity	a. All people are entitled to live in a safe and healthy environment irrespective of their personal attributes or location. b. People should not be disproportionately affected by harm or risks of harm to human health and the environment. c. The present generation should ensure the state of the environment is maintained or enhanced for the benefit of future generations.	The EES studies assessed the project's potential to harm human health and the environment. The safety study concluded that the safety risks are expected to be limited and not disproportionate to those already experienced due to current operations at Geelong Refinery and within the Port of Geelong. Mitigation measures have been proposed to ensure that the state of the environment is	Section 7.0

Principle	Principle description	Summary of project response	Sections in this report that principle is addressed
		maintained and would not cause irreversible damage.	
Accountability	Members of the public should: a. have access to reliable and relevant information in appropriate forms to facilitate a good understanding of issues of harm or risks of harm to human health and the environment and of how decisions are made under the Act; and b. be engaged and given opportunities to participate in decisions made under the Act, where appropriate to do so; and c. have their interests taken into account in decisions made under the Act.	The EES process has enabled relevant information to be provided to members of the public to facilitate a good understanding of the issues of harm or risks of harm to human health and the environment from the operation of the project. This process provides opportunities for members of the public to provide feedback and raise issues, which have been considered in the design process and formation of mitigation measures.	Section 5.0
Conservation	Biological diversity and ecological integrity should be protected for purposes that include the protection of human health.	Mitigation measures and monitoring have been proposed to protect biological diversity and ecological integrity of the marine environment in Corio Bay.	Section 7.0

6.2 General Environmental Duty

Central to the EP Act is the General Environmental Duty (GED). The GED is an ongoing duty to prevent the risk of harm to human health and the environment. According to Section 25(1) of the EP Act, the GED requires that a person or entity who is engaging in an activity that may give rise to risks of harm to human health or the environment, to minimise those risks, so far as reasonably practicable.

When determining what is reasonably practicable, Section 6(2) of the EP Act gives regard to the following:

- the likelihood of those risks eventuating
- the degree of harm that would result if those risks eventuated
- what a person concerned knows, or ought reasonably to know
- the availability and sustainability of ways to eliminate or reduce risks
- the cost of eliminating or reducing risks.

Satisfaction of the GED requires a proactive approach to risk identification, assessment and the implementation of controls to minimise impacts to human health and the environment so far as is reasonably practicable. Section 7.0 of this DL application identifies the potential impacts to human health and the environment from the operation of the FSRU and the mitigation measures to minimise potential impacts so far as is reasonably practicable.

Section 25(4) of the EP Act specifies five broad areas of risk control. Table 6-1 summarises each of the five broad areas of risk control and where in the DL application and EES they are addressed.

Table 6-1 Broad areas of risk control

Broad areas of risk control	Where it is addressed
Use of plant, equipment, processes and systems to eliminate or minimise risk	Section 7.0 *Environmental assessments* Section 8.0 *Best available techniques and technology*
Ongoing and systematic identification and evaluation of risks to identify further risk	Section 7.0 *Environmental assessments* Technical Report A: *Marine ecology and water quality impact assessment* (Appendix E) Technical Report C: *Greenhouse gas impact assessment* (Appendix F) Technical Report G: *Contamination and acid sulfate soils impact assessment* (Appendix G) Technical Report H: *Air quality impact assessment* (Appendix H) Technical Report I: *Noise and vibration impact assessment* (Appendix I) Technical Report N: *Safety, hazard and risk assessment* (Appendix J)
Control measures	Section 7.0 *Environmental assessments* Chapter 14: *Environmental Management Framework* (Appendix D) Technical Report A: *Marine ecology and water quality impact assessment* (Appendix E)

Broad areas of risk control	Where it is addressed
	Technical Report C: *Greenhouse gas impact assessment* (Appendix F) Technical Report G: *Contamination and acid sulfate soils impact assessment* (Appendix G) Technical Report H: *Air quality impact assessment* (Appendix H) Technical Report I: *Noise and vibration impact assessment* (Appendix I) Technical Report N: *Safety, hazard and risk assessment* (Appendix J)
Incident response systems	Section 11.0 *Environmental management during operation* Chapter 14: *Environmental Management Framework* (Appendix D) Technical Report N: *Safety, hazard and risk assessment* (Appendix J)
Substance handling, management and transport	Section 7.7 *Waste* Technical Report G: *Contamination and acid sulfate soils impact assessment* (Appendix G) Technical Report N: *Safety, hazard and risk assessment* (Appendix J)
Provision of information, instruction, supervision and training to any person engaging in the activity to enable those persons to comply with the GED	Chapter 14: *Environmental Management Framework* (Appendix D)

6.3 Environment Reference Standard

Under the EP Act, the ERS provides the indicators and objectives needed to support environmental values. The ERS is a reference tool and does not set compliance limits or specific obligations that must be followed.

The ERS is a tool that can be used to assess the impacts on human health and the environment that may result from a proposal or activity. This application of the ERS must be seen within the context of the GED and preventing harm from pollution and waste as part of the broader environment protection framework under the EP Act. Because it is preventative in nature, this framework seeks to maintain environmental values and minimise risks of harm to human health and the environment, rather than setting and authorising acceptable levels of pollution and waste. The focus on prevention allows for continual improvement in managing these risks as knowledge expands and more effective risk-reduction techniques and technologies emerge.

The ERS covers the following aspects of Victoria's environment, all of which are relevant to the EES and this FSRU DL application:

- Part 2 – Ambient air (refer to Section 7.3 and Technical Report H: *Air quality impact assessment* [Appendix H])
- Part 3 – Ambient sound (refer to Section 7.4 and Technical Report I: *Noise and vibration impact assessment* [Appendix I])

- Part 4 – Land (refer to Section 7.6 and Technical Report G: *Contamination and acid sulfate soils impact assessment* [Appendix G]); and
- Part 5 - Water (refer to Section 7.5, Section 7.6 and Technical Report A: *Marine ecology and water quality impact assessment* [Appendix E])

7.0 Environmental assessments

7.1 Supporting EES documentation

An EES has been prepared for the project under the *Environment Effects Act 1978 (Vic)*. The EES has been prepared in accordance with the scoping requirements and relevant legislation, policy and guidelines and has been informed by the environmental impact assessments and specialist studies completed for the EES. This DL application has been informed by the EES and the supporting specialist studies prepared for the project.

The EES chapters and associated specialist studies that were used to prepare this DL application include the following:

- Chapter 3: *Project alternatives and development* (refer to Appendix B)
- Chapter 6: *Stakeholder and community engagement* (refer to Appendix C)
- Chapter 14: *Environmental Management Framework* (refer to Appendix D)
- Technical Report A: *Marine ecology and water quality impact assessment* (refer to Appendix E)
- Technical Report C: *Greenhouse gas impact assessment* (refer to Appendix F)
- Technical Report G: *Contamination and acid sulfate soils impact assessment* (refer to Appendix G)
- Technical Report H: *Air quality impact assessment* (refer to Appendix H)
- Technical Report I: *Noise and vibration impact assessment* (refer to Appendix I)
- Technical Report N: *Safety, hazard and risk assessment* (refer to Appendix J)
- Attachment II: *Risk to the project from climate change* (refer to Appendix K)

A summary of the integrated environmental impact assessments and their relevance to the Environment Reference Standard (ERS) and Principles of the EP Act are provided in Sections 7.2 to 7.7 .

7.2 Climate change and greenhouse gas (GHG)

Preparation of this section of the DL application was based on information provided in the EES Technical Report C: *Greenhouse gas impact assessment* (refer Appendix F) and the EES Attachment II: *Risk to the project from climate change* (refer to Appendix K). The greenhouse gas (GHG) technical report has undergone an external peer review to ensure that the report adequately addresses the matters set out in the EES scoping requirements and to ensure that the study sufficiently examines and clearly documents the potential environmental impacts of the operation of the FSRU.

7.2.1 Summary of greenhouse gas emissions

The project would produce GHG emissions through various activities associated with both the construction and operation phases, however, emissions would primarily result from operation of the FSRU.

The total construction Scope 1, 2 and 3 emissions for the project are estimated to be 62,168 tonnes of carbon dioxide equivalent (t CO_2-e). Scope 1 and 2 emissions during the construction period are estimated to be 6,878 t CO_2-e which equates to 0.01 per cent of Victoria's annual GHG emissions. This is considered to be a minor additional contribution to the State's GHG emissions. Of the total construction Scope 1, 2 and 3 emissions for the project, an estimated 15,901 t CO_2-e would be related to the transport of the FSRU to Geelong.

Diesel fuel consumed by vehicles, vessels and plant and equipment during construction of the Refinery Pier extension, treatment facility and pipeline, as well as dredging activities are the key contributing activities to GHG emissions during the construction phase. Mitigation measures will be implemented to avoid or minimise GHG emissions during construction where possible during the construction phase, such as using locally sourced materials and engaging with a local workforce to reduce emissions associated with travel. Construction activities will be coordinated to reduce unnecessarily extending the

construction period and to avoid inefficient use of equipment, and plant and equipment will be selected with consideration of fuel efficiency.

During operation, fuel consumed by the FSRU would be the primary source of GHG emissions accounting for majority of the Scope 1 emissions. Fugitive emissions from STS transfer of LNG is also a contributor to GHG emissions during operation. The total annual Scope 1, 2 and 3 operational emissions for the project are estimated to be:

- Open loop – 47,906 t CO_2-e
- Closed loop – 178,985 t CO_2-e
- Combined system – 65,280 t CO_2-e

The project's estimated emissions during operation are estimated to contribute the equivalent of 0.05 per cent (FSRU open loop operation), 0.19 per cent (FSRU closed loop operation), and 0.07 per cent (FSRU combined loop operation) of Victoria's GHG emissions per annum.

As closed loop mode consumes natural gas in the regasification process, it emits more Scope 1 GHG emissions than open loop mode to convert the same amount of LNG to natural gas. To reduce GHG emissions produced during operation, mitigation measures would be implemented to avoid or minimise emissions where possible. The most significant opportunity to minimise GHG emissions during the project's operation would be to adopt open loop as the usual mode of operation of the FSRU. Estimated GHG emissions would be approximately four times less in the usual open loop operating mode compared to closed loop.

The main benefit of the open loop regasification mode is that seawater from Corio Bay can be used to heat the LNG via an intermediate heating medium in a heat exchanger. This is an efficient and readily available means of heating the LNG without using additional fuel to generate heat for LNG vaporisation. Furthermore, for this project the potential impact of discharging the seawater from the FSRU heat exchangers is able to be mitigated by transferring the seawater to the refinery for reuse as cooling water.

To further reduce emissions, plant and equipment for the project's operation would be selected with consideration of fuel efficiency to reduce the consumption of fossil fuels. Engaging a local workforce where possible would reduce transport emissions associated with transport and air travel. Safety controls and emergency management practices would be put in place in the case of unplanned activities, incidents, and emergencies (i.e., unplanned maintenance or venting) to reduce the likelihood of releasing fugitive GHG emissions.

Following the implementation of mitigation measures to avoid and minimise GHG emissions from project construction and operation, residual Scope 1 and Scope 2 GHG emissions would be quantified and offset to compensate for emissions produced.

Viva Energy would incorporate energy use and GHG emissions associated with the operation of the gas terminal into existing reporting requirements under the *National Greenhouse and Energy Reporting Act 2007 (Cth)* ('NGER Act'). An energy management system would be implemented in accordance with the International Organisation for Standardisation (ISO) 50001 *Energy Management Systems* (ISO 50001) for the operation of the FSRU. The ISO 50001 provides a framework for organisations to take a systematic approach to achieve continual improvement of energy performance and efficiency and reductions in GHG emissions. This framework is considered to be part of global best available techniques or technology, and involves:

- developing energy use baselines
- developing energy management plans
- identifying performance indicators
- setting targets for improvement.

Progress would be regularly monitored, reported and reviewed. Implementation of this system would also involve external certification by ISO-accredited auditors (typically on a three year cycle) in which both compliance with the ISO standard and performance improvement would need to be demonstrated to maintain certification.

7.2.2 Climate change risk to the project

This section discusses the potential impacts of climate change on the project. This section is based on the climate change risk assessment presented in EES Attachment II: *Risk to the project from climate change* (refer to Appendix K).

Victoria's *Climate Change Act 2017* recognises that *'Victoria is particularly vulnerable to the adverse effects of climate change'* and that it must *'build the resilience of the State's infrastructure, built environment and communities through effective adaptation and disaster preparedness action'*. The adverse impacts of climate change pose increased risks of damage, failure, disruption, reduced safety and cost to the construction and operation of infrastructure assets over their lifespans. Early preparation and planning through assessing the long-term risks and implementing appropriate adaptation measures supports safety and resilience throughout the project lifecycle.

A climate change risk assessment was undertaken consistent with *AS 5334-2013 Climate change adaptation for settlements and infrastructure – A risk-based approach* (Standards Australia, 2013) focusing on the potential climate change risks that may impact the project.

A summary of climate change hazards with potential to impact the FSRU is outlined in Table 7-1.

Table 7-1 Summary of climate change hazards with the potential to impact the FSRU

Hazard	Description
Extreme temperature and/or heatwave	• Average temperatures have been increasing in Victoria over the last two decades and are projected to continue to increase in the future (very high confidence) (CSIRO 2019). • In Victoria, average maximum temperatures are projected to increase by approximately 1.4ºC (average) and 2.6ºC (maximum) in 2050. The highest recorded temperature at the weather station closest to the project area (Avalon airport) was 47.9ºC on the 7 February 2009. • The number of consecutive extreme heat days (days above 30ºC) is projected to increase from 3.6 days historically, to 4.3 days in 2050.
Extreme rainfall event	• The intensity of heavy rainfall events is projected to increase, however, the magnitude of change, and the time when change may be evident against natural fluctuations, cannot be reliably projected. • Australia Rainfall and Runoff (2019) recommends an allowance of 11.9% be made for increases in in the intensity of rainfall when undertaking flood assessments.
Bushfire	• Climate change is likely to result in increased frequency and intensity of bushfire weather conditions (high confidence) (CSIRO 2019). Historically the project area had an average of 1.7 days severe fire danger days per year. This is projected to more than double to 4.6 days in 2090 (data for 2050 not available) (CSIRO and BoM 2015).
Drought	• Annual rainfall is likely to decrease by an average of 11% and maximum of 20% by 2050, resulting in reduced water availability (average to high confidence) (CSIRO 2019). The impacts of reduced water availability are likely to be exacerbated by increased evapotranspiration, that is, the transfer of what from land or plants to the atmosphere.
Storm event / high wind speeds	• There is uncertainty over wind projections. Wind gust may increase in intensity, whereas average wind speed may decrease by an average of 2.6% and maximum of 3.3% by 2050 (CSIRO 2050). • Frequency of storm events may reduce; however, the intensity may increase.
River flood	• Riverine flooding from Hovells Creek may result from the increases in intensity of extreme rainfall events.
Sea level rise	• Changes in sea level are primarily the result of rising ocean temperatures leading to thermal expansion and changes in ocean mass due to the melting of glaciers and ice sheets. Sea level rise may be exacerbated by a combination of

Hazard	Description
	factors including astronomical tides, storm surges and wind events. Modelling for storm tide and storm surge has not been undertaken for this assessment. • In Greater Geelong, sea level is expected to increase by 0.15m to 0.32m in 2050.
Ocean acidity	• The ocean becomes more acidic as it absorbs CO_2 from the atmosphere. In 2090, pH is projected to be 0.3 units lower (a rise in acidity).
Ocean temperature	• Sea surface temperatures are projected to increase by 1.9 to 3.8ºC in 2090.
Enhanced atmospheric CO_2 concentration	• Current levels of background CO_2 are in excess of 400 ppm and these levels are likely to rise towards 930ppm in the next 80 years (CSIRO and BoM 2015) • Enhanced atmospheric concentrations of CO_2 and increased temperatures are projected to accelerate the penetration of CO_2 into concrete structures, resulting in more rapid carbonation / degradation of exposed concrete.

Of the 47 risks to the project identified through the climate change risk assessment, eight were rated 'High'. No risks were rated 'Extreme', with the remaining risks being rated 'Medium' or 'Low'. These ratings take into consideration existing controls and mitigation measures implemented for the project. The risks rated 'High' were primarily associated with the following hazards: storms; extreme rainfall, sea level rise and extreme heat. The 'high' risks are summarised in Table 7-2**.** Refer to EES Attachment II: *Climate change risk report* (Appendix K) for further detail about the full risk register.

Table 7-2 Summary of high-rated climate change risk to the FSRU

ID*	Risk description	Hazard	Existing controls	Risk rating	Proposed additional controls/ adaption options
9	Storm event (including storm surge, high wind speeds and hail) causes physical damage to the FSRU, safety impacts to workers onsite and delays to supply vessels resulting in reparation costs	Storm event, high wind speeds	• Safe operating procedures • Pier designed for environmental conditions (e.g., mooring analysis) • Post-event inspections and maintenance	**High**	• Factor projections into basis of design (mooring analysis) for pier and associated structures
10	Sea level rise results in misalignment of mooring and marine loading arm (MLA) connections between pier and FSRU resulting in damage to assets and safety impacts to workers onsite	Sea level rise	• Safe operating procedures • Pier designed for environmental conditions (e.g., mooring analysis) • Post-event inspections and maintenance	**High**	• Factor projections into basis of design (mooring analysis) for pier and associated structures
20	Storm event (including storm surge, high wind speeds and hail) causes physical damage to the construction site and construction equipment (e.g., cranes, marine-based activities) resulting in damage to assets, loss of equipment and safety impacts to workers onsite	Storm event, high wind speeds	• Operational procedures in event of a storm	**High**	• Review operational procedures for pier personnel • Marine Contractor's 'Severe Weather Plan' to document weather criteria for protocols to stop work and make safe in the event / forecast of a storm

ID*	Risk description	Hazard	Existing controls	Risk rating	Proposed additional controls/ adaption options
22	Storm event (including storm surge, high wind speeds and hail) causes damage to pier from berthed or berthing vessels resulting in reparation costs and safety impacts to workers	Storm event, high wind speeds	• Mooring lines / fenders • Window of operation (environmental limits set by Ports Victoria	**High**	• Factor projections into basis of design for pier and associated structures
23	Sea level rise coupled with storm surges and/or high tides causes inundation of facility site and access routes as well as accelerating coastal erosion, resulting in safety impacts to workers and damage or loss of asset	Sea level rise	• AS 1170 suite of codes (environmental loading), AS 4997 maritime structures and elements, AS 3600 for concrete, AS 4100 for steel, AS 2159 Piling	**High**	• Factor projections into basis of design for pier and associated structures
25	Extreme heat conditions cause exhaustion or heat related illness for the onsite workforce resulting in safety impacts to workers and production delays	Extreme temperature and/or heatwave	• Safe operating procedures • OHS protocols (fitness for work, etc.) • Continuous automated process	**High**	• Contractor Safety, Health, Environment and Sustainability (SHES) plan to document conditions to 'stop work' prior to dehydration / heat exhaustion
31	Sea level rise causes inundation of above ground pipeline and access routes situated close to the pier resulting in damage to the pipeline and safety impacts to workers	Sea level rise	• Safe operating procedures • Design to environmental conditions •	**High**	• Factor climate change projections into basis of design for pipeline and associated structures
41	Extreme rainfall event causes temporary inundation of facility site and access routes resulting in safety impacts to workers, supply disruption and/or damage to or loss of assets	Extreme rainfall event	• Multiple access points and suppliers • Remote operations	**High**	• Flexibility in supply of nitrogen • Agreement with Australia Energy Market Operator for relief of gas specification • Potential for onsite nitrogen production

*ID refers to risk register risk reference number. The risk register is provided in EES Attachment II: *Climate change risk report* (refer to Appendix K)

Viva Energy would maintain a register of risks to monitor climate-related impacts, projections and policy, and update and implement adaptation measures to minimise climate change risk throughout the life of the project.

Consultation with the project design team has determined that the climate change risks posed to the project are considered manageable over the project lifecycle on the basis that the identified design- and operation-related adaptation measures would be adopted.

7.2.1 Compliance of GHG emissions with GED and ERS

To minimise GHG emissions to the extent practicable during the operation of the FSRU, controls that would be implemented would include:

- Engaging a local workforce where possible to minimise transport related emissions
- The selection of plant and equipment that will incorporate consideration of fuel efficiency to reduce the consumption of fuels
- Development of a waste management plan that considers waste reduction, segregation and disposal to minimise emissions from transport of waste and emissions from landfill
- Implementation of an energy management system in accordance with International Organisation for Standardisation (ISO) 50001 *Energy Management Systems* (ISO 50001) for the operation of the FSRU to monitor energy use and continually improve energy performance and efficiency to reduce emissions
- Safety controls and emergency management practices in case of unplanned incidents to minimise the release of fugitive emissions
- Following the implementation of mitigation measures to avoid and minimise greenhouse emissions from project construction and operation, residual Scope 1 and Scope 2 greenhouse emissions would be quantified and offset to compensate for emissions produced

Further information is provided in Technical Report C*: Greenhouse gas impact assessment* (refer to Appendix F) and Chapter 14: *Environmental Management Framework* (refer to Appendix D).

Additionally, Viva Energy has recently announced its plans to reduce carbon emissions. This includes a net zero target for scope 1 and 2 emissions for non-refining operations by 2030, and for all operations by 2050. The commitment to offset Scope 1 and 2 emissions for the life of the Gas Terminal Project sits within climate change policy (at all levels of Government), with offsets being an element of overall strategy in the transition to renewable energy.

7.2.2 BATT energy consumption and GHG emissions management

The more efficient the engine, the less fuel consumption and GHG emissions per unit of power generated. The FSRU will be fitted with four Wärtsilä 50DF four-stroke dual-fuel engines. Based on manufacturer specifications, the Wärtsilä engines have a maximum thermal efficiency of 47% higher than any other gas engine. With a heat rate (efficiency) of 7300 kJ/kWh the Wärtsilä engines are considered as best available technology for powering the FSRU both in terms of propulsion and also on-board power generation.

Natural gas burns more efficiently than other fuel sources such as diesel oil or fuel oil. Figure 7-1 shows the GHG emission intensity of various fuels per gigajoule (GJ) of energy content based on emission factors outlined in the *National Greenhouse Accounts Factors - Australian National Greenhouse Accounts* (Department of the Environmental and Energy (DoEE) 2018).

The Wärtsilä 50DF is a dual fuel engine and can be run on natural gas or marine diesel oil/light fuel oil. The engine will operate predominantly on boil-off gas from LNG storage rather than marine diesel oil, which is only used as the pilot flame fuel or back up fuel during emergency and maintenance, which further reduces GHG emissions.

The four Wärtsilä 50DF dual-fuel engines and the boilers on board the FSRU are fitted with economisers which enables the use of waste heat from the flue gases (exhaust gases) within the process, reducing the overall consumption of energy and therefore reducing GHG emissions.

Energy consumption and GHG emissions are significantly less during operation in open loop mode in comparison to operation in closed loop mode. This is due to consumption of energy in the boilers to heat the feedwater and generate steam for the regasification process. Operation in open loop mode is the preferred option for this project to maximise the synergy between the FSRU and the refinery and to reduce GHG emissions.

Natural gas imported to Refinery Pier would be injected to the Victorian gas transmission network for a variety of domestic, industrial and commercial purpose in south-eastern Australia. The project also

maintains energy security to support the state's growth and development. LNG imports offer a flexible option of short-term and long-term energy supply that will provide customers with a secure, stable source of energy supply as the energy sector becomes decarbonised and transitions to more renewables.

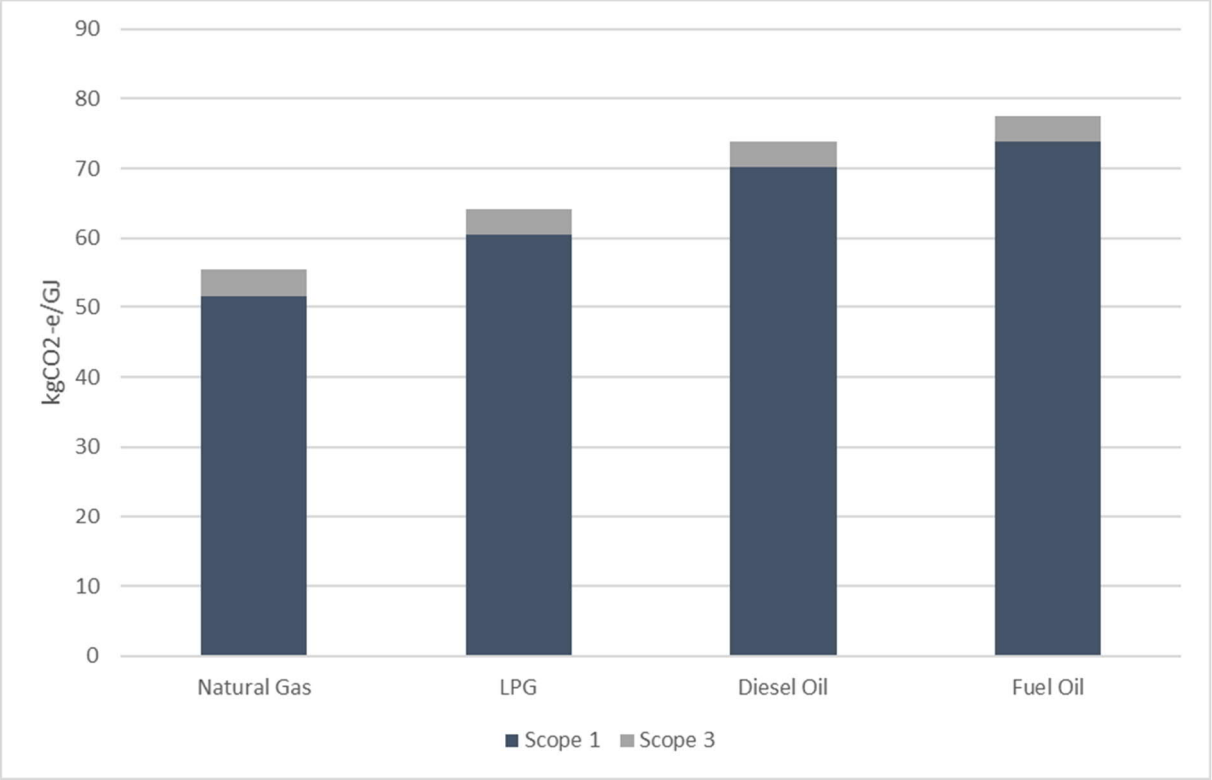


Figure 7-1 Comparison of GHG emission intensity of various fuels per GJ of energy content (DoEE 2019)

Boil-off gas (BOG) management facilities would also be in place on the FSRU to capture small amounts of natural gas that evaporates from LNG in the cargo tanks. The BOG would be used to fuel the onboard generators for operation of pumps and other equipment used onboard.

In addition, the FSRU will be equipped with a minimum send out compressor which would allow excess BOG to be compressed to the same specifications of the natural gas export system and sold into the Victoria wholesale gas market.

7.3 Air emissions

This section summarises the impacts on air quality detailed in Technical Report H: *Air quality impact assessment* (refer to Appendix H). The air quality technical report has undergone Technical Reference Group review (which includes EPA) to ensure that the report adequately addresses the matters set out in the scoping requirements and to ensure that the study sufficiently examines and clearly documents the potential environmental impacts related to the operation of the FSRU. Air emissions from construction activities are not related to the FSRU directly and as such, will not be discussed further in this DL application.

7.3.1 Summary of air impacts on human health and the environment

During operation of the FSRU, fuel combustion in the engines and boilers would emit air pollutants. The primary pollutants from the FSRU gas-fuelled engines are expected to be nitrogen oxides (NO_x), CO, and to a lesser extent, volatile organic compounds (VOC) (USEPA, 2000). The primary pollutants for the FSRU liquid-fuelled engines are expected to be particulate matter (PM_{10} and $PM_{2.5}$) and SO_2. CO, VOC, hazardous air pollutants (HAP) and particulate matter are primarily the result of incomplete combustion. For natural gas-fired engines, formaldehyde accounts for approximately two-thirds of the total HAP emissions (USEPA 2000). PAH, benzene, toluene, xylenes and others account for the remaining one-third of HAP emissions.

Modelling was undertaken to predict FSRU emissions across a range of operational scenarios. Table 7-3 summarises the six operational scenarios modelled with, and, without an LNG carrier berthed alongside the FSRU. LNG carriers would be berthed alongside the FSRU for up to 20% of the year while unloading LNG and would use boil-off gas at a rate of 0.9 tonnes per hour. The presence of an LNG carrier, in addition to its air emissions, may also influence the modelling results by creating a barrier effect next to the FSRU.

Due to the potential to reuse discharge water from the FSRU in the refinery, open loop is the preferred mode of operation. However, the FSRU would also be able to operate in closed loop mode using gas-fired boilers to generate steam to heat the LNG, although this mode would only be used in the event that the refinery is unable to accept discharge water from the FSRU (e.g., during maintenance of the seawater transfer pipe). Due to the additional equipment required to operate in closed loop mode (e.g., gas-fuelled boilers) higher air emissions are expected.

Table 7-3 Summary of operational modelling scenarios

Modelling scenario	Description
Gas-fuelled, Summer, Open loop	Open loop, gas production rate of 250 TJ/day 2 engines operating at 5,250kW
Gas-fuelled, Summer, Closed loop	Closed loop, gas production rate of 250 TJ/day 2 engines operating at 5,250kW, 1 boiler operating at 100 per cent load
Gas-fuelled, Winter, Open loop	Open loop, gas production rate of 500 TJ/day 3 engines operating at 5,250kW
Gas-fuelled, Winter, Closed loop	Closed loop, gas production rate of 500 TJ/day 3 engines operating at 5,250kW, 2 boilers operating at 100 per cent load
Gas-fuelled, Peak load, Closed loop	Four natural gas-fuelled engines and two natural gas-fuelled boilers operating at 100 per cent load
Liquid-fuelled	Two liquid-fuelled engines operating at 1776kW (~25% load), total fuel usage 14.6t/d

Pollutant concentrations resulting from operation of the FSRU are summarised in Table 7-4. Results are presented as maximum concentrations at a sensitive or industrial receptor for the five years of meteorology data (2016 to 2020). Modelling was undertaken for the 'FSRU', and the 'FSRU with LNG carrier' unloading. Predicted pollutant concentrations at a receptor are presented as 'incremental' (no background) and cumulative (FSRU plus background) concentrations. The maximum cumulative results were then compared against the adopted criteria.

All modelled scenarios demonstrate that predicted pollutants are well below the adopted criteria and meet all regulatory requirements. It is important to note that peak demand cases would be infrequent. The peak demand case that has been modelled is for operation in closed loop mode as this would result in higher air emissions than the preferred open loop mode and represents a worst-case scenario. The air modelling assessment demonstrates that air quality impacts from the FSRU operations would be minor and emissions are unlikely to have regionally or State significant effects on the air environment.

Table 7-4 Summary of maximum modelling predictions at a receptor location (µg/m³)

Operating Scenario		Summer open loop	Summer closed loop	Winter open loop	Winter closed loop	Peak load	Liquid-fuelled
Nitrogen dioxide (NO_2)		1-hour average 99.9th percentiles (µg/m³)					
FSRU	Incremental	17.7	21.0	26.5	32.3	49.6	8.9
	Cumulative	45.9	49.2	54.7	60.5	77.8	37.1
FSRU and LNG carrier	Incremental	25.4	27.9	34.4	39.8	58.0	17.7
	Cumulative	53.6	56.1	62.6	68.0	86.2	45.9

Operating Scenario		Summer open loop	Summer closed loop	Winter open loop	Winter closed loop	Peak load	Liquid-fuelled
Background		28.2					
Criterion		150					
Carbon monoxide (CO)		**Maximum 8-hour average (µg/m³)**					
FSRU	Incremental	35.0	45.9	51.8	73.6	97.4	84.0
	Cumulative	339.0	349.9	355.8	377.6	401.4	388.0
FSRU and LNG carrier	Incremental	38.1	49.2	55.3	76.9	100.7	90.7
	Cumulative	342.1	353.2	359.3	380.9	404.7	394.7
Background		304					
Criterion		10,310					
Sulfur dioxide (SO_2)		**1-hour average 99.9th percentiles (µg/m³)**					
FSRU	Incremental	-	-	-	-	-	3.2
	Cumulative	-	-	-	-	-	9.7
Background		6.5					
Criterion		262					
PM_{10}		**Maximum daily average (µg/m³)**					
FSRU	Incremental	1.6	2.1	2.3	3.5	5.0	9.3
	Cumulative	29.1	29.6	29.8	31.0	32.5	36.8
FSRU and LNG carrier	Incremental	1.8	2.4	2.6	3.7	5.2	9.5
	Cumulative	29.3	29.9	30.1	31.2	32.7	37.0
Background		27.5					
Criterion		50					
$PM_{2.5}$		**Maximum daily average (µg/m³)**					
FSRU	Incremental	1.3	1.8	2.0	2.9	4.2	7.8
	Cumulative	12.8	13.3	13.5	14.4	15.7	19.3
FSRU and LNG carrier	Incremental	1.5	2.0	2.2	3.1	4.3	8.0
	Cumulative	13.0	13.5	13.7	14.6	15.8	19.5
Background		11.5					
Criterion		25					
Benzene		**1-hour average 99.9th percentiles (µg/m³)**					
FSRU	Incremental	0.089	0.092	0.134	0.139	0.224	0.172
	Cumulative	9.69	9.69	9.73	9.74	9.82	9.77
FSRU and LNG carrier	Incremental	0.091	0.094	0.136	0.140	0.226	0.174
	Cumulative	9.69	9.69	9.74	9.74	9.83	9.77
Background		9.6					
Criterion		580					
Formaldehyde		**30-min average 99.9th percentiles (µg/m³)**					
FSRU	Incremental	13.0	27.8	19.4	50.5	32.5	-
	Cumulative	19.7	34.5	26.1	57.2	39.2	-
FSRU and LNG carrier	Incremental	13.2	27.9	19.7	50.6	32.8	-
	Cumulative	19.9	34.6	26.4	57.3	39.5	-

Operating Scenario		Summer open loop	Summer closed loop	Winter open loop	Winter closed loop	Peak load	Liquid-fuelled
Background		6.7					
Criterion		100					
PAH		**Maximum yearly average (µg/m³)**					
FSRU	Incremental	0.00000052	0.00000054	0.00000078	0.00000081	0.00000136	0.00000095
	Cumulative	0.05400052	0.05400054	0.05400078	0.05400081	0.05400136	0.05400095
FSRU and LNG carrier	Incremental	0.00000053	0.00000055	0.00000079	0.00000082	0.00000137	0.00000096
	Cumulative	0.05400053	0.05400055	0.05400079	0.05400082	0.05400137	0.05400096
Background		0.054					
Criterion		0.15					

The EP Act requires a DL and OL for prescribed permission activities. The Environment Protection Regulations 2021 classifies activities that discharge or emit to the atmosphere at least 100 kilograms per day of volatile organic compounds (VOC), particulates, SOx (oxides of sulfur) and NO_x (nitrogen oxides) or 500 kilograms per day of CO as permission activities type L01 (General discharges or emissions to the atmosphere).

Based on emissions data provided in manufacturer specifications NO_x, CO and VOC emissions are predicted to exceed the permission activity thresholds when the FSRU operates in open loop mode with four engines at 100% load or in closed loop mode with 4 engines and 2 boilers at 100% load. In addition, NO_x and VOC emissions are predicted to exceed the permission activity thresholds when the FSRU operates in open loop mode with 2 engines. Given the low sulfur content in natural gas being burnt in the FSRU, emissions of SO_2 from the gas-fired FSRU are expected to be negligible and have not been included in the assessment. SO_2 emissions were assessed for the liquid-fuelled FSRU scenario (2 engines at 25% load) which has a higher sulfur content. SO_2 emissions are not predicted to exceed the permission activity threshold in this scenario.

Consequently, the FSRU would require a DL and OL for these air emissions. Table 7-5 compares emissions to the permission activity thresholds in Schedule 1, Item 73 of the regulations.

Table 7-5 Comparison of FSRU emissions to prescribed permission activity thresholds

Substance	Operating Scenario	Total emissions		Permission activity threshold (kg/day)	Exceeds Threshold (Yes / No)
		g/s	kg/day		
NO_x (as NO_2)	Summer, 2 engines, Open Loop, 250TJ/d	3.5	302	100	**Yes**
CO		3.2	277	500	No
VOC		1.4	123	100	**Yes**
Particulates		0.2	17	100	No
NO_x (as NO_2)	Peak Load 4 Engines and 2 Boilers at 100% load	15.5	1336	100	**Yes**
CO		12.1	1048	500	**Yes**
VOC		4.3	371	100	**Yes**
Particulates		0.9	81	100	No
SO_2	Liquid-fuelled, 2 engines at 25% load	0.2	14	100	No

Additionally, the impact from the project's emissions needs to be considered in the context of the cumulative impact with other air pollution sources and background air pollution levels. Evaluating

cumulative effects requires the knowledge of existing or background concentrations of the contaminants being assessed. This includes how background concentrations vary during the year due to seasonal or other temporal trends. It is necessary to incorporate the background concentrations of air pollutants as they provide a baseline level, to which the predicted impact of a new development can be added, thus producing a cumulative air quality impact that is suitable for comparison against regulatory criteria or for use in health risk assessments.

The background concentrations adopted for the project are considered conservative, especially where the highest value was selected. The background pollutant concentration for any given hour or day during operation of the project is likely to be much lower than those presented in Technical Report H: *Air quality impact assessment.*

To further assess the potential cumulative impacts detailed in Technical Report H: *Air quality impact assessment,* time varying background concentrations have been added to the corresponding model predictions at nearby sensitive and industrial receptors. The receptors assessed were Receptor 1, 7, 14, 19, 27, 28, 29, 30 and 31 (refer to Section 5.2 of Technical Report H: *Air quality impact assessment).*

An analysis of results showed that incremental concentrations are highest at industrial Receptor 30 (R30). Results for R30 are presented in Table 7-7 to Table 7-10 to show worst-case project impacts. Incremental results at all other receptors are much less than those predicted for R30.

In terms of cumulative concentrations, it is recognised that simple compliance with the criterion does not necessarily indicate that health impacts would not occur. Other factors are also important, of which frequency of occurrence is of primary importance. The cumulative concentrations for R30 were ranked according to their concentration throughout the modelling period and the results plotted in Figure 7-2 to Figure 7-5.

The pollutants assessed using time varying background concentrations are NO_2, PM_{10}, $PM_{2.5}$ and SO_2. Details and justification for each pollutant are summarised in Table 7-6.

Table 7-6 Summary of pollutants assessed using time varying background concentrations

Substance	Assessed using time varying background concentrations	Monitoring Station	Comments
Nitrogen dioxide (NO_2)	**Yes**	Geelong South	2020 data used for time varying background assessment. The highest measured background concentration was 99.3 µg/m^3 in January 2020.
Carbon monoxide (CO)	No	Geelong South	Highest measured background concentration (3,310 µg/m^3) was well below criterion (10,300 µg/m^3). Maximum incremental increase at a receptor 97.4 µg/m^3. Given the low incremental concentrations, further assessment was not considered necessary.
PM_{10}	**Yes**	Viva AAQMS	2020 data used for time varying background assessment. The highest measured background concentration was 148.7 µg/m^3 in January 2020.
$PM_{2.5}$	**Yes**	Geelong South	2020 data used for time varying background assessment. The highest measured background concentration was 155.0 µg/m^3 in January 2020.
Sulfur dioxide (SO_2)	**Yes**	Viva AAQMS	2019 data used for time varying background assessment. The highest measured background concentration was 193.7 µg/m^3 in July 2019.
PAH	No	Viva AAQMS	2016 to 2020 background concentration data was not available, cumulative concentrations are expected to be well below the criterion.

Substance	Assessed using time varying background concentrations	Monitoring Station	Comments
Benzene	No	Viva AAQMS	Highest available background statistic has been applied to modelling results in Section 7 of Technical Report H: *Air quality impact assessment*, cumulative concentrations are well below the criterion.
Formaldehyde	No	Viva AAQMS	Highest available background statistic has been applied to modelling results in Section 7 of Technical Report H: *Air quality impact assessment*, cumulative concentrations are well below the criterion.

Nitrogen Dioxide

Measurements of 1-hour average NO_2 made at Geelong South from 2016 to 2020 are presented in Section 5.4 of Technical Report H: *Air quality impact assessment*. Measured concentrations were well below the AAQ NEPM for 1-hour NO_2 of 150 µg/m^3 during the whole period. The highest measured 1-hour concentration was 99.3 µg/m^3 in January 2020.

Time varying background concentrations for 2020 have been added to the corresponding model predictions at nearby sensitive and industrial receptors for the peak load FSRU plus LNG carrier operating scenario (worst-case). The five highest predicted concentrations at industrial receptor 30 are presented in Table 7-7, the left side of the table shows the total predicted concentration on days with the highest background, and the right side shows the total predicted concentration on days with the highest predicted incremental concentration.

All time varying cumulative results are predicted to be well below the criterion of 150 µg/m^3. Incremental increases from the FSRU plus LNG carrier at peak load are negligible when backgrounds concentration are high.

Table 7-7 Summary time varying background assessment for NO_2, Industrial receptor 30, 2020

Date / Time	NO_2 1-hour average (µg/m^3)			Date / Time	NO_2 1-hour average (µg/m^3)		
	Background	Increment*	Cumulative		Background	Increment*	Cumulative
15/01/2020 6:00	99.3	0.000060	99.3	17/12/2020 2:00	2.8	63.1	65.8
16/01/2020 0:00	99.3	0.00030	99.3	9/01/2020 20:00	30.2	61.8	92.0
15/01/2020 5:00	95.3	0	95.3	12/12/2020 21:00	8.3	61.1	69.4
24/07/2020 7:00	84.6	0	84.6	11/03/2020 20:00	38.2	59.6	97.8
25/07/2020 1:00	84.6	0	84.6	12/12/2020 23:00	7.9	59.2	67.1

Note * Peak load FSRU plus LNG carrier operating scenario

The 1-hour average NO_2 cumulative concentrations for R30 in 2020 were ranked according to their concentration throughout the worst-case modelling year and the results plotted in Figure 7-2. This plot shows that the frequency of elevated cumulative concentrations is small with peak concentrations dropping quickly to levels that would not be discernible from the existing background concentrations.

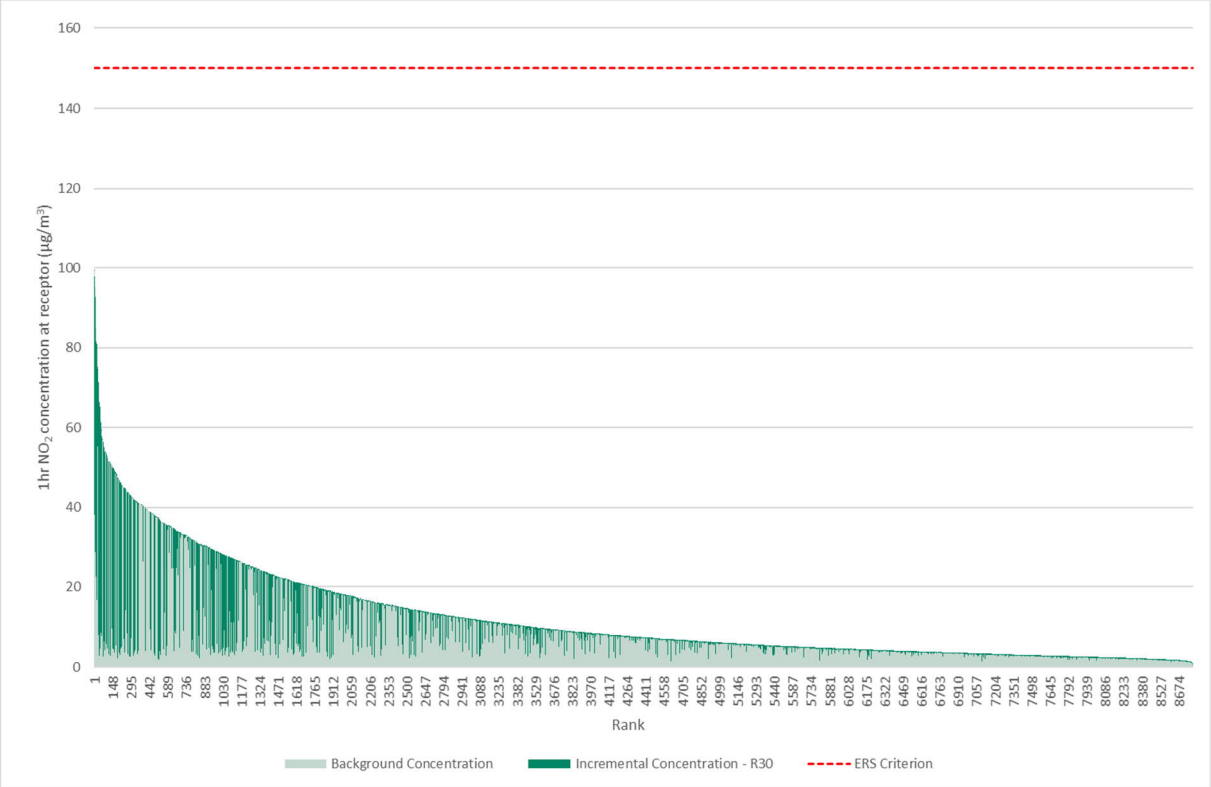


Figure 7-2 Ranked cumulative NO_2 concentrations at R30, 2020

Sulfur dioxide

Measurements of 1-hour average SO_2 made at Viva AAQMS from 2016 to 2020 are presented in Section 5.4 of Technical Report H: *Air quality impact assessment*. Measured concentrations were well below the AAQ NEPM for 1-hour SO_2 of 262 µg/m^3 throughout the monitored period. The highest measured concentration was 193.7 µg/m^3 in July 2019 at Viva AAQMS.

Time varying background concentrations for 2019 have been added to the corresponding model predictions at nearby sensitive and industrial receptors for the liquid-fuelled operating scenario (worst-case). The five highest predicted concentrations at industrial receptor 30 are presented in Table 7-8, the left side of the table shows the total predicted concentration on days with the highest background, and the right side shows the total predicted concentration on days with the highest predicted incremental concentration.

All time varying cumulative results are predicted to be well below the criterion of 262 µg/m^3. Incremental increases from the liquid-fuelled FSRU are negligible when backgrounds concentration are high.

Table 7-8 Summary time varying background assessment for SO_2, Industrial receptor 30, 2019

Date / Time	SO_2 1-hour average (µg/m^3)			Date / Time	SO_2 1-hour average (µg/m^3)		
	Background	Increment*	Cumulative		Background	Increment*	Cumulative
13/07/2019 15:00	193.7	0.0012	193.7	24/12/2019 22:00	0.52	3.45	3.97
26/11/2019 20:00	134.0	0	134.0	11/01/2019 21:00	4.19	3.28	7.47
26/02/2019 3:00	123.3	0	123.3	24/01/2019 6:00	4.97	2.95	7.92
26/11/2019 16:00	116.2	0.00062	116.2	4/07/2019 17:00	1.05	2.72	3.77

Date / Time	SO_2 1-hour average (µg/m^3)			Date / Time	SO_2 1-hour average (µg/m^3)		
	Background	Increment*	Cumulative		Background	Increment*	Cumulative
30/03/2019 13:00	113.9	0.0012	113.9	12/10/2019 3:00	0.26	2.70	2.96

Note * Liquid-fuelled operating scenario

Similarly, to NO_2, the 1-hour average SO_2 cumulative concentrations for R30 in 2019 were ranked according to their concentration throughout the worst-case modelling year and the results plotted in Figure 7-3. This plot shows that the frequency of elevated cumulative concentrations is small with peak concentrations dropping quickly to levels that would not be discernible from the existing background concentrations.

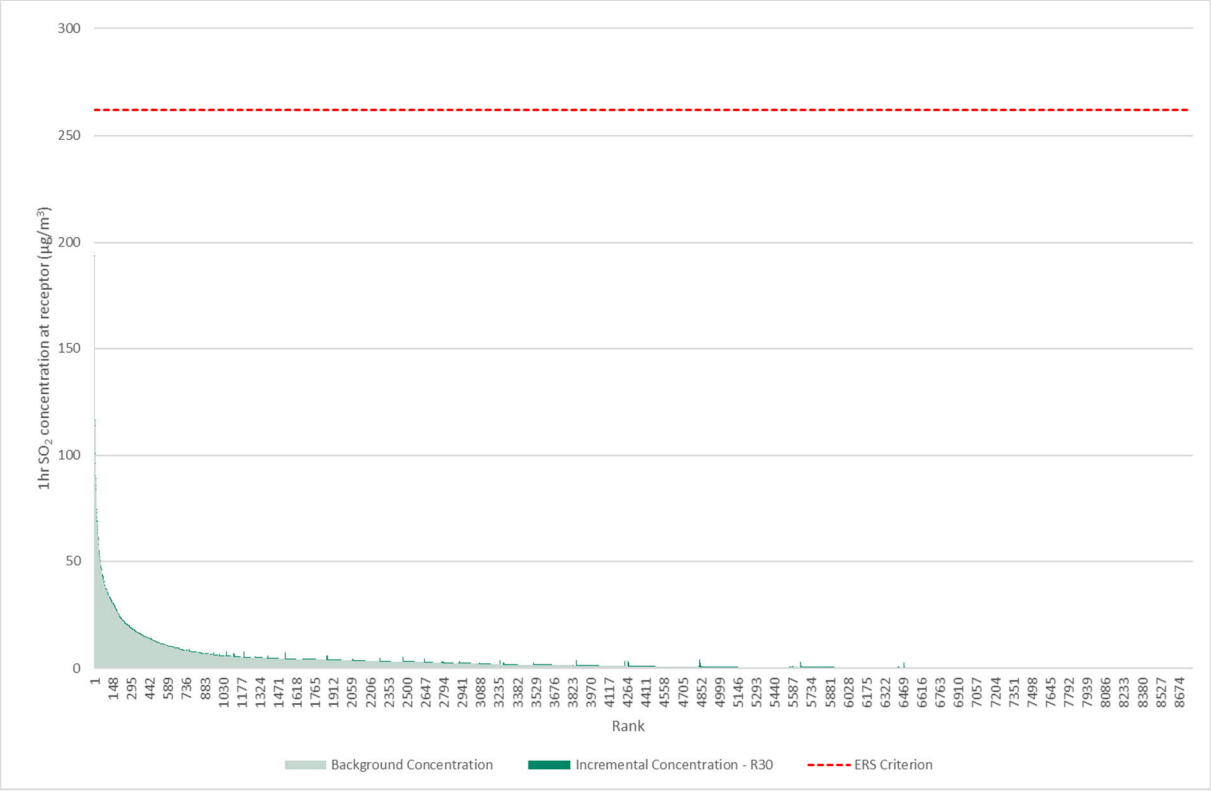


Figure 7-3 Ranked cumulative SO_2 concentrations at R30, 2019

PM_{10}

Measurements of 24-hour average PM_{10} made at Viva AAQMS from 2016 to 2020 are presented in Section 5.4 of Technical Report H: *Air quality impact assessment*. Measured concentrations were well below the ERS for 24-hour average PM_{10} of 50 µg/m^3 for most days during the five-year period. However, there were several exceedances with the highest measured concentrations of 148.7 µg/m^3 at Viva AAQMS and 199.4 µg/m^3 at Geelong South measured in January 2020. These elevated concentrations were most likely due to smoke caused by bushfire activity that was prevalent along the east coast of Australia in summer 2019-2020. There were 12 exceedances of the 24-hour PM_{10} criterion at Viva AAQMS and 32 at Geelong South in the five-year period.

Time varying background concentrations at Viva AAQMS (considered most representative of the project site) for 2020 have been added to the corresponding model predictions at nearby sensitive and industrial receptors for the peak load FSRU plus LNG carrier operating scenario (worst-case). The eight highest predicted concentrations at industrial receptor 30 are presented in Table 7-9, the left side of the table shows the total predicted concentration on days with the highest background, and the right side shows the total predicted concentration on days with the highest predicted incremental concentration.

Time varying results demonstrate that background PM_{10} concentrations dominate cumulative concentrations when the criterion of 50 µg/m^3 is exceeded. Incremental increases from the FSRU plus LNG carrier at peak load are negligible and will not result in additional exceedances of the criterion.

Table 7-9 Summary time varying background assessment for PM_{10}, Industrial receptor 30, 2020

Date	PM_{10} 24-hour average (µg/m^3)			Date	PM_{10} 24-hour average (µg/m^3)		
	Background	Increment*	Cumulative		Background	Increment*	Cumulative
13/01/2020	148.7	0.829	149.6	9/02/2020	23.8	4.9	28.7
14/01/2020	148.6	0.011	148.6	10/02/2020	10.7	4.3	15.0
6/01/2020	88.6	0.246	88.9	8/08/2020	9.9	3.4	13.2
3/01/2020	68.6	0.328	68.9	7/08/2020	12.1	2.7	14.8
31/01/2020	59.6	0.196	59.8	18/01/2020	24.4	2.6	27.0
6/02/2020	40.4	0.208	40.6	27/10/2020	12.5	2.5	15.0
10/01/2020	38.2	0.005	38.2	28/10/2020	11.3	2.1	13.3
16/11/2020	34.2	0.002	34.2	12/12/2020	18.8	1.6	20.4

Note * Peak load FSRU plus LNG carrier operating scenario

The 24-hour average PM_{10} cumulative concentrations for R30 in 2020 were ranked according to their concentration throughout the worst-case modelling year and the results plotted in Figure 7-4. This plot shows that the frequency of elevated cumulative concentrations is small with peak concentrations dropping quickly to levels that would not be discernible from the existing background concentrations.

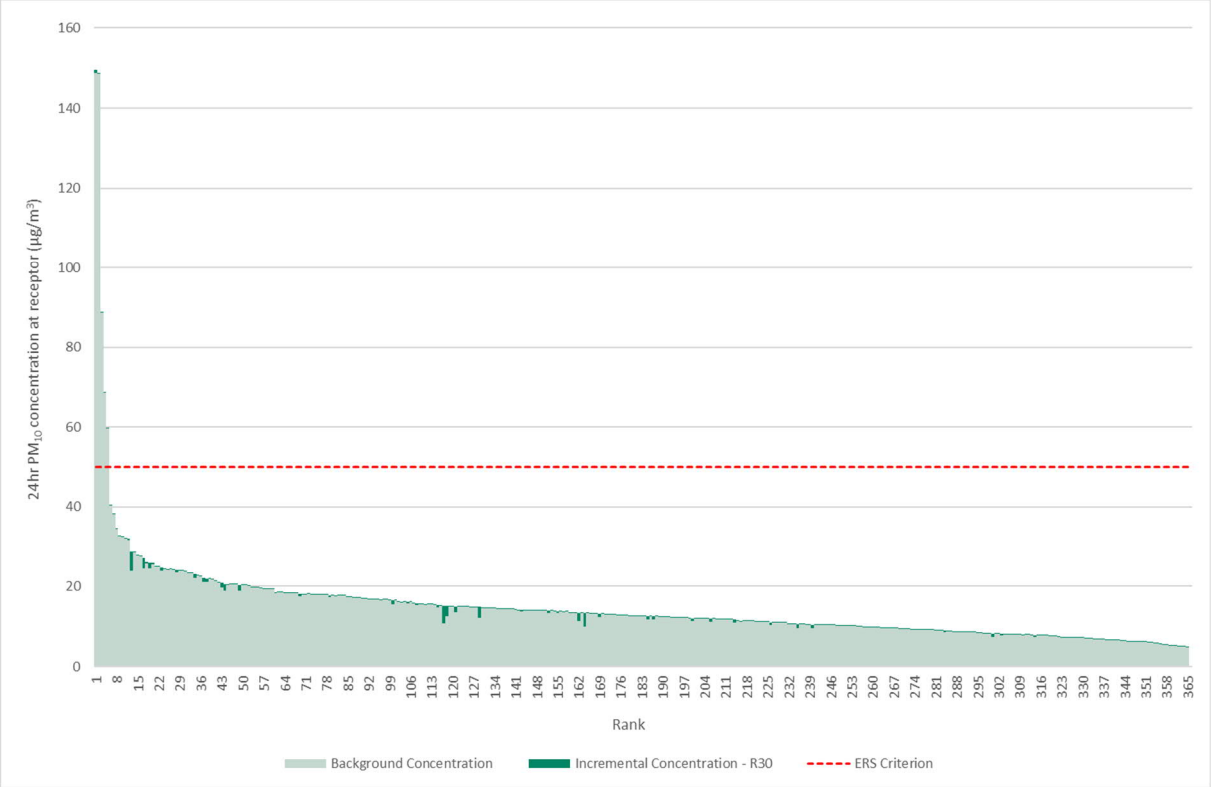


Figure 7-4 Ranked cumulative PM_{10} concentrations at R30, 2020

$PM_{2.5}$

Measurements of 24-hour average $PM_{2.5}$ made at Geelong South from 2016 to 2020 are presented in Section 5.4 of Technical Report H: *Air quality impact assessment*. Measured concentrations were generally well below the ERS for 24-hour average $PM_{2.5}$ of 25 µg/m^3 throughout the monitored period. However, there were a few rare exceedances of the ERS, notably in January 2020, when the highest measured concentrations were 155.0 µg/m^3 was recorded. The elevated concentrations in January 2020 were most likely due to smoke caused by bushfire activity that was prevalent along the east coast of Australia in summer 2019-2020. There were 10 exceedances of the 24-hour $PM_{2.5}$ criterion at Geelong South in the five-year period, with seven of those during the December 2019 to January 2020 period.

Time varying background concentrations at Geelong South for 2020 have been added to the corresponding model predictions at nearby sensitive and industrial receptors for the peak load FSRU plus LNG carrier operating scenario (worst-case). The eight highest predicted concentrations at industrial receptor 30 are presented in Table 7-10, the left side of the table shows the total predicted concentration on days with the highest background, and the right side shows the total predicted concentration on days with the highest predicted incremental concentration.

Time varying results demonstrate that background $PM_{2.5}$ concentrations dominate cumulative concentrations when the criterion of 25 µg/m^3 is exceeded. Incremental increases from the FSRU plus LNG carrier at peak load are negligible and will not result in additional exceedances of the criterion.

Table 7-10 Summary time varying background assessment for $PM_{2.5}$, Industrial receptor 30, 2020

Date	$PM_{2.5}$ 24-hour average (µg/m^3)			Date	$PM_{2.5}$ 24-hour average (µg/m^3)		
	Background	Increment*	Cumulative		Background	Increment*	Cumulative
15/01/2020	155.1	0.069	155.1	9/02/2020	0.0	4.1	4.1
14/01/2020	132.7	0.009	132.7	10/02/2020	0.0	3.6	3.6
13/01/2020	74.9	0.694	75.6	8/08/2020	4.7	2.8	7.5
6/01/2020	72.6	0.206	72.8	7/08/2020	4.3	2.3	6.6
3/01/2020	28.7	0.274	29.0	18/01/2020	12.9	2.2	15.1
16/01/2020	27.9	0.001	27.9	27/10/2020	5.7	2.1	7.8
29/06/2020	23.5	0.112	23.6	28/10/2020	3.8	1.7	5.5
4/01/2020	23.2	0.003	23.2	12/12/2020	6.5	1.3	7.8

Note * Peak load FSRU plus LNG carrier operating scenario

Similarly, to PM_{10}, the 24-hour average $PM_{2.5}$ cumulative concentrations for Receptor 30 across all modelled years were ranked according to their concentration with the results plotted in Figure 7-5. This plot shows that the frequency of elevated cumulative $PM_{2.5}$ concentrations is very small (similar in extent to PM_{10}) with concentrations unlikely to be discernible from the existing background concentrations.

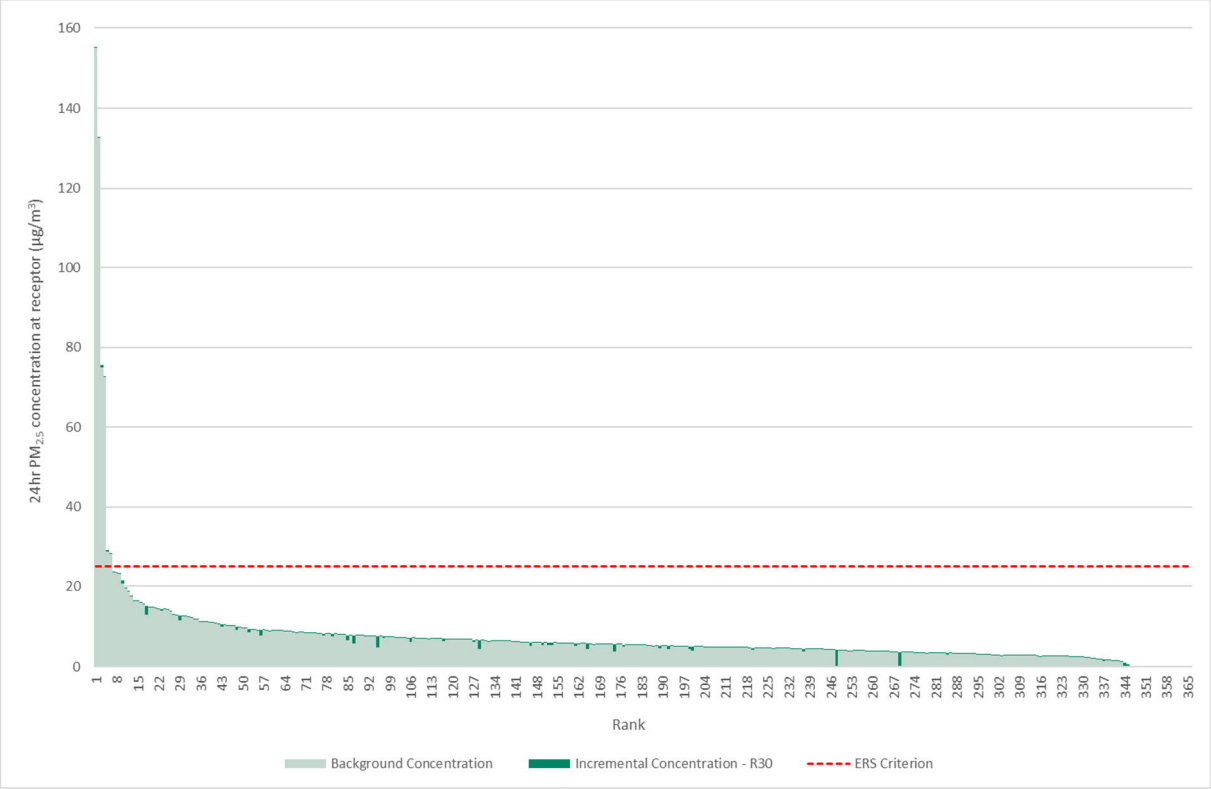


Figure 7-5 Ranked cumulative $PM_{2.5}$ concentrations at R30, 2020

Summary of time varying background results

The potential air quality impact of the FSRU has been assessed using time varying background concentrations for NO_2, SO_2, PM_{10} and $PM_{2.5}$. The dispersion modelling has used a conservative approach based on worst-case operational scenarios and measured background concentrations (2016 - 2020).

Time varying cumulative NO_2 and SO_2 results are predicted to be well below the criteria at all sensitive residential and industrial receptors. Incremental increases from the project are negligible when backgrounds concentration are considered. Time varying cumulative results demonstrate that background PM_{10} and $PM_{2.5}$ concentrations dominate cumulative concentrations when the criteria is exceeded. Incremental increases from the FSRU plus LNG carrier at peak load are negligible and will not result in additional exceedances of the criterion and in most cases would not be discernible from the background pollutant levels.

It is important to note that peak demand cases would be infrequent i.e., a few days per month based on market demand and that the peak demand case that has been modelled is for closed loop mode as this would result in higher emissions that the preferred open loop mode and represents a worst-case scenario.

The air modelling assessment using a 90^{th} percentile or time varying background concentration demonstrates that air quality impacts from the FSRU operations would be minor and emissions are unlikely to have regionally or State significant effects on the air environment.

7.3.1.1 Odour

The operation of the FSRU is not expected to generate odour emissions as the anticipated air pollutants do not generate odour. Therefore, an odour emissions assessment was not conducted. In addition, odour associated with the storage and handling of waste will be managed and conducted in accordance with legislative requirements to ensure that there are no odour emissions.

7.3.2 Compliance of air emissions with GED and ERS

To minimise emissions from the FSRU to the extent practicable in accordance with the requirements of the ERS, equipment and the burners in the boilers and engines would undergo regular maintenance as per manufacturer's specifications.

Performance monitoring during the operation phase of the project would include emissions testing of the FSRU and continued ambient air quality monitoring at the Viva Energy Ambient Air Quality Monitoring Station (Viva AAQMS). Emissions testing would be conducted to confirm whether FSRU emission rates comply with design specifications and any operating licence requirements. Ambient air quality monitoring would be used to detect impacts on local air quality from FSRU operations and to ensure that air emissions are consistent with design specifications.

Further information is provided in Technical Report E*: Air quality impact assessment* (refer to Appendix H) and Chapter 14: *Environmental Management Framework* (refer to Appendix D).

7.3.3 BATT air quality management

As part of the FSRU development licence, best available techniques or technology would be demonstrated for activities affecting the quality of the environment such as energy use, greenhouse gas emissions, discharges to air, noise emissions, discharge to surface water and solid waste generation.

From an air quality perspective, BATT design parameters and emission standards would be applied to ensure emissions would be minimised to the extent practicable.

The candidate engines and boilers for the FSRU are the Wärtsilä 6L50DF dual-fuel engine, Wärtsilä 8L50DF dual-fuel engine, and Mitsubishi MAC-90BF boiler. Both the engines and boilers would be run on natural gas with marine diesel oil used only as a pilot fuel and during emergency, maintenance or start-up. The use of natural gas as a fuel, rather than diesel, provides the advantage of considerably lower pollutant emissions. In addition, the candidate engines and boilers have low-NO_x emissions technology that is currently the best in class for natural gas-fired power plants. A comparison of the candidate plant's NO_x emission factors compared with reference plant, is presented in Table 7-11. The Wärtsilä engines and Mitsubishi boiler provide an 80 per cent and 65 per cent respective reduction in NO_x emissions compared with the reference plant (USEPA 2000b). The use of the candidate plant for the project is considered best-practice from an air quality emissions perspective.

Table 7-11 Comparison of NOx emissions: candidate FRSU plant and reference plant

Pollutant	Emission factor (g/kWh)			
	Wärtsilä 6L50DF/ 8L50DF	Reference 4-stroke lean-burn reciprocating engine[1]	MAC-90BF	Reference gas-turbine[2]
NOx	1.2	6.3	0.17	0.49

[1] From AP42 Table 3.2-2 (USEPA 2000b)

[2] From AP42 Table 3.1-1 for uncontrolled natural gas-fired turbines (USEPA 2000a)

7.4 Noise emissions

Preparation of this section of the DL application was based on information provided in the EES Technical Report I: *Noise and vibration impact assessment* (refer to Appendix I). The noise and vibration technical report has undergone Technical Reference Group review (which includes EPA) to ensure that the report adequately addresses the matters set out in the scoping requirements and to ensure that the study sufficiently examines and clearly documents the potential environmental impacts related to the operation of the FSRU.

7.4.1 Summary of noise impacts on human health and the environment emissions assessment

Operational noise produced by the FSRU was identified as having potential to result in adverse effects to the amenity of nearby sensitive receivers:

Key noise sources associated with operation of the FSRU include the regasification boiler exhaust, FSRU engine exhaust, LNG carrier engine exhaust, tugboat exhausts and marine loading arms. It has been assumed that all equipment and facilities will operate 24 hours per day, seven days per week.

Operational vibration produced by the project is not expected to result in human disturbance or structural damage of surface structures. Vibration impacts to above or below ground infrastructure would be controlled by engineering design requirements.

All modelled scenarios during the operation of FSRU are predicted to be within limits set by the Environment Protection Regulations 2021 at sensitive receivers. The noise limits for the night period (10pm to 7am) are the most stringent criteria, and therefore all noise emitting activities will be minimised to the extent practicable.

There is the potential for cumulative noise impacts from nearby existing industries, combined with the noise emissions from the project during operation, at Geelong Grammar, Biddlecombe Avenue and School Road dwellings. However, it is considered highly unlikely that this exceedance would occur as it represents the 'worst case' night time scenario which would involve an LNG carrier moored adjacent to the FSRU operating at full production in closed loop mode with nitrogen trucks unloading nitrogen and nitrogen injection occurring simultaneously at the treatment facility during the night period. The concurrence of all these activities occurring simultaneously would be unlikely and would be managed by scheduling activities accordingly to eliminate the potential for all operational activities to occur at the same time during the night period.

7.4.2 Compliance of noise emissions with GED and ERS

In order to minimise noise emissions to the extent practicable, controls to manage noise from the operation of the FSRU would include (but are not be limited to) the following:

- Preparation of an operational management plan to ensure all activities are correctly scheduled to minimise noise emissions. For example, during the night period, limit the number of activities occurring concurrently
- Additional cumulative impact management strategies would be developed in consultation with the relevant stakeholders
- Operational noise monitoring would be undertaken within the first 3 months of operation to confirm operational noise levels, verify cumulative noise impacts and implement additional mitigation measures if required.

Further information is provided in Technical Report I*: Noise and vibration impact assessment* (refer to Appendix I) and Chapter 14: *Environmental Management Framework* (refer to Appendix D).

7.4.3 BATT noise control measures

The FSRU is designed and constructed in accordance with prevailing requirements and recommendations from authorities such as IMO and the SIGTTO. Therefore, the vessel is equipped with systems and solutions to operate efficiently and limit noise impact on the surrounding environment.

In accordance with IMO requirements, the FSRU is designed to maintain an (external) noise level below 90 dB(A) anywhere on deck. The design features to minimise noise emissions from noise emitting equipment on board the FSRU is summarised in Table 7-12.

Table 7-12 Summary of design features to minimise noise emissions from equipment on board of FSRU

Ref	Noise emitting equipment	Design features
F1	Engine room walls and roof	The four Wärtsilä 50DF dual-fuel engines will be located below deck. A sound pressure level of 95 dB(A) within the engine room is expected based on Hyundai noise level measurements. As the engines are located below deck a reduction of 45 dB(A) is expected due to hull/walls and roof of the engine casing (above deck).
F2	Engine exhaust	The four Wärtsilä 50DF dual-fuel engines will be equipped with silencers installed in the exhaust funnel to limit noise emission levels. The sound power level at the tip of each exhaust opening is assumed to be attenuated to 100 dB(A).
F3	Regasification boiler exhaust	The regasification boilers will be located on the lower deck. Noise breakout from these enclosures is not considered to be a significant noise source on the FSRU.

Ref	Noise emitting equipment	Design features
		The sound power level at the tip of each operating source has been assumed to be no more than 93 dBA.
F4	Control valves	The FSRU will contain six control valves in the regasification area, two control valves on the starboard side deck area and six control valves in steam heater skid area. An assumed combined sound power level of 101 dB(A) has been based on the design requirements to meet the IMO *Code of noise levels on board ships*.

7.5 Water resource use, reuse and discharge to Corio Bay

Preparation of this section of the DL application was based on information provided in the EES Technical Report A: *Marine ecology and water quality impact assessment* (refer to Appendix E).

The marine ecology and water quality impact assessment has undergone an external peer review to ensure that the report adequately addresses the matters set out in the scoping requirements and to ensure that the study sufficiently examines and clearly documents the potential environmental impacts and risks of the operation of the FSRU. The peer review found, overall, the methodology and modelling used were appropriate for the purposes of this EES.

The usual regasification mode of the FSRU for this project is open loop. The open loop regasification mode of operation proposed for the project would involve transfer of the cooled discharge water from the FSRU (approximately 7°C below ambient temperature) via a seawater transfer pipe to the existing refinery seawater intake for reuse in the refinery as cooling water. The marine ecology and water quality impact assessment assessed a number of different operational scenarios including operation of the FSRU in the event that the refinery was permanently decommissioned in the future and the option for reuse of the FSRU discharge water was no longer available. In this scenario, the FSRU would operate in open loop mode, with diffuser discharge to Corio Bay.

The potential impacts of the FSRU with the refinery in operation are discussed in the following sections below:

- Section 7.5.1.1 *Open loop operation with refinery reuse of FSRU discharge*
- Section 7.5.1.3 *Closed loop operation*
- Section 7.5.3.1 *Predicted temperature plumes – closed loop operation*
- Section 7.5.3.2 *Predicted chlorine plumes – closed loop operation*

A separate DL application (refer to DL application no. APP013841) has been prepared for the refinery which describes the potential impacts related to discharges from the four existing refinery discharge outlets.

Further detail on temperature and chlorine related impacts from discharge via the four existing refinery discharge outlets following reuse of FSRU discharge is provided in Section 8.5, Section 8.6, Section 8.8, Section 9.8, Section 9.9 and Section 9.12 of EES Technical Report A: *Marine ecology and water quality impact assessment* (Appendix E).

The potential impacts of the FSRU post decommissioning of the refinery are discussed in the following sections below:

- Section 7.5.1.2 *Open loop operation with diffuser*
- Section 7.5.3.1 *Predicted temperature plumes – peak diffuser discharge*
- Section 7.5.3.2 *Predicted chlorine plumes – peak diffuser discharge and Predicted chlorine plumes – average diffuser discharge*.

Further detail on temperature and chlorine related impacts during diffuser discharge is provided in Section 8.7, Section 9.10 and Section 9.11 of EES Technical Report A: *Marine ecology and water quality impact assessment* (Appendix E).

Proposed licence limits for wastewater discharge (i.e., FSRU discharge water) are outlined in Section 9.0.

7.5.1 Proposed mode of regasification and indicative production profile

7.5.1.1 Open loop operation with refinery reuse of FSRU discharge

The FSRU will require seawater for different purposes during operation. The use of seawater as process water and cooling water is the preferred and most feasible option for operation of the FSRU as it is readily available in large quantities and at low cost compared to other sources of water (e.g., potable water or recycled water).

Most FSRUs around the world operate in open loop mode and discharge directly into the receiving waters in which they are located. In contrast, the usual mode of operation proposed for this project (described below) makes use of the synergy created by having the FSRU proximal to the Viva Energy refinery and provides a significant environmental enhancement through reuse of the FSRU discharge water for refinery cooling purposes.

The usual regasification mode of the FSRU for this project would involve open loop. The open loop regasification mode of operation proposed for the project would involve transfer of cooled water from the FSRU (approximately 7°C below ambient temperature) via a seawater transfer pipe to the existing refinery seawater intake for reuse in the refinery as cooling water.

The refinery currently uses approximately 350 ML/day of seawater for cooling purposes which heats the seawater to approximately 9°C above the entry water temperature of Corio Bay. Reuse of the FSRU discharge as refinery cooling water would reduce the temperature of the warmed seawater discharged to approximately 2°C above the entry temperature when the FSRU discharge rate is 350 ML/day. The FSRU discharge would replace all or some of the seawater intake from Corio Bay by the refinery. If the FSRU seawater output is lower than the refinery requirement for seawater, the refinery would simply draw the remaining volume of seawater through the existing refinery seawater intake and the refinery cooling water discharge would be greater than 2°C above the entry temperature due to less cooled water from the FSRU. Following reuse, the seawater would be discharged via the four existing refinery discharge outlets.

The usual open loop mode of operation proposed is an environmental enhancement as:

- It removes the need for two separate water intakes and two separate discharges from the refinery and the gas import terminal project if they were to be operated independently and without the synergy of co-location
- The project involves no change in the existing refinery seawater intake rate of 350 ML/d, no change to the existing refinery discharge rate of 350 ML/d, no change to the existing refinery chlorine concentration at the four refinery discharge points and a reduction in the temperature of the discharge plumes.

As this application solely relates to the operation of the FSRU, only direct discharges from the FSRU into the marine environment are discussed in this DL application. A separate DL application (refer to DL application no. APP013841) has been prepared for the refinery which describes the potential impacts related to discharges from the four existing refinery discharge outlets.

7.5.1.2 Open loop operation with diffuser

The project also provides for the direct discharge of some, or all, of the FSRU discharge water into Corio Bay via a diffuser located under the Refinery Pier extension.

The diffuser would only be required in the event that the refinery was permanently decommissioned in the future and the option for reuse of the FSRU discharge water in the refinery was no longer available. While the potential impacts of the diffuser have been assessed in the EES to enable its introduction in the event of a refinery closure, there would be no requirement for its use at the commencement of the project as the refinery is planned to be operational at that time.

Consideration was also given to whether there would be any periods where refinery demand for cooling water was lower than the volumes of water being discharged from the FSRU necessitating use of the diffuser for discharge of the surplus water. The only times where there would be potential for this to

occur would be during refinery maintenance shutdowns. The refinery conducts significant maintenance shutdowns on average every second year where up to half of the refinery is taken offline for 2-3 months. During these times, cooling water is still required for the operational part of the refinery and is in the range of 200 – 250 ML/day. Based on this level of demand for cooling water even during refinery maintenance periods and based on the projected seasonal FSRU production rates discussed in Section 7.5.1.4 shown in Table 7-13, the FSRU would still be the primary source of cooling water for the refinery during refinery maintenance and there may be no requirement for diffuser use.

The major planned refinery shutdowns are conducted during spring or autumn every second year and not in winter which is the only time where a surplus of FSRU discharge water would be expected. Based on forecast gas production rates during these times (Table 7-13), the FSRU would be producing an estimated 208 ML/day of discharge water. As such, it is likely that all of the discharge water would still be required by the refinery for cooling purposes during shutdowns with little or no requirement for use of the diffuser. Major refinery shutdowns are planned events with long lead times so there is certainty over the timing and scope of maintenance activity.

On the basis that the refinery is still planned to be operational at the commencement of the project and requiring 350 ML/day of cooling water, and that there are currently no planned major maintenance shutdowns reducing refinery cooling water demand until 2028, construction of the diffuser may occur at some point after the project became operational. In the event that there was the potential for surplus water to be generated, the FSRU production rates and water output would be managed to match the refinery demand of 200-250 ML/day of cooling water if the diffuser was not constructed at the time. A description of the process control logic is provided below for this scenario.

During a refinery maintenance period where there is lower cooling water demand, back pressure control valves would switch from low pressure control selector to flow control selector and restrict the flow of water into the refinery cooling water system. On a separate control loop which responds to high pressure, the header valves on the distributor would open to lower the pressure and this would allow the remaining flow to be discharged via the diffuser. If the diffuser was not constructed at this point in time the pressure on the header valves on the distributor would increase and there would be no diffuser to discharge the flow and lower the pressure. In this case, the high pressure in the header valves would be detected at the FSRU centrifugal water pumps which would subsequently lower the amount of water flow. The control system on the FSRU would automatically detect this and the control loop would reduce the LNG regasification rate. Therefore, an unintended over production request for natural gas would require more water generation than can be handled and would result in safe automatic management of the FSRU output without operator intervention.

In addition to the above, any planned decommissioning of the refinery in the future would provide ample lead time for diffuser construction which would be required for project operation in this situation.

7.5.1.3 Closed loop operation

The project also makes provision for use of the FSRU in closed loop mode which would be utilised in very limited instances where discharge water may not be able to be transferred to the refinery. Closed loop is not preferred as the usual operating mode as it uses up to 2.5% of the LNG cargo to heat the LNG and has higher greenhouse gas emissions than open loop operation. Notwithstanding this, closed loop operation also forms part of the project being put forward for regulatory approvals subject to the outcomes of the EES to enable its use in the limited instances outlined below.

Closed loop operating mode would only be utilised in the unlikely event that the FSRU was unable to discharge water through the seawater transfer pipe to the refinery, for example, during FSRU maintenance or due to a pump or pipe failure. Under this scenario, the refinery would simply revert to its current process of drawing 350 ML/day of cooling water through the existing refinery intake and discharging through its existing discharge points consistent with its operating licence and the FSRU would operate in closed loop mode. The reason that closed loop operation would be utilised in this eventuality is that it does not involve an ongoing water intake (after initial intake of approximately 500 m^3 of seawater) or have any ongoing water discharge from the FSRU associated with the regasification process as the seawater is continuously recycled within the FSRU. This is important as the EES has not assessed the refinery and the FSRU operating independently and in parallel with separate seawater intakes and discharges in operation at the one time.

The potential impacts associated with the closed loop regasification mode have been assessed in detail in the EES.

7.5.1.4 Indicative production profile

The estimated gas production profile for the project is shown in Table 7-13. This indicative profile is based on typical gas demand rates throughout the year. The FSRU is anticipated to produce up to 500 TJ/day of gas which would require approximately 300 ML/day of seawater for the regasification process. On a limited number of peak demand days, the gas production rate would fluctuate throughout the day, but the maximum daily flowrate of seawater would be 350 ML/day.

Table 7-13 Estimated rates of gas production throughout the year

Season	Estimated gas production (TJ/day)	Number of regasification trains	Seawater consumption (ML/day)
Summer (Dec – Feb)	250	1	148
Autumn (Mar – May)	350	2	208
Winter (Jun – Aug)	500	2	300
Spring (Sept – Nov)	350	2	208

The three operating modes for the FSRU outlined in this section are being put forward for regulatory approvals subject to the outcomes of the EES and provide flexibility and an ability to respond to changing circumstances. The potential impacts associated with all three operating modes have been thoroughly assessed in Technical Report A: *Marine ecology and water quality impact assessment* (Appendix E) and are considered to be able to meet the evaluation objectives established for the EES. A summary of the potential marine ecology and water quality impacts is provided in Section 7.5.3.

7.5.2 FSRU water use

During operation, the FSRU would use seawater for a range of purposes, with regasification being the primary water using activity as described in previous sections. The FSRU water usage rate for regasification would vary depending on the mode of operation and the rate of gas production.

In addition to regasification, the FSRU would use seawater for the following purposes during operation:

- emergency fire water
- water curtain (a spray to ensure there is no direct contact between LNG carriers and the hull of the FSRU in the event of an LNG spill)
- cooling water for machinery (main generator and auxiliary cooling water)
- ballast water during LNG transfer.

Cooling water from the generators and auxiliary machine systems would be redirected to the open loop regasification cycle for reuse rather than being directly discharged to Corio Bay.

Ballast water would be taken on to the FSRU as well as discharged from FSRU to maintain vessel stability and longitudinal strength. During regasification, the FSRU would take in seawater as ballast to compensate for the reduction of LNG volume in the cargo tanks. The ballast water would then be discharged to sea during LNG transfer from the next visiting LNG carrier. LNG carriers would arrive full of LNG and would not need to discharge ballast water on arrival. As the LNG carrier unloads their cargo, they would take on ballast water to compensate for the reduction in cargo volume.

Periodic and continuous seawater flows associated with FSRU water usage during operation in open loop and closed loop are outlined in Table 7-14. The seawater consumption rates for open loop are based on the proposed winter gas production rate of 500 TJ/day. Seawater intake and discharges for combined loop would be the same as for open loop.

Table 7-14 FSRU seawater use

Water usage	Assumptions	Maximum consumption rates (ML/day)		Temperature difference
		Open loop	Closed loop	
Periodic flows				
Ballast water during LNG loading	Maximum ballast capacity	42	42	-
Water curtain	-	4.5	5.8	-
Fire water	Fire water system would be tested for 1 hour every 2 weeks	1.6	1.6	-
Continuous flows				
Heating for regasification operation	Based on gas production rate of 500 TJ/day	300	-	-7°C
Cooling of freshwater generators	-	2.1	2.1	+8°C
Regas backflush filter	Regas filters would be flushed for 1 hour each day	0.6	-	-
Cooling of auxiliary machinery systems	-	-	45.5	+5°C
Cooling of main generators	-	-	16.6	+7.5°C
Cooling of atmospheric dump condenser	The temperature difference is based on full steam dumping. If all excess BOG can be exported to shore through BOG management, steam dump is not required, and the dump condenser seawater cooling system would not be running.	-	80.4	+16.5°C

7.5.3 Summary of marine ecology and water quality impacts

This section summarises the potential impacts from direct discharge into the marine environment during operation of the FSRU including discharge via a diffuser during operation in open loop mode as well as direct discharge from the FSRU during operation in closed loop mode. Technical Report A: *Marine ecology and water quality impact assessment* (Appendix E) conducted to support the project EES provides more detailed information on the investigations and impact assessments conducted in response to the EES scoping requirements.

7.5.3.1 Temperature

This section describes the potential impacts on the marine environment associated with warm or cool water discharges (dependent on operating mode of FSRU) into Corio Bay during operation of the project.

Predicted temperature plumes – peak diffuser discharge

The backup discharge arrangement for the project would involve discharge from the FSRU directly into Corio Bay through a diffuser located under the new pier. The diffuser would be used to discharge excess seawater during refinery maintenance periods when the rate of FSRU discharge could exceed the refinery demand for seawater or in the event that the refinery was permanently decommissioned in the future and the option for reuse of the FSRU discharge water was no longer available. A full refinery shut down was assumed as a worst case for modelling this scenario. However, in reality, the maintenance regime at the refinery involves one half of the refinery being taken offline for 2-3 months

every second year with the other half of the refinery remaining operational. When in a maintenance period with half of the refinery offline, cooling water demand is still in the range of 200-250 ML/day. Based on the projected FSRU seasonal production rates, it is likely that the FSRU would still be the primary source of refinery cooling water even during maintenance periods as winter is the only season where FSRU discharge materially exceeds the refinery cooling water demand of 200-250 ML/day. However, refinery maintenance is typically conducted in spring and autumn, not winter, so it is unlikely that there would be surplus FSRU discharge water during winter. As such, the diffuser is likely to be used on limited occasions.

Notwithstanding the above, in this modelled worst-case scenario the FSRU would operate in open loop mode using 350 ML/day and would discharge all of the cooled seawater (approximately 7°C below ambient temperature) through a 300 m long diffuser with 100 small high-velocity ports and located 0.5 metres below Lowest Astronomical Tide (LAT) under the new pier extension.

The diffuser would be designed to achieve high dilution and to ensure that the diluted discharge has a temperature change of less than 0.4°C from ambient. The high-velocity ports would discharge the seawater at around 5 metres per second (m/s) and at an angle of 30° away from the underside of the pier. The cool seawater would be spread out across a number of outlets rather than being concentrated directly from a single point of discharge on the FSRU. This configuration would result in greater mixing and dilution. The predicted dilution in this case is 20:1 which means that there would be 20 parts of seawater for every 1 part of discharge.

As the diluted plume is cooler water, it is slightly more dense than ambient seawater and would form a plume of diluted effluent, about 3 m thick, on the seabed in the dredge shipping channel. Figure 7-6 shows the predicted 50-percentile (median) temperature difference at the seabed for the future peak diffuser discharge case. The temperature of the plume on the seabed would be between 0.4 to 0.8°C below ambient temperature and the plume would form over an area of approximately 65 ha on the seabed at 10-13 m water depths. There would be negligible change in water temperature on the surface and at mid-depth of the water column. The temperature plume does not reach the Ramsar site including Limeburners Bay.

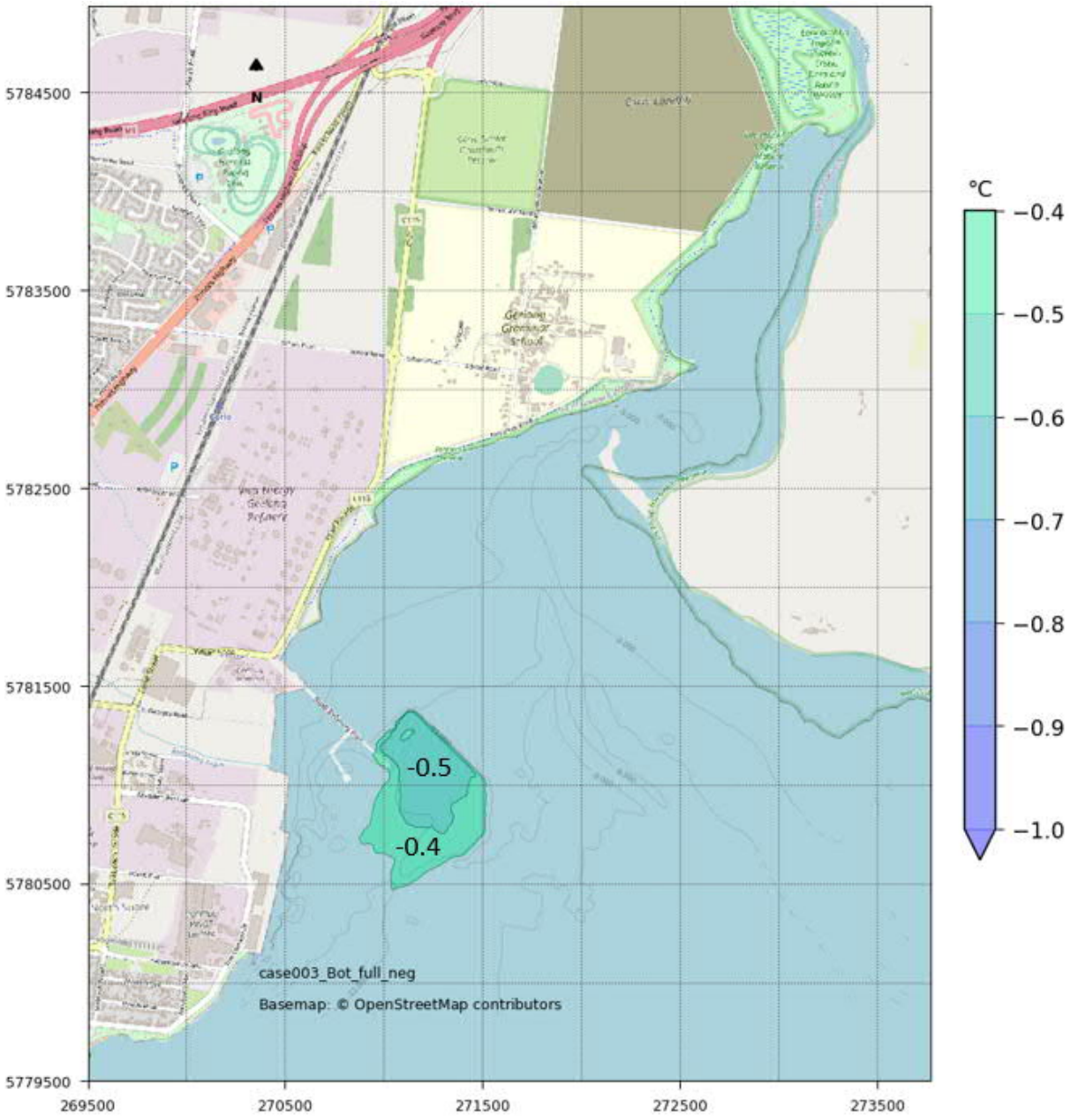


Figure 7-6 Predicted 50th percentile (median) temperature change – future peak diffuser discharge case

Predicted temperature plumes – closed loop operation

The FSRU can also operate in closed loop mode where seawater is recycled within the FSRU rather than being discharged. Closed loop mode would only ever be used in the event that the discharge water was unable to be piped to the refinery due to FSRU maintenance or an issue with the pipeline, pumps or the like. Closed loop would be used in this instance as the EES has not assessed both the refinery and FSRU operating in parallel with separate water intakes and discharges.

Closed loop regasification would use gas-fired steam boilers to heat a closed loop of circulating seawater within the FSRU as an intermediate heating medium for heat exchange in the LNG regasification trains. Around 500 m^3 of seawater from Corio Bay would be required to fill the FSRU heat exchange piping. The seawater would then be continually circulated in the heat exchange process instead of being discharged from the FSRU as per open loop mode. Seawater would only be discharged to Corio Bay through two small pipes at the rear of the FSRU when switching back to open

loop when the issue preventing discharge to the refinery was rectified. Discharged seawater from the closed loop process would be around 5 ºC warmer than the ambient water temperature.

Figure 7-7 show the predicted 90-percentile (peak) temperature difference at the surface for the future closed loop operation scenario. The temperature contours plotted are 0.6°C, 0.7°C, 0.8°C and 0.9°C above ambient temperature. The maximum predicted temperature rise for operation in closed loop mode would be less than 1°C. In summary, the temperature plume for the closed loop operation is smaller than the existing plume from the refinery discharge and less intense, as the maximum temperature rise is less than 1°C outside a small mixing zone. The temperature plume does not reach the Ramsar site including Limeburners Bay.

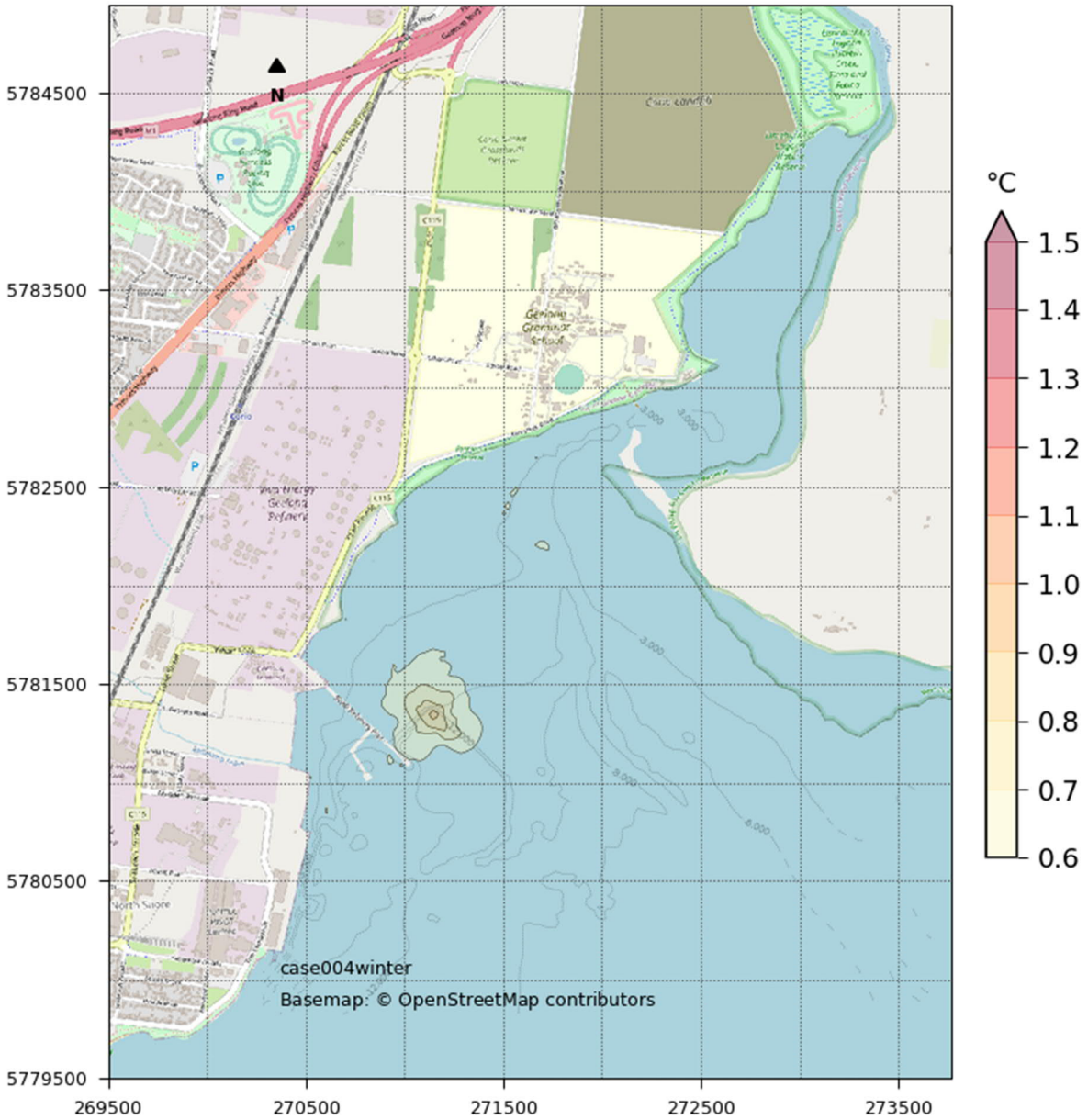


Figure 7-7 Predicted 90th percentile (peak) temperature change – future closed loop operation case

Threshold limits for seawater temperature change

The Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) list temperature as a stressor of aquatic ecosystems and the potential effects as a "*Loss of native biota*".

Aquatic ecosystems are regulated by temperature. Biota, and physical and chemical processes, such as oxygen solubility and hydrophobic interactions, are sensitive to temperature changes. Large changes in temperature occur naturally as part of normal diurnal (daily) and seasonal cycles.

Growth, metabolism, reproduction, mobility and migration patterns can be altered by changes in water temperature. Fauna endeavour to remain near the centre of their tolerance range. High temperatures (usually over 40°C) and low temperatures (usually under 5°C) are considered deleterious. Current discharges from the refinery do not enter the deleterious ranges and the modelled discharges from the project for any of the FSRU operating modes/discharge locations would not enter the deleterious ranges. As such, the marine discharges associated with the project are not considered to have any adverse impacts on marine biota. The temperature plumes from the project, do not extend to the Ramsar site or have any impact on ambient water temperature within the site.

A mixing zone is an area where an effluent discharge undergoes initial dilution close to the point of the licenced discharge point and where threshold or guideline values would be exceeded. The size and extent of the mixing zone would be designated in the EPA licence. The Australian and New Zealand Environment and Conservation Council (ANZECC) 2000 Guidelines were used to derive appropriate threshold temperature change limits at the edge of the mixing zone as a function of depth. The limits were derived based on the natural temperature variations within Corio Bay. Table 7-15 summarises the adopted threshold limits for seawater temperature change as a function of water depth. The limits are widest at the water surface (the intertidal zone) at -3/+3°C and decrease to -2/+2.5°C in shallow water (0 to 2 m depth). The adopted threshold limits are more stringent in deeper water at -1/+2°C in water between 2 to 5 m depths and +1/-1°C for depths beyond 5 m.

Table 7-15 Threshold limits for seawater temperature changes

Depth	Cooling limit (°C)	Warming limit (°C)
Intertidal	-3	+3
0 – 2 m	-2	+2.5
2 – 5 m	-1	+2
5 – 15 m	-1	+1

The cool diffuser plume would sit in deeper waters where the -1°C would apply at the edge of the designated mixing zone. The predicted temperature within the 65 ha cool plume on the seabed for discharge through the diffuser would be between 0.4 to 0.8°C below ambient temperature and would therefore satisfy the derived threshold limits during project operation.

This section has outlined the results of modelling undertaken to predict the temperature plume associated with the operational modes of the FSRU. Under all operational modes, the discharge water meets guideline values.

7.5.3.2 Chlorine

This section describes the potential impacts on the marine environment associated with chlorinated discharges into Corio Bay during operation of the project. Chlorine is used to control biofouling in the refinery cooling water system at present and would also be used in the FSRU for the same purpose. The chlorine would be converted by natural chemical transformation to other chlorine produced oxidants (CPO) such as bromoform through a series of rapid reactions as it travels through pipes and heat exchanges and would be subsequently discharged at low concentrations to Corio Bay. The residual chlorine discharged into Corio Bay from the project would be at the same levels as currently discharged from the refinery as the FSRU discharge water would be reused in the refinery as cooling water with the same amounts of chlorine dosing and discharged from the exiting refinery discharge points.

Guideline value of chlorine in the marine environment

As described earlier, a mixing zone is an area where an effluent discharge undergoes initial dilution close to the point of the licensed discharge point and where threshold or guideline values would be exceeded. The size and extent of the mixing zone would be designated in the EPA licence. The guideline value for chlorine was determined by considering the Victorian EPA Environment Reference Standard (ERS), the Australian and New Zealand Guidelines for Fresh and Marine Water Quality

(ANZG) and a recent Commonwealth Scientific and Industrial Research Organisation (CSIRO) paper specifically addressing the chlorine limit in marine waters (Batley and Simpson, 2020).

The ERS is a fundamental component of the *Environment Protection Act 2017 (Vic)* (EP Act). While the ERS does not specify a limit for chlorine, the EP Act introduces a new permissions scheme including the requirement for a development licence and operating licence for the operation of the FSRU where chlorine limits could be specified. The ANZG lists a chronic guideline value for chlorine in freshwater of 3 µg/L, however, does not list a guideline value for chlorine in marine water.

Batley and Simpson (2020) published a Guideline Value for chlorine in seawater in 2020 using the method of derivation described in ANZG. Batley and Simpson plotted a species sensitivity diagram as shown in Figure 7-8, using data from short-term (mostly 48-hour or 96-hour) toxicity tests in marine waters with renewal of chlorine. The exposure period to chlorine in the tests was mostly 96 hours, but some tests with a lower exposure time were also included.

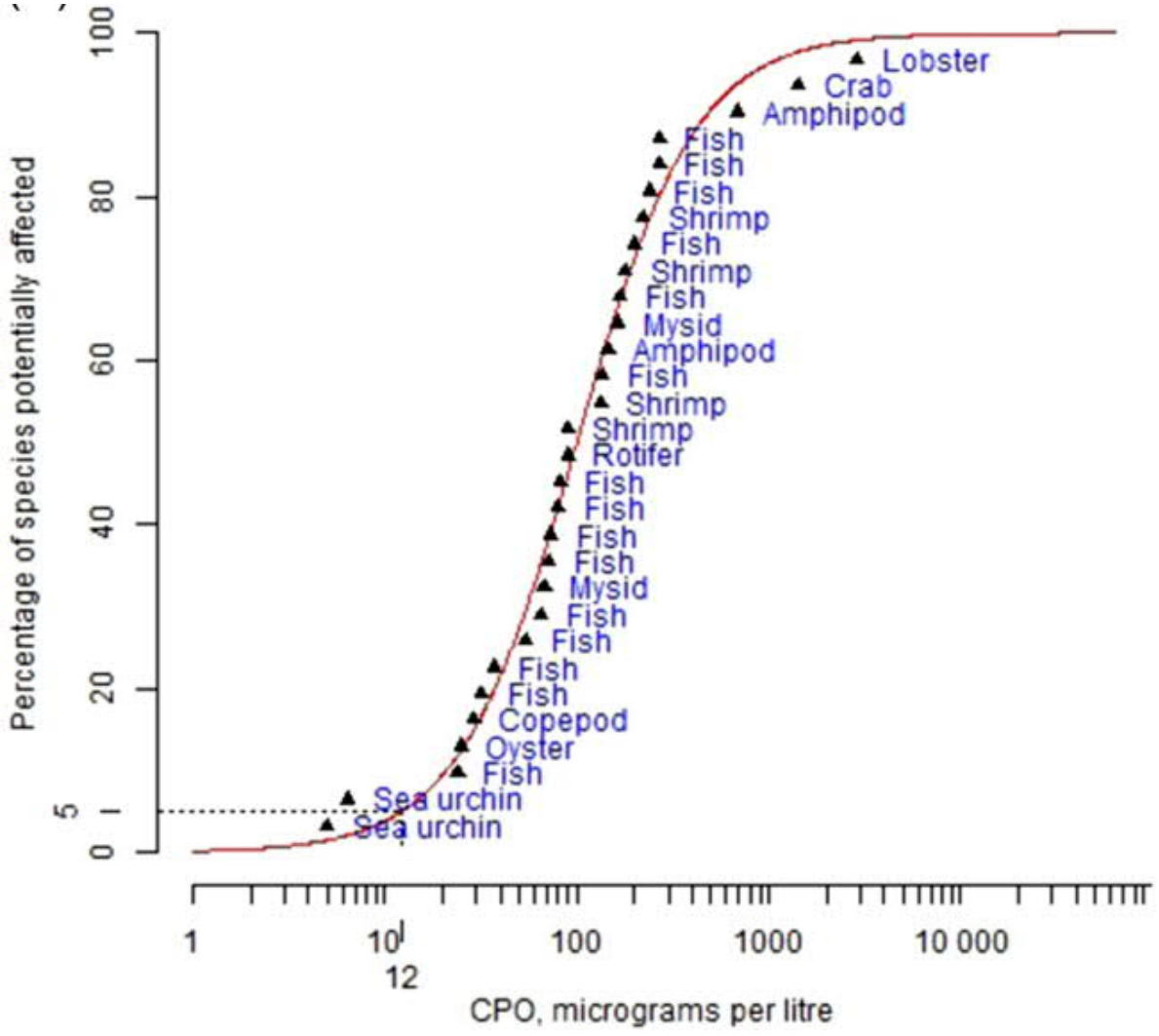


Figure 7-8 Species sensitivity diagram for effects of chlorine

The tests with the two lowest CPO levels were for sea urchins. Threshold CPO concentrations which would apply over a period of 24 hours were determined to be

- CPO of 3.7 µg/L for 99% species protection
- CPO of 12 µg/L for 95% species protection
- CPO of 21 µg/L for 90% species protection

To convert the Lethal Concentration 50 (LC50) (i.e., the concentration of CPO in seawater that would be lethal to 50% of species in a single exposure) to a no or low effect concentration (Lethal Concentration 10 (LC10)), a factor of 0.6 was applied by Batley and Simpson.

According to the guidelines the level of species protection that applies to an aquatic ecosystem depends on the existing conditions (current or desired health status of an ecosystem relative to the degree of human disturbance. The 95% species protection applies to Corio Bay as it is classified as a slightly to moderately modified environment. The guideline value for CPO in Corio Bay at the edge of the designated mixing zone is therefore 7.2 µg/L (95% species protection 12 µg/L x 0.6).

As the Geelong refinery has been discharging chlorine into Corio Bay for more than 60 years, it provided an opportunity to assess the potential impacts on the marine environment from these existing discharges. This is particularly relevant as the chlorine discharge from the project, after the FSRU water is reused in the refinery for cooling water, will be at the same levels as the current refinery discharges.

Field surveys in Corio Bay conducted for this study show very large numbers of sea urchins breeding in the current refinery mixing zone in waters with 5 to 10 µg/L of CPO (see Figure 7-9). This is of interest in that sea urchins are considered to be the most sensitive sea animal to chlorine as outlined above in the discussion on toxicity. It is possible that the laboratory test does not represent what happens in nature, and that the sea urchin results in the species sensitivity diagram are artificially low. The impact assessment for the project has been conducted on the basis that the guideline value for CPO in Corio Bay is 7.2 µg/L.



Figure 7-9 Sea urchins in Corio Bay under the refinery plume

Predicted chlorine plumes – peak diffuser discharge

As described in previous sections, the backup discharge arrangement for the project would involve discharge from the FSRU directly into Corio Bay through a diffuser located under the new pier. The diffuser would be used to discharge excess seawater during refinery maintenance periods in the event that the rate of FSRU discharge exceeded the refinery demand for seawater or in the event that the refinery was permanently decommissioned in the future and the option for reuse of the FSRU discharge water was no longer available. A full refinery shut down was assumed for this scenario which is highly conservative as refinery maintenance occurs every second year with half the refinery being taken offline and the other half operating and still requiring cooling water in the range of 200-250 ML/day. As such, it is highly unlikely that the diffuser would operate at maximum discharge rates as the FSRU will still be piping most or all of its discharge water to the refinery even during maintenance periods. Based on FSRU production rates outlined in an earlier section, the winter months are the only period when there

is potential for the FSRU to generate more water than required by the refinery during maintenance. However, refinery maintenance is typically conducted in spring or autumn so the need for discharging through the diffuser in winter is unlikely.

In this scenario the FSRU would operate in open loop mode using 350 ML/day and would discharge the seawater (with a residual CPO concentration of up to 100 µg/L) through a 300 m long diffuser with 180 small high-velocity ports and located 0.5 metres below Lowest Astronomical Tide (LAT) under the new pier extension.

The diffuser for cool water discharge from the FSRU would be designed to achieve a minimum initial dilution of 20:1 to ensure that the diluted discharge has a chlorine concentration less than the guideline value.

The diffuser would be designed to achieve high dilution and to ensure that the diluted discharge has a chlorine concentration less than the guideline value of 7.2 µg/L. The high-velocity ports would discharge the seawater at approximately 5 metres per second (m/s) and at an angle of 30° away from the underside of the pier. This configuration would result in greater mixing and dilution. The predicted dilution in this case is 20:1 which means that there would be 20 parts of seawater for every 1 part of discharge.

Initial dilution of 20:1 would reduce the chlorine level from 100 µg/L to 5 µg/L. Figure 7-10 shows the predicted 50-percentile (median) CPO concentration at the seabed (as the cooler seawater would sink) for this scenario. The entire plume on the seabed would have CPO concentrations below 5.4 µg/L which is well below the 7.2 µg/L guideline value for chlorine in marine waters. The chlorine plume would be localised would not reach the Ramsar site including Limeburners Bay.

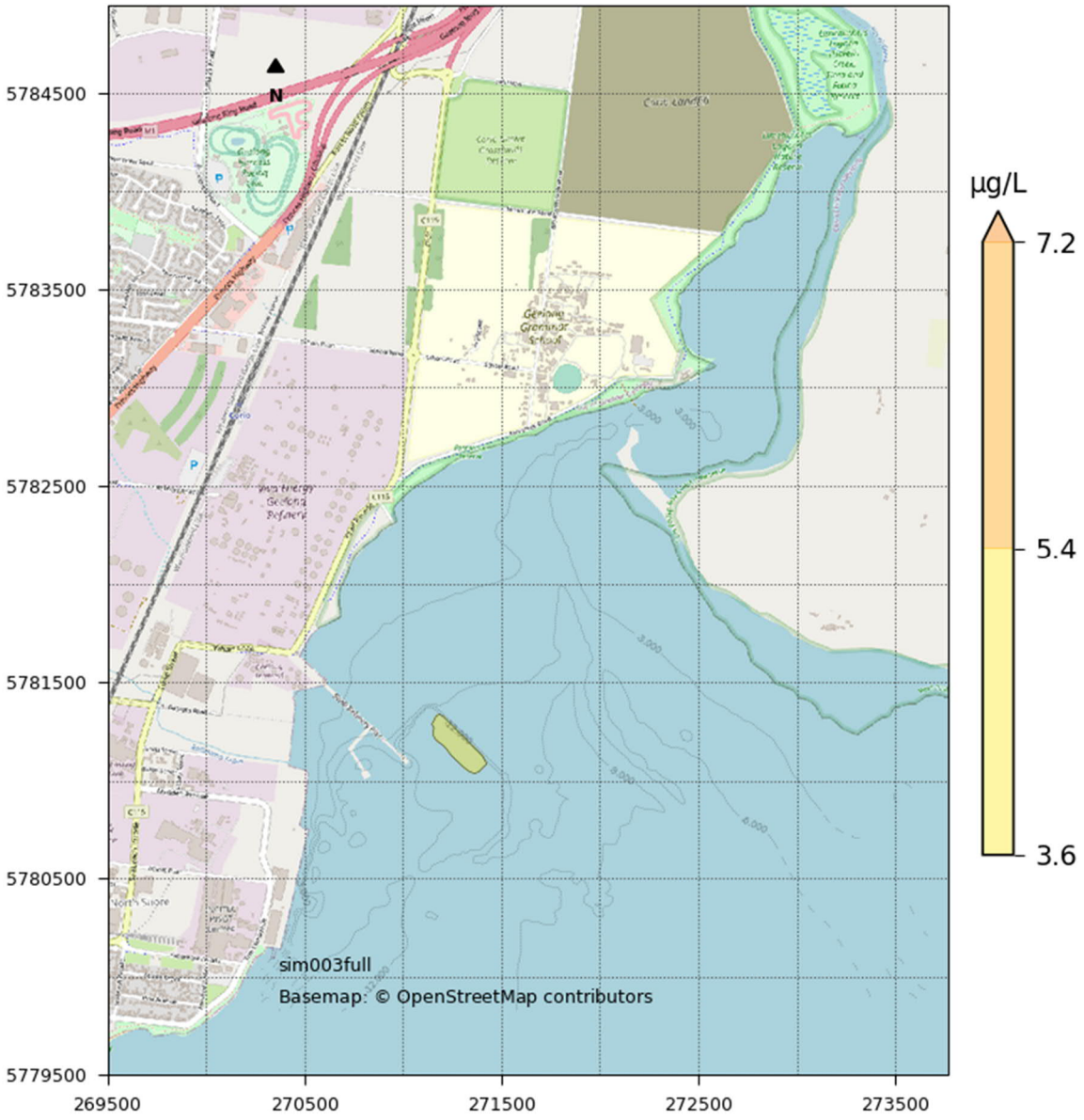


Figure 7-10 Predicted 50th percentile (median) chlorine plumes – future peak diffuser discharge

Predicted chlorine plumes – average diffuser discharge

In this scenario the FSRU would operate in open loop mode using 250 ML/day and would discharge the seawater (with a residual CPO concentration of up to 100 µg/L) through the diffuser. The diffuser is 300 m long however, during the average flow scenario only 240 m of the diffuser would be used to maintain a high port velocity.

Figure 7-11 shows the predicted 50-percentile (median) CPO concentration at the seabed (as the cooler seawater would sink) for this scenario. The plume for this scenario would have chlorine concentrations in the range of 4 to 5 µg/L and would encompass a total area of 2.8 ha on the seabed. The plume would spread out in the deep waters of the channel; however, the spatial extent would be limited by the decay of chlorine compounds in the plume. As with the peak diffuser discharge scenario discussed in the previous section, the entire plume on the seabed would have CPO concentrations below 5 µg/L which is well below the 7.2 µg/L guideline value for chlorine in marine waters. The chlorine plume would be localised and would not reach the Ramsar site including Limeburners Bay.

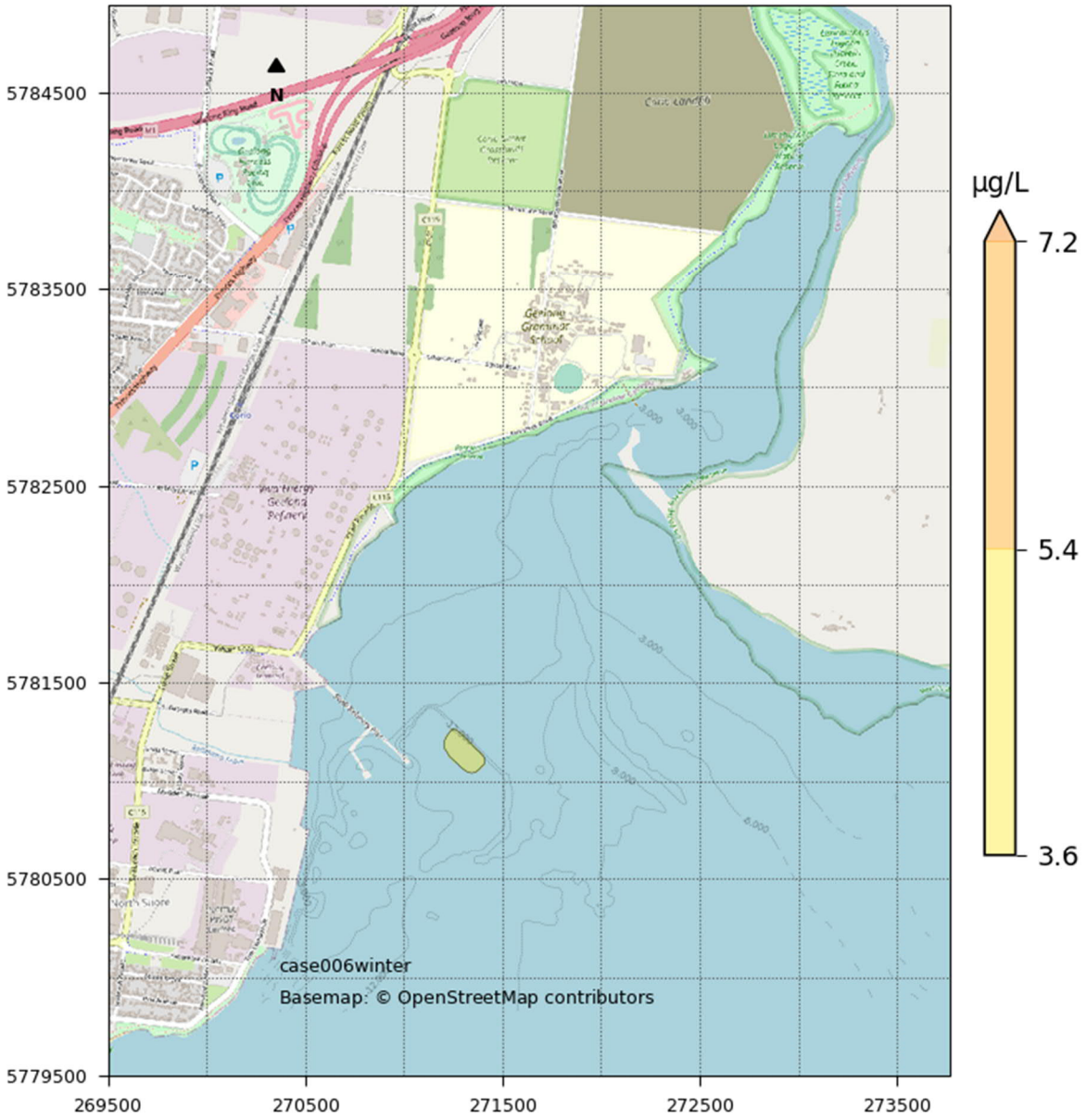


Figure 7-11 Predicted 50th percentile (median) chlorine plumes – future average diffuser discharge

Predicted chlorine plumes – closed loop operation

As described in previous sections, the FSRU can also operate in closed loop mode (water recycled within the FSRU) whereby a proportion of the LNG would be regasified using LNG-fired boilers on the FSRU. This mode of operation would be used in the event that either maintenance on the FSRU or an operational issue precluded seawater to be piped to the refinery. As such, it is expected that closed loop operating mode would rarely be utilised.

In this scenario the FSRU would operate in closed loop mode as the EES has not assessed the impacts of the refinery and FSRU operating in parallel with their own seawater intakes and discharges. Closed loop regasification would use gas-fired steam boilers to heat a closed loop of circulating seawater within the FSRU as an intermediate heating medium for heat exchange in the LNG regasification trains. Around 500 m^3 of seawater from Corio Bay would be required to fill the FSRU heat exchange piping. The excess heat generated by closed loop operation would be discharged as a warm water plume at approximately 5°C above ambient temperature with residual chlorine concentrations at 100 µg/L

through two small pipes at the rear of the FSRU and only at the point when the vessel was switching back to open loop operating mode.

Figure 7-12 shows the predicted 50-percentile (median) CPO concentration at the surface for the closed loop operation scenario. The maximum CPO concentration within the plume would be less than 5 µg/L which is well below the 7.2 µg/L guideline value for chlorine in marine waters. The chlorine plume would be localised and would not reach Limeburners Bay or the Ramsar site.

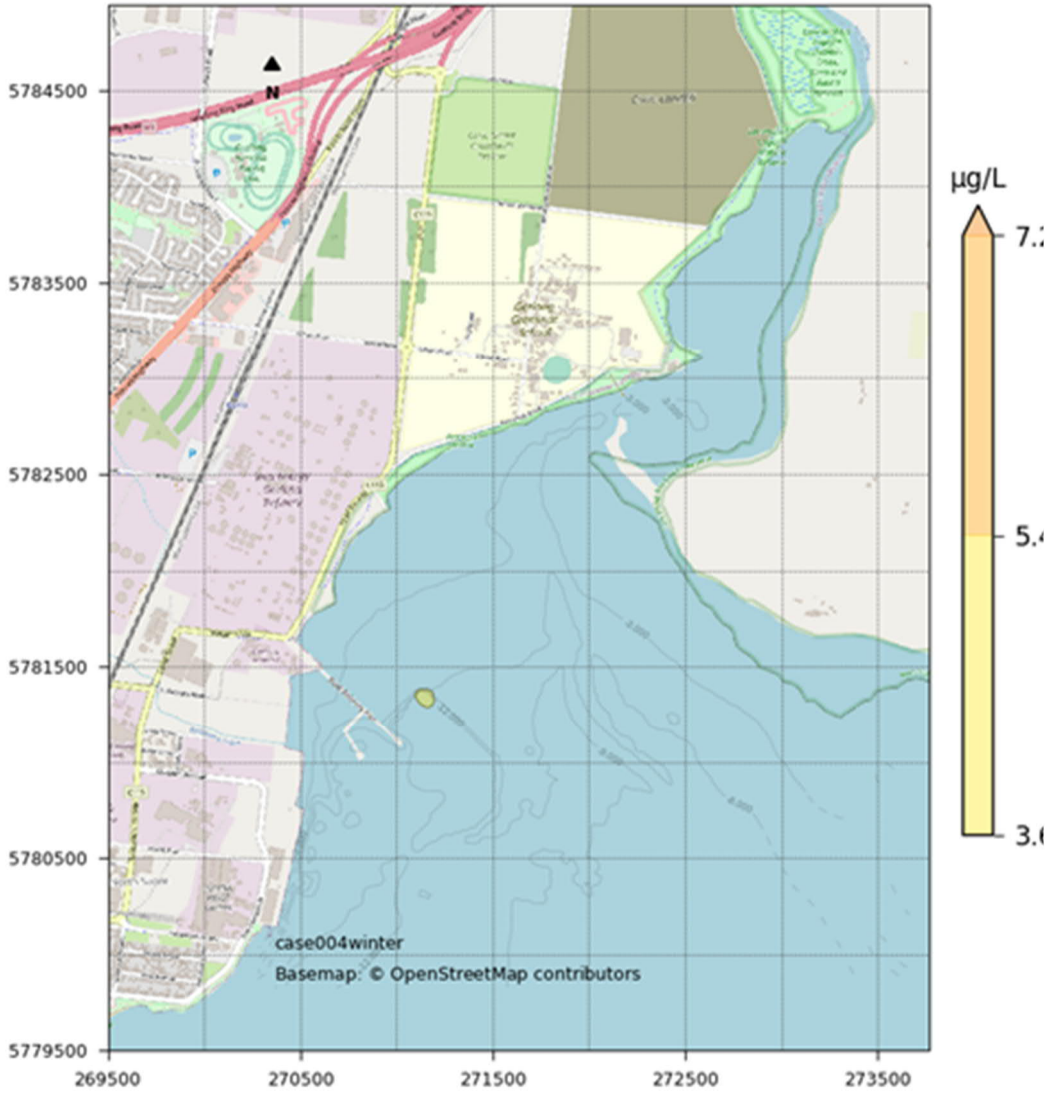


Figure 7-12 Predicted 50h percentile (median) chlorine plumes – future closed loop operation case

7.5.4 Compliance of water resource use with GED and ERS

To minimise potential impacts to the marine environment so far as reasonably practicable during the operation of the FSRU, controls that would be implemented include:

- Maximising the reuse of discharge from the FSRU in the refinery to be consistent with existing discharges that have been occurring for over 60 years
- Designing the seawater intake to minimise the entrapment of small and large fish, and other free-swimming biota
- Locating the seawater intake on the FSRU at least 2 m below the water surface, and at least 2 m above the seabed, to minimise entrainment

- Design of the diffuser for cool water discharge from the FSRU to achieve a minimum initial dilution of 20:1
- Use of well-established measures to control and minimise the introduction of marine pests
- Maintenance of the FSRU anti-foul coating to avoid contamination impact
- Use of a well-established spill management plan, which would be upgraded as required to include operation of the FSRU
- Managing the seawater chlorination process at the FSRU to minimise the concentration of chlorine in seawater
- Monitoring of flow rate, temperature, and residual chlorine from all major discharges from the FSRU. Monitoring will be conducted to keep a record of all discharges, confirm that the discharge rate and chlorine concentration are within the values stipulated in the EPA licence conditions and, if not, provide the trigger for remedial action.

Further information is provided in Technical Report A: *Marine ecology and water quality impact assessment* (refer to Appendix E) and Chapter 14: *Environmental Management Framework* (refer to Appendix D).

7.5.5 Managing stormwater run-off discharges

The FSRU does not require a detailed stormwater management assessment as it will be continuously moored at Refinery Pier.

The deck of the FSRU is equipped with deck scuppers to collect stormwater, sea spray and wash water. The scuppers are closed during normal operation and opened during a rain event, storm or during testing of the firewater system to allow the water to drain overboard. Equipment on the FSRU deck that may be subject to oil spills or leaks are equipped with coamings to collect and contain spills. The coamings and scuppers will be regularly inspected for oil spills and any contaminated water.

Any contaminated water from the deck will be collected and manually pumped to the bilge holding tank which would then either be discharged to shore/barge for off-site disposal by a licensed waste contractor or sent to the oily bilge separator on board the FSRU where the bilge water will be treated to an oil content of less than 15 part per million (ppm). Oil is sent to the Oily Bilge Tank and treated water is sent to the Clean Bilge Holding Tank prior to off-site disposal by a licensed waste contractor.

Small volumes of stormwater runoff from the sides of the FSRU into Corio Bay are expected. Due to the small volume of stormwater run-off discharges, potential impacts of these discharges on the receiving environment have not been assessed. The risk of oil spills or leaks on the deck of the FSRU is considered low as the equipment located on the deck of the FSRU that may be sources of oil spills or leaks have been minimised. In addition, these pieces of equipment (e.g., winches or cranes) contain small inventories of oil.

7.6 Land and groundwater

The proposed activity does not involve an emission or discharge to land or groundwater.

7.7 Waste

Industrial waste generated during operation of the FSRU including, but not limited to wastewater, sludge and bilge water will be managed in accordance with EP Act, Environment Protection Regulations, any supporting legislation and would need to consider the GED. The Environment Protection Regulations provide detail on how waste should be classified (Schedule 5) and categorised (Schedule 6) where required. Once categorised, waste can only be sent to a place authorise to receive that waste.

Operation of the FSRU in open loop mode will result in the generation of a maximum of 350 ML/day of industrial wastewater (L200) which will be transferred to the existing refinery seawater intake via a seawater transfer pipe for reuse in the refinery as cooling water. The reuse of discharge from the FSRU in the refinery for cooling water purpose will be maximised to minimise potential environmental impacts and to manage industrial waste in line with the waste management hierarchy. Following reuse within the

refinery, the industrial wastewater will be discharge back into Corio Bay via 4 existing licenced discharge outlets. A separate Development Licence (refer to DL application no. APP013841) is required for the refinery to discharge or deposit industrial wastewater from another source (FSRU).

Only small quantities of other industrial waste are expected to be generated during the operation of the FSRU, however this would likely include priority waste and reportable priority waste (refer to Section 7.7.2).

Both priority waste and reportable priority waste are industrial wastes which require additional controls due to their higher levels of risk to human health and the environment. Reportable priority waste carries the highest level of controls. Duties specific to reportable priority waste include reporting to EPA each time the waste is exchanged (waste tracking) and transport only in permitted vehicles.

7.7.1 Management of FSRU waste

The FSRU is classed as an oceangoing LNG carrier and is required to follow MARPOL regulations. This implies that while the FSRU is anchored/moored the vessel is not allowed to discharge any potentially oily water (e.g., bilge) to sea, even though the water would be treated in a separator to have an oil content below 15 parts per million (ppm).

Produced bilge water, grey water, sludge and sewage would be collected, treated as required and stored in holding tanks onboard the FSRU. The tanks would be emptied periodically to a barge or truck via flexible connections or piped onshore, and the content sent to an external authorised treatment plant.

A sludge tank would collect sludge from marine diesel oil (MDO) and lube oil (LO) purifiers. The sludge would then either be pumped to deck for discharge to shore, or pumped to a Sludge Dewatering Unit where the sludge would be separated into bilge water and pumped to the Bilge Holding Tank and oil residue which would be pumped to the Oily Bilge Tank

The Oily Bilge Tanks would contain oil residue from drains, drip trays, oil separators, sludge dewatering unit. The oily bilge (sludge) would be pumped to deck for discharge to a barge or truck for offsite disposal.

Bilge water is collected in a dedicated holding tank. From here it may either be pumped to deck for discharge to a barge or truck for offsite disposal or pumped to the Oily Bilge Separator where the bilge water would be treated to an oil content of less than 15ppm and sent to the Clean Bilge Tank. Oil discharge from the separator would be sent to the Oily Bilge Tank.

FSRU waste would be managed with a waste management system that will be established as part of the broader Environment Management Plan, in accordance with the EP Act, Environment Protection Regulations, any supporting legislation and the GED.

7.7.2 Summary of waste generation

A summary of the waste that is anticipated to be generated through the operation of the FSRU is provided in Table 7-16.

Table 7-16 Summary of waste generated from FSRU operation

Waste type	Likely Classification	Volume	Source	Destination
FSRU discharge water	Industrial wastewater (L200)	350,000 m^3/day	Industrial wastewater generated as a result of the regasification process on board the FSRU during operation in open loop mode.	FSRU discharge will be transferred to the existing refinery seawater intake via a seawater transfer pipe for reuse in the refinery for cooling water purposes.

Waste type	Likely Classification	Volume	Source	Destination
Grey water	Priority waste	300 – 400 m^3/month	Wastewater generated in accommodation and office facilities on board the FSRU from sources without faecal contamination (i.e., sinks, showers, baths, washing machines and dishwaters etc.).	Grey water will be stored in a holding tank on board of the FSRU prior to off-site treatment at a lawful place and disposal by a licensed waste contractor.
Black water	Priority waste	30 m^3/month	Wastewater generated in toilets on board the FSRU.	Black water will be treated in the Sewage Treatment Plant (STP) on board the FSRU in accordance with relevant Commonwealth and State regulations, and the IMO/ Australian Maritime Safety Authority (AMSA) regulations and subsequently stored in a treated sewage holding tank prior to off-site disposal by a licensed waste contractor.
Sludge	Reportable priority waste	15 – 25 m^3/month	Sludge from liquid fuel and lubricant oil purifiers, as well as oil residue from drain, drip trays, oil water separators and the sludge unit produced during ongoing operation of the FSRU.	The sludge will be collected in holding tanks on board the FSRU prior to off-site treatment and disposal by a licensed waste contractor. This is likely to be reportable priority waste under the Environment Protection Regulations and will be subject to waste tracking and will only transported by permitted vehicles.
Bilge water	Reportable priority waste	70 – 100 m^3/month	Wastewater generated in the bilge of the FSRU (lowest space of the ship) and does not drain off the side of the deck.	Bilge water will be collected in a holding tank on board of the FSRU, which would then either: 1) be pumped to deck for discharge to shore/barge for off-site disposal by a licensed waste contractor, or 2) sent to the Oily Bilge Separator where the bilge water will be treated to an oil content of less than 15 part per million (ppm). Oil is sent to the Oily Bilge Tank and treated water is sent to the Clean Bilge Holding Tank prior to off-site disposal by a licensed waste contractor. This is likely to be reportable priority waste under the Environment Protection Regulations and will be subject to waste tracking and will only transported by permitted vehicles.
Mixed solid waste	Industrial waste	Unknown	Mixed solid waste (such as food scraps, paper, glass, packaging and other recyclables) generated from accommodation and office facilities on board of the FSRU.	All solid wastes produced on-board the FSRU will be collected and disposed of by a licensed waste contractor.

Industrial wastewater generated onboard the FSRU during operation in open loop mode will be discharged into the seawater transfer pipe for reuse within the refinery for cooling water purposed. All other waste generated on board the FSRU will be treated and/or stored and pumped to deck for off-site

disposal by a licensed contractor, in accordance with the relevant Commonwealth and State regulations, and the IMO regulations.

7.7.3 BATT waste management

The waste hierarchy (refer to Figure 7-13) has been applied for the minimisation and management of industrial wastes generated as a result of operation of the FSRU.

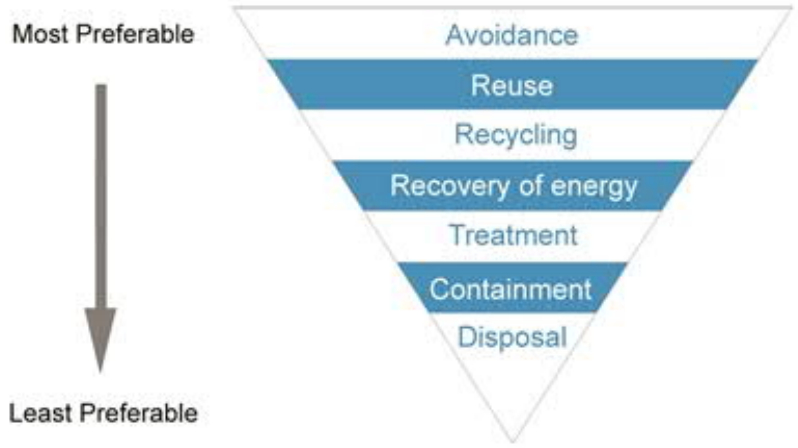


Figure 7-13 Waste hierarchy (EPA 2020)

Operation of the FSRU in open loop mode will result in the generation of a maximum of 350 ML/day of industrial wastewater (L200) which will be transferred to the existing refinery seawater intake via a seawater transfer pipe for reuse in the refinery as cooling water. The reuse of discharge from the FSRU in the refinery for cooling water purpose will be maximised to minimise potential environmental impacts and to manage industrial waste in line with the waste management hierarchy. Following reuse within the refinery, the industrial wastewater will be discharge back into Corio Bay via 4 existing licenced discharge outlets. A separate Development Licence (refer to DL application no. APP013841) is required for the refinery to discharge or deposit industrial wastewater from another source (FSRU).

Segregation of solid and liquid waste streams will be implemented to maximise their potential reuse and recycling, and to ensure that the appropriate level of treatment is being applied to each waste type. Segregation of waste generated on board the FSRU results in small volumes of concentrated waste that is easier to manage with targeted treatment rather than large volumes of diluted and mixed waste streams that require multiple levels of treatment. In addition, waste is segregated to allow waste receivers to make use of waste reuse potential.

Treated and raw waste will be collected in secured waste storage containers on board the FSRU that are designed for different types of waste generated. The containers will be lidded to mitigate fauna access. Collected waste will then be pumped (liquid waste streams) to shore and transported by licensed contractors for disposal at appropriately licensed facilities. Solid waste may be lifted by crane to the pier if there is truck access or lifted by crane to a barge and/or supply vessel prior to being transported by licensed contractors for disposal at appropriately licensed facilities.

8.0 Best available techniques and technologies

The type of FSRU proposed is designed and constructed in accordance with prevailing requirements and recommendations from authorities such as the International Maritime Organisation (IMO) and the Society of International Gas Tanker and Terminal Operators (SIGTTO). The FSRU will be issued a Class notation (classification) by (Det Norske Veritas and Germanischer Lloyd (DNV GL). The FSRU is equipped with systems and solutions to operate efficiently and to limit the impact on the surrounding environment.

The FSRU will be fitted with four Wärtsilä 50DF dual-fuel engines (one 6L50DF and three 8L50DF engines). The Wärtsilä 50DF was selected as these engines are 22% more efficient than the average gas engine power generator and are considered as best available technology for powering the FSRU both in terms of propulsion and also on board power generation. The four engines will be fitted with economisers that enable the use of waste heat from the flue gases (exhaust gases) within the process and silencers in the exhaust funnels to limit noise emission levels.

The FSRU will be fitted with two MAC-90BF gas-fired boilers. The boilers will only be required in either closed loop mode or combined loop mode to heat the LNG. The boilers will operate on boil-off gas and will also be fitted with economisers to enable the use of waste heat from the flue gases. In addition, the boilers have a flue gas recirculation system installed as a NOx control technique to minimise NOx emissions.

In the open loop regasification operational mode, heated cooling water from engine room consumers and the auxiliary machinery is transferred to the regasification seawater loop instead of being discharged directly to sea. This feature reduces the overall seawater consumption and makes use of waste heat within the process.

The FSRU has a larger maximum allowable LNG tank pressure (0.7 bar (g)) than conventional LNG carriers (0.25 bar (g)) and has the ability to use a temporary increase in tank pressure to manage generated boil-off gas. Boil-off gas (BOG) will be used as the primary fuel for both the engine and boilers on board the FSRU. The regasification system is equipped with a recondensing system that includes a re-condenser to condense excess boil-off gas back to LNG during regasification operations. Excess BOG would potentially be directed into the refinery natural gas system to be used as a fuel at times where BOG production surpasses FSRU generator demand. The need for BOG piping connecting the FSRU to the refinery natural gas system would be determined during detailed design. If required, BOG would be compressed on the FSRU and transferred via a hose connection to piping that would run along the pier structure. This connection would provide an additional source of natural gas for the refinery. The flow of BOG into the refinery natural gas system would be controlled using pressure control and priority would be given to BOG from the FSRU to reduce refinery gas consumption from the transmission network. The FSRU BOG injection point would be located near the existing fuel gas injection points at the refinery.

In addition to the large conventional ballast water pumps, the FSRU will be equipped with an additional small ballast pump, for optimised ballast water handling during regasification operations when the LNG tank inventory rate of change is much lower than during normal LNG loading or discharge operations.

The diffuser was designed as an alternative discharge arrangement for the project for use during refinery maintenance shutdown periods where discharge water from the FSRU exceeded refinery demand or in the event that the refinery was permanently decommissioned. The diffuser was designed to achieve high dilution and mixing through high velocity discharge via multiple ports (approximately 100) along the entire length of the pier i.e., the longest diffuser that could be fitted on the pier extension was selected (approximately 300m). The high-velocity ports would discharge the seawater at approximately 5m/s and at an angle of 30° away from the underside of the pier. The spacing and configuration of the 100 high ports along the length of the diffuser has been designed to maximise the rate of mixing and to achieve a dilution of 20:1 which means that there would be 20 parts of seawater for every 1 part of discharge. The diffuser design is predicted to reduce the chlorine concentration from 100µg/L to 5µg/L by the time the plume reaches the seabed. In addition, the diffuser design is predicted to reduce the temperature change to less than 0.4°C from ambient by the time the plume reaches the seabed.

Other design options such as distributors above the water line e.g., water curtain or sprays as an alternative to a diffuser located below the water line, however, these options did not have enough power to achieve the mixing and dilution required.

9.0 Proposed licence limits and mixing zones

Licences for activities which discharge to air or water may set maximum limits for specified pollutants. Exceedances of the limits in the discharge tables may trigger a requirement to notify EPA of the exceedance and may constitute a breach of a licence condition. In addition, licence holders continue to have obligations under the GED to minimise harm which may arise from all activities as far as reasonably practicable.

A mixing zone is an area where an effluent discharge undergoes initial dilution close to the point of the licensed discharge point and where threshold or guideline values would be exceeded. The size and extent of the mixing zone would be designated in the EPA licence.

The proposed licence limits and mixing zones for the FSRU are discussed in the subsequent sections.

9.1 Wastewater discharge

The Geelong Refinery holds EPA Licence 46555 which sets licence conditions for the four existing refinery discharge outlets (W1, W3, W4 and W5). A separate Development Licence application (refer to DL application no. APP013841, Viva Energy Refining Pty Ltd) has been prepared for the refinery to enable discharge or depositing of industrial wastewater from another source (FSRU) through the four existing refinery discharge outlets. That application demonstrates that a modification to existing licence conditions would not be required as discharges through the four existing discharge outlets would remain compliant and within existing licence limits following the reuse of the FSRU discharge water in the refinery cooling water system.

New licence limits for wastewater discharge and new mixing zones would be required for direct discharge from the FSRU via the diffuser and direct discharge from the FSRU during operation in closed loop mode as well as ballast water discharge. Proposed licence limits and dimensions for the mixing zones are summarised in Table 9-1 from the proposed discharge points shown in Figure 9-1.

Table 9-1 Proposed wastewater discharge licence conditions

Discharge point	Description	Indicator	Limit type	unit	Discharge limit	Mixing zone
W6	Diffuser discharge	Flow Rate	Mean Daily flow	ML/day	350	a distance of 50 metres from discharge point W6 (diffuser)
		Dissolved oxygen as mg/L	Minimum	mg/l	5	
		Total residual chlorine	Maximum	mg/l	0.12	
		Total residual chlorine	Annual Median	mg/l	0.1	
		Suspended solids	Above Ambient	mg/l	5	
		Temperature	Maximum	°C	35	
		Temperature below ambient	Below Ambient	°C	8	
W7	Closed loop operation (FSRU – Starboard)	Flow Rate	Mean annual flow	ML/day	12	a radius of 30 metres from discharge point W7
		Flow Rate	Maximum flow	ML/day	120	
		Dissolved oxygen as mg/L	Minimum	mg/l	5	

Discharge point	Description	Indicator	Limit type	unit	Discharge limit	Mixing zone
		Total residual chlorine	Maximum	mg/l	0.12	(closed loop operation)
		Total residual chlorine	Annual Median	mg/l	0.1	
		Suspended solids	Above Ambient	mg/l	5	
		Temperature	Maximum	°C	35	
		Temperature above ambient	Above Ambient	°C	12	
W8	Closed loop operation (FSRU – Port)	Flow Rate	Mean Daily flow	ML/day	8	a radius of 30 metres from discharge point W8 (closed loop operation)
		Flow Rate	Maximum flow	ML/day	80	
		Dissolved oxygen as mg/L	Minimum	mg/l	5	
		Total residual chlorine	Maximum	mg/l	0.12	
		Total residual chlorine	Annual Median	mg/l	0.1	
		Suspended solids	Above Ambient	mg/l	5	
		Temperature	Maximum	°C	35	
		Temperature above ambient	Above Ambient	°C	12	
W9	Ballast Water	Flow Rate	Mean annual flow	ML/day	6	a radius of 20 metres from discharge point W9
		Flow Rate	Maximum flow	ML/day	80	
		Dissolved oxygen as mg/L	Minimum	mg/l	5	
		Total residual chlorine	Maximum	mg/l	0.1	
		Total residual chlorine	Annual Median	mg/l	0.05	
		Suspended solids	Above Ambient	mg/l	8	
		Temperature	Maximum	°C	35	

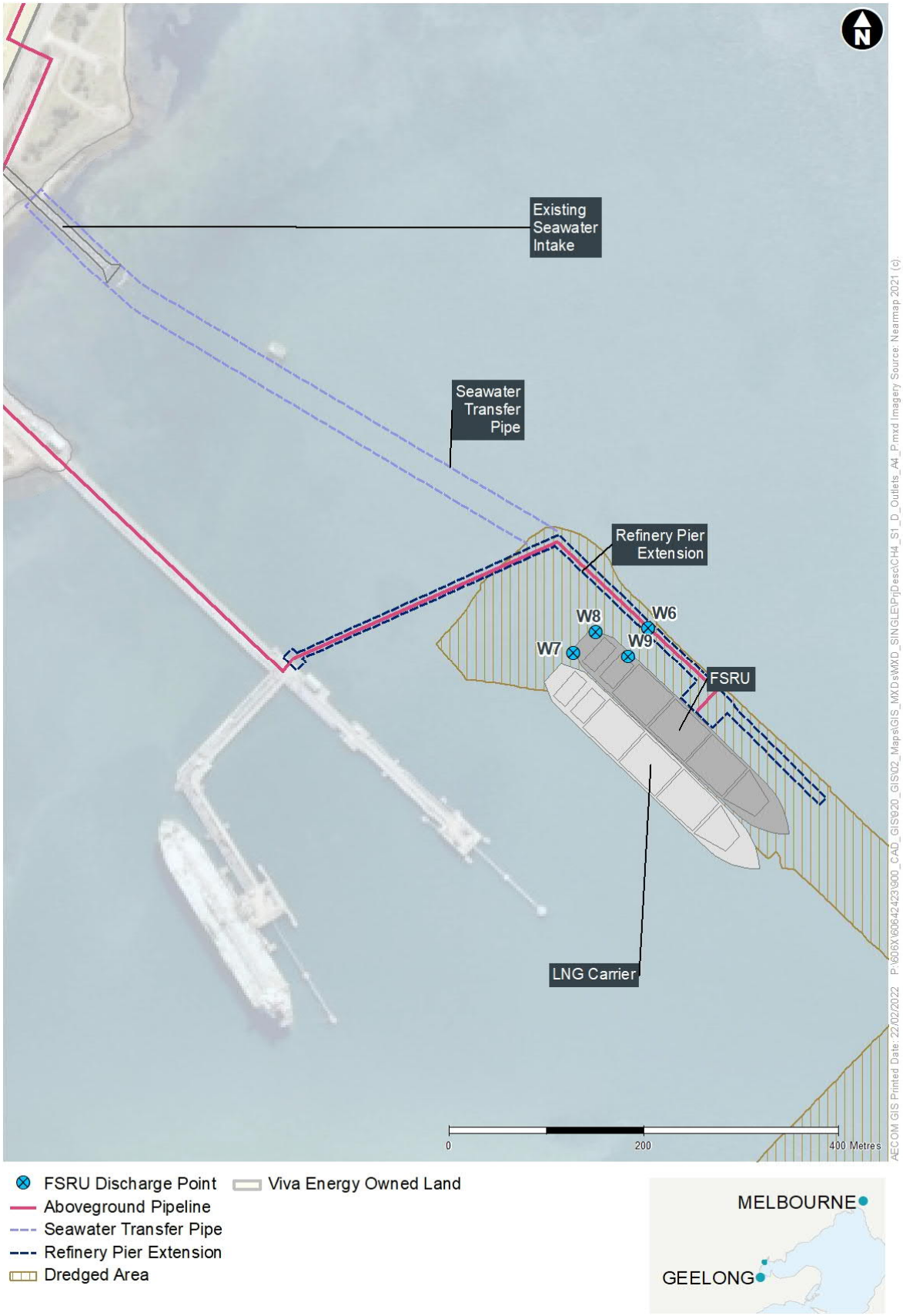


Figure 9-1 Proposed FSRU discharge points

9.2 Air emissions

Table 9-2 below provides a summary of the proposed FSRU engine limits to air. The proposed limits consider both gas-fuelled and liquid-fuelled scenarios. These limits are considered conservative as they assume worst case – 4 engines and 2 boilers operating at 100% load all year, plus 25% tolerance. The discharge points are shown in Figure 9-2.

Table 9-2 Proposed FSRU engine emission limits to air

	Yearly bubble limit for FSRU emissions from 4 engines and 2 boilers (gas)	Bubble limit for FSRU emissions from 4 engines and 2 boilers (liquid fuel)
NOx (as NO_2)	530 t/y	530 t/y
CO	410 t/y	410 t/y
VOC	180 t/y	180 t/y
Particles	-	130 g/min
SO_2	-	520 g/min

Note: Licence limits calculated based on Hoegh LNG technical specifications (refer to Table 4-12 and Appendix B of AQIA) at 100% load plus 25% tolerance. It is assumed a licence is required for boilers rated over 20MW (proposed FSRU boilers are rated 60MW (Environment Protection Regulations 2021). Marine diesel oil used as a pilot fuel and during emergency, maintenance or start-up. Particulates and SO_2 emissions assumed minor for gas fuelled engine emissions.

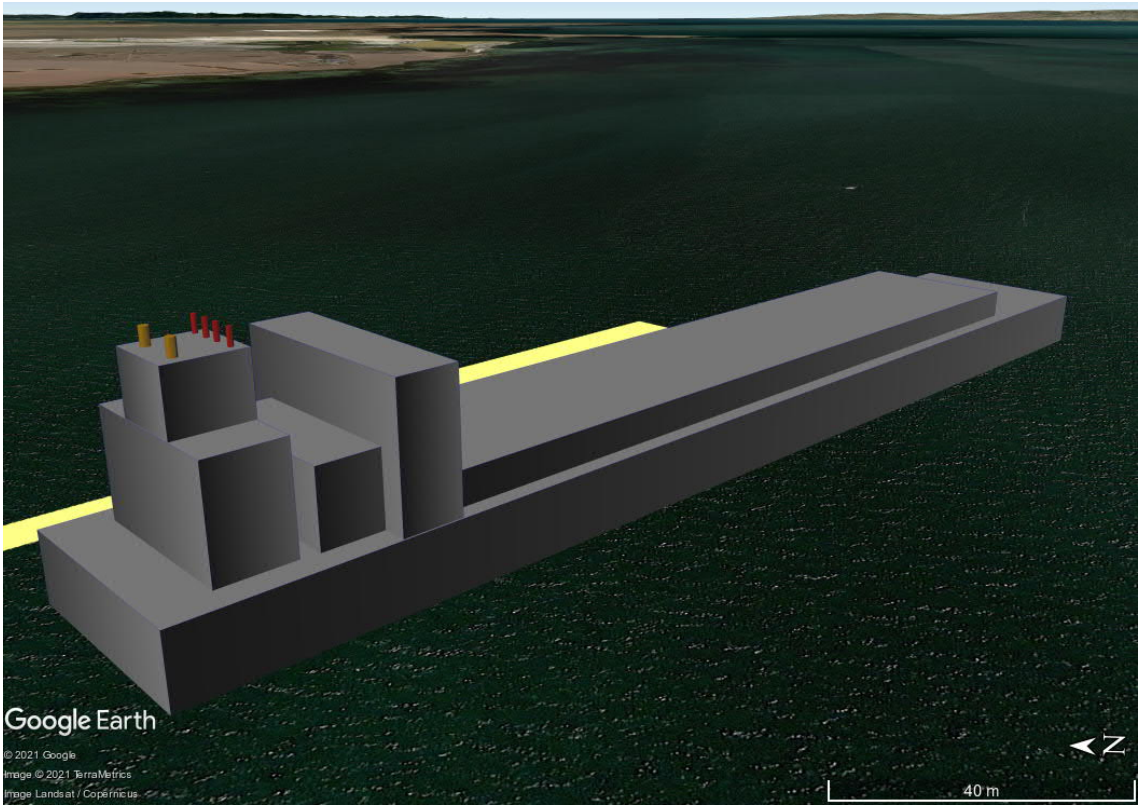


Figure 9-2 FSRU orientation and location of boilers (orange) and engines (FSRU red) discharge points

10.0 Commissioning / proof of performance

A significant advantage of selecting an offshore FSRU based approach for the project, compared to an onshore alternative is that the FSRU would be commissioned for optimal operating parameters prior to arriving at Refinery Pier. Following the arrival of the FSRU at Refinery Pier it will need to be connected to important infrastructure such as the seawater transfer pipe. These connections would be tested prior to commencement of operation for function and serviceability.

Testing activities would include but are not limited to the following:

- Hydrotesting or service pressure testing of various piping sections and equipment connected to the FSRU
- Instrumentation functional checks for correct recording of values and stroke testing and validation of valves
- Control loop checks to verify whether the outcome to input signals match design intention
- System commissioning including preparation of pipes by charging with water to remove air from the system
- FSRU interface commissioning including:
    - Checking signals between FSRU and shore
    - Charging FSRU equipment with water
    - Function testing of regasification water networks
- Recording of data to validate expected flow and pressure performances

Air, noise and marine discharge from the FSRU during operation were modelled and potential impacts predicted as part of the preparation of the EES. Modelling and predictions of discharges were based on the FSRU manufacturer technical specifications. Proof of performance would be verified through monitoring to check actual impacts against predicted values and to ensure compliance with conditions of statutory approvals. Proposed environmental monitoring during operation of the FSRU is discussed in Section 11.3.

Viva Energy and their contractors will have in place contingency measures to facilitate an efficient and effective response where environmental monitoring indicates that discharges are greater than what was modelled and predicted or operation of the FSRU is non-compliant with statutory approval conditions. While Viva Energy is unable to assess at this point where contingency measures may be required, some examples of the types of measures which could be adopted if needed include:

Marine discharges

- If higher residual chlorine was detected in the discharges during monitoring after project inception, the refinery would use its existing procedure to control for chlorine dosing and maintain the discharge chlorine concentration within licenced levels.
- If the FSRU discharged cooled water into Corio Bay via the proposed diffuser located on Refinery Pier (for example, if the refinery ceased operation in the future and the cooling water reuse option was not available), and higher residual chlorine levels than expected were detected, the chlorine addition to seawater on the FSRU could be adjusted downward.
- If there was a longer period where chlorine levels from the diffuser discharge were higher than predicted, the diffuser could be modified (e.g., additional smaller discharge ports) to increase mixing and dilution.
- If the FSRU discharged cooled water into Corio Bay via the proposed diffuser located on Refinery Pier (for example, if the refinery ceased operation in the future and the cooling water reuse option was not available), and monitoring indicated that the cold-water plume from the FSRU was more extensive than predicted, the diffuser could be modified to increase mixing and dilution.

Air emissions

Should verification monitoring detect unacceptable levels of air emissions, additional measures would be implemented to minimise emissions which could include:

- Alteration of discharge exhaust parameters to increase air dispersion, such as
  - vertical outlet orientation (instead of being tilted 45° aftwards)
  - increasing height of exhaust emission points
  - change to exhaust flow rate or temperature
- Operating FSRU engines when meteorology conditions (particularly wind direction and speed) are favourable
- Reducing the load and number of engines operating at any one time.

Examples of contingency measures that could be implemented are discussed further in Chapter 14: *Environmental Management Framework*.

11.0 Environmental management during operation

11.1 Environmental management system

The existing Viva Energy HSSE Management System has been designed to facilitate compliance with the Australian regulatory regimes of the relevant jurisdictions within which Viva Energy operates and is consistent with the Viva Energy Business Principles and Code of Conduct. The HSSE Management System would serve as a reference document for this project and would help guide planning, development and implementation of management plans for the operation of the FSRU to prevent or minimise impacts to the environment and human health.

Approval under the *Planning and Environment Act 1987* will be required for the project via a Planning Scheme Amendment to the Greater Geelong Planning Scheme. It is proposed to apply a Specific Controls Overlay with an Incorporated Document. The Incorporated Document would allow the use and development of land for the project to be undertaken in accordance with specific conditions contained within the Incorporated Document. The proposed Incorporated Document requires the preparation of an EMP which would set out the process and timing for development of an OEMP that would stipulate the environmental management requirements for the FSRU operation.

The OEMP will include detailed management protocols for the management of:

- Air quality
- Hazardous substances management
- Noise and vibration
- Sediment, erosion and water quality (including surface water and groundwater)
- Marine monitoring
- Traffic and transport.

A monitoring program will be developed (discussed further in Section 11.3) to monitor operation of the FSRU and ensure compliance with conditions of statutory approvals such as the DL and OL.

In addition, operation of the FSRU will be required to comply with all protocols of Ports Victoria as the port operator. Ports Victoria appoints the Harbour Master, and it is the Harbour Master, under the *Marine Safety Act 2010*, that must ensure the safety of persons and the safe operation of vessels, and in addition minimise the impact of vessel operations on the environment.

The safety and environment management plans that are developed for the operation of the FSRU need to be compliant with the operating standards and protocols for the Port of Geelong are set out in the Ports Victoria Harbour Master's Directions and Port of Geelong Safety and Environmental Management Plan and Maritime Security Plan managed by GeelongPort. In the event of an incident (safety,

environmental, or security), the Harbour Master or the Duty Marine Controller (being the designated Person in Control) can activate the GeelongPort and Ports Victoria joint Emergency Management Plan and the initial response dictated for the incident. The FSRU will adhere to specific emergency response regulations and requirements such as MARPOL Annex I, requiring vessels to carry an approved Shipboard Oil Pollution Emergency Plan (SOPEP), and emergency response plans. These plans would be consistent with existing Viva Energy operational environmental management plans and emergency response plans and would form part of the existing overall management system.

11.2 FSRU maintenance and monitoring

The project life is anticipated to be approximately 20 years. The project would operate 24 hours a day, 7 days a week, in line with the refinery's existing hours of operation and as required by gas demand. LNG carriers arriving at the Refinery Pier may arrive at any time of day, which would be communicated with the harbour master.

The FSRU would be staffed on a 24-hour continuous shift basis to supervise, operate and maintain the facility and ensure high uptime and safe operations. The FSRU would have an adequate level of spares and consumables, storage space, workshops and maintenance support facilities to achieve gas delivery consistent with customer demand.

Hoegh LNG in collaboration with Viva Energy will develop, implement and maintain a continuous risk-based monitoring program to assess environmental management at the site and to monitor implementation of the EPA operation licence conditions. A summary of the proposed monitoring programs is shown in Table 11-2.

In addition, a number of management measures will be implemented to ensure potential impacts are managed including:

- **Stakeholder Engagement Management Strategy:** Stakeholder Engagement Management Strategy would be implemented to facilitate ongoing consultation with relevant stakeholders (including Councils, authorities, businesses, residents and community groups) throughout the operational life of the project to ensure that all stakeholders have access to complete information regarding the nature of the proposed activities and their likely impacts. If required, advance notice will be given to affected residents, business or industries prior to commencement of works.
- **Complaints Management System:** A complaints management system that is consistent with the existing Geelong Refinery stakeholder and complaints management system would be put in place. The following details would be recorded in the system:
    - Name of persons receiving complaint.
    - Name of person making the complaint.
    - Date and time of complaint.
    - Nature of the complaint.
    - Actions taken to rectify.
    - Actions to minimise risk of reoccurrence.
    - Name of person(s) responsible for undertaking the required actions.
    - Communication in response to the complaint.

    Performance related to air and noise emissions would be monitored based on the data within the complaints management system

Waste management performance will be monitored based on the Operational Waste Management System that will be developed and implemented.

11.2.1 Inspections and maintenance

FSRU performances, including gas send-out flow, pressure, temperature over periods of time, and internal fuel consumption, would be monitored, recorded and reported. A monitoring and testing program would be implemented to guarantee the FSRU environmental impacts remain within limits

approved by regulators and authorities. The monitoring and testing program would include, but not limited to, air emissions, noise, greenhouse gas emissions and seawater discharges from the FSRU.

The FSRU would be inspected in accordance with Flag State and Classification Society requirements which would include annual, intermediate (every 2.5-years) and renewal (every 5-years) surveys. The FSRU would also be regularly inspected in accordance with the Ship Inspection Report Program (SIRE) from the Oil Companies International Marine Forum (OCIMF). A Performance Based Inspection (PBI) program would also be developed and submitted to the Australian Maritime Safety Authority. An indicative maintenance and inspection program is show in Table 26.

The maintenance strategy would involve four key components:

1. Planned maintenance on a 60-month cycle which would require shutdown of the LNG regasification system to facilitate inspections and repairs. No impacts to the marine environment are anticipated during these activities as they would occur internally, and the sea chest would be covered during these activities.
2. Planned maintenance on hourly intervals on equipment that can be maintained during normal operation without a shutdown. No impacts to the marine environment are anticipated during these activities as they would occur internally.
3. Condition based monitoring which would involve functional and planned performance tests to identify issues and rectification within normal operational windows or scheduled/planned maintenance cycles.
4. Marine based maintenance which would be completed every 30 months to validate ship conditions and renew authority to stay in position without dry dock. The sea chest would be covered to allow for maintenance without impact to marine waters.

Table 26 Indicative maintenance and inspection program

Equipment	Maintenance	Interval	Duration	Will this impact on send out rate?
Suction drum	Inspection	60 months	1 day[1]	Yes
Knockout drum	Inspection	60 months	1 day[1]	Yes
Booster pumps	CBM	3 months	1 hour	No, done under operation
Propane pumps	CBM	3 months	1 hour	No, done under operation
Booster pumps	Overhaul	60 months	2 days[1]	Yes
Propane pumps	Overhaul	60 months	2 days[1]	Yes
Regasification skid valves	Moved and greased	3 months	1 hour	No
Regasification skid valves	Inspection	12 months	1 hour	No
Regasification skid valves	Overhaul	60 months	1 day[1]	Yes
Regasification skid valve actuators	Overhaul	60 months	1 day	No
Sendout valves	Overhaul	60 months	2 days	Yes
Sendout valve actuators	Overhaul	60 months	1 day	Yes
Regasification automation	CBM	6/12 months	1 day	No
Regasification and cargo safety valves	Overhaul	60 months	1 day	No
Suction drum safety valves	Overhaul	60 months	1 day	Yes
Cargo and spray pump alarms	Test	60 months	1 day	No

Equipment	Maintenance	Interval	Duration	Will this impact on send out rate?
Cargo tanks	Inspection	60 months	1 day	No
Switchboard	Inspection	60 months	1 day	No
Transformers	Inspection	60 months	1 day	No
Overboard valves	Inspection	60 months	1 day	No
Propeller shaft	Inspection	180 months	5 day	No impact during contract period
Rudder	Underwater inspection	30 months	1 day	No
Propeller	Underwater inspection	30 months	1 day	No
Underwater hull	Underwater inspection	30 months	1 day	No

[1] Durations are not accumulated e.g., suction drum and knockout drum inspection would be undertaken concurrently

11.3 Environmental monitoring

Viva Energy will undertake a monitoring program as discussed in the Table 11-2 below.

Table 11-2 Summary of proposed monitoring programs for operational phase of the FSRU

Environmental aspect	Description	Monitoring event	Monitoring method	Monitoring Frequency
GHG	Implementation of energy management systems in accordance with the International Organisation for Standardisation (ISO) 50001 Energy Management Systems (ISO 50001) for the operation of the FSRU will include conducting an audit on the FSRU to identify continual improvement of energy performance and efficiency and reductions in GHG emissions.		The energy management system would measure and review the progress of: • Energy use baselines • Energy management plans • Performance indicators • Targets for improvement.	External certification by ISO-accredited auditors on a 3 year cycle
Air Quality	An air quality monitoring program will be designed and implemented to monitor FSRU emissions and confirm FSRU emission rates comply with design specifications.	Stack emissions monitoring of the FSRU	Stack testing will be conducted when the engines are being run on gas fuel. The concentration of the following pollutants will be sampled: • NO_2 • CO • Total VOC • Formaldehyde.	Annual
Noise	Verification noise monitoring should be conducted on noise produced by the FSRU within 3 months of commencement to confirm noise emission and the schedule of activities.	Verification noise monitoring	Noise measurements should be undertaken in accordance with current Victorian EPA requirements to verify operational noise levels and verify cumulative noise impacts at Geelong Grammar, Biddlecombe Avenue and School Road dwellings (north-east). • The measurements should be adequate to be represent a typical 30-minute period for the applicable day, evening or night period and undertake in accordance with the measurement procedure outlined in Part I, section B of the Noise Protocol. • Measurements are recommended for all operating scenarios to verify the noise emissions. • Measurements should be undertaken as part of the Environmental Management Plan in response to any community complaints.	Once within 3 months of commencing commercial operation

Environmental aspect	Description	Monitoring event	Monitoring method	Monitoring Frequency
Water	Monitoring of seawater discharges	Monitoring rates and characteristics of all discharges	Monitoring and recording of the flow rate, temperature and residual chlorine concentration of all major discharges, excluding fire water, water curtain and ballast water will be conducted. Monitoring will be conducted to keep a record of all discharges, confirm that the discharge rate and chlorine concentration are within the values stipulated in the OL conditions and, if not, provide the trigger for remedial action.	All seawater discharges

12.0 References

Australian Energy Market Operator (AEMO) (2021). Available: https://aemo.com.au/en/energy-systems/gas/gas-forecasting-and-planning/gas-statement-of-opportunities-gsoo. Accessed February 2021.

Australia Rainfall and Runoff (ARR) (2019). *ARR Data Hub*. Available: http://data.arr-software.org/. Accessed March 2021.

Batley, Graeme E., Simpson, Stuart L. (2020). *Short-Term Guideline Values for Chlorine in Marine Waters*. Environmental Toxicology and Chemistry, 39. 754-764. doi:10.1002/etc.4661.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BoM) (2015). *Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report*, Australia.

CSIRO 2019 Barwon Climate Projections 2019. Clarke JM, Grose M, Thatcher M, Round V & Heady C. Melbourne Australia

EPA (2020). Your environment - Waste. Available: https://ref.epa.vic.gov.au/your-environment/waste. Accessed 20 February 2020.

EPA publication 2011: Development licence application guidance. July 2021.

Department of the Environment and Energy (DoEE) (2018). *National Greenhouse Accounts Factors, Australian National Greenhouse Accounts*, Australian Government. October 2018.

Standards Australia (2013. *AS5334-2013 Climate change adaptation for settlements and infrastructure-a risk-based approach*, Standards Australia.

USEPA (2020). *User's Guide for AERSURFACE Tool*, February 2020.

USEPA (2000a). AP42 AP 42, Fifth Edition, Volume I Chapter 3: Stationary Internal Combustion Sources. Section 3.1 Stationary Gas Turbines. April 2000.

USEPA (2000b). AP42 AP 42, Fifth Edition, Volume I Chapter 3: Stationary Internal Combustion Sources. Section 3.1 Natural Gas-fired Reciprocating Engines. August 2000.

Appendix A

ASIC extract

ASIC
Australian Securities & Investments Commission

Australian Company

VIVA ENERGY GAS AUSTRALIA PTY LTD
ACN 645 450 059

Extracted from ASIC's database at AEST 14:31:18 on 19/10/2021

Company Summary	
Name:	VIVA ENERGY GAS AUSTRALIA PTY LTD
ACN:	645 450 059
ABN:	35 645 450 059
Registration Date:	27/10/2020
Next Review Date:	27/10/2021
Status:	Registered
Type:	Australian Proprietary Company, Limited By Shares
Locality of Registered Office:	DOCKLANDS VIC 3008
Regulator:	Australian Securities & Investments Commission

Further information relating to this organisation may be purchased from ASIC.

Appendix B

Project alternatives and development

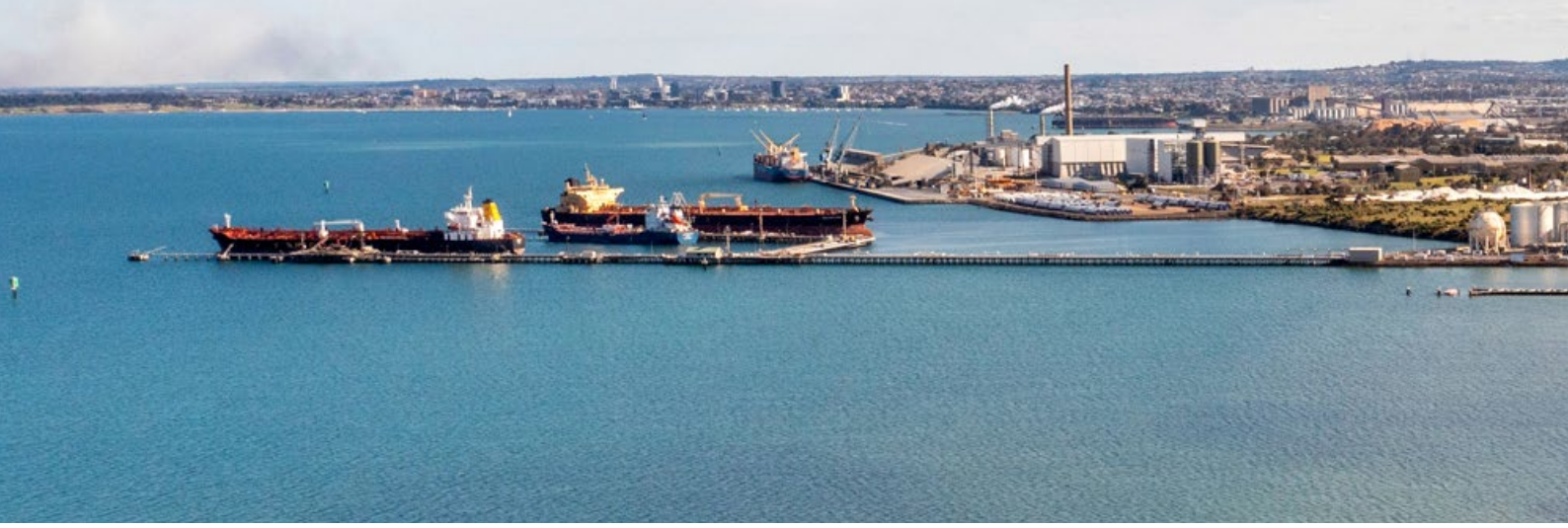


Chapter 3

Project alternatives and development

This chapter describes the process used by the proponent to develop the proposed Viva Energy Gas Terminal Project (the project), including the identification and evaluation of alternatives considered prior to adoption of the preferred development proposal selected for assessment in this Environment Effects Statement (EES). The selected development proposal for the project is described in Chapter 4: Project description.

This chapter also provides an overview of feasible design alternatives that were considered for each of the project components, including relevant environmental considerations.



3.1 Relevant EES scoping requirements

Section 3.4 of the EES scoping requirements requires the proponent to outline feasible alternatives considered for the project and to include an explanation of how specific alternatives were shortlisted for evaluation within the EES. The EES is also required to assess and document the likely environmental, social and economic effects of the feasible alternatives, particularly where these offer potential to minimise and/or avoid significant environmental effects, while meeting the project objectives.

The scoping requirements state that the assessment of feasible alternatives and their effects should include:

- Selection of the floating storage and regasification unit (FSRU) approach
- Site selection for the FSRU over that of onshore regasification
- Selection of the proposed regasification mode from the range of available options, including variations to the FSRU design and potential to use a combination of closed and open loop systems
- Discussion of interdependency between the FSRU design and the refinery operations and how in the event of maintenance periods or shutdown these will operate independently of each other
- Selection of the proposed pipeline route
- Identification and assessment of design alternatives for the other project components
- Environmental considerations.

The assessment should also consider the short, medium and long-term advantages and disadvantages of different alternatives considered.

In addition, the scoping requirements require the effects of the preferred project to be compared to those of other feasible alternatives or to a 'no project' base case. Where appropriate, the assessment of environmental effects of feasible design alternatives should address matters set out in the scoping requirements. The depth of investigation of feasible alternatives should be proportionate to their potential to minimise potential adverse effects as well as meet project objectives.

3.2 Overview

A number of feasibility and preliminary assessments were undertaken to identify and evaluate feasible design alternatives to be considered for each of the project components. These include:

- Preliminary engineering and design studies to assess different regasification technologies, including onshore and offshore alternatives and site selection
- A cooling water synergy study to assess potential synergies between the FSRU and the existing Geelong Refinery in terms of utilising FSRU discharge water as cooling water in the refinery
- A pipeline route options assessment study
- A nitrogen storage tank selection study.

Project design alternatives have been assessed with consideration of the likely environmental, social, economic and safety effects. Following selection of the FSRU as the preferred regasification approach rather than construction of an onshore regasification plant, potential sites for the project were identified and assessed comparatively. Selecting Refinery Pier adjacent to the existing Geelong Refinery as the preferred site allowed the project to make use of existing infrastructure within a developed industrial and port setting.



With the FSRU selected as the preferred regasification technology, and Refinery Pier selected as the preferred project location, further design development was undertaken including:

- Minimisation of the dredged area at the proposed Refinery Pier berth
- FSRU design including seawater intake and discharge
- Potential regasification alternatives
- Treatment facility design and location
- Pipeline route refinement
- Integration of sustainability principles into all aspects of project design.

Further information on the design development and alternatives considered for each of the project components is provided in the following sections.

3.3 Selection of the offshore or onshore regasification alternative

As part of the initial screening phase of the project, both onshore and offshore regasification and storage technologies were considered. A comparative assessment was undertaken for onshore and offshore alternatives to determine the most suitable option for the project.

The key difference between an onshore and offshore alternative is the location of the regasification equipment. An onshore regasification alternative would involve a floating storage unit (FSU) continuously moored at Refinery Pier storing liquefied natural gas (LNG) until required for processing and a regasification plant located onshore. The FSU is an LNG storage ship that does not have regasification equipment on board. The FSU would store LNG to then be transported to the onshore regasification plant via cryogenic piping (piping that allows for transfer of material at a temperature range from negative 150 degrees Celsius to absolute zero).

In comparison, the offshore alternative involves a floating storage and regasification unit (FSRU) continuously moored at Refinery Pier, which is also an LNG storage ship, but with regasification equipment onboard. The FSRU would store and regasify the LNG onboard.

3.3.1 Onshore regasification facility

To locate the regasification equipment onshore within the existing refinery, a significant land area footprint would be required, along with modification to existing refinery infrastructure. The following equipment that would otherwise be located on an FSRU would need to be located within the refinery for an onshore alternative:

- Boil Off Gas Compressors
- Recondenser / Suction drum
- Booster pumps
- Vapourisers.

A preliminary assessment was undertaken to determine where the regasification equipment could be located within the existing constraints of the refinery site. An initial location was considered at the current fire station at the refinery.

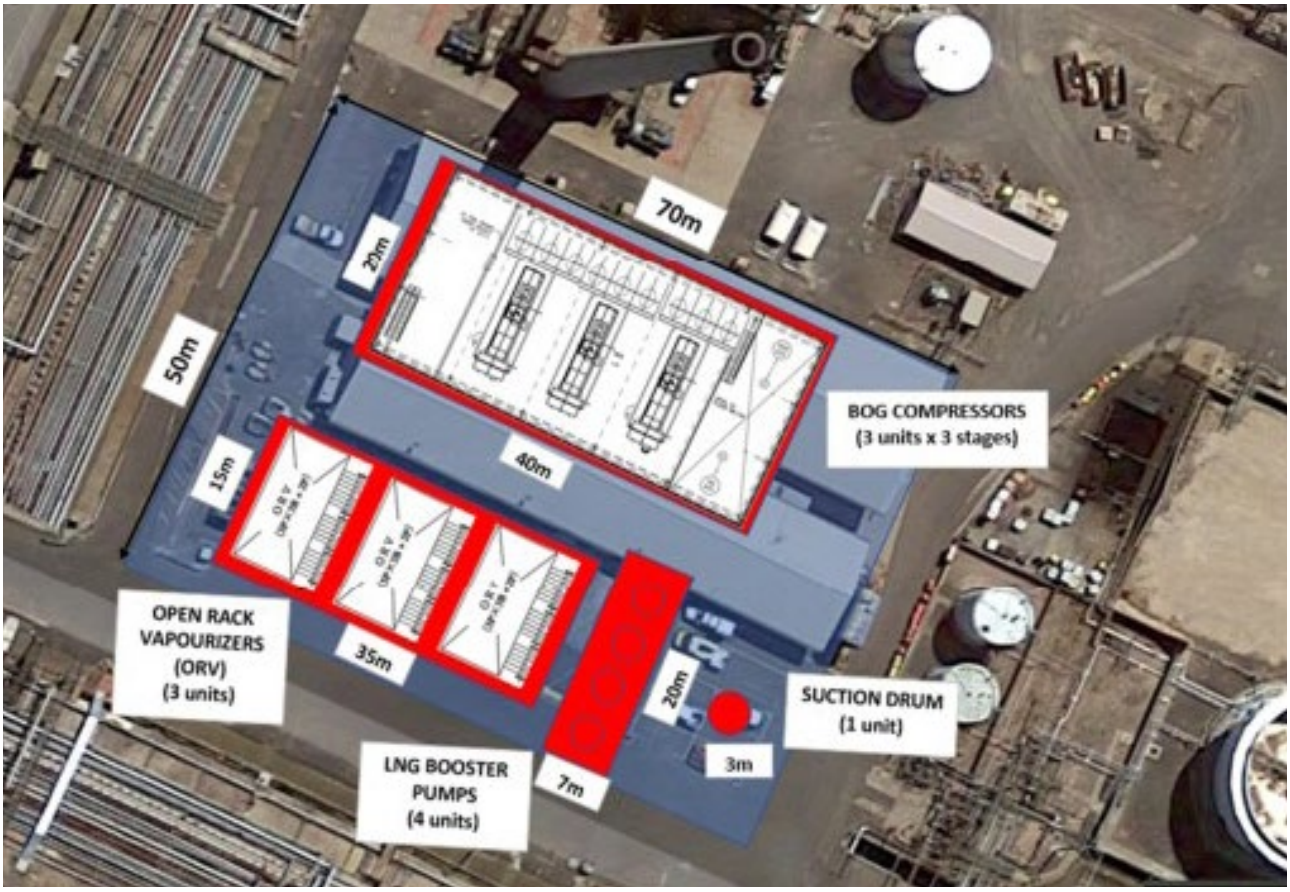


Figure 3-1 Onshore regasification equipment option layout

Figure 3-1 shows an indicative layout of the regasification equipment in the considered location, with the existing fire station relocated elsewhere on the site. However, there were concerns regarding the proximity of the proposed infrastructure to other refinery equipment, with the potential for minimum separation distances for the equipment unable to be achieved.

Due to the limited space within the refinery, potential to locate the regasification equipment outside of the refinery premises was considered. However, this option was not progressed further on the basis that it would require extensive cryogenic piping to transfer the LNG from the FSU to the regasification equipment, removed the benefits of locating the facility outside of the existing major hazard facility boundaries and would represent a more energy intensive and costly alternative.

3.3.2 Comparative analysis

A comparative analysis was undertaken for the onshore and offshore alternatives by evaluating the advantages and disadvantages of each option.

The onshore facility alternative was assessed as requiring up to an additional year to construct due to complexities within the refinery site. Locating the regasification equipment within the refinery would require a large onshore footprint, significant modification to existing refinery infrastructure and generate a larger number of safety considerations when compared with the offshore option.

Comparatively, the FSRU with regasification equipment onboard is able to be moored at the end of an extension to the existing Refinery Pier, with less construction requirements. This provides additional separation distance from nearby public areas and refinery infrastructure. The space required for onshore facilities under this option was considered to be minimal and pose a lower safety risk in relation to other refinery equipment. A significant benefit of the offshore FSRU option considered for the project was the fact that, on completion of the project, the FSRU could be easily relocated elsewhere in the world without the need for decommissioning of extensive onshore infrastructure with associated impacts, energy use and costs.

A significant environmental benefit from the decision to locate either an onshore or offshore facility on or adjacent to the existing refinery was an

ability to recycle the FSRU discharge water into the refinery for cooling purposes, effectively replacing the current intake of refinery cooling water from Corio Bay and not requiring a second water intake for the project if operated independently. The onshore plant option was considered marginally better from an infrastructure viewpoint to enable this reuse option than the offshore FSRU which requires additional pipework to pump the discharge water into the refinery, but this was not considered to be a significant differentiator.

Full reuse of the seawater discharge from the FSRU would have significant environmental benefits, however, there may be limited instances where seawater discharge from the FSRU could exceed the intake requirements for the refinery (e.g., when parts of the refinery are shut for maintenance or if the refinery was closed at a future point and reuse of cooling water was no longer an option). In the event that this did occur, excess seawater would need to be discharged directly to Corio Bay.

Two alternatives were considered for this discharge in the event that it was required, namely direct discharge from the FSRU or discharge via a diffuser located under the new pier. Of the two alternatives, discharge via the diffuser was selected on the basis that it creates rapid dilution of the cool water discharge with the surrounding waters and results in a localised cold water plume and mixing zone in the immediate area of the FSRU and jetty. Without the diffuser, the cold water plume on the bottom of Corio Bay would be larger in extent. With use of the diffuser as preferred option, the offshore option is considered better than an onshore regasification plant as surplus water from the onshore plant would require additional pipework and energy to discharge via the diffuser. Conversely, there may be instances where seawater discharge from the FSRU is lower than the intake requirements for the refinery (e.g., when the production rate for the FSRU is low due to reduced demand). In the event that this did occur, the refinery would draw the remaining volume of seawater required through the existing inlet.

Table 3-1 provides a comparison of the onshore and offshore alternatives considered for the project, including the relevant advantages and disadvantages that were considered during the screening phase.

Table 3-1 Comparison between an onshore facility and an offshore FSRU

Criteria	Onshore regasification	FSRU
Location	• Situated on land • Requires a larger footprint on land for storage and regasification equipment • Limited space within the refinery, requiring modification to the existing layout	• Moored at the end of a pier • Able to make use of existing Refinery Pier • Smaller footprint on land compared to the onshore option • Located in port waters, away from nearby public areas and refinery infrastructure
Construction requirements	• Construction works would be on a brownfield site and involve significant modifications to existing refinery infrastructure • Requires a larger construction footprint due to greater scale of onshore infrastructure compared to the FSRU • Potential increased environmental risks from contaminated soil exposure and waste disposal during construction associated with footprint of onshore facilities	• The FSRU is an existing vessel requiring potential minor construction works. The vessel would be commissioned for optimal operating parameters prior to arriving at Refinery Pier • Smaller construction footprint on land compared to the onshore alternative, as less infrastructure is required

Criteria	Onshore regasification	FSRU
Construction schedule	• Construction of the onshore facility would take considerably longer as it requires the procurement and construction of many items of equipment to form the regasification facilities onshore and relocation of existing infrastructure at the refinery • Construction could take up to a year longer than the offshore alternative (up to 30 months to construct the entire project)	• Shorter construction timeframe for the offshore alternative- approximately 18 months to construct the entire project • Approximately 18 months to complete FSRU chartering agreement, approvals and project-specific modifications
Risk and safety	• Locating regasification equipment within the refinery and in proximity to existing equipment could create safety issues requiring detailed consideration in the design and operation of the facility • Separation distances would have to be maintained and access ways and maintenance programs would be affected • Regasification equipment would be closer to public access areas	• The FSRU would be located away from the refinery and at a greater distance from public access areas • If any safety, emergency or operational issues arise, the FSRU could depart the berth if required and remain at sea until the issue is resolved or return to a shipyard for maintenance. An alternate vessel could be sourced if required
Interference with port users	• Minimal impact on port users and existing Viva Energy operations • This option would require continuous mooring of the FSU and regular visits from LNG carriers. • Degree of interference with other port users would be to the same extent as the FSRU option.	• Minimal impact on port users and existing Viva Energy operations • This option would require continuous mooring of the FSRU and regular visits from LNG carriers. • Degree of interference with other port users would be to the same extent as the onshore option.
Capital expenditure	• Approximately 33% higher capital expenditure for the onshore alternative due to additional equipment requirements such as pumps, vapourisers and compressors which would otherwise be already present on the FSRU	• Lower capital expenditure due to the FSRU already being equipped with the necessary infrastructure
Synergy with refinery cooling system	• Locating regasification equipment within the refinery would provide a simpler connection between the water discharge from the vapourisation process and the refinery cooling water infrastructure, as the preferred option to manage discharge water is to reuse and recycle as a replacement for the current cooling water drawn from Corio Bay	

Criteria	Onshore regasification	FSRU
Environmental impacts	• Potential environmental impacts would be similar to the FSRU option, predominantly associated with the required dredging and the discharge of cooler water into Corio Bay • A greater onshore footprint would be required for this option, with potential increased environmental risks from contaminated soil exposure and waste disposal • Use of the diffuser for discharge from the FSRU (described in the FSRU column) could still occur but would require additional pipework and energy use to transfer surplus water from the onshore plant to the diffuser	• Potential environmental impacts would be similar to the onshore option, predominantly associated with the required dredging and the discharge of cooler water into Corio Bay • This option would require the seawater transfer pipe, which may result in impacts to the seabed • Where the seawater discharge from the FSRU exceeds the intake requirements for the refinery seawater could be discharged through a diffuser located under the new pier. Discharge through a diffuser would minimise impacts as the cold water discharge would be spread out across a number of outlets and rapidly diluted rather than concentrated directly from a single discharge point on the FSRU
Visual amenity and social considerations	• This option would involve a vessel permanently moored at Refinery Pier with frequent visits from LNG carriers, resulting in the same visual impact as the FSRU option. This is considered 'business as usual' within the port environment. • Regasification plant and equipment located closer to sensitive receptors and communities onshore.	• This option would involve a vessel permanently moored at Refinery Pier with frequent visits from LNG carriers, resulting in the same visual impact as the onshore option. This is considered 'business as usual' within the port environment. • Regasification equipment located away from onshore sensitive receptors.
Refinery Major Hazard Facility (MHF) Safety Case	• Regasification within the refinery would likely require a significant facility modification and resubmission of the refinery MHF Safety Case	• A new Safety Case and MHF Licence would be required for the FSRU
Operational expenditure	• Operational expenditure is slightly less (less than 10%) for the onshore alternative • Additional operational personnel would be required to operate the vapourisation facilities	• Operational expenditure is slightly more for the offshore alternative • Small operational crew would be required for the FSRU
Decommissioning	• Regasification infrastructure would be redundant after project closure and would require decommissioning of the onshore plant	• The FSRU would depart the pier upon completion of the project and be used elsewhere • Pier infrastructure, treatment facility and seawater discharge pipe would need to be decommissioned or alternate uses would need to be found

3.3.3 Selection of the preferred regasification alternative

Following completion of the comparative analysis to evaluate the advantages and disadvantages of each option, the offshore FSRU alternative was selected based on a combination of the factors discussed in **Section 3.3**.

It was determined that selecting an offshore FSRU based approach for the project, compared to an onshore alternative, provided the following advantages:

- Eliminates the requirement for a large onshore footprint to construct the necessary regasification equipment, which if located outside of the refinery premises due to limited space, would require expensive cryogenic piping to transfer the LNG from the pier
- It would not require significant modification to existing refinery equipment and layout
- A lower safety risk due to the distance of the FSRU from public access areas and refinery infrastructure, providing a greater safety buffer
- Construction requirements would be considerably less as the FSRU would arrive commissioned for operation with only potential minor modifications required
- Can be developed in a shorter timeframe, compared to the onshore alternative which could take an estimated 6 to 12 months longer to construct
- Provides greater flexibility should there be a change in gas market demand as the FSRU can simply depart from its mooring and be reused elsewhere in the world
- The FSRU would not require decommissioning of extensive land-based infrastructure that would be associated with the onshore option.

3.4 Site selection for the FSRU

The Port of Geelong and Corio Bay area was selected as the preferred area to locate the project in order to meet the key objectives of the project. These objectives included providing a new secure and stable source of gas to the south-eastern Australia domestic and industrial gas market, and to ensure forecasted annual supply shortfalls in Victoria are avoided.

Under the Australian Energy Market Operator's (AEMO) central gas demand scenario in the 2021 Gas Statement of Opportunity (GSOO), there is still over 500 petajoules (PJ) of gas needed in south-eastern Australia[1] including around 200PJ for Victoria every year until at least 2040. Locating the project in the Port of Geelong and Corio Bay area supports these project objectives by providing an existing port and industrialised setting close to the major population centres of Melbourne and Geelong and close to the existing Victorian gas transmission pipeline network.

Three locations were considered for the project, all of which are located close to Geelong with two in Corio Bay inner harbour and one in the outer harbour. The following three options were considered:

- Refinery Pier (either rebuilding existing Refinery Pier No.1 or a new pier extension to create Refinery Pier No.5)
- Lascelles Wharf No. 4
- Point Henry Pier.

The location of each of these options is shown in **Figure 3-2**.

Offshore FSRU location options, particularly along the western shoreline of Port Phillip Bay which is relatively proximal to the Victorian gas network, were given consideration at the project screening stage. They were not progressed to the next stage of assessment after the initial screening stage for the following reasons:

- Potential locations would be outside of existing port and industrial areas and likely to display more environmental constraints than an existing port setting
- Locations closer to Melbourne would be more problematic due to factors including shipping congestion, potential conflict with recreational boating, visual impact and difficulty obtaining onshore pipeline access for connection to the Victorian gas network
- Weather at anchorage in a more exposed setting could preclude Ship to Ship (STS) operations (transfer of LNG) at critical times; particularly during winter when demand is greatest which could potentially affect reliability of Victorian gas supply

1 *AEMO 2021 GSSO Figure 7, page 22*

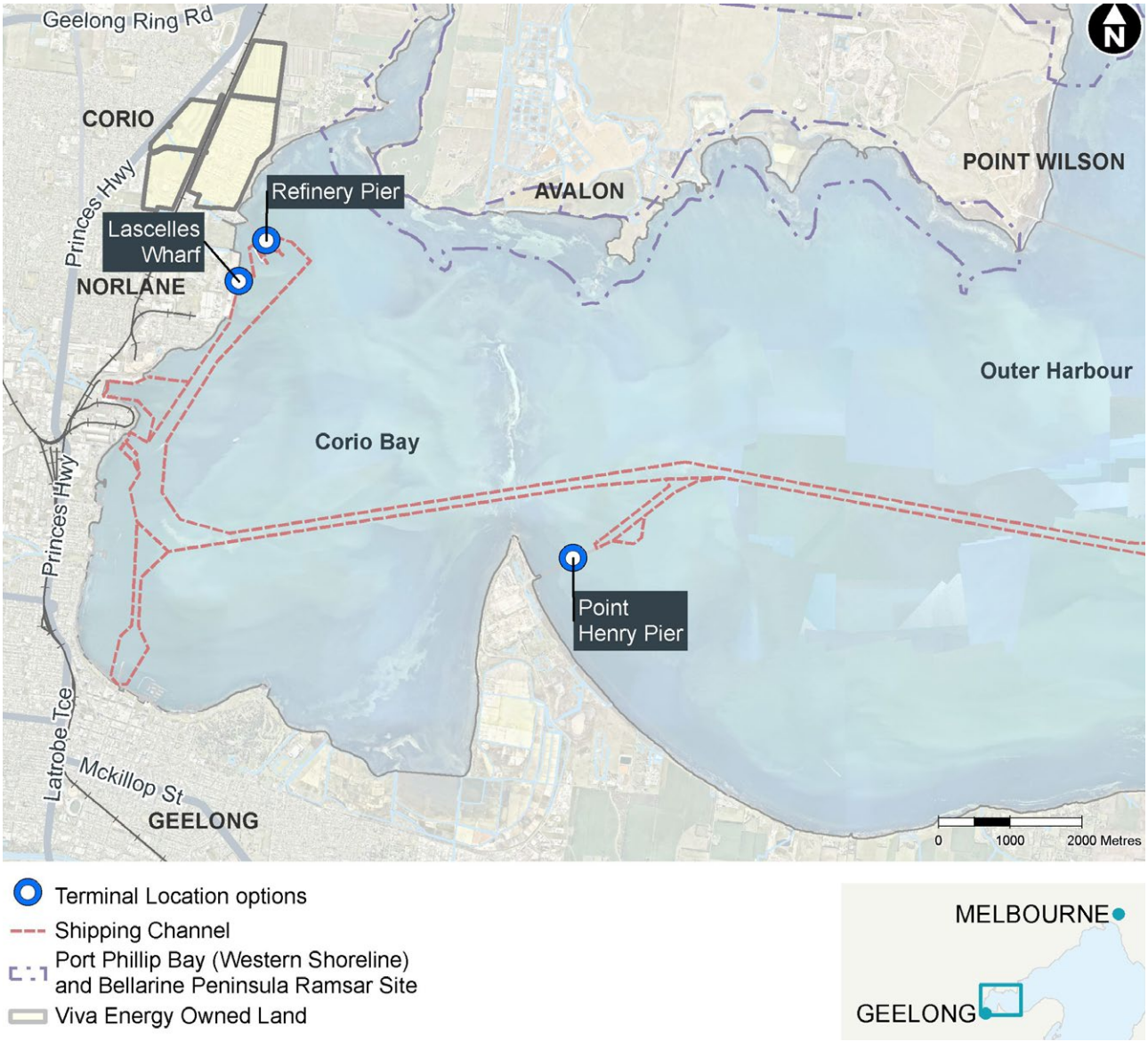


Figure 3-2 Gas terminal location options

- Subsea pipeline construction is complex with significant infrastructure required
- If located in the western area of Port Phillip Bay, the underwater section of the pipeline required would be greater than 15km and could pass through a Ramsar site depending on the proposed offshore location
- The location could potentially conflict with the announced Bay West port proposal
- An offshore location does not align with the vision for an Energy Hub at the Geelong Refinery
- Locating the FSRU offshore would not enable synergies to be captured with the Geelong Refinery such as seawater reuse and the potential for boil off gas usage at the refinery.

The assessment concluded that the proposed location at Refinery Pier proximal to the existing Viva Energy Geelong Refinery has significant benefits when assessed and compared with the alternatives having regard to a range of environmental, social, engineering, operational and economic parameters. These benefits are outlined in more detail in following sections.

3.4.1 Refinery Pier

Refinery Pier is located adjacent to Viva Energy's Geelong Refinery. There are four berths currently at Refinery Pier which service refinery operations importing and exporting liquid hydrocarbons. Refinery Pier No. 1 and Refinery Pier No. 2 are generally used for refined product export, with No. 1 usually reserved for loading bunkering vessels. Refinery Pier No. 3 and Refinery Pier No. 4 are used for importing crude oil, jet fuel and bitumen.

Refinery Pier options

The options considered for Refinery Pier were utilisation of an existing berth or construction of an additional pier to provide a new berth. Of the current berths at Refinery Pier, berthing the FSRU would only be possible at Refinery Pier No. 1 and No. 4. as only these berths would have sufficient manoeuvring space for berthing an LNG carrier adjacent to the FSRU. However, the Refinery Pier No. 4 utilisation rate for crude oil import of at least 50% precludes the conversion of this berth to LNG import without causing significant adverse impact on refinery operations.

Due to this constraint, the two options considered for Refinery Pier were utilisation of the existing berth at Refinery Pier No. 1 or construction of an additional pier arm for Refinery Pier No. 5. Table 3-2 provides a comparative assessment of Refinery Pier No. 1 and Refinery Pier No. 5.

Of the two pier options considered, Refinery Pier No. 5 was considered to be the preferred option due to the minimal impact on existing refinery operations and other port users, fewer safety risks associated with construction and operation of a new pier compared to upgrading and utilising an operating pier and a potential lower amount of dredging and dredged spoil disposal.

Locating the project at Refinery Pier would provide the following benefits when compared to other alternate locations at Lascelles Wharf and Point Henry Pier:

- Fits with existing refinery operations of managing liquid hydrocarbon products
- Provides the shortest distance of the three options for the new gas pipeline to connect into the South West Pipeline (SWP) adjacent to land owned and operated by Viva Energy
- Would have minimal visual impact being proximal to the existing refinery and port landscape
- Can accommodate LNG carriers with less localised dredging required for the berth pocket and swing basin
- Close proximity to the refinery gives the potential for FSRU seawater discharge to be utilised in the refinery cooling water process.

The proposed layout for Refinery Pier No. 5 is shown in Table 3-3.

Table 3-2 Refinery Pier No.1 and Refinery Pier No.5 comparative assessment

Criteria	Refinery Pier No. 1	Refinery Pier No. 5
Additional construction required	• Refinery Pier No. 1 is 65 years old and is capable of berthing vessels up to 185m long. Major structural and dimensional upgrades would be required to accommodate the larger vessels to 300m. This would be equivalent to the construction of a new pier. • Pipeline and berthing fender upgrades would also be required at Refinery Pier No. 2 and No. 3 to allow these berths to accommodate the shipping that is currently serviced by Refinery Pier No.1.	• A new piled pier head would be required, while the pipeline / utilities gantry and road access would be connected to the existing pier access.
Interference with port users	• Berth upgrade activities would result in periods of unavailability for Refinery Pier No. 2 due to its proximity to No. 1. Loss of both berths concurrently would impact refinery operations. • A permanent loss of this berth for both refinery and Quantem operations would increase berth utilisation on the remaining three berths resulting in operational impact as the remaining piers would approach maximum capacities.	• Minimal impact on Refinery Pier No. 1 operations during construction • Minimal impact on port users during operation.
Safety	• Construction around an operating pier would increase safety risk and significantly limit refinery operations during construction due to unavailability of Refinery Pier No. 2 • Proximity of LNG vessels to Refinery Pier No. 2 would increase operational safety risk and potentially result in constraints on refinery operations.	• LNG shipping safety studies and risk assessments identified fewer constraints and less interference with refinery operations by constructing a new remotely located berth specifically for the project • Less interference with other berth operations would reduce potential operational safety risks associated with an increased use of other berths.
Dredging quantities	• Navigational simulations have identified a substantially similar dredge footprint and dredge volume as Refinery Pier No. 5 as dredging quantities are a result of vessel manoeuvring requirements.	• Approximately 490,000m^3 for the berth pocket and swing basin.
Environmental impacts	• Similar dredging quantities would have a very similar impact on the marine environment due to the close proximity of locations.	• Similar environmental impact due to similar dredging quantities at close proximity.

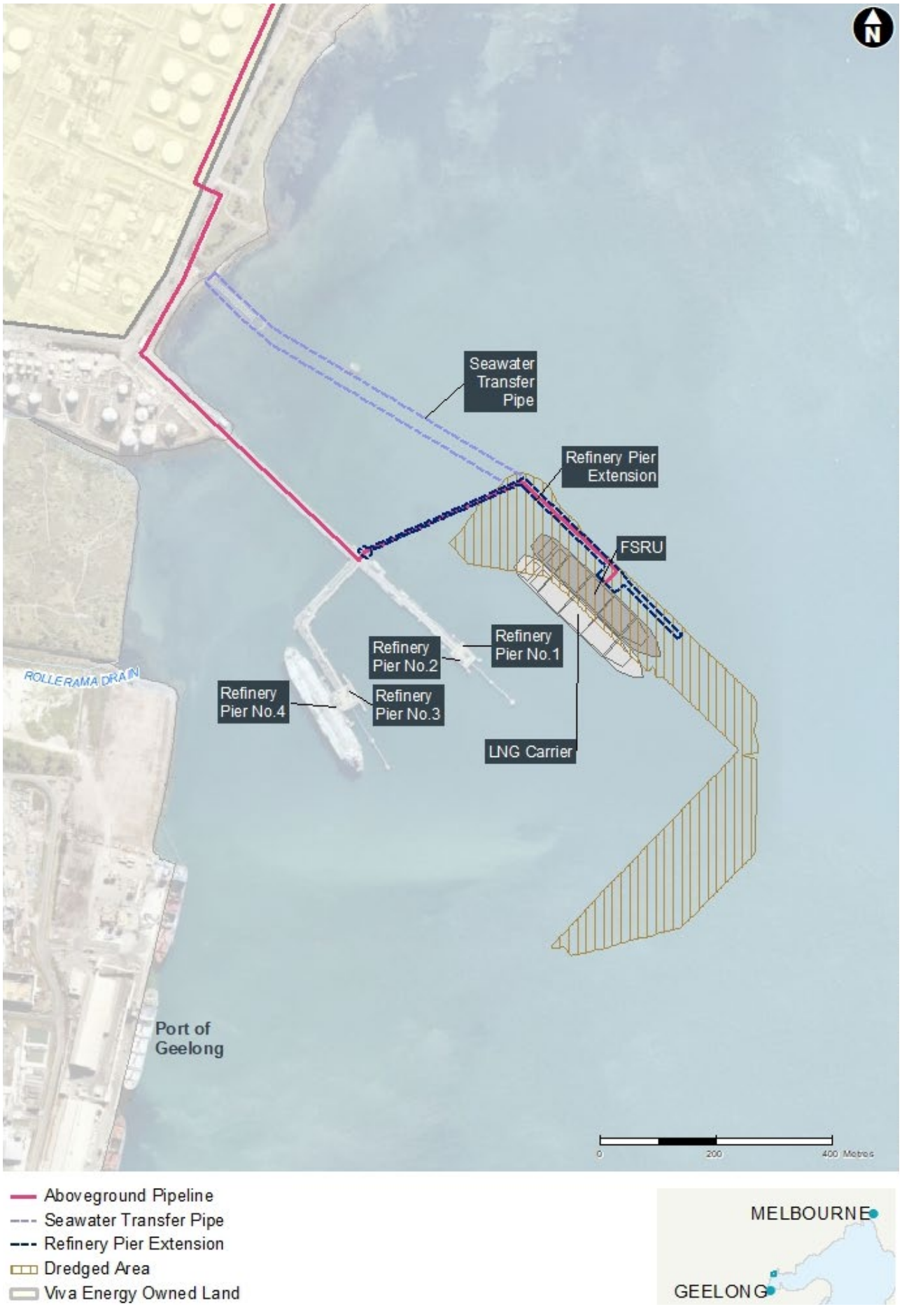


Figure 3-3 Refinery Pier No.5 layout

3.4.2 Lascelles Wharf No. 4

Lascelles Wharf is located to the north of Corio Bay, just south of the Refinery Pier. The wharf currently has three dry bulk handling berths in use. A fourth berth would need to be constructed at the northern end of the wharf to allow for continuous mooring of the FSRU and this area has been identified by GeelongPort for possible future development.

The proposed location is currently used to store wind turbines following offloading. Both excavation and dredging would be required at the site in order to allow sufficient space for tankers to access Refinery Pier No. 4 located to the immediate east whilst both the FSRU and LNG carrier are moored at Lascelles Wharf No. 4. Based on the preliminary layout proposed for Lascelles Wharf No. 4, the distance between a tanker berthed at Refinery Pier No. 4 and an LNG carrier berthed alongside the FSRU would be in the range of 100m to 150m.

This option would be dependent on ship manoeuvring simulations and safety studies to confirm feasibility. There would be a potential for impact to existing Refinery Pier No. 4 operations from the FSRU moored at this location, along with an impact on potential future developments due to ship manoeuvring at this location.

The preliminary layout considered for Lascelles Wharf No. 4 is shown in **Figure 3-4**.

Locating the project at Lascelles Wharf No. 4 would provide the following benefits:

- It has been identified by GeelongPort for possible future development, however, use for the Gas Terminal Project would only be considered if the footprint on the wharf was minimal so as to not preclude future development
- A short distance for the pipeline to connect into the South West Pipeline (SWP) although it would require a creek crossing when compared with the Refinery Pier No. 5 option.

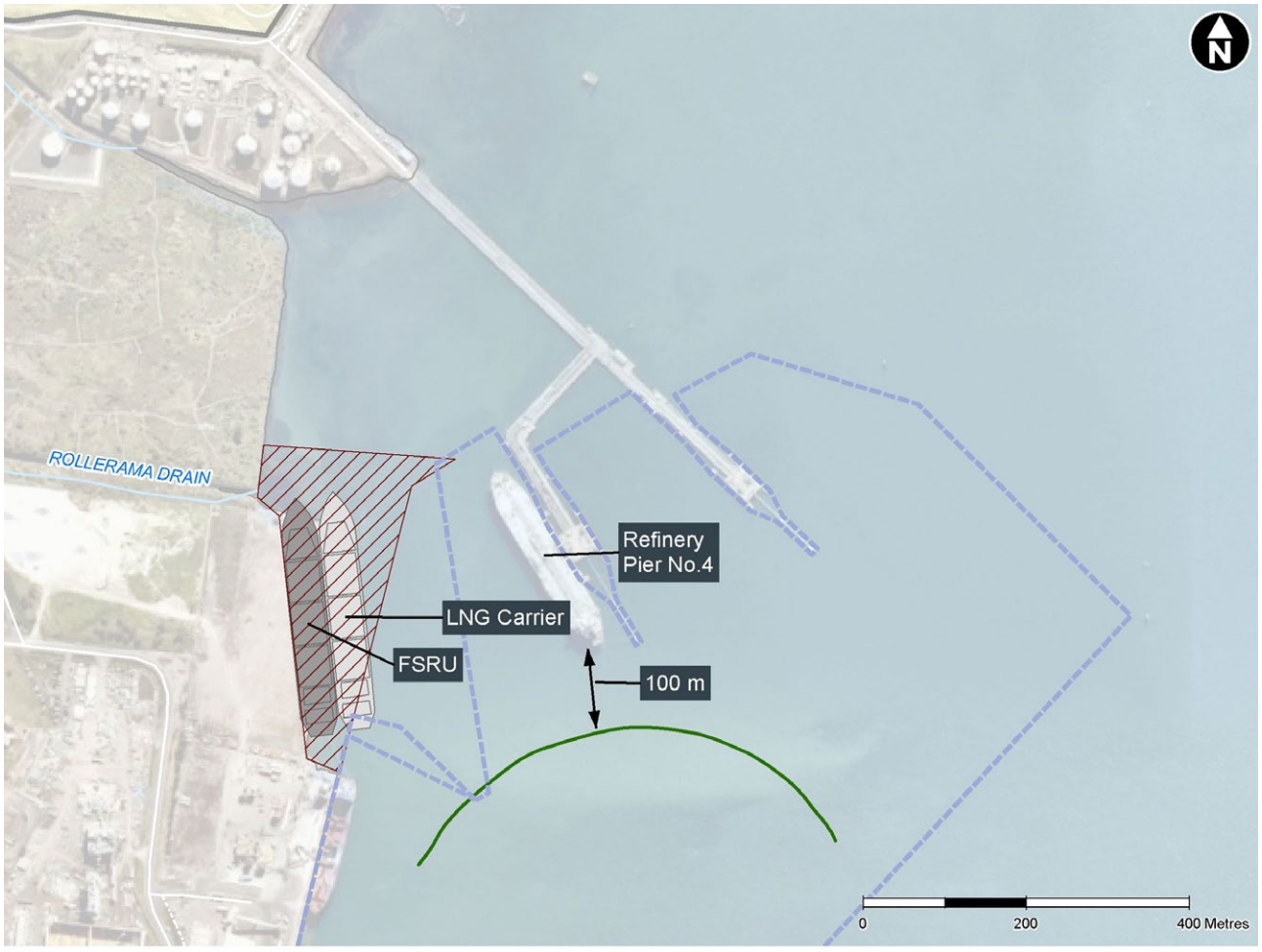


Figure 3-4 Lascelles Wharf No. 4 layout

3.4.3 Point Henry Pier

The Point Henry Pier is located to the south of the Outer Harbour as shown in **Figure 3-2** The approach channel is located between the Hopetoun Channel and the Wilson Spit Channel. The existing pier is part of the former Alcoa works but has not been used since that facility closed in 2014.

This option would require additional dredging of the approach channel, dredging of a new swing basin and substantial modification to the existing pier structure. Construction of a Point Henry Pier berth would have minimal impact on port operations however, the required dredge volume would be significant. The preliminary layout considered for Point Henry Pier is shown in **Figure 3-5**.

The associated pipeline route from Point Henry Pier would be very long, circling Geelong if located onshore or would be a very challenging subsea pipeline that would need to cross the shipping channel if located offshore. In addition, there is a likelihood of future channel deepening campaigns that could impact a subsea pipeline.

Locating the project at Point Henry Pier would provide the following benefits:

- The location does not require LNG carriers to transit through the Corio Channel city bend and the narrower part of the Port of Geelong approach channel
- Construction works, being located in the Outer Harbour, would have minimal impacts on port operations as there would be limited interaction with port users during operation.

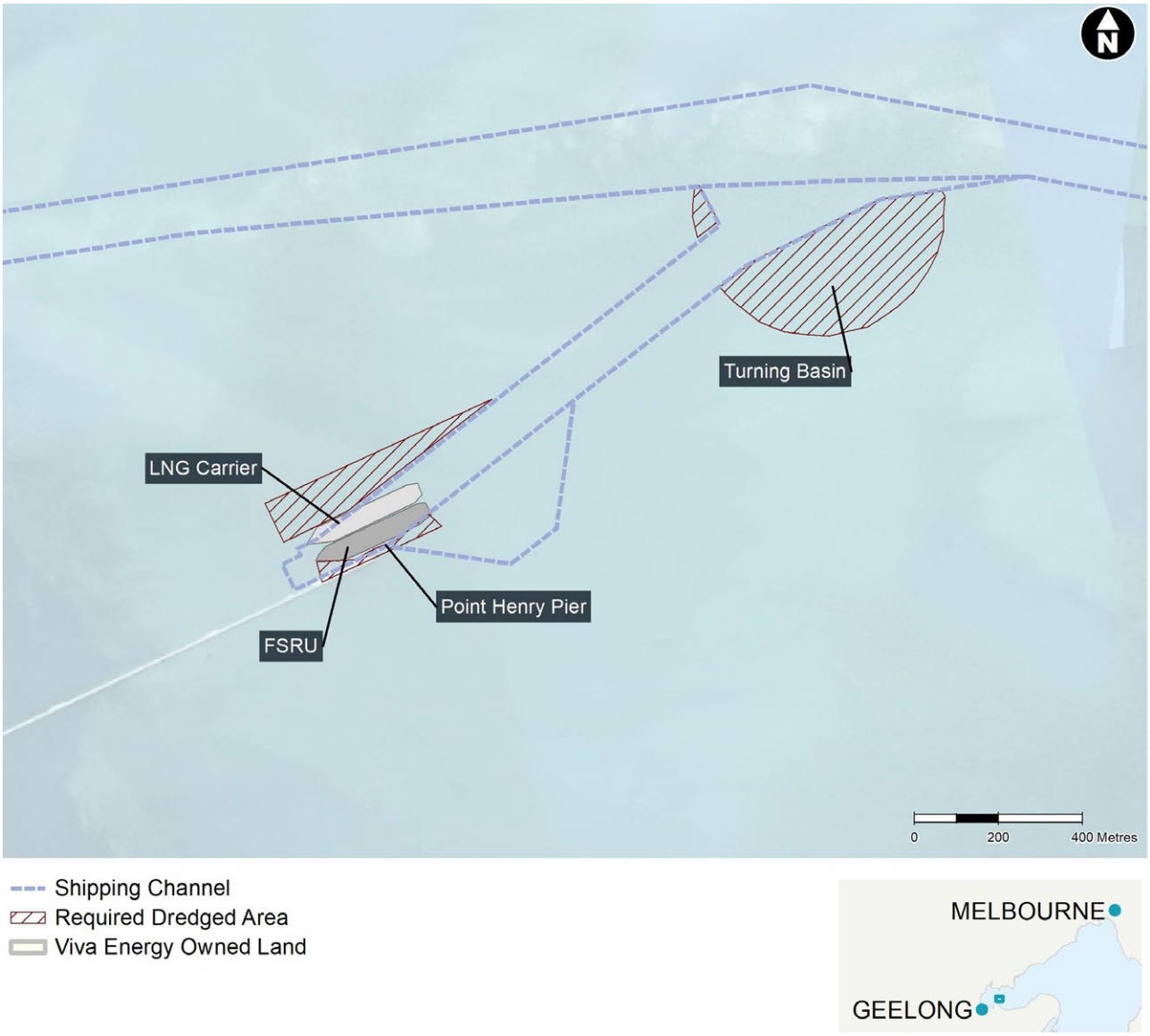


Figure 3-5 Point Henry Pier layout

3.4.4 Comparative assessment

A high-level comparative assessment was undertaken for the three sites to determine the preferred location and suitability for the gas terminal. The comparative site evaluation was performed by reviewing a range of criteria for each of the locations to determine their suitability. A summary of the comparative assessment of the three sites is provided in **Table 3-3**.

Table 3-3 Comparative assessment for gas terminal locations

Criteria	Refinery Pier No. 5	Lascelles Wharf No. 4	Point Henry Pier
Navigational issues	• Minimal navigation issues, final berth at the end of the channel with a typical berthing arrangement	• LNG carriers would be berthed into a compact berth due to dry bulk vessels to the south and tankers at Refinery Pier No. 4 to the east • Likely a high risk manoeuvre required by pilots and tug operators	• LNG carriers would be towed astern along the approach channel to the berth, deemed a higher risk by pilots and tug operators
Interference with port users	• Minimal impact on Refinery Pier No. 1 operations during construction • Minimal impact on port users during operation	• Impact on Lascelles Wharf and Refinery Pier No. 4 operations during construction • Would impact on other port users during LNG carriers manoeuvre (vessels at Lascelles Wharf and tankers at Refinery Pier No.4) • Would potentially prevent future port expansion by GeelongPort	• Minimal impact on other port users due to the location of the pier being in the outer harbour
Dredging quantities	• Approximately 490,000m^3 for the berth pocket and swing basin	• Approximately 955,000m^3 for the berth pocket and swing basin (includes 235,000m^3 of material required to be excavated from the existing wharf)	• Approximately 1,000,000m^3 for the berth pocket and swing basin
Additional construction required	• A new piled pier head would be required, while the pipeline/ utilities gantry and road access would be connected to the existing pier access.	• Substantial work required, including a new wharf with considerable landside excavation	• Existing pier does not have capacity for a FSRU, strengthening and new dolphins required.
Power and utility availability	• Easy access to power and utilities from existing pier facilities	• Requires new source of power and utilities	• Requires new source of power and utilities

Criteria	Refinery Pier No. 5	Lascelles Wharf No. 4	Point Henry Pier
Land acquisition	• Minimal land acquisition required for pipeline. Onshore facilities to be located at the refinery	• The pipeline and utilities corridor to the refinery would likely require land acquisition	• Onshore land would need to be acquired for facilities buildings and the onshore pipeline corridor
Pipeline connection	• Shortest distance of the 3 options • Would run through the refinery and use the existing pipeline corridor/road reserve to the SWP tie in	• Second shortest option • Would require an additional creek crossing prior to running through the refinery	• Longest option • Would require a long onshore route around Geelong or a challenging route under the existing shipping channel
Residential proximity	• Closest residential area is North Shore, 1.5km to the south. However, extension of existing pier operation considered 'business as usual' for hydrocarbon management at Refinery Pier and within port environment	• Closest residential area is North Shore, 1km to the south • Onshore construction works would be required, likely to result in noise impacts	• Closest residential area is 5km. • Construction impacts likely to occur as equipment and materials would travel through Geelong
Visual amenity and social considerations	• Visual impact from the north of Corio Bay, however, still fits in the port and refinery context. • Limited impact on surrounding communities and sensitive receptors as land use fits within existing context of the port setting	• Close proximity to North Shore would result in visual impacts for residents. The FSRU would be considerably larger than the current vessels that berth at the wharf.	• Major visual impact on surrounding business and residential area • Point Henry has been chosen for potential future development and return to public land (Moolap Development), and would create visual impact concerns for local homeowners and businesses
Environmental	• Potential for contaminated dredged material due the nature of Refinery Pier operations • Lower degree of environmental impact due to lower dredging quantities	• Potential impacts from pipeline creek crossing • Potential for contaminated dredged material as the wharf was previously used as a refuse landfill area • Greater dredging quantities required would have a greater impact on the marine environment	• Potential for contaminated dredged material due to the proximity of the aluminium smelter • Pipeline would likely have impacts due to its lengthy route • Greater dredging quantities required would have a greater impact on the marine environment

Criteria	Refinery Pier No. 5	Lascelles Wharf No. 4	Point Henry Pier
Seawater re-use	• Can re-use seawater discharge from the regasification process within the refinery by directing seawater discharge to the existing refinery seawater intake	• Not able to re-direct seawater discharge from Lascelles Wharf to the existing refinery seawater intake due to location of Lascelles Wharf No. 4	• Not able to re-direct seawater discharge to the existing refinery seawater intake due to significant distance
Economics	• Can utilise existing personnel and facilities at the refinery during operation • Capital expenditure costs associated with new pier arm and pier infrastructure	• Can utilise existing personnel and facilities at the refinery during operation • Costs associated with new pier arm and pier infrastructure • Higher dredging volumes would make it more costly	• Would require new facilities and personnel located at the site • Highest capital expenditure of all options due to a new wharf being required and significant dredging volumes • Higher costs associated with a longer and more challenging pipeline route

3.4.5 Selection of the preferred site for the FSRU

Following completion of the comparative assessment to evaluate the advantages and disadvantages of each of the locations, Refinery Pier No. 5 was selected as the preferred site for the FSRU.

Co-locating the project with the existing Geelong Refinery and within the Port of Geelong offers significant opportunity to minimise potential environmental effects and utilise a number of attributes that exist within the port and industrial setting. In particular, the ability to redirect and reuse the cooled water discharge from the FSRU in the adjacent refinery process rather than discharging the water directly into Corio Bay provides a significant opportunity to enhance the overall environmental performance of the project. The short distance to the SWP connection point into the Victorian gas network is also a significant benefit of the preferred option as it only requires a 7km pipeline of which 3 kilometres would be located aboveground along Refinery Pier and within the refinery premises, and 4 kilometres would be underground which, where practicable, would be constructed within or adjacent to the existing pipeline corridor.

The Refinery Pier No. 5 option was considered to be the preferred option on the basis that it:

- Would have minimal navigation issues, being the final berth at the end of the channel with a typical berthing arrangement. This option would have minimal impact on other port users during both construction and operation.
- Would have easy access to power and utilities, including firefighting systems, available from the existing pier facilities.
- Would require no additional onshore land acquisition for the treatment facility, as the pier is adjacent to the refinery.
- Would enable onshore pipework to be routed through the refinery and onshore facilities to be located on Viva Energy owned land as required.
- Enables use of the existing pipeline corridor to the SWP tie-in point at Lara.
- Would have minimal visual impact compared to the other options as Refinery Pier is considered 'business as usual' and within a port environment.
- Has a lower dredging volume than alternative options.
- Has potential synergies with refinery operations including re-use of the FSRU seawater discharge in the refinery cooling water system.
- Has lower capital expenditure than the Lascelles Wharf option, where a new wharf would have to be constructed, and lower operating costs than the Point Henry Pier option through utilisation of existing facilities and refinery personnel.

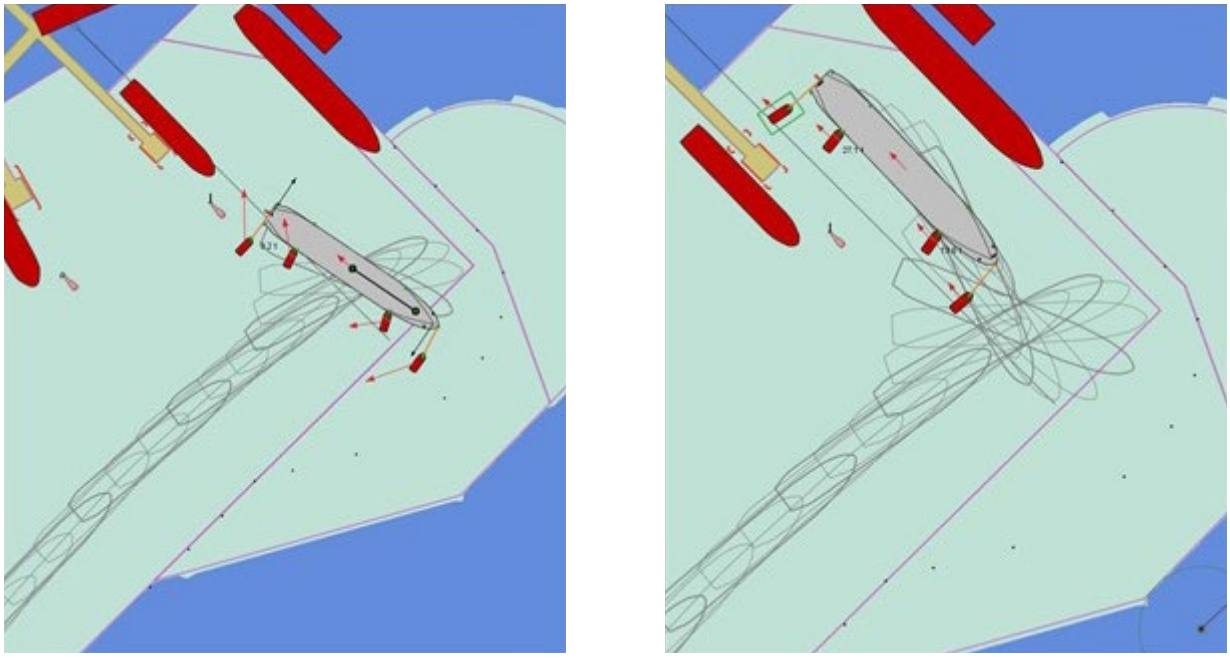


Figure 3-6 Visual representation of the LNG carrier approach (Smartship Australia, 2021)

In addition to the advantages of selecting Refinery Pier No. 5 for the FSRU, use of the existing refinery site for the land-based components of the project also provides a number of other benefits. Preliminary assessments indicated that the refinery site offered a significant number of attributes which made it a suitable location including:

- Location within and adjacent to an existing port and industrial complex.
- The refinery is already a designated Major Hazard Facility (MHF) with stringent controls on safety and risk in place including significant separation distances from sensitive land uses.
- Highly modified environment, landscape and visual setting.
- Ecological studies conducted during 2020 indicate the absence of any significant flora and fauna on the refinery site and proposed pipeline corridor.
- Absence of watercourses on the project site.
- Long history of Viva Energy co-existing with its neighbours at the proposed treatment facility site within the refinery.
- Longstanding relationships with nearby stakeholders as a basis for direct engagement on the proposed project.
- Ability to extend the existing Refinery Pier rather than create new pier infrastructure.
- All land-based infrastructure, such as the treatment facility, is planned to be located within the existing refinery footprint with buffer/ separation distances to sensitive receptors.
- Limited number of sensitive receptors proximate to the current refinery and proposed project area.
- Short underground gas transmission pipeline distance (approximately 4km) between the proposed treatment facility and the connection point into the SWP at Lara.
- Due to existing MHF separation distances from sensitive land uses, potential impacts such as safety, hazard, noise and air quality from the proposed FSRU and land-based facilities should be readily manageable and meet compliance requirements.
- A large portion of the proposed pipeline corridor traverses land held by Viva Energy, Greater Geelong City Council and VicRoads with a small number of landholder interactions required.
- Direct access to the treatment facility for nitrogen supplies via the Princes Freeway and Shell Parade which are VicRoads gazetted High Productivity Freight Vehicle roads.
- Availability of existing environmental monitoring data from the refinery for a range of parameters such as noise, air quality and groundwater provide baseline conditions for assessment of impacts from the project.
- Supports Viva Energy's vision to transform the Geelong Refinery into the Geelong Energy Hub to help build a sustainable operation and long-term energy security.

3.5 Dredging design development

During the preliminary Front End Engineering Design (FEED) for the project, it was assumed that LNG carriers would be required to turn around in the swing basin prior to berthing adjacent to the FSRU for transfer of LNG. Initial designs estimated approximately 1.1 million m^3 of dredged material would be required to be removed adjacent to the existing shipping channel to provide sufficient water depth at the new berth and within the swing basin to allow for the vessel to turn prior to berthing.

Further berthing simulations for the selected site of Refinery Pier No. 5 were undertaken for multiple vessel types in a variety of weather conditions. Following these simulations and further design development, it was determined that an LNG carrier would be able to safely back up with the assistance of four tugs in a considerably smaller swing basin. It was also confirmed that the LNG carrier would be able to safely depart the berth. **Figure 3-7** provides a visual representation of the LNG carrier approaching the berth with the assistance of the tugs.

This resulted in a reduction to the required swing basin and subsequently a reduction in dredging requirements. This design development resulted in a reduction in the estimated volume of dredging to approximately 490,000m^3. A comparison between the original dredge footprint and the proposed dredge footprint is shown in **Figure 3-7**.

This refinement to the berthing arrangements was considered to represent a major environmental enhancement on the original project design and represents a lesser amount of dredging when compared with the other project locations considered.

A number of dredge sediment disposal options were assessed to determine the most suitable option for disposal and management of the 490,000m^3 of dredged material. It was determined that disposal at an existing dredged material ground (DMG) in Port Phillip Bay to the east of Point Wilson located approximately 26km from Refinery Pier was the preferred option subject to regulatory approvals. The DMG has been used for disposal of sediments from past dredging programs in Corio Bay and displays similar sediment characteristics to the dredged spoil from the project. It is also by far the closest disposal ground in Port Phillip Bay with attendant benefits of reduced travel time, cost and energy use. Potential onshore options for disposal of dredged sediments were considered to be less favourable as the low level of contamination in the sediments does not require treatment under regulatory guidelines and costs and energy use associated with treatment, storage, drying and ultimate disposal on land would be significantly higher. The findings of the disposal options assessment are documented in Technical Report B: *Dredged sediment disposal options assessment*.

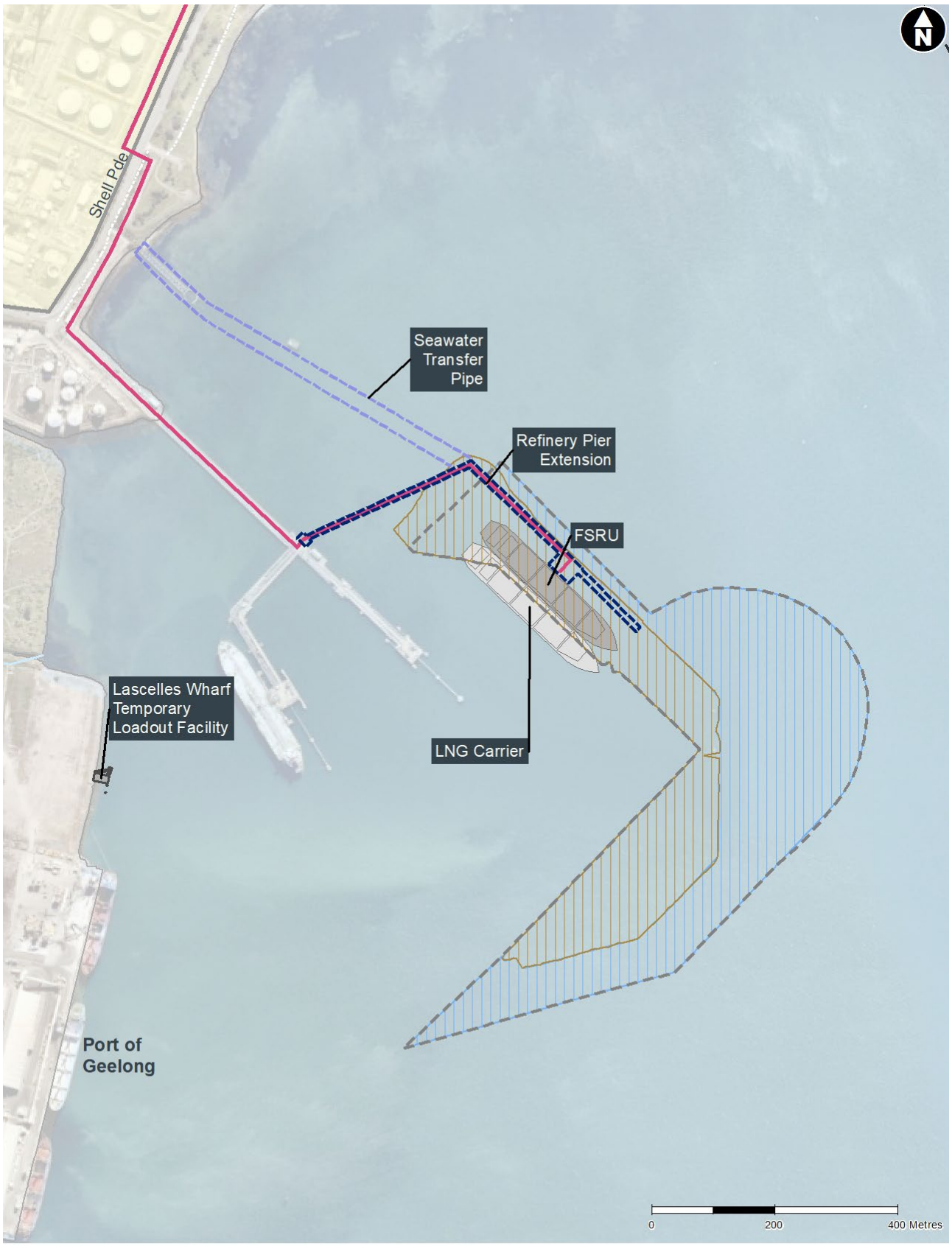


Figure 3-7 Comparison of the original dredge footprint and the proposed dredge footprint

3.6 FSRU design development

The following section outlines the key aspects involved in the design development of the FSRU, including the design of the seawater intake and discharge processes, an assessment of regasification mode alternatives and selection of the proposed regasification mode for the FSRU.

After the selection of Refinery Pier as the preferred site for the FSRU, key features of the FSRU including the seawater intake and seawater discharge ports were designed progressively. This included assessment of the different regasification modes and the volumes of seawater intakes and discharges under a range of operating scenarios to develop a functional FSRU operating design that would operate efficiently and avoid or minimise adverse environmental impacts.

3.6.1 Seawater intake

Design development of the FSRU seawater intake has taken into consideration potential impacts on the marine environment. Seawater would be drawn into the FSRU through the vessel sea chest or dedicated water inlet ports in the hull. Two intakes would be located on the FSRU, one on the port side approximately five metres below the sea surface, and one starboard side approximately eight metres below the sea surface.

The intake velocity of the FSRU seawater intake has been reduced to 0.15 metres per second (m/s) in accordance with the US EPA requirement and to be able to demonstrate best practice. Reducing the intake velocity allows mobile marine organisms to swim away. The intakes would also be fitted with grilles spaced at less than 100 mm x 100 mm to prevent the intake of fish and other matter into the FSRU.

3.6.2 Seawater discharge

Refinery cooling water synergy

During design development for the project, a potential synergy was identified between the FSRU cold water discharge and the seawater intake for cooling water currently used at the refinery. The discharge volume from the FSRU would be approximately 300,000m^3/day for regasification of 500TJ/day during the winter months. On a limited number of peak demand days, the gas production rate would fluctuate throughout the day, but the maximum daily flowrate of seawater would be 350,000m^3/day. The Geelong Refinery currently uses a similar volume of seawater for cooling purposes (350,000m^3/day). It was considered that the refinery cooling water flowrate could be offset by the FSRU cold water discharge flow rate.

Where seawater discharge from the FSRU exceeds the intake requirements for the refinery (e.g., when parts of the refinery are shut for maintenance), excess seawater from the FSRU would be discharged to Corio Bay through a diffuser located under the new pier. Conversely, where seawater discharge from the FSRU is lower than the intake requirements for the refinery, for example, when the production rate for the FSRU is low due to reduced demand, the refinery would draw the remaining volume of seawater require through the existing inlet. The cooled (7°C below ambient temperature) seawater discharge from the FSRU regasification system would be directed to the existing refinery seawater intake for reuse within the refinery and would replace the seawater intake volume currently extracted by the refinery.

The FSRU would be located approximately 500m south-east of the refinery cooling water intake and the cooled water discharge would be directed to the cooling water intake by means of a pipe which would run beneath the seabed.

Currently, the refinery inlet takes in seawater at ambient temperature and discharges the cooling water through EPA licensed outlets at a warmer temperature. The resulting average temperature of the water discharged through the outlet from the refinery is approximately 8-10°C above ambient seawater temperature. Diverting the cooled water discharge from the FSRU to the refinery inlet reduces the temperature of the water taken into the refinery by approximately 7°C. This in turn reduces the temperature of cooling water discharged from the refinery by 7°C. The resulting outlet temperature averaged across the refinery discharge points would then be approximately 1-3°C above ambient seawater temperature, compared to the current 8-10°C above ambient temperature from normal refinery operations. **Table 3-4** provides an overview of the effect of the FSRU seawater discharge on the refinery cooling water discharge points.

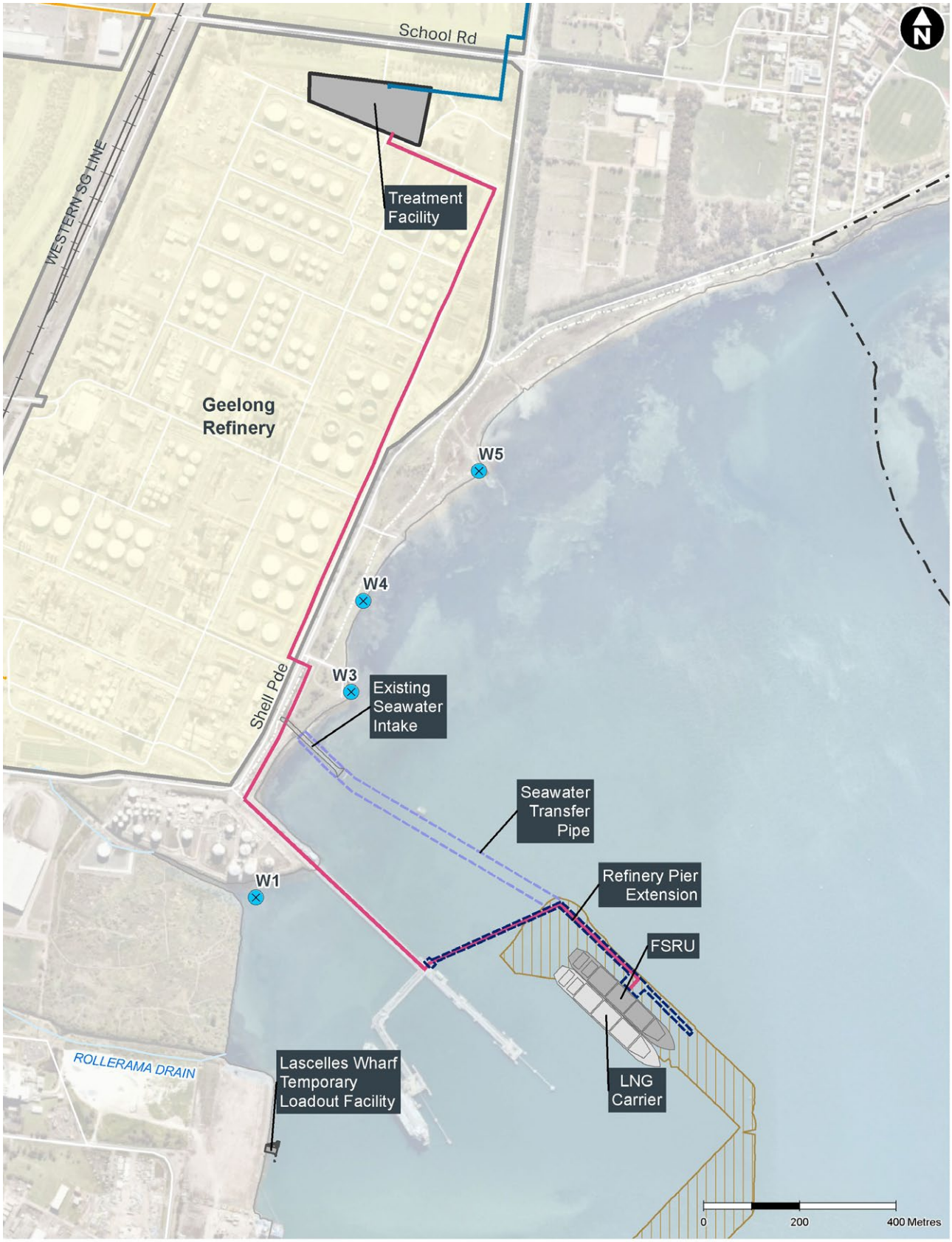


Figure 3-8 Refinery seawater intake and discharge points

Table 3-4 Impact of the FSRU discharge on the refinery outlet cooling water temperature (Ambient seawater temp = 10°C)

Cooling water outlet location	Outlet temperature (no FSRU)		Outlet temperature (with FSRU)	
	Temperature (°C)	Above ambient seawater temperature (°C)	Temperature (°C)	Above ambient seawater temperature (°C)
W1	19	9	14	4
W4	18	8	13	3
W5	20	10	15	5
Average	19	9	14	4

Using the cooled water discharge from the FSRU as a source of refinery cooling water would provide the following benefits:

- Reduces the potential environmental impact associated with discharging cold water (7°C below ambient seawater temperature) from the FSRU at a single location below the vessel
- Reduces the potential environmental impact at the refinery cooling water outlet locations by lowering the discharge temperature from 9°C to 4°C above ambient seawater temperature
- Reduces the potential environmental impact by spreading the FSRU discharge flowrates across the three refinery outlet locations. This results in a more diffuse and lower concentration of warm temperature water being discharged.

In addition to FSRU seawater discharge being approximately 7°C cooler than ambient seawater temperature, discharge from the FSRU after it has been used in the heat exchange process would also contain short-lived residual chlorine. The refinery cooling water discharge also currently contains short-lived residual chlorine. However, it was considered that management of residual chlorine in the discharge water at acceptable environmental limits was achievable utilizing existing management practices at the refinery and that this would be further developed in the detailed design process.

It was also considered necessary to develop an option to directly discharge the FSRU regasification water (7°C below ambient seawater temperature) into Corio Bay in situations where the refinery may be 'offline' for maintenance or other reasons and reuse in the cooling water process could not occur.

It was considered that the best option to manage this cooled water discharge was via a diffuser located on the jetty extension which would spread the cold water across a number of outlets rather than concentrated directly from a single discharge point on the FSRU.

FSRU design modifications

To transfer the cooled water discharge from the FSRU to the refinery, modifications to the FSRU design would be required. Standard FSRU design would involve direct discharge into the receiving waters in which the vessel was located.

To enable reuse of the FSRU discharge as refinery cooling water which is a major environmental enhancement when compared with direct discharge to Corio Bay (normal FSRU discharge approach), modifications to the vessel would be required. These modifications would consist of the FSRU seawater discharge being directed to a common line located above the upper deck at the forward side of the vessel, where it would reach a manifold on the port side. The seawater return manifold would have four take-off trains, equipped with Quick Release Couplings (QRC) and flexible hoses for the transfer of the cold seawater to an export pipeline routed towards the refinery cooling water inlet.

Each seawater discharge manifold train would be located outside the ship hull at an optimal location following the shape of the vessel. The pipeline trains would be extended downwards on the upper deck and connected to the offloading/discharge hoses via QRC. **Figure 3-9** and **Figure 3-10** show the proposed FSRU regasification seawater overboard manifold system.

The cooled water discharge from the FSRU would be transported to the existing refinery cooling water intake by means of a DN1200 pipeline, approximately 500 metres long. This pipeline is proposed to be buried approximately 2 metres below the seabed and utilise a trenched option, rather than the pipe being anchored to the seabed, to protect the pipe and ensure that it remains submerged during low tide. The seawater discharge pipe would run along the straight arm of the new pier in a pipe rack, however, unlike all other piping that would run along the pier arm back towards the existing Refinery Pier, the seawater discharge pipe would continue straight along the seabed and into the existing refinery seawater intake.

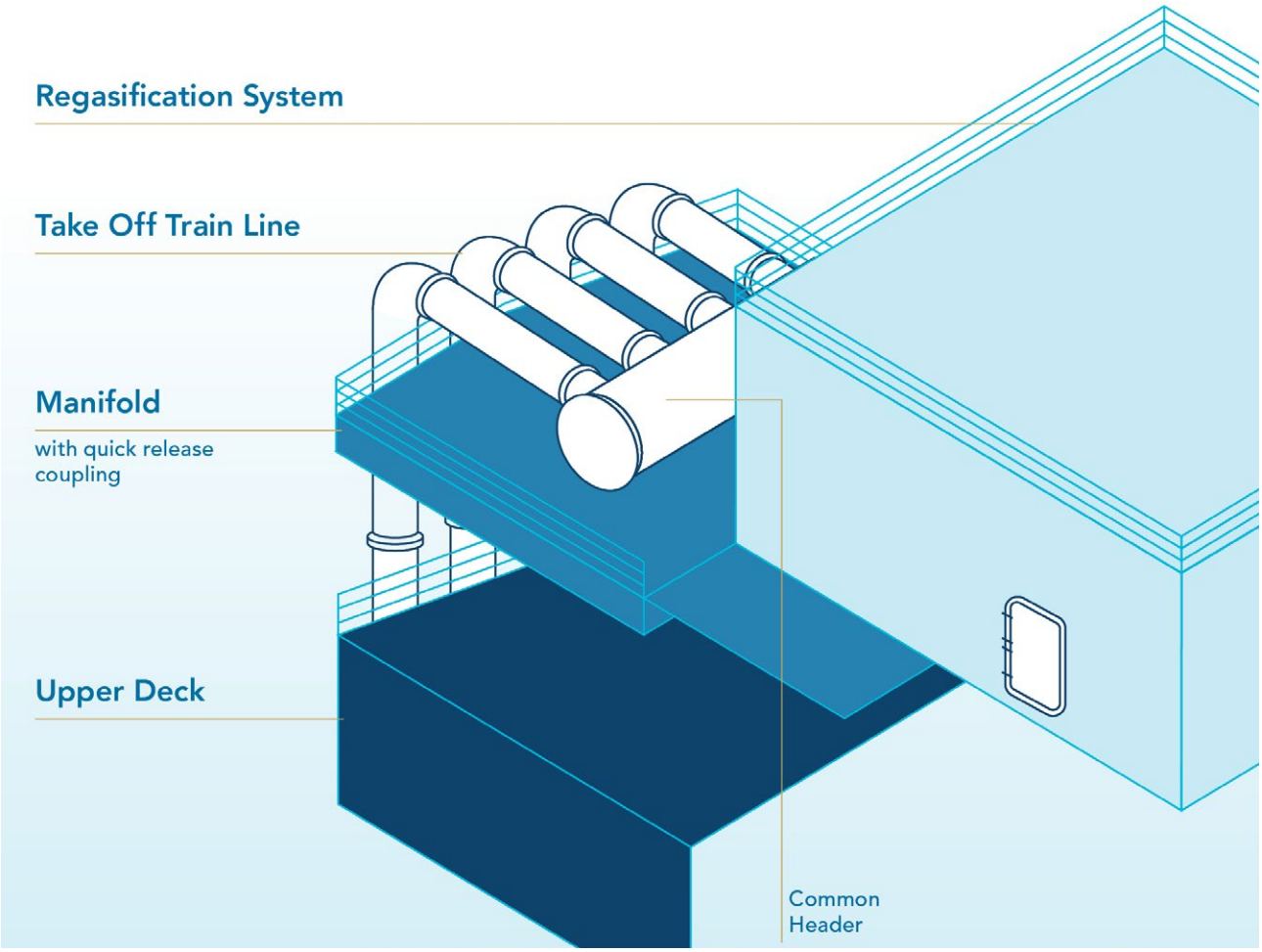


Figure 3-9 Proposed design for the FSRU regasification seawater system overboard manifold



Figure 3-10 Example of a regasification seawater system overboard manifold integrated onto an FSRU

3.6.3 Alternative regasification modes

The FSRU converts stored LNG into natural gas via a process called regasification using onboard regasification equipment. A heat-exchanger is used as an interface to transfer heat from a heat source to the LNG in the regasification train. The regasification trains can operate in either open loop mode which uses seawater as the heat source, closed loop mode which uses gas-fired boilers as the heat source or combined loop utilising a combination of the other modes. Combined loop was not considered as an operating option for the project as it is only used in very limited circumstances, in particular, to heat seawater when it falls below a specified temperature prior to regasification.

There are a number of methods for regasification of LNG available and the selection of an optimum process depends on plant site location, climatic conditions, throughput capacities, energy efficiency and environmental and regulatory compliance. **Table 3-5** outlines the different methods that are available for LNG regasification. Ambient air vaporisation (AAV) was not considered appropriate for the project due the unsuitable climate conditions at Geelong.

Table 3-5 Regasification alternatives

Regasification process	Description	Advantages	Disadvantages
Open loop system	Uses seawater to heat the LNG. Seawater is continuously drawn in via intakes, passes once through a heat exchange system and is then returned directly to the sea. Propane would be used as the intermediate fluid	• Most commonly used system globally for FSRUs • Simpler process of regasification • Lower greenhouse gas emission compared to closed loop	• Potential marine impacts from FSRU discharge • Potential for entrainment during seawater intake
Closed loop system	A closed loop of circulating seawater within the FSRU is used as an intermediate heating medium by gas-fired steam boilers in the LNG regasification trains. Propane would be used as the intermediate fluid	• Lower seawater intake and discharges than open loop	• Higher greenhouse gas emissions than open loop • Higher consumption of LNG for fuel • Greater capital expenditure costs for gas-fired boilers
Ambient air vaporisation	Utilises air as the heating medium and avoids the use of seawater and fuel gas as heating mediums	• Less potential impact on marine environments as it does not involve discharge of cooled seawater	• Better suited to regions where ambient temperature is high all year round • In cooler climates, a heat system is required to supplement the AAV process • Larger infrastructure required • Can produce vapour fogs

Open loop system

An open loop system on the FSRU uses seawater to heat the LNG. Seawater is continuously drawn in via intakes, passes once through a heat exchange system and is then returned directly to the sea at temperatures of 7 °C below ambient water temperature. Propane would be used as an intermediate fluid, whereby seawater would be used to heat the propane, and the propane would then heat the LNG. The energy used to pump the seawater through the heat exchanger consumes about 1.5% of the send out gas for power generation, similar to onshore terminals (Songhurst 2017). Seawater is generally used as a heat source for warming and vaporising the LNG, except in cold climates where there is a risk of freezing the seawater (Patel et al. n.d.). Open loop is the most commonly used system globally for FSRUs.

Closed loop system

A closed loop system uses gas-fired steam boilers to heat a closed loop of circulating seawater within the FSRU as an intermediate heating medium for heat exchange in the LNG regasification trains. Propane would also be used as an intermediate fluid in closed loop, whereby steam from the gas-fired boilers would be used to heat the propane, and the propane would then heat the LNG. Around 500 m^3 of seawater would be required to fill the FSRU heat exchange piping. Instead of being discharged from the FSRU as per open loop mode, the seawater is continually circulated in the process. Seawater would only be discharged to Corio Bay when maintenance is required (anticipated to be annually) or when the FSRU changes between operating modes. Discharged seawater from the closed loop process would be around 5 °C warmer than the ambient water temperature.

This method uses 2.5% of the send out gas to heat the circulating fluid to vaporise the LNG compared to 1.5% for open loop (Songhurst 2017). This contributes to an increase in greenhouse gas emissions when compared to open loop operation and reduces the regasification plant output. Due to the environmental and economic implications, closed loop systems are becoming less commonly used.

Combined loop mode

To provide flexibility, there is a trend for new build FSRUs to have both open and closed loop capability, which is referred to as 'combined loop'. The combined loop mode operates similar to open loop mode; however, seawater is heated via steam from gas-fired boilers prior to reaching the regasification system on the FSRU. The seawater is continuously drawn into the FSRU through seawater inlets and the seawater is heated by heat exchange with steam. Seawater use associated with combined loop regasification mode is the same as seawater use for open loop regasification.

Selection of the preferred regasification mode

The main benefit of the open loop regasification mode is that seawater from Corio Bay can be used by the onboard regasification plant on the FSRU to heat the LNG. This is an efficient and readily available means of heating the LNG without using additional fuel to generate heat for LNG vaporisation. Greenhouse gas emissions from open loop mode are substantially less than closed loop mode.

The preferred regasification mode of the FSRU is for operation in open loop mode, with modifications so that the FSRU seawater discharge from the regasification process can be redirected and reused within the adjacent refinery cooling water process. This provides significant environmental benefits as it results in the FSRU largely replacing the current seawater intake for the refinery and means that there is only one intake and one marine discharge when both the refinery and FSRU are operating at the one time. The alternative of direct discharge from the FSRU to Corio Bay would result in two separate water intakes and discharges from the refinery and FSRU. Use of the cooled water from the FSRU also reduces energy use and costs in the refinery.

The open loop mode of operation was considered to be the preferred option for the project based on environmental and economic grounds. The EES has also assessed the closed loop mode of operation as this would be used in the event where the refinery would not be able to accept discharge from the FSRU e.g., malfunction of the seawater transfer pipe.

Further information on the proposed regasification mode for the project is provided in Chapter 4: *Project description*.

3.7 Treatment facility design development

The following section outlines the key aspects involved in the design development of the onshore gas treatment facility, including site selection and facility layout, and potential nitrogen supply sources considered.

The treatment facility is where nitrogen and odorant injection, and gas metering would occur and where the pipeline would change from aboveground to underground prior to its connection to the Victorian gas network.

3.7.1 Site selection for the treatment facility

Site selection for the treatment facility was undertaken with consideration of site safety and security, suitable access for nitrogen trucks, access for operation and maintenance, and visual amenity.

A review was completed within the existing refinery boundaries to identify potential locations. The refinery was considered a 'base case' preferred location as an alternative to potentially locating the treatment facility external to the refinery. An external location was considered less desirable as it would not capitalise on the synergies associated with a refinery location and would be likely to have more potential environmental and amenity impacts. It was determined that the site selection process would only consider external site alternatives if the refinery option proved non-viable. Two areas within the refinery boundaries were identified for consideration: at the southern end of the refinery near the existing fire station (Option 1) and at the northern boundary within an existing laydown area known as Nerita Gardens (Option 2). A summary of the assessment is outlined in **Table 3-6** and the two areas that were considered are presented on **Figure 3-11**.

Table 3-6 Treatment facility location comparative analysis

Criteria	Southern end of Refinery	Northern boundary of Refinery
Truck Access	• Good truck access to the refinery through existing heavy vehicle gazetted roads. Difficult access within the refinery for access and egress due to tight location.	• Good truck access through refinery and existing heavy vehicle gazetted roads
Visual Amenity	• Located adjacent to refinery equipment with an existing industrial outlook	• Located adjacent to existing tanks with screening from trees at the site boundary
Security	• Site would be difficult to separate from refinery operations making it challenging to secure the site for separate pipeline metering station access should this be required • Site would be secure within existing MHF	• Site would be secure within existing MHF with potential for separate pipeline metering station access available, should this be required
Operational / Maintenance Access	• Easy access for personnel to site through using existing site staff to support operations and maintenance	• Easy access for personnel to site through using existing site staff to support operations and maintenance
Area	• Site location very restricted and challenging to fit facility within available space	• Sufficient room for facility
Environmental impacts	• Would require excavation of already disturbed area within the refinery, with the potential to disturb sediments that may contain some contaminants. • Potential impacts would be similar to the option in the north of the refinery	• Would require excavation of already disturbed area within the refinery, with the potential to disturb sediments that may contain some contaminants. • Potential impacts would be similar to the option in the south of the refinery



Figure 3-11 Treatment facility location alternatives

After the assessment, the Nerita Gardens area at the northern boundary of the site was identified as the preferred location for the treatment facility as it was a less restricted area than the southern site and did not involve location of the facility in close proximity to existing refinery plant and equipment. Safety studies (refer Technical Report N: *Safety, hazard and risk assessment* for further detail) completed during facility design have resulted in optimisation of the location of the facility within the Nerita Gardens area so as to minimise risk to refinery neighbours and the public.

3.7.2 Nitrogen supply sources

Following regasification on the FSRU, the gas would be transferred to the treatment facility where nitrogen injection into the gas may be required to bring it up to standards specified by the Australian Energy Market Operator (AEMO), prior to the gas entering the network. There were three options considered for the supply of nitrogen to the injection facility:

- Direct supply of nitrogen gas from a third-party
- Onsite nitrogen gas generation
- Onsite liquid nitrogen storage.

Third-party supply

Viva Energy currently sources nitrogen gas directly from a third-party co-located with the refinery. It is used within the refinery for activities such as purging and drying to pipeline pigging and pressure testing. However, the capacity of that plant would be much less than the potential amount of nitrogen gas required for this project. The advantage in having a third-party supply is that the nitrogen could be turned on and off as required, removing the cost and difficulties associated with installing, operating and maintaining the associated nitrogen equipment which could potentially be sitting idle for long periods of time if the LNG is lean (contains more than 95% methane) and meets specification. The disadvantage is that it is unlikely that a third party would be able to supply the required maximum rate of nitrogen necessary for the required duration.

Onsite generation

A wide range of nitrogen generation packages are commercially available, however, at the potential rates required for nitrogen injection, several large units would need to be installed on site and would constitute a nitrogen generating plant. An example of a nitrogen generation pack is shown in **Figure 3-12**. The disadvantage of this option was considered to be that a significant amount of compression power would be required. This could result in power loads in excess of 5 MW with additional load required for interstage cooling making the operating costs associated with this option extremely high.

Onsite production would, however, provide another potential synergy with current refinery operation. Production of nitrogen also results in the production of high purity oxygen which could be captured and used elsewhere in the refinery (e.g., for combustion). Also, as Viva Energy currently sources third-party nitrogen for use in the refinery, having the ability to produce nitrogen would remove this dependence.

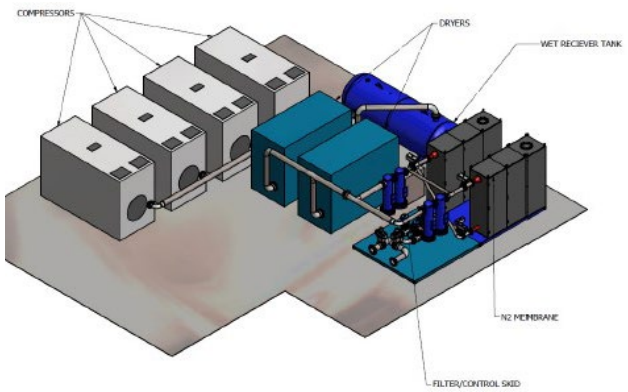


Figure 3-12 Example of a nitrogen generation pack

Onsite liquid nitrogen storage

This option would involve liquid nitrogen being trucked to the refinery from nitrogen suppliers and stored in cryogenic tanks installed at the treatment facility. The advantage of the onsite liquid nitrogen storage option is that the power required to pump liquid nitrogen from the storage tanks to vapourisers prior to injection is considerably less than for an onsite nitrogen gas generation package. The disadvantage is that the associated tanks, pumps, vaporisers and trim heaters all require significant space within the refinery.

Selection of the preferred nitrogen supply source

After detailed assessment, onsite liquid nitrogen storage was selected as the preferred option for nitrogen supply as it would be the most economical solution primarily by avoiding the need for compressors to generate nitrogen onsite.

There are two main types of storage for liquid nitrogen which are widely used for treatment facilities involving nitrogen injection. These are flat bottom tanks (FBT) and vacuum insulated vessels (VIV). The FBT is considered to be the best option for storing large amounts of liquid nitrogen, usually over 15,000m^3, with VIV the preferred option for volumes less than 250m^3.

It is anticipated that up to 575m^3 of nitrogen would be required per day based on a preliminary assessment of a 'rich' high energy density North West Shelf LNG composition. To discharge 170,000m^3 of North West shelf natural gas continuously at 500 TJ/day from the FSRU, it would take approximately 9 days and require 4,625m^3 of nitrogen.

To meet the nitrogen demand, the treatment facility would comprise of multiple liquid nitrogen storage vacuum insulated vessels containing up to 1200m^3 of liquid nitrogen. Nitrogen would be sourced from a variety of existing nitrogen providers by truck to both refill this storage volume but also to supplement the nitrogen consumed during rich LNG cargo campaigns.

Based on a comparative assessment of the two options which considered design, construction and safety and risk factors, VIV was considered to be the preferred storage option for the project for the following reasons:

- Less energy consumption
- Lower noise and vibration
- Shorter construction duration, with equipment being delivered fully assembled
- Greater accessibility for maintenance and inspection
- Lower visual profile
- Flexible operation with multiple tanks allows for future expansion
- Overall cost is approximately 50% less than the FBT option
- Lower potential for leaks or spills.

VIV can be positioned horizontally or vertically, with larger ground area required for horizontal placement. An example of a VIV is shown in **Figure 3-13**.

3.7.3 Blending with refinery gases

In order to reduce the nitrogen demand, the possibility of blending gases available within the refinery (e.g., hydrogen and/or carbon dioxide) was explored. The supply of such gases could not be guaranteed and would require additional pipework to be added. For these reasons this option was not further developed.



Figure 3-13 Example of VIV liquid nitrogen storage

3.8 Pipeline design development

The following sections describe the design development of the pipeline including selection and refinement of the proposed pipeline route and construction methodology, and selection of the pipeline tie-in facility location.

3.8.1 Pipeline route selection and refinement

The proposed pipeline route has been defined iteratively over a two-year period (since late 2019) through desktop and field studies and assessments, and engagement with stakeholders and landowners and occupiers.

The commencement point for the pipeline was determined by the selection of a new pier arm (Refinery Pier No. 5) extending to the northeast from the existing Refinery Pier as the proposed location for mooring of the FSRU (refer to **Section 3.4**). Selection of the termination point for the pipeline is discussed in **Section 3.9**.

Alternative pipeline routes were initially considered in a workshop to select a 'favourable route'. Since then, the design process and landowner, occupier and stakeholder consultation has continued resulting in further refinement of the route, as described below.

The criteria adopted for initial comparison of the pipeline route options were:

- Victorian Transmission System
- Safety/SIMOPs issues
- Constructability
- Land access
- Commercial
- Environmental and social
- Financial.

The route was considered in four segments with the selected 'favourable route' being a combination of favourable options from each segment. The identified segments were:

- Segment 1 – Refinery Pier
- Segment 2 – from Shell Parade to the treatment facility at the northern boundary of the refinery site, adjacent to School Road
- Segment 3 – from School Road to Bell Road
- Segment 4 – from Bell Road to the SWP tie-in point, Lara.

An overview of the segment options considered is shown in **Figure 3-14**.

Segment 1

As identified, in consultation with GeelongPort and Ports Victoria, this route runs along the new pier extension in a new pipe rack to the existing Refinery Pier and then within the existing pipe track (on the northern side of the pipe track) to the point where the existing pipelines divide adjacent to the Refinery Pier Gatehouse.

Segment 2

Three potential options were identified for this segment which extends from the Shell Parade to the treatment facility at the northern boundary of the refinery site, adjacent to School Road.

- Option 2A Refinery Road 9 - This option passes under Wharf Road adjacent to or in the existing under-crossing to run aboveground west of Road 9 within the refinery pipe trench to the treatment facility site north of Road 16.
- Option 2B Shell Parade - This option follows the existing pipe trench on the eastern side of Shell Parade north across the refinery cooling water intake. After crossing under Shell Parade, the pipeline continues underground in the Shell Parade road verge adjacent to the eastern boundary fence of the refinery to north of Road 16. The route turns west to enter the refinery and into the treatment facility site. The route is parallel to the white oil pipeline (WOPL) between Foreshore Road and Road 16.
- Option 2C Western railway line - This route crosses over the existing pipe track to run underground in the Wharf Road verge to Lowe Street. The route crosses into Lowe Street and runs west to the Western railway line reserve. Turning north the route runs in the reserve on the eastern side of the railway line, traversing the refinery employee car park leased from VicTrack. The route enters the refinery south of Road 16 to a potential alternative treatment facility site in the northwest corner of the refinery. This option would intersect with a heritage overlay site, the former Corio Distillery Complex on Lowe Street.

Option 2A was selected as the favourable option following the constraints analysis. The high asset co-location, third-party asset crossing and workspace constraints affecting all route options could be managed by the pipeline being located aboveground on existing pipe track and primarily within the refinery. Additionally, this would minimise potential land access / tenure issues.

The route was subsequently revised to avoid the highly constrained Wharf Road under-crossing and refinery entry such that it follows Option 2B along

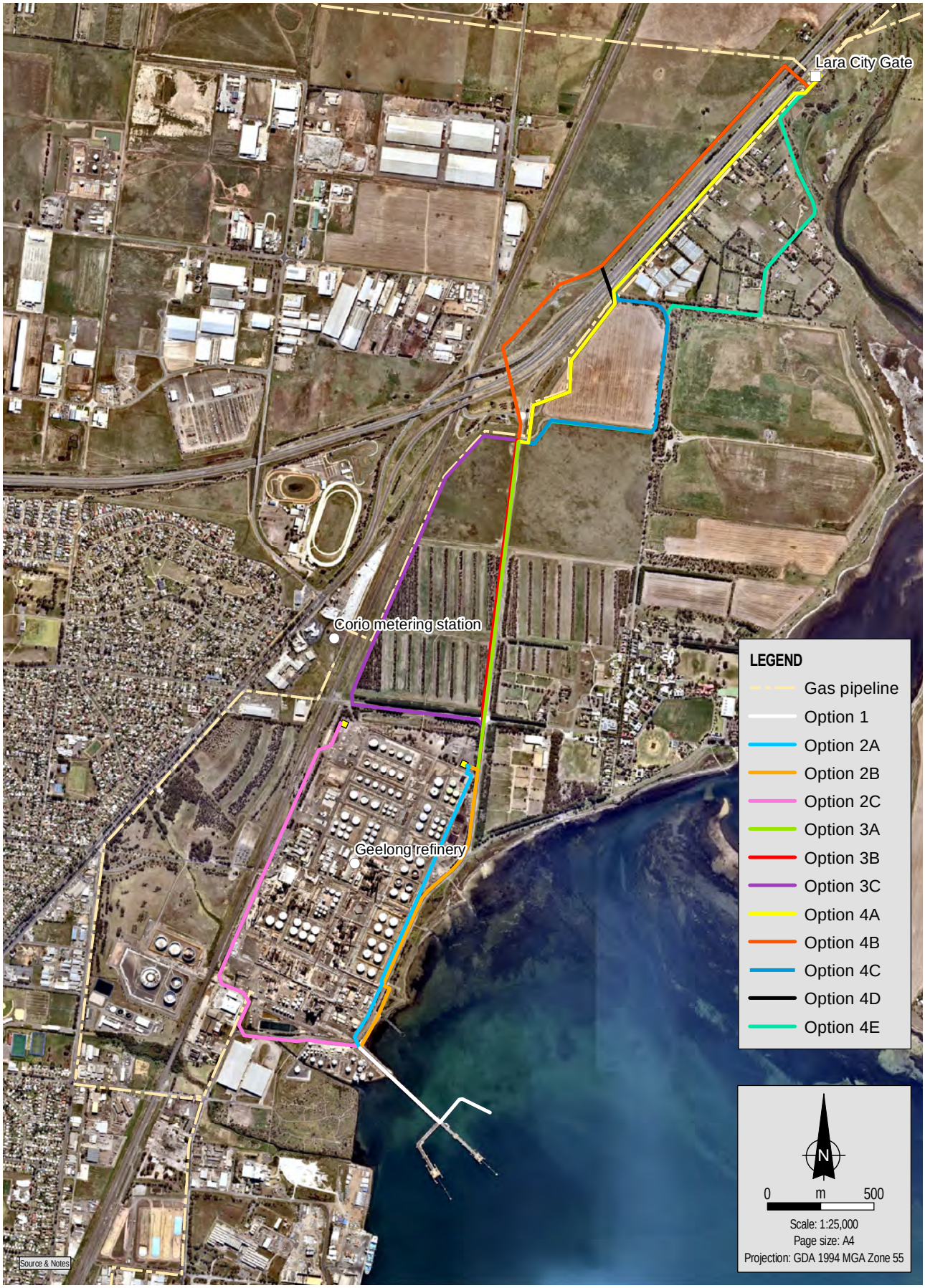


Figure 3-14 Pipeline route alternatives (source: Coffey, 2020)

the existing pipe trench on the eastern side of Shell Parade and across the cooling water intake before crossing under Shell Parade and entering the refinery.

Optimisation of the location of the treatment facility site within the refinery laydown area known as Nerita Gardens (refer **Section 3.7.1**) has resulted in the aboveground pipeline section in the refinery Road 16 pipe trench being extended.

Segment 3

Three potential route options were identified in this segment, which extends from treatment facility at the northern boundary of the refinery site to Bell Road.

- Option 3A Shell Parade – This option runs east to Shell Parade from the treatment facility site, turning north to run in the road verge to School Road. After crossing the School Road-Shell Parade roundabout, the route continues north in the road verge to the Bell Road intersection. The route is parallel with and adjacent to the Westernport-Altona-Geelong crude oil pipeline (WAG), black oil pipeline (BOPL) and WOPL.,
- Option 3B Viva Energy/private & public property adjacent to Shell Parade – This option adopts the same route as 3A from the treatment facility to the School Road-Shell Parade roundabout but then runs north through the Viva Energy-owned paddocks and the Corio Native Grassland Reserve on the western side of Shell Parade to the Bell Road intersection.
- Option 3C Viva Energy/private & public property adjacent to the Western railway line – This option adopts the same route as 3A from the treatment facility to the School Road-Shell Parade roundabout. At the roundabout it turns west to run in the School Road verge. East of the Western railway line level crossing, the route enters the Viva Energy-owned paddocks to run north in the paddocks and then adjacent to the APA Brooklyn–Corio Gas Pipeline through the Corio Native Grassland Reserve to Bell Road.

Option 3A was initially chosen as the favourable option following the constraints analysis as it avoids potential impacts on the Corio Native Grassland Reserve.

Subsequently, following 'dial before you dig' enquiries and assessment of as-built location of assets, Option 3A was found not to be viable due to insufficient space being available in the Shell Parade road verge. Option 3B became the favourable option following further detailed ecological surveys which confirmed that native grassland and associated flora and fauna species would not be affected by the proposed alignment. The route was also revised to reduce traffic disruption by not interfering with the School Road roundabout and exiting the refinery site a short distance to the west.

Optimisation of the location of the treatment facility site (refer **Section 3.7.1**) has resulted in the underground pipeline section within Nerita Gardens being extended.

Segment 4

Five potential route options were identified in this segment, which extends from Bell Road to the SWP tie-in point at Lara.

- Option 4A Macgregor Court – From Bell Road the route follows the APA Brooklyn–Corio Gas Pipeline north to Cummins Road crossing under Bell Road and Macgregor Court to follow the gas pipeline on the eastern side. At Cummins Road, the route crosses Macgregor Court to run in the road verge on the western side parallel with and adjacent to the WAG and BOPL. At the northern end of Macgregor Court, the route is within the Lara City Gate access road which it follows to the facility, situated within Hovells Creek Reserve.
- Option 4B Rennie Street – From Bell Road this option heads north and crosses under the Princes Freeway to Rennie Street, west of the freeway. Then it follows Rennie Street northwards in farmland on the western side of the road. This route has two potential connection points, one on the SWP at a new facility west of the Princes Freeway and the other at Lara City Gate.
- Option 4C Bell Road, Biddlecombe Avenue, Cummins Road and Macgregor Court – This option runs east along Bell Road then turns north and heads along Biddlecombe Avenue. It then turns west and heads along Cummins Road until it reaches the Macgregor Court intersection where it then follows Option 4A.
- Option 4D Macgregor Court and Rennie Street – This option adopts Option 4A to Cummins Road where it proceeds as per Option 4B.
- Option 4E - Bell Road, Biddlecombe Avenue, Cummins Road and Turnstyle Court – This option adopts Option 4C to Cummins Road, where it then turns east and heads along Cummins Road. From there it turns north into Turnstyle Court, through the Hovells Creek Reserve carpark and to Macgregor Court where it turns to run along the Lara City Gate access road which it follows to the facility, situated within Hovells Creek Reserve.

Option 4A was selected as it is the most direct route. Subsequently, this route was revised so to avoid potentially affecting native grassland identified during further detailed ecological surveys by crossing Shell Parade north of the Bell Road intersection. The route was also revised to avoid affecting cultivated farmland to the east of Macgregor Court (south) (identified through ongoing landowner consultation) by remaining in the road verge.

To avoid land access constraints (identified through ongoing landowner consultation), Option 4A was subsequently realigned further to the west of Macgregor Court (south) and adjacent to the Princes Freeway. This section of pipeline would be constructed using HDD due to space constraints from pipeline and other infrastructure assets on the western side of Macgregor Court (south) and to avoid disturbance of native grass and threatened fauna habitat in the Macgregor Court road verge.

As a result of the change described above, Option 4A was further revised such that after crossing the APA Brooklyn-Corio Gas Pipeline, the pipeline continues north on the western side of Shell Parade traversing one private rural residential property and crossing under Rennie Street – Shell Parade roundabout. To reduce traffic disruption by not interfering with the Rennie Street – Shell Parade roundabout and impact on the affected landowner, this section of pipeline would also be constructed using HDD.

Space constraints in the Lara City Gate access road identified through 'dial before you dig' enquiries and assessment of as-built location of assets, also necessitated the route being altered to traverse private rural residential land at the northern end of Macgregor Court running parallel with and between the WAG and the APA Brooklyn-Corio Gas Pipeline before entering Hovells Creek Reserve.

3.9 South West Pipeline tie-in location

Two tie-in cases for connection to the SWP were considered:

- Tie-in to the DN500 Iona -Lara Gas Pipeline (SWP) - PL231 at Lara
- Tie-in to the DN350 Brooklyn-Corio Gas Pipeline (SWP) - PL81 close to C115 (Rennie Street - Shell Parade) roundabout.

It was determined that there could be potential flow constraints at the proposed gas production rate associated with a DN350 pipeline. Adopting a larger pipeline size for the project would not assist in resolving the issue if the DN350 Brooklyn – Corio Gas Pipeline location was chosen as the tie-in point would then become a bottleneck and prevent further increases in production. It was therefore not recommended to use the Brooklyn-Corio Gas Pipeline tie-in location, even though it is closer to the refinery and would be easier to construct.

For the purposes of selecting a 'favourable route' (see **Section 3.8**), it was concluded that tie-in to the SWP would be either within or close to the existing Lara City Gate Station facility on the eastern side of the Princes Freeway or across the freeway in existing farmland where a new facility would need to be constructed.

Subsequently, it was considered that the Lara City Gate tie-in location had the advantage of offering the potential for tie-in to an existing connection without the need to 'hot tap' (a procedure that makes a new pipeline connection while the pipeline remains in service). Furthermore, if a new facility were to be constructed on the western side of the Princes Highway, it would mean acquiring land and utilities such as power would also need to be installed.

This section has outlined the various alternatives and options considered during the development and design phase of the project. Detailed consideration has been given to a wide range of options related to preferred project location, onshore and offshore regasification alternatives, treatment facility location and pipeline alignments. It is considered that the detailed and thorough investigation of alternatives has led to optimisation of the project and enabled the most appropriate project to be considered in this EES.

Appendix C

Stakeholder and community engagement



Chapter 6

Stakeholder and community engagement

This chapter describes the engagement and consultation approach and activities that have been undertaken by Viva Energy in relation to the Viva Energy Gas Terminal Project (the project).

Viva Energy recognises the importance of public participation in developing and refining the project. An extensive engagement and consultation program was undertaken to ensure that the community and interested stakeholders were informed, involved and able to actively contribute to the development of the project and preparation of the Environment Effects Statement (EES).



6.1 Consultation requirements

The *Ministerial guidelines for assessment of environmental effects* under the *Environment Effects Act 1978* (Ministerial Guidelines) state that a specific objective of the EES assessment process is 'to provide public access to information about potential environmental effects as well as fair opportunities for participation in assessment processes by stakeholders and the public'.

The Minister for Planning's decision to require an EES for the project included a requirement that:

"The proponent is to prepare and submit to the Department of Environment, Land, Water and Planning (DELWP) its proposed EES consultation plan for consulting the public and engaging with stakeholders during the preparation of the EES. Once completed to the satisfaction of DELWP, the EES consultation plan is to be implemented (and updated as appropriate) by the proponent, having regard to advice from DELWP and the TRG."

In addition, the final scoping requirements for the project state that under its EES Consultation Plan:

"… the proponent informs the public and stakeholders about the EES investigations and provides opportunities for input and engagement during the EES investigations."

A Consultation Plan for the Viva Energy Gas Terminal Project (Consultation Plan) was prepared in accordance with the final scoping requirements and the EES Consultation Plan Advisory Note and published on the DELWP website in April 2021. The Consultation Plan was updated in July 2021 to include an updated project timeline and project approvals schematic, and to provide a separate rolling Consultation Activities Plan for the upcoming months. The Consultation Plan is available at:

https://www.planning.vic.gov.au/environment-assessment/browse-projects/projects/viva-energy-gas-terminal-project

6.2 Pipelines Act 2005

In November 2020, a Pipeline Consultation Plan was prepared in accordance with Part 4, Division 1 of the *Pipelines Act 2005* (Vic) ('Pipelines Act') and requirements of the Pipelines Regulations 2017 (Pipelines Regulations). Section 17 of the Pipelines Act outlines the requirements for a consultation plan for engaging in discussion with landholders directly affected by the proposed pipeline component of the project.

It was agreed that the Consultation Plan, described in **Section 6.1** above, would respond to the requirements of the *Environment Effects Act 1978* (Vic) ('Environment Effects Act') and the Pipelines Act. In July 2021 the Consultation Plan superseded the Pipeline Consultation Plan and applied up until public exhibition of the EES and approvals documentation including the application for a pipeline licence.

In addition to outlining how Viva Energy would inform and consult with the public and stakeholders during preparation of the EES, the Consultation Plan also set out the process for consultation with landowners and occupiers about the proposed pipeline. The information Viva Energy, as the pipeline proponent, would provide to owners and occupiers of land in accordance with Section 17 of the Pipelines Act was also integrated into the Consultation Plan.



6.3 Approach

Viva Energy's core business values – integrity, responsibility, curiosity, commitment and respect – are the foundation of how the company approaches its business endeavours. Viva Energy's commitment to sustainable development requires balancing short and long term interests, as well as integrating economic, environmental and social considerations into business decision-making. Viva Energy's Business Principles and Code of Conduct can be located on the website: www.vivaenergy.com.au in the 'Our Company – Corporate Governance' section. These values have been implemented throughout the consultation and engagement process for the project.

The key objectives of Viva Energy's approach to stakeholder engagement and consultation during preparation of the EES were to implement:

- A process where stakeholders would be informed about the project and associated investigations and technical studies
- A program which would encourage participation and allow stakeholders the opportunity for input
- A process which would give stakeholders the opportunity to provide feedback on the EES.

Throughout the development of this EES, Viva Energy proactively engaged with the community and stakeholders who could potentially be affected by the project. This proactive engagement was conducted to ensure that there was a thorough understanding of the project scope and any potential impacts and to establish a transparent feedback process. Engagement and consultation varied from informing stakeholders using a range of communication methods to involving them, where appropriate and possible, in decisions about the project design and management of potential impacts. All stakeholder communications were kept concise and easy to understand with clear and consistent messages. Where possible, some project material was translated into other languages.

As Viva Energy developed an integrated Consultation Plan which responded to the Environment Effects Act and the Pipelines Act, consultation requirements under the Pipelines Act were implemented alongside the EES consultation requirements.

6.3.1 Engagement principles

Viva Energy recognises that regular dialogue and engagement with stakeholders is essential to project success and maintaining a social licence to operate. Engagement and consultation activities were undertaken in accordance with Viva Energy's Business Principles and Code of Conduct, Australian Pipelines and Gas Association (APGA) Stakeholder Engagement Guideline and the International Association for Public Participation (IAP2) Spectrum of Public Participation. Under this framework, stakeholder engagement proceeded with reference to five overarching principles of effective consultation, as outlined below in **Figure 6-1.**

6.3.2 Engagement phases

Figure 6-2 outlines the six phases of engagement activities for the project.

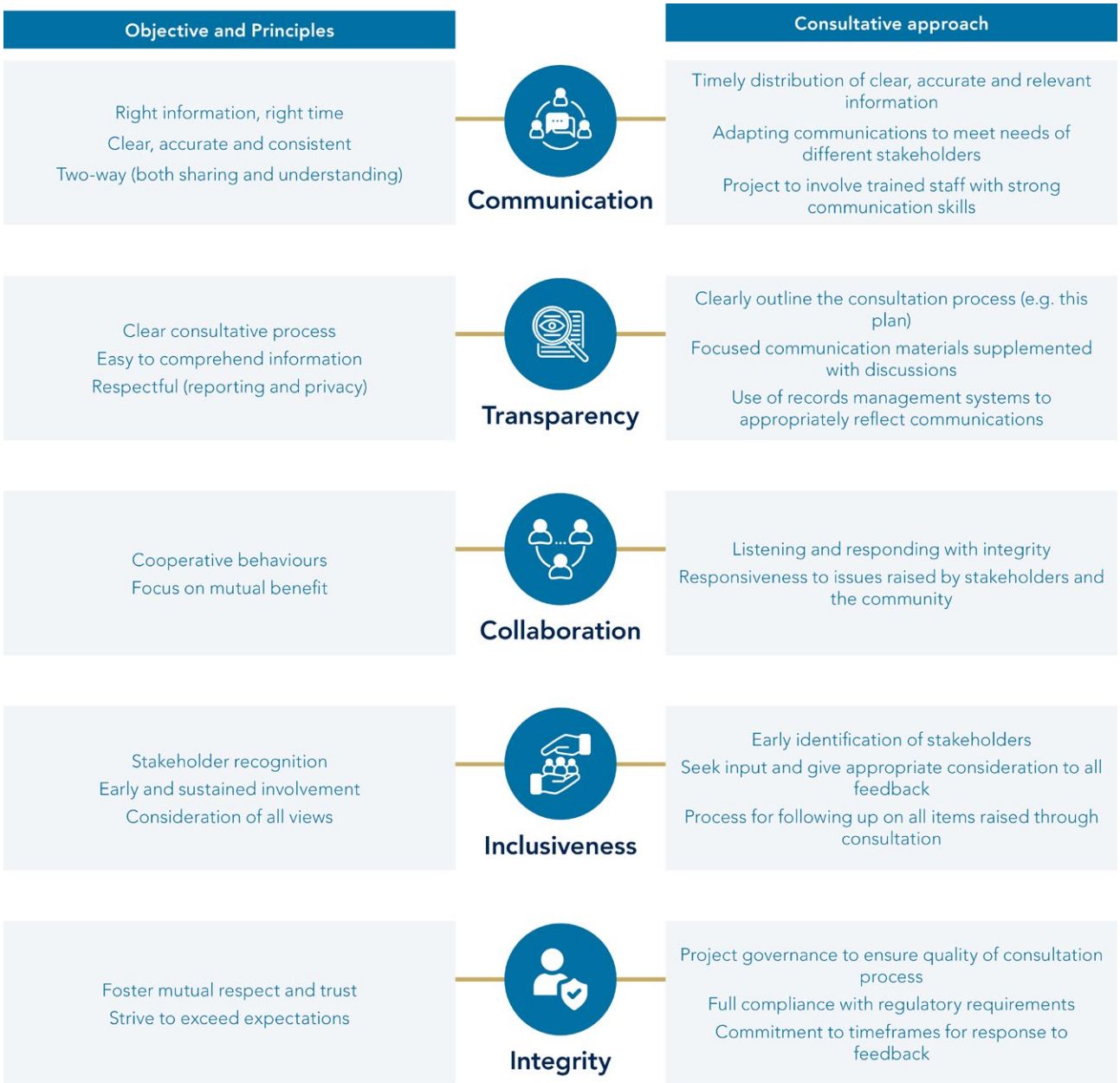


Figure 6-1 Principles of Effective Consultation (adapted from Ministerial Council on Mineral and Petroleum Resources Principles of Stakeholder Engagement)

Early Engagement | Oct 19' - Dec 20' — 1

- To generate and raise awareness of the project
- To announce project commercial partners
- Outline rationale for the project
- Outline components of Gas Terminal Project
- Provide overview of regulatory approvals process
- Commence Pipelines Act consultation process
- Assessments also commenced during this phase (such as terrestrial and marine biodiversity, and marine water quality) to ensure all studies were completed on an annual basis.

Post-EES Decision | Dec 20' - Mar 21' — 2

- December 2020, the Minister for Planning announced an EES was required for the project.
- Viva Energy submitted a draft study program and consultation plan to DELWP for consideration.
- DELWP established a technical reference group (TRG) to review the EES studies and draft documentation, and released the draft scoping requirements for comment.
- Phase 2 of the engagement aimed to create understanding around the EES and Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) processes and give stakeholders opportunity to make submissions on the Minister's draft scoping requirements for the project
- Outline regulatory approvals process and ways that stakeholders and the broader community can engage in the process.
- Increase awareness and understanding among local communities about refinery operations and the Gas Terminal Project

EES Preparation | Feb 21' - Late 21' — 3

- Phase 3 covers the period when investigations and technical studies were conducted for the EES.
- To provide updates to stakeholders and the community on study outputs
- To address areas of concern raised by stakeholders and community members.

EES Public Exhibition and Inquiry | Early - Mid 22' — 4

- Phase 4 includes the formal consultation process to support the EES process including public exhibition of the EES, the Planning Scheme Amendment, the Pipeline Licence Application and the EPA Development Licence.
- This phase will involve the appointment of an inquiry to review the EES and public submissions. A report will be prepared by the Panel following conclusion of the inquiry to inform the Minister's assessment.
- Engagement activities would support the public exhibition process by providing information on the EES and submission process.

Construction | Late 22' Onwards — 5

- If the project receives statutory approvals following the EES process, stakeholder engagement would be reviewed to consider how to best engage with the community during construction. Engagement during construction would keep community and stakeholders informed and would include consultation with potentially affected members of the community where required about specific mitigation measures.

Operation | Mid 24' Onwards — 6

- If the project is approved and constructed, Viva Energy would continue to consult with the community and stakeholders during the project's operational life.

Figure 6-2 Six phases of engagement activities for the project

6.4 Engagement tools

Viva Energy used a broad range of engagement and consultation tools to provide the community and stakeholders with multiple opportunities to engage and provide feedback about the project. A summary of the engagement and consultation tools used is provided in **Table 6-1**.

Table 6-1 Key approvals required for the project

Engagement Tool	Description
Webpage	A dedicated page on the Viva Energy website was established (www.vivaenergy.com.au/gas-terminal) as a central repository of information regarding the project and was updated regularly throughout the EES development phase as new information became available. The website included all communications collateral, details of community information sessions and shopping centre information booths, and project contact details. Video recordings of community information sessions were also made available on the webpage for those who were unable to attend.
Video	Short informational videos providing a simplified explanation of key elements of the project, such as how the gas terminal would work were produced and shared on Facebook, the Viva Energy webpage and YouTube. These videos also included interviews with project team members providing information on topics of interest such as safety and the marine environment. In response to feedback from representatives from local culturally and linguistically diverse (CALD) communities, project overview videos were also produced in Karen, Persian and Swahili.
'Refinery Update' newsletters	A series of 'Refinery Update' newsletters were prepared and distributed via letter-box drop to the Norlane, Corio, North Geelong and North Shore residents, near neighbours of the proposed pipeline in Macgregor Court, and neighbouring industries and businesses of the refinery. Each 'Refinery Update' was also published as an advertorial in the Geelong Independent newspaper.
E-news updates	An E-news update was sent via email on a regular basis (approximately monthly) to registered 'subscribers' and interested stakeholders. The E-news update covered project updates and key milestones, addressed FAQs and highlighted opportunities for engagement and consultation.
Social media	Facebook was a key communications tool for the project. The Facebook page was regularly updated with information about the project and links to information on the webpage. Posts of videos and photos from community information sessions/booths and other consultation sessions were shared and promoted. Information about key project milestones was also posted on the Viva Energy LinkedIn and Twitter feeds.
Letters and emails	Letters and emails were used as consultation tool initially to introduce the project (or specifically the proposed pipeline) to landowners and occupiers and near-neighbours, and to provide relevant contact details. Letters or emails were also used for formal correspondence (such as those which fulfil requirements under the Pipelines Act) and to formally respond to stakeholders regarding specific issues, concerns or requests.
Factsheets	Online and printed collateral was developed to provide further detail about key areas of the project. These were provided at community information sessions/booths and were published on the project webpage. Relevant contact details and an invitation to engage and provide feedback were included on all factsheets. In response to feedback from representatives of local CALD communities project overview factsheets were produced in Arabic, Chinese, Croatian, Italian, Karen, Macedonian, Serbian and Swahili.

Engagement Tool	Description
Study summaries	Study summaries providing a simplified explanation of the technical studies conducted in support of the EES were developed and published on the Approvals Process and EES section of the webpage.
Media & advertising	The project received national, state and local media coverage throughout the preparation of the EES. Paid advertising was also used to inform people about the project, engagement and consultation activities and ways to provide feedback. Articles about the project were published in the Northerly Aspects magazine which has a distribution of approximately 13,000 in Corio, Norlane and North Shore. Advertisements / advertorials ranging from a quarter to full page were published in local newspapers, including: Geelong Independent – with a distribution reach of approximately 25,000 and over 6,000 digital subscribers in the Lara, Corio, Norlane, North Geelong, Herne Hill, Bannockburn, Batesford and Bell Post Hill areas. Geelong Advertiser – with a hardcopy and digital readership of approximately 60,000 covering Geelong, the Bellarine Peninsula and surrounding area. Geelong Times – with a hard copy and digital reach of approximately 25,000 in the Geelong CBD, Corio, North Geelong, Lara, Bell Post Hill and Batesford areas.
Meetings	Numerous meetings (both in-person and virtual) were held with affected landowners and occupiers or near-neighbours along the proposed pipeline route to provide general project updates and discuss / negotiate and seek feedback on project and pipeline-specific matters. Meetings (both in-person and virtual) were also held with stakeholders and community representatives, individually or in small groups. These meetings were arranged to provide project updates and information about technical studies and investigations that were underway. The meetings also provided Viva Energy with an opportunity to seek input from stakeholders and the community as well as listen to, understand and respond to any concerns.
Project email address	A community enquiry email address (energyhub@vivaenergy.com.au) was established to facilitate direct correspondence with the project team. The project email address was promoted via the project webpage and all communications collateral. Emails and responses were recorded in a stakeholder management database.
Community information sessions and booths	Community information sessions (both in-person and virtual) were held to provide an opportunity for community and stakeholders to meet the project team and ask questions and/or express any concerns. Information was presented by the project team and feedback was collected to gain an understanding of community interest and concerns and tailor future engagement activities to cover community concerns and areas of interest. In response to feedback, some sessions focused on a particular area of interest (e.g., local amenity including air quality, traffic and noise and vibration) and included presentations from technical specialists on studies and assessments. Handouts and displays were available at each session. Sessions were advertised and held in accessible venues across Geelong to allow a wide cross section of the community to attend. Additionally, video recordings of the information sessions were made available via the website to further disseminate the information presented. Drop-in sessions were also held at pop-up community information booths at a variety of Geelong shopping centres.
Business and industry forums	Viva Energy presented at a number of Geelong business and industry association events, such as the Geelong Chamber of Commerce and Geelong Business Club, to promote awareness of the project, understand perceptions and concerns, and discuss potential opportunities for local businesses.

Engagement Tool	Description
Government briefings	Briefings were held with elected government representatives to inform them of the progress of the project.
Utility and infrastructure provider workshops	Workshops with utility and infrastructure provides were held during the design and development stage (e.g., involving utility and infrastructure providers in constructability reviews and the pipeline Safety Management Study workshops).
Project 1800 number	A toll free 1800 number was established for the project (1800 515 093) which was provided in communications collateral and displayed on the project webpage. All calls and responses were recorded in the stakeholder management database.

6.5 Stakeholders

6.5.1 Stakeholder identification

The Geelong Refinery is Viva Energy's largest facility with the operation employing around 700 people. The refinery and associated operations have been part of the local Geelong community since 1954 and supply more than half of Victoria's fuel needs. Each year more than $200M in wages and services is injected into the local economy.

For many years Viva Energy has provided operational updates to the community via local newspapers, Refinery Update newsletters, letter drops, social media, stakeholder and community meetings and briefings, as well as participation in local Geelong events.

Viva Energy also has a longstanding and active Community Program. In addition to the national Community Partners, Viva Energy also has partnerships with a range of local Geelong community organisations. These include Northern Futures and the Geelong Football Club – sponsoring their inaugural AFLW team and their Next Generation Academy. Refinery employees give generously to a range of local community organisations such as Give Where You Live for which Viva Energy matches contributions.

The project team was able to leverage the community's understanding of refinery operations and existing stakeholder relationships, as well as build new relationships. These existing networks enabled Viva Energy to identify groups and individuals who could be potentially impacted by the project, would have an interest in the project, or would need to be engaged as part of the approvals processes.

Viva Energy has maintained a list of stakeholders for this project since October 2019. An initial version of this list was included in the Consultation Plan and the list has been reviewed and updated as the project has developed.

The identified stakeholders have been grouped into the following seven categories:

1. Government
2. Neighbours and local residents
3. Business and industry
4. Community and interest groups
5. Recreational users of Corio Bay
6. Traditional Owner and Indigenous groups
7. Viva Energy workforce

Existing knowledge of the stakeholders was also used to inform and support the assessment of potential social and business impacts (see Technical Report L: *Social and Business Impact Assessment*) which included the following activities:

- Review of data pertaining to the local area held by the Australian Bureau of Statistics
- Review of technical assessments prepared in support of the EES
- Review of feedback from community information sessions and other engagement activities.
- Interviews with stakeholders and the community.

6.5.2 Government

Technical reference group (TRG)

In accordance with the scoping requirements, a TRG was convened and chaired by DELWP on behalf of the Minister for Planning. The TRG provided advice to Viva Energy throughout the development of the EES, advising on:

- Applicable policies, strategies and statutory provisions
- Scoping requirements for the EES
- Design and adequacy of technical studies for the EES
- The proponent's public information and stakeholder consultation program for the EES
- Responses to issues arising from EES investigations
- Technical adequacy of draft EES documentation
- Coordination of statutory processes.

The member organisations of the TRG for the project are listed in **Table 6-2**.

Regulators

In addition to the government departments represented on the TRG, a number of other regulators were engaged throughout the EES process. These are listed in **Table 6-3**.

Table 6-2 Technical Reference Group member organisations

Technical Reference Group members	
DELWP Impact Assessment Unit	DELWP Pipeline Regulation
DELWP - Heritage Victoria	DELWP Barwon South West
Department of Jobs, Precincts and Regions - First Peoples – State Relations	Greater Geelong City Council
Environment Protection Authority (EPA) Victoria	Energy Safe Victoria
WorkSafe Victoria	Ports Victoria
Corangamite Catchment Management Authority	Wadawurrung Traditional Owners Aboriginal Corporation

Table 6-3 Project regulators not represented on the TRG

Other project regulators	
Commonwealth Department of Agriculture, Water and Environment (DAWE) - Environmental Approvals Division	Transport Safety Victoria – Maritime Safety
Commonwealth Department of Home Affairs – Aviation and Maritime Security (AMS) Division	Victorian Fisheries Authority
Australian Maritime Safety Authority (AMSA)	Department of Transport - VicRoads
Australian Energy Regulator	Parks Victoria

Local government

The project is located within the City of Greater Geelong local government area. Greater Geelong City Council has been engaged during the EES process through its participation in the TRG meetings, regular project update meetings, and briefings and presentations to Councilors and council executives. The project was first introduced to the Greater Geelong City Council in a briefing to the mayor and council Chief Executive Officer (CEO) in December 2019 and ongoing engagement has included:

- Meetings to discuss the proposed pipeline route, pipeline survey access and land access for pipeline construction and operation (including the status of the voluntary transfer scheme for the former New Corio Estate sub-division).
- Regular meetings to discuss the project's proposed amendment to the Greater Geelong Planning Scheme and other regulatory approval related matters
- Briefing for Councillors and council executives in February 2021 and October 2021 which included updates on the project and the EES process.

6.5.3 Neighbours and local residents

Landowners and occupiers

Engagement with landowners and occupiers potentially affected by the proposed pipeline (including near-neighbours) commenced in November 2020 and has continued throughout the preparation of the EES and application for a pipeline licence. Engagement with landholders continued as the project progressed to discussions with respect to land access and tenure. A Pipeline Consultation Plan was prepared in November 2020 as part of Viva Energy regulatory requirements to gain a pipeline licence and to complete the pipeline component of the project. In July 2021, following the Minister's decision requiring an EES to be prepared, a project Consultation Plan was developed which superseded the Pipeline Consultation Plan. The Consultation Plan applied up until public exhibition of the EES and other approvals documentation including the application for a pipeline licence.

Active engagement provided potentially affected landholders with a background of the project and the reason behind the requirement for a pipeline. Landholders were consulted throughout project development on the proposed pipeline alignment and proposals to minimise impacts to properties during project construction.

The consultation methods used by Viva Energy to engage with landowners and occupiers as well as the different stages of consultation were developed in accordance with the requirements of the Pipelines Act and the approved Consultation Plan.

The initial stage involved early engagement with landholders and the establishment of a landholder database (including information such as title searches, addresses and contact details) following approval of the Pipeline Consultation Plan in November 2020. The search results indicated that there were approximately 10 private landowners, other than Viva Energy, including Geelong Grammar School, Ports Pty Ltd and the Baptist Union of Victoria along the proposed pipeline alignment. It was found that the majority of private individual landowners held small parcels of land within the historical New Corio Estate subdivision which was never developed. The small parcels that would be traversed by the proposed pipeline route are now within the protected 'Corio Native Grasslands Reserve' and remain undeveloped and vacant, and subject to a Council voluntary transfer scheme. The proposed pipeline route would also traverse a number of land parcels that are owned and managed by statutory authorities including VicRoads and City of Greater Geelong. Near-neighbours of the pipeline include Geelong Grammar School Corio campus and the rural-residential properties on the east side of Macgregor Court, Lara.

Stage 2 involved obtaining land access for survey purposes from affected landholders for technical studies for the EES and other studies for design development. Notices of Intention to Enter Land for Survey were issued during this phase. Ministerial consent under Section 25 of the Pipelines Act was granted for three parcels of land within the former subdivision for which, despite Viva Energy taking all reasonable steps, agreement to enter the land for survey could not be reached. Note that the width of the proposed Construction Right of Way (ROW) was reduced to 19 m to minimise the number of affected land parcels within the Reserve.

During stage 3 of landholder engagement, Notices of Pipeline Corridor were issued to all owners and occupiers of land within the pipeline corridor pursuant to Section 27 of the Pipelines Act. Consultation has been ongoing with landowners with regard to land access and tenure.

Following submission of the application for a pipeline licence at the same time as lodgement of the EES, the Notice of Pipeline Application will be published in a newspaper circulating generally in Victoria.

Should all approvals be obtained, communication will continue with affected landowners and occupiers throughout the construction and operation phases of the project.

A summary of the engagement to end-November 2021with landowners and occupiers is set out below.

- Number of property visits/meetings - 41
- Number of phone conversations – 74
- Number of emails – 187
- Number of letters – 91

Local residents

Viva Energy has engaged and will continue to engage with local residents through various communication channels.

Viva Energy hosted eight community information sessions. Six of these were in person at public venues in Geelong in February 2021, April 2021, May 2021, July 2021, November 2021 and December 2021. Due to COVID19 restrictions prohibiting in-person gatherings, Viva Energy hosted two virtual community information sessions via webinar in August 2021 and October 2021. The number of attendees at the information sessions ranged between 8 and 40. In order to make these sessions available to a range of people, the project hired local venues (Geelong Library and Heritage Centre, Norlane Community Centre and Geelong West Town Hall) and held meetings at different times of the day to encourage public participation. Community information (pop-up) booths were held in March 2021 at the local Corio Village shopping centre and November 2021 at Westfield Geelong. Due to COVID19 restrictions the shopping centre booths planned for June and September were initially postponed and then cancelled. The community information sessions and booths were widely publicised through newspaper advertisements, Refinery Update newsletters and project E-news updates, on the project webpage and social media, and in meetings and briefings.

Refinery Update newsletters with information about the project and upcoming consultation activities were letter-box dropped to residents and businesses surrounding the project area in December 2020, April 2021, August 2021, October 2021 and November 2021. The number of newsletters distributed initially was approximately 1,500, however in the October and November letter-box drops, the number was increased to approximately 4,500 to include additional parts of Corio on the western side of the Princes Highway. In addition, articles about the project were included in the quarterly Northerly Aspects newsletter which is letter-box dropped to all residents of Corio, Norlane and North Shore.

The North Shore Residents Group was extensively engaged during the EES process. Viva Energy met twice with representatives of the Residents Group, and then separately with individual members to address particular topics of concern. Viva Energy also responded to Facebook posts and Letters to the Editor in local newspapers from this group.

Viva Energy continued to engage with community members virtually and by phone and email during the COVID19 restrictions.

Geelong Grammar School Corio campus is situated to the north east of the refinery on the shores of Limeburners Bay and provides both a day school and boarding facilities. The project was first introduced to Geelong Grammar School during an in-person meeting in June 2020 and ongoing engagement with the school has included meetings with the principal and staff, and formal presentations to the Audit, Finance and Risk Committee (of the School Council). As the results of technical studies became available, regular meetings were scheduled to present the outcomes of the assessments. Viva Energy also facilitated a presentation to the school by WorkSafe Victoria on major hazard facility regulation.

Culturally and linguistically diverse (CALD) communities

The northern suburbs of Geelong are culturally and linguistically diverse. Northern Bay College in Corio is a key member of the northern suburbs community and for many students and their families it forms an important connection between the individual / home and the wider community. Viva Energy has had a long-standing relationship with Northern Bay College including sponsoring a student 'breakfast club'. Viva Energy engaged with students and their families to help translate and produce factsheets about the project in Arabic, Chinese, Croatian, Italian, Karen, Macedonian, Serbian and Swahili, and videos, featuring the Project Manager, translated and subtitled in Karen, Persian and Swahili.

6.5.4 Business and industry

Local business and industry

Viva Energy, through its existing Geelong Refinery communications network, is in regular engagement with local businesses and industries such as Quantem, Barwon Water, LyondellBasell, Midway, Incitec Pivot, Corio Distillery and Winter & Taylor Commercial Vehicles.

Viva Energy met, and engaged with, local business associations including Geelong Manufacturing Council, Geelong Chamber of Commerce, Committee for Geelong, Geelong Region Alliance G21 and the Geelong Business Club providing briefings and presentations at association events and functions, and utilising these organisations to disseminate project information more broadly among their members.

Port users and commercial shipping

The FSRU would be situated at an extension to Refinery Pier within the Port of Geelong, Corio Bay. Ports Victoria (formerly Victorian Regional Channels Authority) manages commercial navigation in the port waters in and around Geelong and is responsible for the safe and efficient movement of shipping, and for maintaining shipping channels and navigation aids. Since privatisation in 1996, wharf and landside infrastructure has been privately owned and operated by GeelongPort. Key users of the port in addition to Viva Energy include Incitec Pivot, Midway and Quantem. Spirit of Tasmania (operated by TT-Line) has announced that in 2022 it will move its Victorian port operations to a new passenger and freight terminal at Corio Quay.

Viva Energy first engaged with Ports Victoria in March 2020 and ongoing and regular contact has continued since that time, through their representation on the TRG, regular meetings (both in-person and virtual) and participation in workshops. Viva Energy has worked closely with Ports Victoria in the development of the EES chapter on Maritime and Port Operations Safety in order to address this area which some community members have raised as a concern. As the operator of an existing dredged material ground east of Point Wilson, Ports Victoria has also been extensively engaged on the project dredged material disposal options study.

Viva Energy also used Ports Victoria's regular port user forums as an opportunity to disseminate project updates and information including an introductory briefing to port-users on 26 November 2020.

As the port manager, and licensor of Refinery Pier, GeelongPort has been consulted since project inception. As the results of technical studies have become available, the outcomes of the assessments have been presented at meetings with GeelongPort.

Representatives of pilotage provider, Port Phillip Sea Pilots, have participated in maritime simulation workshops which determined that an LNG carrier would be able to safely back up in a considerably smaller swing basin than initially designed. This resulted in a reduction to the estimated volume of dredging by more than half.

6.5.5 Community and interest groups

Throughout preparation of the EES, Viva Energy has sought feedback from community and interest groups by providing briefings and attending meetings, inviting them to public events including community information sessions and using these groups to disseminate information to the wider community.

During development of the EES, Viva Energy actively engaged with and responded to environment interest and advocacy groups such as Environment Victoria, Geelong Sustainability, Gas Free Geelong and Geelong Environment Council. Viva Energy also responded to all community and interest groups which made a submission on the publicly exhibited draft Scoping Requirements.

Limeburners Bay and the northern shores of Corio Bay are designated as wetlands of international importance under the Convention on Wetlands of International Importance (Ramsar Convention). The proximity of the project to the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site and the potential for impacting the site's ecological values has been a source of community interest. Viva Energy has engaged with the Ramsar Coordinating Committee and with environment interest groups such as Geelong Field Naturalists Club, Bellarine Catchment Network, Birdlife Bellarine Peninsula and Bellarine Landcare specifically seeking input to technical studies and inviting them to attend community information sessions on the assessment of potential impacts to the Corio Bay marine environment and Ramsar site.

6.5.6 Recreational users of Corio Bay

There are various public boat ramps around Corio Bay in the vicinity of the project area including on the adjacent foreshore reserve and within Limeburners Bay. Several private yacht clubs also facilitate recreational boating and yachting in Corio Bay.

Viva Energy has engaged with key recreational user organisations including the Royal Geelong Yacht Club, Lagoon Boat Club and Victorian Recreational fishing body - VRFish (the peak body for recreational fishing in Victoria). In some cases, these organisations provided project information to their members: VRFish for example, notified members of the exhibition of the draft Scoping Requirements and encouraged them to make a submission.

6.5.7 Traditional Owners & Indigenous groups

The project area is within the traditional lands of the Wadawurrung Traditional Owners Aboriginal Corporation (WTOAC).

Viva Energy first engaged with WTOAC about the project in October 2020 and ongoing and regular contact has continued since that time, through their representation on the TRG and development of the project's Cultural Heritage Management Plan (CHMP). A total of two days was spent with WTOAC completing field work and cultural heritage surveys in the project area for the CHMP together with a number of meetings and exchanges of correspondence. A results meeting with representatives from WTOAC was held in June 2021 in relation to the outcomes of the field work and nominated management measures for inclusion in the CHMP. Further meetings were held in August 2021 and September 2021 to review any requirement for additional field work based on proposed changes to the construction footprint and it was concluded that adequate surveys have been conducted (due to the extent of previous disturbance in the area). Technical Report O: *Aboriginal cultural heritage impact assessment* provides more detail on the outcome of the CHMP assessments.

Viva Energy provided an introduction to the project to the Wathaurong Aboriginal Cooperative in July 2021 and also engaged First Peoples – State Relations through the TRG meetings.

6.5.8 Viva Energy workforce

The Viva Energy workforce was initially engaged following the project announcement and was updated regularly as the project progressed. Initially this was through a series of in-person 'Town Hall' meetings and presentations from project team members. With the introduction of COVID19 restrictions, this changed to on-line forums. In addition, project communications material was circulated through internal 'Refinery Report' newsletters, emails from the CEO, the company intranet and company social media channels.

6.5.9 Wider community

Viva Energy also has a dedicated page on its website to keep the community informed about the project and the EES process. Viva Energy has encouraged interested parties to sign up to receive E-news Updates and to provide feedback or comments via the 1800 number or by email. Viva Energy also used Facebook, Twitter and LinkedIn to provide updates about the project and the EES process to the wider community. All key documentation was also made available on the DELWP website.

Viva Energy conducts a regular survey to monitor the views of the wider Geelong community on our business and our refinery operations. The research targets community members directly surrounding the refinery, the broader Geelong region and also the surf coast areas. In October 2021, some additional questions about the gas terminal were included to gauge the level of understanding and also reactions to the project. The research found that of those community members who knew about the project, the majority were supportive of the proposal.

6.6 Overview of engagement to date

In October 2019, Viva Energy commenced preliminary engagement to introduce the Gas Terminal Project as part of the broader Geelong Energy Hub to individuals and stakeholders that would be directly involved in or impacted if it were to proceed. This initial engagement primarily involved Commonwealth, State and local governments as well as key regulators. Subsequent engagement then expanded to include the refinery's closest neighbours, local Geelong associations and businesses and the broader community primarily through announcements in the media in June and July 2020. Information about the project was made available on the Viva Energy website in November 2020.

Project engagement increased significantly following the Minister's decision in December 2020 that an EES would be required for the project. A summary of the project's key engagement activities is shown in **Figure 6-3** and summarised in **Table 6-4**.

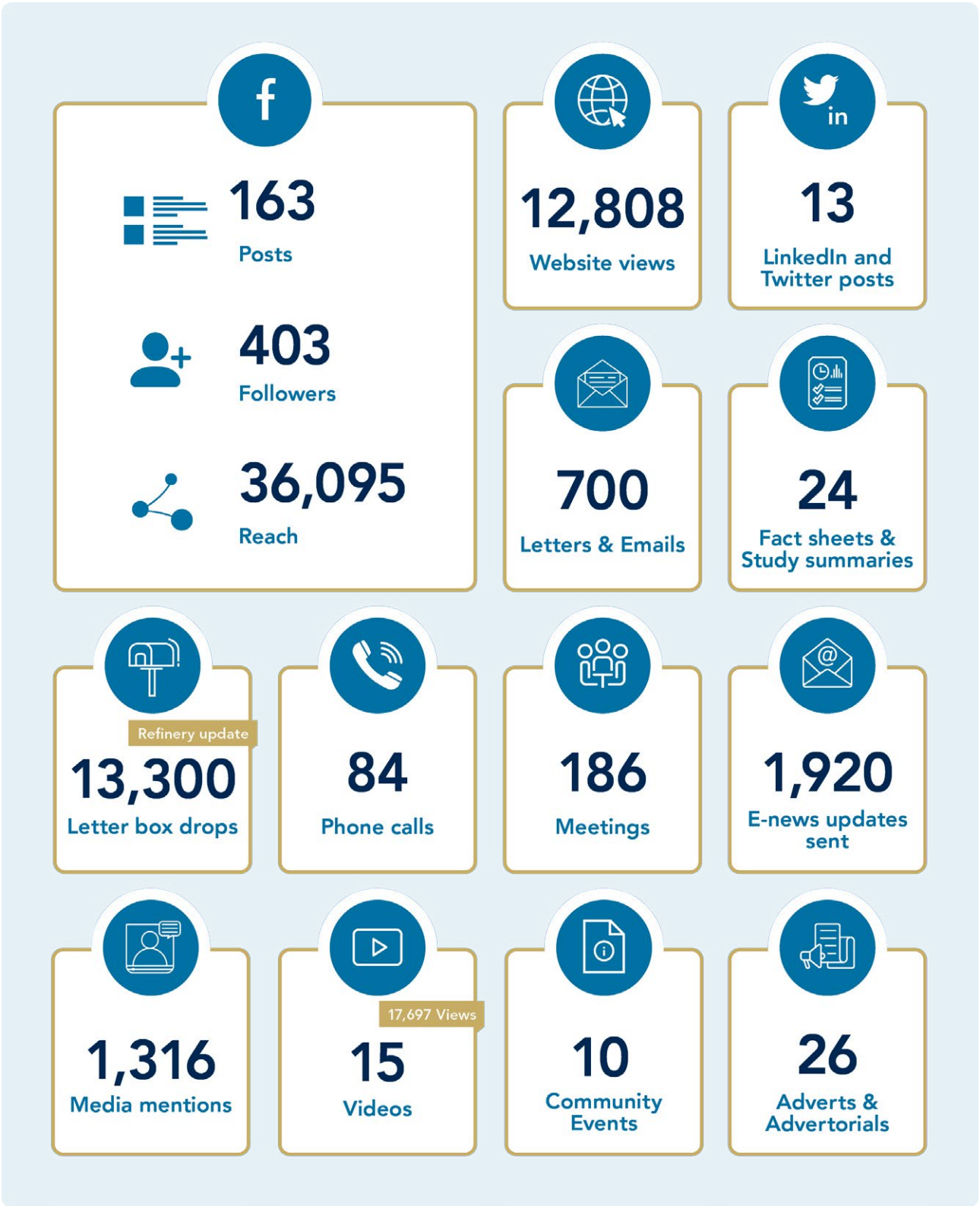


Figure 6-3 Summary of the project's key engagement activities

Table 6-4 Consultation summary from January 2021 to December 2021

Activity	Description	Target Audience	Phases
Media and advertising	Advertisements and advertorials in 3 local newspapers and 1 local magazine with a combined readership of at least 123,000 5 letterbox drops of the Refinery Update newsletter to residents and businesses surrounding the project area. Total distribution of 13,300 1,316 media mentions about the Gas Terminal Project. Included coverage in local papers including the Geelong Advertiser and Geelong Independent and national coverage in The Age, Australian Financial Review and The Australian.	Neighbours and local residents Business and industry Community and interest groups Recreational users of Corio Bay	2 & 3
Community information sessions and booths	Included 6 in-person and 2 virtual community information sessions. In-person events at local, accessible venues. There were 2 pop-up style community information booths at shopping centres.	Neighbours and local residents CALD communities Community and interest groups Recreational users of Corio Bay Wider community	2 & 3
E-news updates	8 editions of the E-news update sent to project update subscribers. Total number of emails sent; 1920	Neighbours and local residents Community and interest groups Wider community	2 & 3
Social media	Facebook for sharing project information; there were 163 posts, there are 403 followers and a reach of 36,095 LinkedIn and Twitter for posting key milestones; there were 13 posts	Neighbours and local residents CALD communities Community and interest groups Business and industry Recreational users of Corio Bay Wider community	2 & 3
TRG meetings	10 meetings held	Members of the TRG convened by DELWP on behalf of the Minister for Planning as part of the EES process	2 & 3

Activity	Description	Target Audience	Phases
Meetings	Both in person and virtual, includes visits to landowners and occupiers in the pipeline corridor and briefings to elected government representatives. There have been 186 meetings.	Government Neighbours and local residents Landowners and occupiers Business and industry Community and interest groups Traditional Owners and Indigenous groups	2 & 3
Webpage	Repository of project materials including; - 24 fact sheets and study summaries - 15 videos There have been 12,808 unique views and 17,697 views of the videos	Neighbours and local residents CALD communities Business and industry Community and interest Groups Traditional Owner and Indigenous groups Wider community	2 & 3
Project email address	Less than 25 email enquiries about the project	Neighbours and local residents Community and interest groups Business and industry groups Recreational users of Corio Bay Wider community	2 & 3
Letters and emails	700 letters and emails used to introduce the project, provide updates and for formal communications with landowners and occupiers	Government Neighbours and local residents Landowners and occupiers Business and industry Community and interest groups Recreational users of Corio Bay Traditional Owner and Indigenous groups	2 & 3
Business and industry forums	Presented at 4 events of the Geelong business community, total number of attendees 192	Business and industry	2 & 3

Activity	Description	Target Audience	Phases
Utility and infrastructure provider workshops	Completion of constructability workshops and pipeline Safety Management Study	Government Business and industry Landowners and occupiers	2 & 3
Employee events	Regular presentations and updates about the project through internal communications channels such as town halls, all-company emails and @workplace	Viva Energy workforce	2 & 3

6.7 Overview of feedback received

There have been some clear themes that have emerged from consultation and engagement activities conducted to date. The most frequently mentioned themes from the feedback were the rationale for the project and safety. There was a great deal of interest around the rationale for the project and the need for a new source of gas supply given public concern over climate change and the use of fossil fuels. Feedback indicated that there was specific concern from some members of the community, in particular local residents, about the safety of the transiting LNG carrier and the FSRU operation at Refinery Pier. The community was also keen to understand the cumulative safety risk of the project with the existing refinery operations. Potential marine impacts of the FSRU's operation on Corio Bay and the Limeburners Bay/Point Wilson section of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site was also a prominent concern.

The section below summarises the feedback received, the project's responses and how (and where) these concerns were addressed in the EES.

6.7.1 Project response to stakeholder concerns

Viva Energy has sought to understand and address stakeholder and community feedback received during preparation of the EES and consider, and where possible incorporate, this feedback in the design of the project. A complete list of mitigation measures is provided in Chapter 14: *Environmental Management Framework*.

In addition, Viva Energy has sought to provide stakeholders and the community with information about the key areas of concern through targeted communications collateral (displays and presentations) and targeted community meetings.

Planning Panels Victoria is responsible for managing any submissions received during the EES exhibition and submission period and the overall submission process.

A summary of responses to issues raised is included in **Table 6-5**.

Table 6-5 Viva Energy responses to stakeholder and community feedback

Issue raised	Response to issue	Location in the EES
Project Rationale		
Questions about how this project fits in the context of broader climate change policy and use of fossil fuels	• Extensive consultation with community and environmental interest groups – particularly highlighting the gas supply/demand balance, the role that gas plays in the Victorian economy and in the transition to lower carbon energies • Viva Energy's commitment to reducing operational (Scope 1 and 2) emissions to net zero by 2050 and as part of this Viva Energy is committed to medium-term 2030 emissions reduction targets for operational Scope 1 and 2 emissions, from a FY2019 base year: – net zero across Retail, Fuels and Marketing (all non-refining parts of the business) – 10% reduction in emissions intensity at the Geelong Refinery – offsetting Scope 1 and 2 emissions from the construction and operation of the gas terminal • An independent study into the Australian east-coast gas market was commissioned. The report identified a gap in the gas supply/demand balance could emerge as early as 2024. LNG import via a gas terminal is the most flexible and cost effective way to address this shortfall. • Geelong Energy Hub communications channels were created emphasising the role of the project as part of the vision for the Geelong Refinery	Attachment I: *Energy demand and market statement* Chapter 2: *Project rationale*
Questions around the project's greenhouse gas emissions	• Selection of 'open loop' regasification as the usual operating mode of the FSRU to reduce greenhouse gas emissions by approximately four times that of closed loop operation. • A number of considerations have been adopted to minimise greenhouse gas emissions from the project including: – Material selection – Equipment selection – Prioritisation of locally sourced suppliers – Potential for excess boil off gas from the FSRU to be used in the refinery – Lighting design • Commitment to offset the project's residual Scope 1 and 2 construction and operation emissions • Study Summary prepared summarising the Greenhouse gas impact assessment	Technical Report C: *Greenhouse gas impact assessment* Chapter 9: *Greenhouse gas emissions*

Issue raised	Response to issue	Location in the EES
Safety		
General concern around safety of gas terminal operation and transportation of LNG	• Extensive consultation with WorkSafe Victoria, Energy Safe Victoria, DELWP Pipelines Regulation and Ports Victoria • Suite of safety studies conducted including HAZID, HAZOP, pipeline Safety Management Study and Quantitative Risk Assessment (QRA) • Pipeline design specification exceeds the requirements of Australian standards • Development of varied collateral to assist in responding to the questions that have been raised regarding the safe operations of the gas terminal and LNG transportation. This has included: – LNG safety fact sheet – Safe and secure operations fact sheet – information in Refinery Update newsletters, and – E-news updates This information was shared on communications channels including Facebook, advertorial in local newspapers and the project website • In response to the frequency of the issue being raised a community information session was held in July 2021 to provide safety study results to date – recognising that further work was underway. The session focused on the LNG carriers and FSRU and provided an opportunity to answer questions. This meeting was recorded and made available online. Further follow up occurred after the session to respond to additional areas of concern • A second community information session focused on safety was held in October 2021 • Developed a Study Summary for the safety, hazard and risk assessments technical report	Technical Report N: *Safety, hazard and risk assessment* Chapter 12: *Safety*
Impact on maritime and port operations safety with increased ship visits to Refinery Pier	• Berthing simulations and modelling of LNG carrier movements undertaken in conjunction with Ports Victoria and pilotage providers • Highlighting that LNG shipping movements will only be a small increase in total shipping visits to the Port of Geelong	Chapter 12: *Safety*

Issue raised	Response to issue	Location in the EES
Concern around increased security and terrorism risk	• An independent vulnerability and security risk assessment was completed by an industry risk management specialist with consideration of the presence of the FSRU and LNG carrier • Security content added to safe and secure operations fact sheet • A security expert was present at the community information sessions in July 2021 and October 2021 and answered direct questions about this topic	Chapter 12: *Safety*
Concerns around a major incident given proximity of transiting LNG carriers to North Shore residents	• Engagement with Ports Victoria has been occurring on an ongoing basis since project inception • Independent vulnerability and security risk assessment was completed for the project • QRA undertaken for LNG carriers in transit through the shipping channel and past North Shore • Results of risk assessments presented at the July 2021 community information session • Safety was also the focus of the October 2021 community information session • Direct responses to concerns raised and videos posted on Facebook and through Geelong Advertiser 'Letters to the Editor' • Offers to meet and discuss safety with the North Shore Residents Group • In line with Viva Energy processes and regulatory standards, prior to visiting the gas terminal all LNG carriers would be assessed and vetted • Strong safety track record of LNG shipping industry • Ships in transit required to follow Ports Victoria direction	Chapter 12: *Safety*
Concerns around a major incident given proximity of transiting LNG carriers to North Shore residents	• Engagement with Ports Victoria has been occurring on an ongoing basis since project inception • Independent vulnerability and security risk assessment was completed for the project • QRA undertaken for LNG carriers in transit through the shipping channel and past North Shore • Results of risk assessments presented at the July 2021 community information session • Safety was also the focus of the October 2021 community information session • Direct responses to concerns raised and videos posted on Facebook and through Geelong Advertiser 'Letters to the Editor' • Offers to meet and discuss safety with the North Shore Residents Group • In line with Viva Energy processes and regulatory standards, prior to visiting the gas terminal all LNG carriers would be assessed and vetted • Strong safety track record of LNG shipping industry • Ships in transit required to follow Ports Victoria direction	Technical Report N: *Safety, hazard and risk assessment* Chapter 12: *Safety*

Issue raised	Response to issue	Location in the EES
Confusion about jurisdictional coverage of exclusion zones and 'buffer zones' around LNG carriers	• Engagement with Ports Victoria has been occurring on an ongoing basis since project inception • Maps developed of current and future maritime exclusion zones • Exclusion zones available on project website clarifying use around LNG carriers in transit • Information provided at July 2021 community information session	Chapter 12: *Safety*
Understanding the outcomes of risk assessments (QRA analysis) and relevance to residents	• QRA was used in an iterative process to inform additional design measures to minimise risk based on results and stakeholder feedback • Cumulative QRA risk profiles developed for project and the refinery • Met with stakeholders to discuss the safety, hazard and risk assessment tools, methodology and outputs • Shared current status of risk assessments for FSRU; treatment facility and cumulative impact assessment • Safety information was posted on project website • Community information sessions held in July 2021 and October 2021 focused on the issue of safety. Meeting materials made available on-line	Chapter 12: *Safety*
Potential for major incident / explosion on the FSRU	• The FSRU would be classified as a Major Hazard Facility (MHF) and would require an accepted MHF safety case and licence issued by WorkSafe Victoria. Multiple studies and assessments have been completed to ensure safety in design and operation • Partnered with reputable FSRU provider Hoegh with strong track record around the world • Engaged FSRU specialist consultants to provide input into design and operational requirements including exclusion zones. • Community information session held July 2021 with content showing QRA for FSRU. Meeting materials made available on-line. This was also discussed at the October 2021 community information session • Facilitated a meeting with Worksafe and Geelong Grammar School to ensure stringent regulatory requirements for a MHF were well understood.	Technical Report N: *Safety, hazard and risk assessment* Chapter 12: *Safety*

Issue raised	Response to issue	Location in the EES
Concern about trucks running off the road and damaging the aboveground pipeline resulting in a major incident. Particular areas of concern are at the Wharf Road / Shell Parade bend (near the Refinery Pier Gatehouse), and at the culvert where the aboveground pipeline crosses underneath Shell Parade from the foreshore.	• Measures proposed following pipeline SMS workshop to address this 'threat' to pipeline integrity include installation of additional "armco" roadside barriers at these two locations. The exact positioning of the additional roadside barriers is to be further investigated as detailed design proceeds	Technical Report N: *Safety, hazard and risk assessment* Chapter 12: *Safety*
Concerns about the FSRU seawater discharge changing the temperature of the bay and chlorination of seawater.	• The gas terminal has been designed to enable reuse of seawater transferred from the FSRU into the refinery for use as cooling water which is an environmental enhancement. Discharge from the refinery after reuse of discharge water would be very similar to the current refinery discharge and continue to comply with current EPA licence conditions • Engagement with EPA regarding licensing requirements. Development Licence applications will seek approval from EPA for the FSRU and for discharge of FSRU wastewater from the refinery. • Additional investigations were completed to understand the existing condition of flora and fauna under the current refinery seawater discharge outlets • Diagrams outlining seawater use design were produced and included in communications material including a video of how the gas terminal would work • Created a fact sheet on the topic of the marine environment • In May 2021, a community information session was held focusing on the marine studies conducted in support of the EES process • Stand at November 2021 community information session presented the results of the marine studies conducted in support of the EES. A technical specialist was available to answer questions	Technical Report A: *Marine ecology and water quality impact assessment* Chapter 8: *Marine environment*

Issue raised	Response to issue	Location in the EES
Questions around understanding what the impact on seawater discharge would be if the refinery was to stop operations	• Communication on the company's commitment to continue refining until at least mid 2028 as part of the Commonwealth Fuel Security Package • Potential impact of direct discharge of cooled seawater from the FSRU to Corio Bay was modelled and assessed. • Use of a diffuser to distribute the cooled seawater through a number of outlets over a larger distance to enable improved mixing has been provided for in the event this is needed for a future mode of operation.	Technical Report A: *Marine ecology and water quality impact assessment* Chapter 8: *Marine environment*
Concern around the scale of dredging and potential impacts on Corio Bay	• Shipping simulations were completed to minimise the dredge footprint and volume of material removal dredging required. The dredged material volume was reduced from 1,000,000 m^3 to 490,000 m^3. • Extensive consultation with Ports Victoria, EPA and DELWP on technical studies and dredged material disposal options assessment • Extensive marine surveys conducted over a 12 month period to characterise the existing environment of Corio Bay • Sediment dispersion modelling was completed in conjunction with a comprehensive offshore sediment sampling and contaminant analysis in accordance with the National Australian Guidelines for Dredging (NAGD) • A dredging methodology assessment was completed to ensure optimal equipment and methods were recommended • A dredged spoil disposal options assessment (DSDOA) was undertaken • Marine and Coastal Act consent required for dredging • Communications developed on Refinery Pier works and localised dredging • Stand at November 2021 community information session focused on localised dredging and dredged material disposal. Technical specialist was available to answer questions • Study Summary prepared to summarise the findings of the marine ecology and water quality impact assessment technical report	Technical Report A: *Marine ecology and water quality impact assessment* Technical Report B: *Dredged sediment disposal options assessment* Chapter 8: *Marine environment*

Issue raised	Response to issue	Location in the EES
Concerns about potential impacts on Ramsar wetlands in Corio Bay	• Proactively engaged with wildlife and bird conservation groups, and the Ramsar Coordinating Committee • Entrainment and discharge/turbidity plume modelling was undertaken to ensure any potential for direct or indirect impacts to the site were mitigated • Light spill assessment conducted. Potential impacts of pier lighting are to be minimised through selection of wildlife sensitive lighting design as per the National Light Pollution Guidelines for Wildlife • A community information session on marine studies to support the EES impact assessment incorporating Corio Bay and the Ramsar site was held in May 2021 • Created a fact sheet with information on the Ramsar site • Developed an informational video on the assessments incorporating Corio Bay and the Ramsar site • November 2021 advertorial focused on marine ecology and referenced Ramsar wetlands	Technical Report A: *Marine ecology and water quality impact assessment* Technical Report J: *Landscape and visual impact assessment* (Appendix A: Light spill impact assessment) Chapter 8: *Marine environment*
Other themes		
Interest in job creation and local and Indigenous content in procurement	• Information on the economic benefits including job creation was made available in Facebook posts, through a project benefits poster and highlighted in meetings and briefings • Indigenous and local content to be implemented as part of the procurement policy for goods and services	Technical Report L: *Social and business impact assessment* Chapter 11: *Amenity and environmental quality*
Questions around effective tools for local community engagement	• Created 8 factsheets and 3 videos for CALD communities • Utilised multiple avenues of communication including pop-up shopping centre booths, face-to-face meetings, community information sessions, letter-box drops and local newspaper adverts • Targeted website and Facebook content	Chapter 5: *Stakeholder Consultation*
Concern around cumulative noise with the refinery	• A noise impact assessment was conducted by specialists in support of the EES process to assess potential noise impacts and identify management measures to reduce impacts on sensitive receptors, including recommendation to minimise 'out-of-hours' construction works • Noise measurements were conducted to establish the baseline noise levels • Community information session via webinar covered noise in August 2021. The recording was made available online after the meeting. • Short video with information about the noise impact assessment was made available on the website and Facebook • Study Summary on the noise and vibration impact assessment technical report published online	Technical Report I: *Noise and vibration impact assessment* Chapter 11: *Amenity and environmental quality*

Issue raised	Response to issue	Location in the EES
Concern around increased traffic using the local roads.	• Consultation occurred with Department of Transport and GeelongPort • Liquid nitrogen delivery to the treatment facility would occur via Refinery Rd consistent with current heavy vehicle movements to the refinery • A transport impact assessment was conducted in support of the EES. Cumulative impacts were assessed with consideration of future Spirit of Tasmania ferry passenger traffic and any overlap with other future projects • A community information session via webinar was held in August 2021 to present the findings of the transport impact assessment. The recording was made available on the project website after the meeting. • Study Summary published summarising the transport impact assessment • Short video with information on the transport impact assessment was created and made available on the project website and social media	Technical Report K: *Transport impact assessment* Chapter 11: *Amenity and environmental quality*
Concern expressed around the size (and consequent visual impact) of the FSRU	• The landscape and visual impact assessment was extended beyond the Theoretical Zone of Visibility to include a viewpoint from the Geelong Waterfront precinct given its high use and significance within the local area • Selection of most appropriate Geelong Grammar School viewpoint for inclusion in the impact assessment was determined in consultation with the School • Photomontages of the FSRU moored at Refinery Pier were created from key viewpoint locations across Geelong – Eastern Beach; Cunningham Pier; North Shore; Geelong Grammar School, demonstrating the visual appearance within what is an existing port and industrial area. These images were displayed at community meetings, on the project website and on Facebook • Comparative height/dimension chart of project infrastructure and LNG carriers was created and displayed via communications channels • Visual impacts were assessed as part of the landscape and visual impact assessment conducted to support the EES • Study Summary published summarising the Landscape and visual impact assessment	Technical Report J: *Landscape and visual impact assessment* Chapter 11: *Amenity and environmental quality*
Request for information regarding future restricted access for recreational users of Corio Bay	• Maps showing the current and proposed exclusion zones were published on the project website • Proactive engagement with VRFish on the project	Chapter 11: *Amenity and environmental quality* Chapter 12: *Safety*

6.8 Ongoing engagement

Viva Energy is committed to continuing to inform, consult and involve community members and stakeholders during the next phases of the project.

The following communications and engagement activities are planned to inform the public about the project, the EES and to encourage participation during the public exhibition of the EES:

- Community information sessions (to be conducted virtually if required due to any COVID19 restrictions) or pop-up booths
- Responding to enquiries through the dedicated project email energhub@vivaenergy.com.au and 1800 number
- Communications regarding the public exhibition of the EES including:
  - Website information
  - Facebook posts
  - E-news update
  - Refinery Update newsletter
  - Advertising in local newspapers

Should statutory approvals be obtained following the EES process, the project will progress to a Final Investment Decision (FID) and then the construction phase. The Environmental Management Framework (EMF) for the project and the conditions of any statutory approvals would inform and contribute to the ongoing engagement approach. During the construction phase, one of Viva Energy's priorities will be to inform the affected landholders, neighbours and community of construction timing and associated impacts prior to works commencing. Viva Energy will actively seek feedback from stakeholders during the construction phase to ensure continuous improvement on its performance.

Viva Energy will undertake the following communications and engagement activities during the construction phase:

- Direct communications with affected landholders and neighbours
- Website information
- Facebook (and other social media) posts
- E-news updates
- Refinery Update newsletters
- Responding to enquiries via the dedicated project email energhub@vivaenergy.com.au and 1800 number.

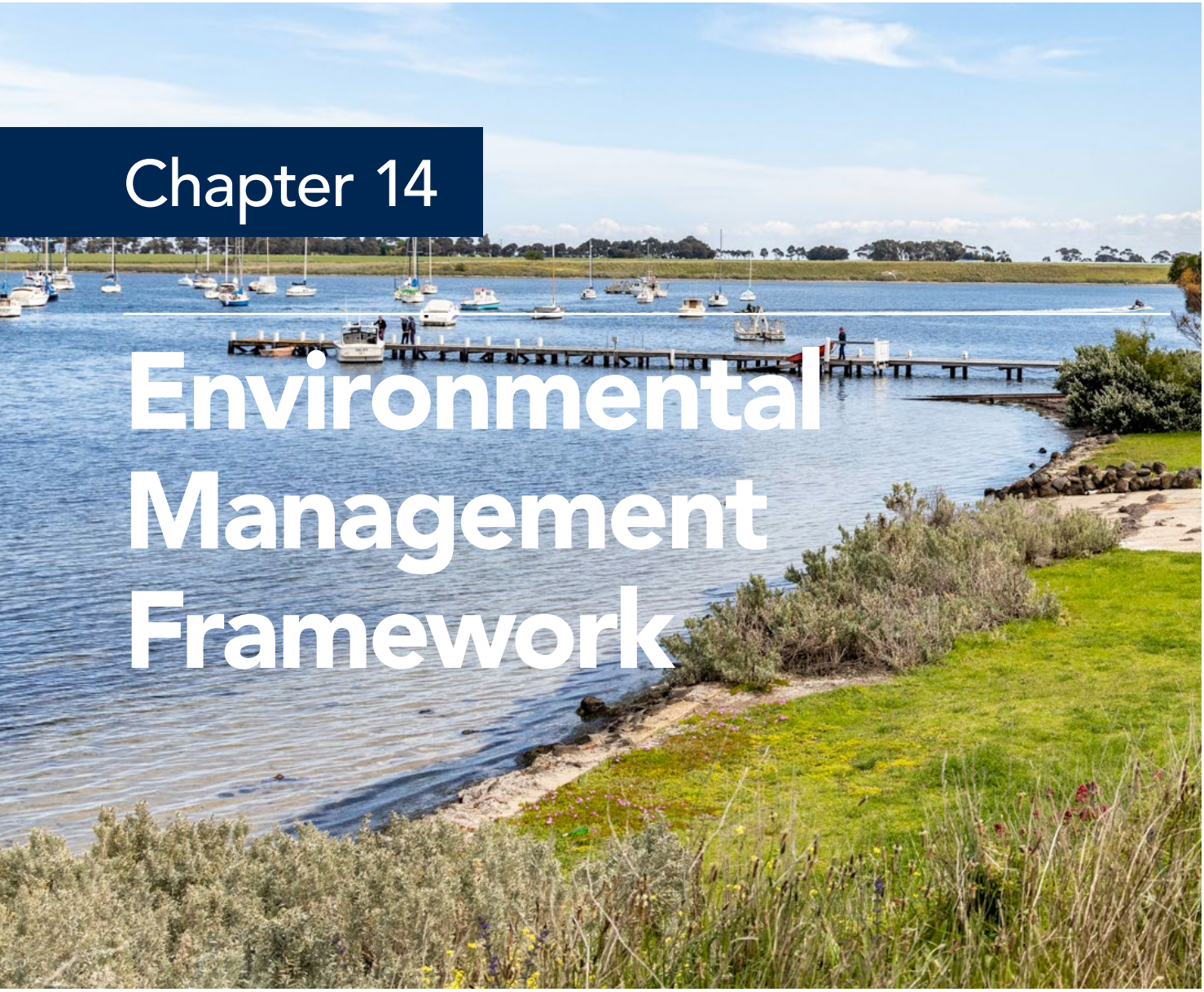
Viva Energy will continue to engage with stakeholders and the community during project operations.

Appendix D

Environmental Management Framework

Chapter 14

Environmental Management Framework



This chapter presents the Environmental Management Framework (EMF) for the Viva Energy Gas Terminal Project (the project). The EMF outlines the environmental requirements of the project and how environmental effects will be managed.

The framework sets out the mitigation measures that would be implemented by the proponent to avoid, minimise or manage potential adverse effects of the project and identifies the relevant statutory approvals that will give effect to these measures. Roles and responsibilities of key stakeholders are defined in the EMF to ensure that there are clear accountabilities for the implementation of the environmental management requirements.

14.1 Overview

Development of this EMF was guided by the Environment Effects Statement (EES) scoping requirements, relevant legislation, policy and guidelines including the statutory approvals and consents that will be required. The EMF and associated mitigation measures have been informed by impact assessments in the specialist studies completed for the EES.

The EMF outlines the relevant statutory approvals and consents required for the project and how mitigation measures will be incorporated within the approval conditions or within environmental management plans to be pursuant to statutory approvals.



Viva Energy Gas Australia Pty Ltd (Viva Energy) will use the EMF, statutory approvals and consents and any associated environmental management plans to implement the mitigation measures and will monitor the implementation of the statutory approval conditions.

The mitigation measures outlined in the EMF have been developed in this EES to avoid, minimise and manage adverse environmental effects. The relevant statutory approval or consent that will give effect to the management and monitoring of potential effects are outlined in **Section 14.3** (statutory approvals and consents). Environmental Management Plans (EMPs) will be prepared to incorporate the mitigation measures and these plans will be approved and enforced pursuant to the relevant statutory approval.

EMPs required under statutory approvals and consents will be subject to updates by Viva Energy to ensure commitments are incorporated and adhered to. Implementation of the approach outlined in this EMF and the subsequent statutory obligations would be effective in controlling adverse effects associated with the construction and operation of the project and would support achievement of the project objectives. They also provide a clear, transparent, robust and comprehensive approach to organisational responsibility and accountability arrangements.

14.2 Scoping requirements

Section 3.7 of the EES scoping requirements establishes the requirement for an EMF to be prepared for the project:

"The proponent is to provide an environmental management framework (EMF) for the project in the EES. The EMF will provide a transparent framework with clear accountabilities for managing and monitoring the environmental effects and hazards associated with the construction and operational phases of the project. The entity responsible for approval of management/environmental plans will be identified."

Table 14-1 outlines the EES scoping requirements for the EMF along with the relevant section within this chapter where these requirements are addressed.

Table 14-1 EES Scoping requirements for the EMF

EES scoping requirement	Relevant section in this chapter
The EMF must outline how potential adverse effects on community, businesses and land uses from changes in air quality and noise, traffic, landscape and visual amenity will be avoided, minimised or mitigated.	**Section 14.7**
Describe the baseline environmental conditions to allow evaluation of the residual environmental effects of the project, as well as the efficacy of applied environmental management and contingency measures	**Section 14.5**
Include an environmental management system, with organisational responsibilities, accountabilities and governance arrangements	**Section 14.8**
Include an environmental risk register that is maintained during project implementation	**Section 14.6**



EES scoping requirement	Relevant section in this chapter
Include environmental management measures proposed in the EES to address specific issues, including commitments to mitigate adverse effects and enhance environmental outcomes.	Section 14.7
Set out procedures for complaints recording and resolution	Section 14.14
Set out procedures for auditing and reporting of performance including compliance with relevant statutory conditions and standards	Section 14.13
Set out procedures to review of the effectiveness of the environmental management framework for continuous improvement.	Section 14.9
The EMF should describe proposed objectives, indicators and monitoring requirements, including for (but not limited to) managing or addressing: • biodiversity values (including MNES and offsets); • marine sediment and water quality, and protection of marine environmental values; • landscape and visual values; • social outcomes and community engagement; • safety outcomes; • maintenance of the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site; • groundwater and surface water quality, surface water flow and groundwater regimes; • solid and liquid waste, including recycling and handling of potentially hazardous or contaminated waste, potential acid sulphate soils and other excavated spoil; • noise and emissions to air including greenhouse gases particularly with respect to managing impacts on amenity during construction; • Aboriginal and historic cultural heritage values; • transport management including managing temporary disruption and changed accessibility during construction; • emergency management; and • site reinstatement.	Section 14.7 and Section 14.11

14.3 Statutory approvals and consents

This section provides an overview of the regulatory framework that would apply for the project to proceed. Further information on the regulatory framework for the project is provided in Chapter 5: *Legislative framework and approval requirements*. Viva Energy must obtain a number of statutory approvals as part of the regulatory approval process. **Table 14-2** and **Figure 14-1** outline the approvals and consents required for the project.

Table 14-2 Statutory approvals and consents

Legislation	Statutory approval authority	Statutory approval
Environment Protection and Biodiversity Conservation Act 1999 (Cth)	Commonwealth Minister for the Environment	Approval of the project which is a controlled action
Marine and Coastal Act 2018 (Vic)	Minister for Energy, Environment and Climate Change	Consent to 'undertake works on marine and coastal Crown land' (dredging) Consent for the 'use and development of marine and coastal Crown land' (Floating storage and regassification unit [FSRU], pier extension and piping from the FSRU to the existing refinery cooling water intake)
Environment Protection Act 2017 (Vic)	Environment Protection Authority (EPA)	Development Licence and Operating Licence for the installation and operation of the FSRU Development Licence or exemption for the Geelong Refinery for a new prescribed activity and a modification to the existing Operating Licence for the Geelong Refinery to permit new prescribed activity (as the holder of the current EPA Licence 46555 Viva Energy Refining Pty Ltd will be the applicant for this Development Licence)
Planning and Environment Act 1987 (Vic)	Minister for Planning	Planning Scheme Amendment (Specific Controls Overlay) to the Greater Geelong Planning Scheme
Pipelines Act 2005 (Vic)	Minister for Energy, Environment and Climate Change Energy Safe Victoria	Pipeline Licence to construct and operate a pipeline, including: • Environment Management Plan (EMP) • Safety Management Plan (SMP) • Pipeline Consultation Plan (PCP)
Aboriginal Heritage Act 2006 (Vic)	First Nations – State Relations and relevant Registered Aboriginal Party	Cultural Heritage Management Plan (CHMP)
Gas Safety Act 1997 (Vic)	Energy Safe Victoria (ESV)	Gas safety case

Legislation	Statutory approval authority	Statutory approval
Occupational Health and Safety Act 2004 (Vic)	WorkSafe Victoria (WSV)	Major Hazard Facility (MHF) Licence for FSRU and amendment to the current refinery MHF Licence for the treatment facility
Flora and Fauna Guarantee Act 1988 (Vic)	Minister for Energy, Environment and Climate Change Minister for Agriculture	If required, a permit for vegetation clearance of FFG Act-listed species on public land.

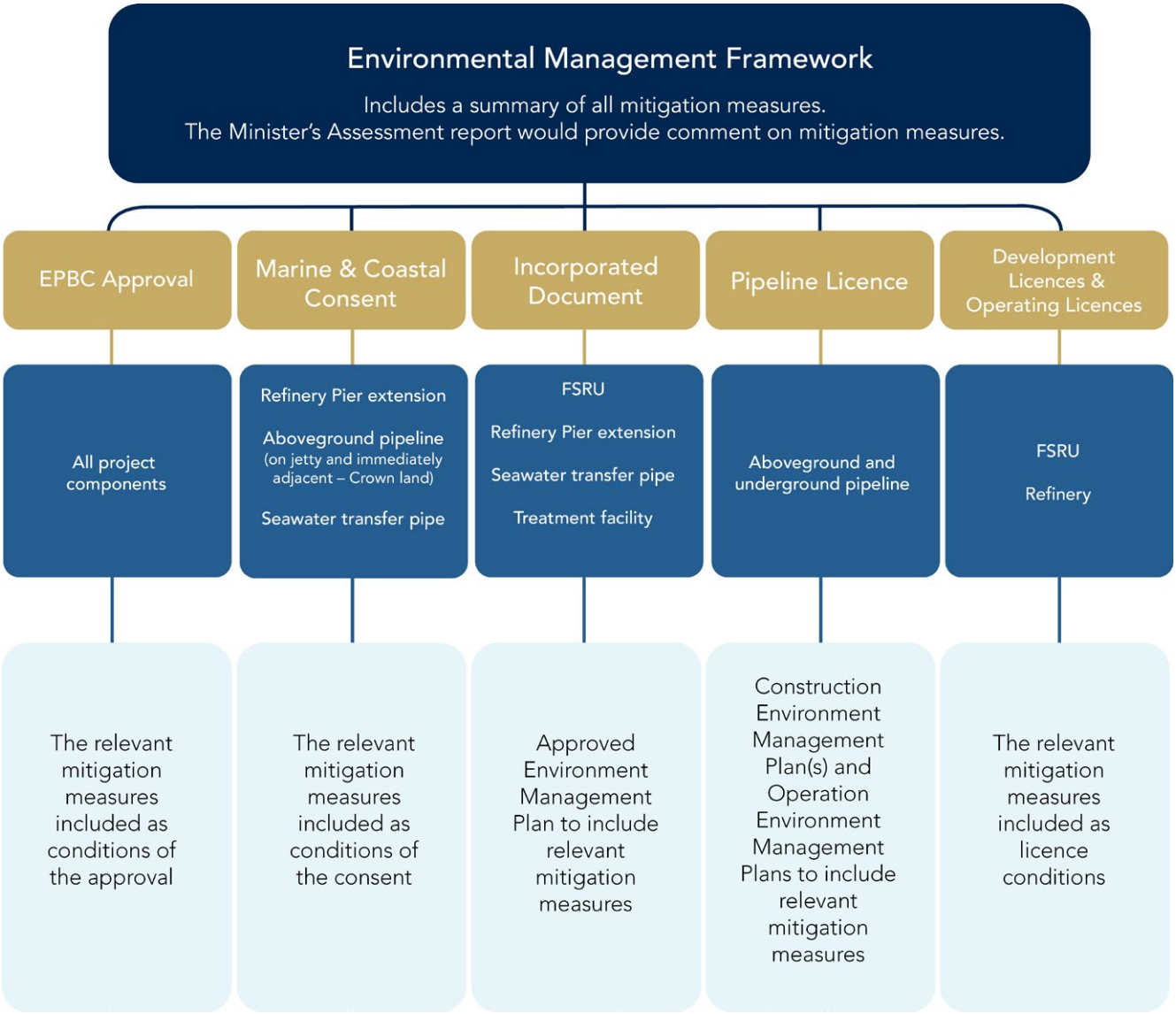


Figure 14-1 Key approvals for each project component

14.4 Roles and responsibilities

Viva Energy will be responsible for:

- Overseeing and engaging the contractors and consultants required for the detailed project design
- Site investigations
- Obtaining secondary approvals
- Procurement
- Construction delivery
- Commissioning and operation of the project.

Viva Energy will also be responsible for supervising the contractor(s) and ensuring that project delivery complies with relevant statutory approvals. Viva Energy will be responsible for reporting compliance and/or environmental management performance to all relevant regulators, as required, under each approval or relevant statutory instrument.

The roles and responsibilities of the key stakeholders relevant to environmental management of the project are outlined in **Table 14-3**.

Table 14-3 Project roles and responsibilities

Stakeholder	Role	Responsibility
Government representatives including EPA, Minister for Planning, Energy Safe Victoria, WorkSafe Victoria, First Nations – State Relations and Minister for Energy, Environment and Climate Change	Regulators	• Incorporate mitigation measures as statutory approvals conditions or require that they be included in EMPs to be prepared and approved under the approval conditions • Administer and enforce statutory approvals • Review and approve, where necessary, relevant environmental management plans • Receive and review audit reports from the Independent Environmental Auditor(s), in compliance with relevant approval conditions, where required.
Victoria Minister for Planning	Regulator	• Review the EMF and mitigation measures in the EES and recommend adoption by relevant regulatory agencies in statutory approvals as part of the Minister for Planning's assessment of the EES • Approve the planning scheme amendment and conditions of the project incorporated document • Review the EMPs required under the project incorporated document • Where relevant, administer and enforce approved environmental management plans as responsible authority for the administration and enforcement of the incorporated document through the planning scheme amendment.
Commonwealth Minister for Environment	Regulator	• Administer and enforce the Environment Protection and Biodiversity Conservation (EPBC) approvals for the project • Review and approve environmental management plans as required under the relevant EPBC approvals • Administer and enforce environmental management plans and strategies approved pursuant to those approvals • Receive audit or monitoring reports as required.
Wadawurrung Traditional Owners Aboriginal Corporation	Regulator	• Evaluate and approve the project CHMP, as the Registered Aboriginal Party.

Stakeholder	Role	Responsibility
Viva Energy Gas Australia Pty Ltd	Proponent	• Obtain applicable statutory approvals for the project • Prepare an EMP and SMP, incorporating mitigation measures and other relevant legislative requirements and approval conditions • Develop contractor tender documentation reflecting requirements from approval conditions and clearly articulating requirements for incorporation of EMP compliance into tender responses • Review and approve contractor environmental management plans prior to being submitted to statutory authorities for approval pursuant to relevant statutory approvals • Monitor contractor's compliance with approved mitigation measures and approvals conditions, as outlined in the approved EMP, Construction Environment Management Plan (CEMP), Operation Environment Management Plan (OEMP) and SMP and take corrective action where required • Viva Energy will be responsible for compliance and/or environmental management performance, compliance with statutory approvals and associated reporting to all regulators as required.
Project contractors and consultants	Proponent appointed for detailed project design, site investigations, obtaining secondary approvals, procurement, construction delivery and commissioning of the project	• Project contractors to prepare management plans in accordance with proponent tender documents, EMP, CEMP, OEMP and SMP and other relevant legislative requirements, and approval conditions that have been obtained by Viva Energy • Ensure compliance with approved EMP, CEMP, OEMP and SMP during project delivery and take corrective action where required • Contractors will be responsible for reporting compliance with approved EMP, CEMP, OEMP and SMP and statutory approvals conditions to Viva Energy • Consultants may be responsible for obtaining secondary approvals on behalf of Viva Energy where required.
Independent Environmental Auditor(s) (IEA)	Proponent appointed independent auditor for review and verification	• Prior to commencement of work, assess contractors' management plans for adequacy in compliance with statutory approvals • Conduct audits of contractors' construction works and operations, at agreed intervals, to assess compliance with EMP and CEMP • Prepare audit reports for project proponent and recommend corrective and preventive actions as required • Submit relevant audit reports to the applicable regulator(s), as applicable • The IEA must include persons with expertise, based on qualifications and experience, appropriate to allow the roles specified for the IEA in the EMF to be properly carried out.

14.5 Existing conditions

Characterising the existing environmental, social and safety conditions in the area is important to develop an understanding of the baseline conditions without the project. The existing conditions assessment allows for the evaluation of the potential environmental, social and safety effects of the project, as well as the efficacy of applied environmental management and contingency measures.

The results of the existing conditions assessments are presented in each of the technical studies developed for the EES.

14.6 Risk screening

A risk-based screening approach has been used for the EES assessment in accordance with the requirements outlined in the 'Ministerial guidelines for assessment of Environmental Effects under the *Environment Effects Act 1978*' (page 14). The risk screening was undertaken to ensure that the level of investigation conducted in each technical study was adequate to inform an assessment of the significance of the project's potential environmental impacts.

An environmental, social and economic issues risk screening tool was used to prioritise and focus the proposed investigations, assessments and approaches to avoiding, minimising or managing potential impacts. The issue screening process involved an evaluation of the potential environmental, social and economic issues associated with the project based on the information collected through a series of initial assessments undertaken into the potential effects of the project.

The results of the risk screening are presented in each of the technical studies developed for the EES.

14.7 Impact assessment and mitigation measures

An environmental impact assessment was undertaken for each of the 18 technical studies based on the defined area of study. This involved an assessment of the nature and extent of identified impacts that the project may have on the existing environment. A number of factors were taken into consideration when determining the significance of potential impacts and in particular, the magnitude, spatial extent and duration of potential impacts on the environment were considered.

Mitigations measures were recommended based on the results of the impact assessment and the hierarchy of controls by technical specialists in order to avoid, minimise, manage or offset potential environmental, social and safety impacts. Where possible, potential impacts were avoided through changes to the design e.g., modification of the pipeline route to avoid areas of environmental sensitivity and reduction of the project footprint to avoid areas of native vegetation. Where impacts could not be avoided, mitigation measures were recommended to minimise and manage potential impacts. Mitigation measures have also been recommended for performance monitoring throughout each phase of the project to monitor and evaluate the residual environmental effects of the project, as well as the efficacy of applied environmental management and contingency measures.

Viva Energy has reviewed the recommended mitigation measures in the EES technical studies and has adopted a comprehensive set of measures to manage potential impacts from the project.

The mitigation measures for the project are outlined in **Table 14-4** below and are to provide controls on project activities that may impact on and give rise to risks for the following subject areas:

- Aboriginal cultural heritage
- Air quality
- Climate change
- Contamination and acid sulfate soils
- Greenhouse gas
- Groundwater
- Historic heritage
- Landscape and visual
- Light spill
- Marine ecology and water quality
- Noise and vibration
- Safety, hazard and risk
- Social and business
- Surface water
- Terrestrial ecology
- Traffic and transport
- Underwater noise.

Table 14-4 Mitigation measures

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Aboriginal cultural heritage EES evaluation objective: To avoid or minimise adverse effects on Aboriginal and historic cultural heritage					
MM-AH01	**CHMP 17816 Conditions** The project will be delivered in accordance with conditions set out in CHMP 17816 to manage any potential harm to known Aboriginal places and values. Typical management conditions include, but are not limited to: • Conditions for harm avoidance and/or harm minimisation measures • Conditions for harm mitigation measures where appropriate, including requirements for surface artefact collection and/or salvage excavations and appropriate analysis and reporting • Conditions for the removal, custody, curation and management of Aboriginal cultural heritage (artefacts) identified during the CHMP. The CHMP will also provide necessary and appropriate mechanisms and processes to manage any potential harm to unknown Aboriginal places and values. Typical management of unknown Aboriginal places and cultural heritage values will include, but not limited to: • Contingency plans for the management of Aboriginal cultural heritage, including Aboriginal ancestral remains, unexpectedly identified during the construction phase of the project • Contingency plans for the removal, custody, curation and management of Aboriginal cultural heritage (artefacts) identified during the project • Review and compliance with the CHMP.	All	CHMP	Construction	Known or unknown Aboriginal cultural heritage values

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Air quality EES evaluation objective: To minimise potential adverse social, economic, amenity and land use effects at local and regional scales					
MM-AQ01	**Dust suppression** Dust suppression will be used at construction areas as required using water sprays, water carts or other devices on: • unpaved work areas • sand, spoil and aggregate stockpiles • during the loading and unloading of dust generating materials.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Airborne dust
MM-AQ02	**Restricted vehicle movements** After arrival at the project site, vehicles, plant and equipment will remain within the construction footprint and on public roads and designated tracks.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Airborne dust
MM-AQ03	**Crushed rock on access tracks** Crushed rock will be placed on existing unsealed access tracks if required and as agreed with relevant stakeholders to prevent vehicle movements raising dust. Crushed rock will also be placed on access tracks subject to mud / slippery conditions.	Pipeline Treatment facility	Pipeline Licence	Construction	Airborne dust
MM-AQ04	**Speed restrictions** Vehicle speed will be restricted to 40 km/h on the construction right of way (ROW) and unsealed access tracks / work areas.	Pipeline Treatment facility	Pipeline Licence	Construction	Airborne dust
MM-AQ05	**Covering vehicle loads** Construction vehicles with potential for loss of loads (such as dust or litter) will be covered when using public roads.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Airborne dust Offensive odours
MM-AQ06	**Weather monitoring** Weather conditions will be monitored for extreme heat and/or wind events using systems such as the Bureau of Meteorology forecasts and works will be modified if conditions are likely to result in air quality impacts at sensitive receptors. The project will use existing refinery weather monitoring processes where appropriate.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Airborne dust Offensive odours

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-AQ07	**Dust monitoring** Observational monitoring of dust along the construction right of way (ROW) and at the treatment facility will be undertaken. If dust is observed to be causing a hazard, then MM-AQ01 will be implemented. If dust levels cannot be contained works will be modified or stopped until the dust hazard is reduced to a manageable level.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Airborne dust
MM-AQ08	**Odorous soils management** In the event that odorous soils are uncovered during construction, the following measures will be undertaken: • Cessation of ground disturbance at the location and within the immediate vicinity. • Assessment of site contamination and determination of appropriate management actions in consultation with suitably qualified personnel. If odorous material is found to be contaminated, EPA will be notified if required in accordance with the requirements of the *Environment Protection Act 2017*.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Offensive odours
MM-AQ09	**Equipment maintenance** Plant and equipment will be maintained in good condition to minimise spills and air emissions that may cause nuisance.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Exhaust emissions
MM-AQ10	**Maintenance of the FSRU burners** Maintenance of the burners in the boilers and engines will be undertaken regularly as per manufacturer's specifications.	FSRU	EPA Development Licence and Operating Licence	Operation	Pollutant emissions

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-AQ11	**Monitoring FSRU emissions** An air quality monitoring program will be designed and implemented to confirm FSRU emission rates comply with design specifications.	FSRU	EPA Development Licence and Operating Licence	Operation	Pollutant emissions
Climate change EES evaluation objective: To provide for safe and cost-effective augmentation of Victoria's natural gas supply having regard to projected demand and supply in context of the State's energy needs and climate policy.					
MM-CC01	**Implement adaptation measures** • Climate projections will be factored into the basis of design, particularly the mooring analysis (alignment of FSRU and other vessels with the pier), materials and coatings choices and site hydrological modelling. This will be done using a risk-based design approach that, rather than simply picking a projection, considers the range of projections, the likely exposure of an asset (considering design life and projection timeframes), its criticality, sensitivity and adaptive capacity, in determining the appropriate design factors. • Safety procedures and protocols will be updated to take into consideration severe weather conditions such as storm events and heatwaves	Refinery Pier extension FSRU Pipeline Treatment facility	Incorporated document EPA Development Licence and Operating Licence Pipeline Licence	Operation	Risks to the project from climate change (storm weather, extreme rainfall events, sea level rise and extreme heat events)
Contamination and acid sulfate soils (onshore) EES evaluation objective: To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site. To minimise generation of wastes by or resulting from the project during construction and operation, including dredging and accounting for direct and indirect greenhouse gas emissions.					
MM-CO01	**Contaminated soils** • Contaminated soils (as identified within Zone 1 – the refinery) will be managed in accordance with: – *Environment Protection Act 2017* – ERS 2021 – PFAS National Environmental Management Plan 2.0 (2020) – EPA Victoria Publication: 1669.4: Interim Position Statement on PFAS	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts Offensive odours

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Stockpiles of trench spoil will be managed in accordance with APGA Code of Environmental Practice – Onshore Pipelines. • Excess soils and HDD screened cuttings for off-site disposal will be sampled and classified in accordance with: – EPA Victoria Publication IWRG702: Soil Sampling – EPA Victoria Publication 1828.2: Waste Disposal Categories - Characteristics and Thresholds • Contaminated spoil for off-site treatment/disposal will be managed in accordance with: – Environment Protection Act 2017 and Environment Protection Regulations 2021. • Any material imported for use as backfill will comply with the EPA Victoria Publication 1828.2 Waste Disposal Categories - Characteristics and Thresholds for 'Fill Material' and the fill material determination. The backfill will be accompanied by relevant documentation confirming its compliance to the 'Fill Material' criteria.				
MM-CO02	**Contaminated groundwater** • Contaminated groundwater will be managed in accordance with: – *Environment Protection Act 2017* – *Environment Reference Standard 2021* – PFAS National Environmental Management Plan 2.0 (2020). • Disturbance of saturated soil and groundwater within the PFAS affected areas will be minimised (refinery and in vicinity of GW05) and the migration of PFAS into the surrounding soil or surface water will be prevented. Disturbance may be minimised by design of the infrastructure not to extend into the water table or to be bypassed by using HDD techniques. • Water from areas that have been identified as contaminated will not be discharged to the environment (land, waterways, sewer).	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Where a wet-trench installation approach is not undertaken contaminated water will be sampled and either treated onsite, depending on contaminant encountered (this may require approval from the EPA Victoria) or disposed offsite to an EPA Victoria licensed facility.				
MM-CO03	**Contaminant migration** Trench dewatering of groundwater or perched water will be avoided. In the unlikely event that dewatering of groundwater or perched water inflow is unavoidable, the trench will be dewatered prior to lowering the pipes.	Pipeline	Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts
MM-CO04	**Unknown contamination** In the event that unknown contamination (including asbestos containing material) is encountered during construction: • Ground disturbance at the unknown contamination location and within the immediate vicinity will be ceased. • Site contamination will be assessed, and the appropriate remedial action will be identified. • The required remediation will be undertaken. • Such material may be identified by visual or olfactory observations, the presence of asbestos and/or other anthropogenic material.	Pipeline Treatment facility	Incorporated document Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts
MM-CO05	**Acid sulfate soils** Where acid sulfate soil has been identified, or is encountered during construction: • Management strategies will be incorporated within the Construction Environmental Management Plan (CEMP) to manage potential ASS risk for a 'Medium' ASS hazard (CASS BPMG, 2010) in accordance with: – Industrial Waste Management Policy (Waste Acid Sulfate Soils) 1999 – EPA Victoria Publication IWRG655.1: Acid Sulfate Soil and Rock – Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils (CASS BPMG, 2010) – National Acid Sulfate Soils Guidance (series of documents) 2018	Pipeline Treatment facility	Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• The CEMP must be approved by the Pipeline regulator in consultation with EPA Victoria. • Construction works will not occur during wet months unless conditions are such that land degradation and surface water management problems can be avoided, or appropriate mitigation measures implemented. • Relevant training will be provided to site-based personnel on the requirements of the ASS management procedure including the recommended time period over which soils may be temporarily stockpiled before treatment commences as recommended by the CASS BPMG (2010). • The duration of stockpiling will be minimised in accordance with the CASS BPMG (2010). • A procedure for managing the unexpected discovery of ASS/PASS will be included in the CEMP. • If ASSs are to be stockpiled for an extended time period (exceeding the CASS BPMG (2010) recommended short-term stockpiling durations), the potential generation of acidic leachate will be managed by treating the stockpile and or spreading a guard layer before stockpiling and/or covering the stockpile. The CEMP will include details for when or if the requirements for containment with bund and a leachate collection system is necessary. • Capture and manage run-off that has the potential to be impacted by stockpile material in accordance with the CASS BPMG (2010). • Develop and implement a monitoring program as part of the CEMP in accordance with the CASS BPMG (2010) to measure the effectiveness of the management strategy and to provide an early warning of any environmental degradation or impact to surface water, groundwater and soils. • Include management procedure for trench dewatering that will limit PASS activation in accordance with the Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils (CASS BPMG, 2010) and the National ASS Guidance 'Guidance for the dewatering of aid sulfate soils in shallow groundwater environments', in the Project CEMP.				

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-CO06	**Drilling mud disposal** Drilling muds will be disposed in accordance: • The *Environment Protection Act 2017* and the Environment Protection Regulations 2021 - Schedule 5 of the Regulations will be used to classify drilling mud for appropriate disposal. Requirements for disposal of drilling mud will be confirmed at the time of construction. • APGA Code of Environmental Practice – Onshore Pipelines.	Pipeline	Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts
MM-CO07	**Hydrotest water** • Hydrostatic test water will be managed in accordance with ERS 2021 (Water) and APGA Code of Environmental Practice – Onshore Pipelines. • Water will be reused where practicable to conserve water and minimise the volume of water to be disposed of. • If water is unable to be reused or recycled, hydrotest water will be treated and disposed within the existing refinery or disposed of in accordance with Environment Protection Regulations 2021.	Pipeline	Pipeline Licence	Construction	Mobilisation of contaminants Human health and environment impacts
MM-CO08	**Fuel and chemical leaks and spills** • Bulk fuel will be stored (if required) in self-bunded tanks in accordance with relevant Australian standards (AS1940-2017 and AS1692-2006). • Refuelling or maintenance of equipment, machinery and vehicles will be conducted at least 20 metres or as far away as is reasonably practical from any waterway with appropriate measures to contain spills. For sensitive sites (i.e., wetlands), refuelling or maintenance of equipment will be conducted no closer than 50 metres. • Hazardous materials will be stored in ventilated, self-bunded and secured containers in accordance with the *Occupational Health and Safety Act 2004* (OHS Act) and *Occupational Health and Safety Regulations 2007* (OHS Regulations). • Dangerous goods will be stored in accordance with the *Dangerous Goods (Storage and Handling) Regulations 2012* and the code of practice for the storage and handling of dangerous goods.	All	Consent under the *Marine and Coastal Act 2018* Incorporated document Pipeline Licence Safety cases	Construction Operation	Mobilisation of contaminants Human health and environment impacts Occupational hazard

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Routine and scheduled maintenance of vehicles and plant/machinery/ equipment will be undertaken to minimise the potential for leaks/spills to occur. • Spill kits and firefighting equipment will be supplied with the chemicals required by legislation. • Dangerous goods and hazardous materials register will be maintained with current SDSs. • If a chemical leak or spill has occurred, the duty to respond to harm as per, Section 31 of the *Environment Protection Act 2017*, may be required.				
MM-CO09	**Waste management** • Waste will be managed in accordance with Environment Protection Regulations 2021 and the APGA Code of Environmental Practice – Onshore Pipelines, including establishment of appropriate and secured waste storage locations on-site, as required. • Waste management procedures will be developed and implemented. • Waste materials will be reused or recycled where practicable. • Wastes will be collected and transported by licensed contractors for disposal at appropriately licensed facilities. • Waste containers will be provided for different types of waste generated onsite. • Refuse containers will be lidded to mitigate fauna access.	All	Consent under the *Marine and Coastal Act 2018* Incorporated document Pipeline Licence	Construction Operation	Mobilisation of contaminants Human health and environment impacts Offensive odours
Greenhouse gas EES evaluation objective: To minimise generation of wastes by or resulting from the project during construction and operation, including dredging, and accounting for direct and indirect greenhouse gas emissions.					
MM-GG01	**Minimise embodied and transport emissions of materials** Low embodied energy and locally sourced materials will be considered and used where practicable to minimise embodied and transport emissions. The proponent will develop criteria for a minimum proportion of supplementary cementitious material content in concrete, recycled steel, and recycled aggregates. The criteria will consider the location where materials are being sourced from to minimise associated transport emissions.	All	Incorporated document Pipeline Licence	Construction	Embodied carbon Transport emissions

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-GG02	**Managing quality of materials** Materials that are low maintenance and durable will be selected to avoid unnecessary replacement. The quality of key materials (i.e., pipe and mooring infrastructure) will be inspected before supplying to site to avoid additional transport and handling of materials.	All	Incorporated document Pipeline Licence	Construction	Transport emissions
MM-GG03	**Source local plant and equipment** Locally sourced plant and equipment (i.e., within Victoria) will be considered and used where practicable to reduce emissions associated with transport. Sourcing local plant and equipment where practicable will be included in the selection criteria for tendering of works associated with plant and equipment.	All	Incorporated document Pipeline Licence	Construction	Transport emissions
MM-GG04	**Coordination of construction activities** Construction activities will be coordinated to reduce unnecessarily extending the construction period and to avoid inefficient use of equipment.	All	Incorporated document Pipeline Licence	Construction	Direct greenhouse gas emissions
MM-GG05	**Sustainable procurement and resource management practices** Sustainable procurement and resource management practices will be adopted to avoid the inefficient use of materials, fossil fuels, and electricity. The proponent will refer to ISO 20400:2017 Sustainable procurement which provides guidance on integrating sustainability within procurement.	All	Incorporated document Pipeline Licence	Construction	Direct and indirect greenhouse gas emissions
MM-GG06	**Local workforce** Local workforce will be engaged where possible. Interstate and international travel will be minimised and where appropriate replaced by virtual engagement. The proponent will complete a transport plan to detail how fuel emissions from employee transport would be minimised.	All	Incorporated document Pipeline Licence	Construction Operation	Transport emissions
MM-GG07	**Plant and equipment fuel efficiency** Selection of plant and equipment will incorporate consideration of fuel efficiency to reduce the consumption of fossil fuels.	All	Incorporated document Pipeline Licence	Construction Operation	Direct greenhouse gas emissions

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-GG08	**Waste – avoid, reduce, reuse** Design will reduce the total quantum of materials required through design refinement and incorporate reuse materials during construction and operation of the project. The proponent will develop a waste management plan that considers waste reduction, segregation of waste, and disposal of waste to ensure that waste is correctly separated and diverted from landfill where appropriate.	All	Incorporated document Pipeline Licence	Design Construction Operation	Direct and indirect greenhouse gas emissions Waste emissions
MM-GG09	**Implementation of Energy Management Systems** An energy management system will be implemented in accordance with the International Organisation for Standardisation (ISO) 50001 *Energy Management Systems* (ISO 50001) for the operation of the FSRU. The ISO 50001 provides a framework for organisations to take a systematic approach to achieve continual improvement of energy performance and efficiency and reductions in greenhouse gas emissions. This framework is considered global best practice, and involves: • developing energy use baselines • developing energy management plans • identifying performance indicators • setting targets for improvement. Progress will be regularly monitored, reported, and reviewed. Greenhouse gas emissions reporting will include public reporting under the NGER scheme and Viva Energy's corporate Sustainability reporting. Implementation of this system will also involve external certification by ISO-accredited auditors (typically on a three year cycle) in which both compliance with the ISO standard and performance improvement will need to be demonstrated to maintain certification.	FSRU	EPA Development Licence and Operating Licence	Operation	Direct greenhouse gas emissions

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-GG10	**Emergency management procedures** Safety controls and emergency management practices will be put in place in the case of unplanned activities, incidents, and emergencies (i.e., unplanned maintenance or venting) to minimise the release of fugitive greenhouse gas emissions. Refer to MM-SHR07.	Pipeline Treatment facility FSRU	Pipeline Licence Incorporated document EPA Development Licence and Operating Licence	Operation	Direct greenhouse gas emissions
MM-GG11	**Certified carbon offsets** Scope 1 and 2 emissions associated with the project will be quantified and offset to compensate for emissions produced during construction and annual emissions produced during operation. Note that offsets will only be considered for project emissions after measures that aim to avoid or minimise emissions have been adopted.	FSRU	Incorporated document	Construction Operation	Scope 1 and 2 greenhouse gas emissions
Groundwater EES evaluation objective: To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site					
MM-GW01	**Loss of registered bores** Through continued liaison with landholders the location of potentially affected bores (due to damage, destruction or loss of access) will be confirmed prior to construction and make-good arrangements agreed if required.	Pipeline	Pipeline Licence	Construction	Impact on local groundwater users

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Historical heritage EES evaluation objective: To avoid or minimise adverse effects on Aboriginal and historic cultural heritage.					
MM-HH01	**Onshore unexpected finds protocol** An onshore unexpected finds protocol will be adopted and implemented if an unknown historic heritage site, value or object is discovered onshore during construction. The protocol will be incorporated into the Construction Environmental Management Plan (CEMP). An archaeology induction will be given by a historical archaeologist to all staff and contractors involved in ground disturbance works prior to their commencement. This protocol will include measures to be implemented if an unexpected find is encountered at any stage during construction.	Pipeline Treatment facility	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Impact or destruction to historical heritage places
MM-HH02	**Offshore unexpected finds protocol** An offshore unexpected finds protocol will be adopted and implemented if an unknown historic heritage site, value or object is discovered offshore during construction. The protocol will be incorporated into the Construction Environmental Management Plan (CEMP). A maritime archaeology induction will be given by a maritime archaeologist to all staff and contractors involved in seabed disturbance works prior to their commencement. This protocol will include measures to be implemented if suspected maritime heritage material is encountered at any stage during construction.	Dredging Temporary loadout facility Refinery Pier extension Seawater transfer pipe	Incorporated document Consent under the *Marine and Coastal Act 2018*	Construction	Impact or destruction to historical heritage places
Landscape and visual EES evaluation objective: To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values. To minimise potential adverse social, economic, amenity and land use effects at local and regional scales					
MM-LV01	**School Road screen planting** Large native Eucalyptus trees will be planted along the School Road boundary to screen the treatment facility from the road.	Treatment facility	Incorporated document	Operation	Impacts on visual amenity of road users

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Light spill EES evaluation objective: To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values. To minimise potential adverse social, economic, amenity and land use effects at local and regional scales					
MM-LS01	**AS 4282: 2019 Control of the Obtrusive Effects of Outdoor Lighting and AS/NZS 1680.5 Interior and workplace lighting: Outdoor workplace lighting** Lighting within outdoor workspaces will be in accordance with requirements set out in standards and guidelines including AS 4282: 2019 and AS/NZS 1680.5.	Dredging Pipeline Treatment facility	Consent under the *Marine and Coastal Act 2018* Pipeline licence Incorporated document	Construction Operation	Impacts on light sensitive wildlife and species due to nighttime construction activities and the treatment facility
MM-LS03	**National Light Pollution Guidelines for Wildlife Including marine turtles, seabirds and migratory shorebirds January 2020 Version 1.0** The *National Light Pollution Guidelines for Wildlife* describes best practice for wildlife sensitive lighting design. Lighting on the extension to Refinery Pier will be in accordance with the design principles outlined in the guidelines which would result in reduced material requirements and energy use, minimise potential impacts to light sensitive species and lead to a reduction in greenhouse gas emissions.	Refinery Pier	Incorporated document	Operation	Impacts on light sensitive wildlife and species due to light spill from the extension to Refinery Pier
Marine ecology and water quality EES evaluation objective: To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values. To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.					
MM-ME01	**Reuse of discharge from the FSRU in the refinery** The reuse of discharge from the FSRU in the refinery for cooling water purposes will be maximised to ensure that: • the volume of seawater withdrawn from Corio Bay is consistent with current operations	FSRU Refinery	EPA Development Licences and Operating Licences	Design Operation	Temperature, chlorine and entrainment impacts related to use and

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• the seawater discharge volume to Corio Bay is consistent with current operations • the residual chlorine discharge to Corio Bay is consistent with current operation • there is a reduction in temperature plume from existing refinery discharge		Consent under the *Marine and Coastal Act 2018*		discharge of seawater
MM-ME02	**Avoid dredging in spring growth season** The 8-week dredging program will avoid the spring season (September, October and November) as this is the period of the year where there is a high growth of seagrass and phytoplankton and key species of fish are in larval or juvenile stage.	Dredging	Consent under the *Marine and Coastal Act 2018*	Construction	Impacts to primary productivity and fishery replenishment from dredging
MM-ME03	**Limit duration of overflow from barges** To limit the extent of the turbidity plume in Corio Bay during dredging, the overflow period for barges associated with a small or medium-size backhoe dredge will be limited to 20 minutes while the overflow period for barges associated with a large size backhoe dredge will be limited to 14 minutes. This will limit the sediment spill rate to below 9 kg/sec and the extent of the turbidity plume.	Dredging	Consent under the *Marine and Coastal Act 2018*	Construction	Impacts to primary productivity and seagrass communities from dredging
MM-ME04	**Install silt curtain between dredging and refinery intake and seagrass** A temporary silt curtain will be installed between the dredging site and the existing refinery seawater intake and seagrass bed to minimise the number of days with elevated suspended solids concentration.	Dredging	Consent under the *Marine and Coastal Act 2018*	Design Construction	Impacts to primary productivity and seagrass communities from dredging
MM-ME05	**Monitor turbidity and light attenuation during dredging, with threshold limits** Turbidity will be monitored during the dredging program continuously at four sites in north Corio Bay, with three sites along the 3 m depth contour at the offshore boundary of the main seagrass beds, and one near the refinery intake.	Dredging	Consent under the *Marine and Coastal Act 2018*	Construction	Impacts to primary productivity and seagrass communities from dredging

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	The following limits are proposed as thresholds for action to restrict turbidity releases: • 12-hour concentration above 15 NTU (trigger warning) • 24-hour concentration above 12 NTU (action required) Turbidity will be monitored continuously at two sites 600 m inshore of the Point Wilson dredged material ground (DMG) to confirm that there is not regular transport of turbidity from barge disposal into shallow water near Point Wilson. Light attenuation will be monitored at the same six sites. Actions that will be taken will most likely involve reducing the period of overflow from barges to zero and slowing the dredging cycle of the backhoe.				
MM-ME06	**Seabed biota monitoring in dredged area and Point Wilson dredged material ground** Two baseline surveys will be made with a 3-month gap prior to dredging, and four post-commissioning surveys in the same locations every 3 months for 2 years of benthic fauna abundance, diversity and composition to detect any significant changes to infauna communities in the dredged area and the recovery of the Point Wilson DMG.	Dredging	Consent under the *Marine and Coastal Act 2018*	Construction and operation	Impacts to primary productivity and seabed biota from dredging
MM-ME07	**Monitoring of plankton during and after dredging** Plankton populations will be monitored at four sites in north Corio Bay (as used in the 2020-2021 plankton surveys) before, during and after the dredging period, at two weekly intervals. The purpose is to identify if there is a bloom of toxic phytoplankton as a result of release of nitrogen or toxic algal spores during dredging. The phytoplankton surveys will commence 4 weeks before dredging and will continue for 8 weeks after dredging has been completed. The standard notifications to EPA and aquaculture will be made in the event that there is a bloom.	Dredging	Consent under the *Marine and Coastal Act 2018*	Construction	Impacts to primary productivity and plankton populations from dredging

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-ME08	**Design seawater intake to minimise entrapment** The seawater intake will be designed to keep the intake velocity in the horizontal plane at a speed below 0.15 m/s at the intake screen to minimise capture of small and large fish and other free-swimming biota and provide the same level of protection as the existing refinery intake. The intake will also be provided with a screen with apertures less than 100mm to prevent large objects and seagrass from being carried into the seawater cooling system.	FSRU	EPA Development Licence and Operating Licence Consent under the *Marine and Coastal Act 2018*	Design Operation	Entrapment impacts related to use and discharge of seawater
MM-ME09	**Locate seawater intake to minimise entrainment** To ensure that a very low percentage of fish larvae are entrained in spring and summer, the seawater intake on the FSRU will be located so that it is at least 2 m below the water surface (to avoid entraining biota from near the surface) and at least 2 m above the seabed (to avoid entraining biota from near the seabed).	FSRU	EPA Development Licence and Operating Licence Consent under the *Marine and Coastal Act 2018*	Design Operation	Entrainment impacts related to use and discharge of seawater
MM-ME10	**Design diffuser to achieve high dilution** The diffuser for cool water discharge from the FSRU will be designed to achieve a minimum initial dilution of 20:1 to ensure that the diluted discharge has a chlorine concentration less than the guideline values and a temperature change from ambient of less than 0.4°C.	FSRU	EPA Development Licence and Operating Licence Consent under the *Marine and Coastal Act 2018*	Design Operation	Temperature impacts related to use and discharge of seawater from the FSRU through the diffuser

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-ME11	Design lighting to minimise adverse overspill Best practice will be used in the design of the lights on the pier extension and will meet the requirements of AS 4282: 2019 *Control of the Obtrusive Effects of Outdoor Lighting and the National Light Pollution Guidelines for Wildlife* (Jan 2020).	Refinery Pier	Incorporated document Consent under the *Marine and Coastal Act 2018*	Design Operation	Impacts to fauna from light spill
MM-ME12	**Implement biosecurity measures on all vessels** There are well-established measures to control and minimise the introduction of marine pests in Corio Bay and all applicable measures will be implemented, including: Antifoul coating to prevent the encrusting of biota on the hull; Vessels from certain ports will be cleaned before entry; Manage ballast water in accordance with the Australian Ballast Water Management Requirements (DAWR, 2017); Manage vessel activities in accordance with the National System for the Prevention and Management of Marine Pest Incursions.	FSRU LNG carriers	Consent under the *Marine and Coastal Act 2018* EPA Development Licence and Operating Licence	Operation	Impacts to the marine environment of Corio Bay through the introduction of marine pests
MM-ME13	**Manage cleaning and antifouling system on FSRU to avoid contamination** The anti-foul coating on the FSRU will be cleaned and maintained periodically. There are established procedures to collect scrapings from the hull and prevent them from accumulating on the seabed. Only approved antifoul coatings will be used for maintenance.	FSRU	Consent under the *Marine and Coastal Act 2018* EPA Development Licence and Operating Licence	Operation	Potential impacts to the marine environment from chemicals used on board the FSRU

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-ME14	**Continue to use and upgrade spill management procedures** Viva Energy and Ports Victoria have a well-established spill management plan. The existing plan will be updated as required and implemented. Where new and improved monitoring procedures are identified these will be implemented.	Refinery Pier FSRU	Incorporated document Consent under the *Marine and Coastal Act 2018* EPA Development Licence and Operating Licence	Operation	Potential impacts to the marine environment from chemicals used
MM-ME15	**Use pilots, tugs and comply with vessel speed restrictions** All vessels will be under the control of experienced and qualified captains and pilots and will only be operated in the dredged channel or for smaller vessels, within the defined operation area. The dredge spoil transport barges and LNG carriers will adhere to Ports Victoria's vessel speed requirements to limit the risk of whale strikes. All vessels and tugs will slow down or stop where necessary if notified of a whale sighting or if a whale is sighted.	Refinery Pier FSRU LNG carriers	Incorporated document Consent under the *Marine and Coastal Act 2018* EPA Development Licence and Operating Licence	Construction Operation	Grounding of vessels leading to a spill into the marine environment Whale strikes
MM-ME16	**Minimise chlorine concentration at the discharge points** The seawater chlorination process at the FSRU and the Refinery will be managed to minimise the concentration of chlorine in the seawater discharges, consistent with good practice while also achieving the purpose of chlorination (which is to avoid internal biofouling).	FSRU Refinery	Consent under the *Marine and Coastal Act 2018* EPA Development Licences and Operating Licences	Operation	Chlorine impacts related to use and discharge of seawater

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-ME17	**Monitor rates and characteristics of all FSRU wastewater discharges** The flow rate, temperature and residual chlorine concentration of all discharges from the FSRU (excluding fire water, water curtain and ballast water) either from the refinery or directly from the FSRU into Corio Bay will be monitored and recorded. Monitoring will be conducted to keep a record of all discharges, confirm that the discharge rate, temperature and chlorine concentration are within the values stipulated in the licence conditions of the refinery EPA Licence and FSRU EPA Licence and, if not, provide the trigger for remedial action.	FSRU Refinery	EPA Development Licences and Operating Licences	Operation	Chlorine and temperature impacts related to use an discharge of seawater
Noise and vibration EES evaluation objective: To minimise potential adverse social, economic, amenity and land use effects at local and regional scale					
MM-NV01	**Managing noise from construction activities** Construction noise and vibration will be managed with reference to **Chapter 4 (Noise and vibration)** of EPA Publication 1834 – *Civil construction, building and demolition guide* (November 2020). This includes the development of a plan to manage noise and vibration during construction in consultation with the relevant stakeholders. The plan will include the following general good practice techniques: • Avoiding the generation of noise and vibration and adopting all reasonably practicable mitigation measures to minimise the impact on the receivers. • Conducting construction during EPA normal construction hours where possible (i.e., Monday to Friday 07:00 am to 6:00 pm, and Saturday 07:00 am to 1:00 pm). • Informing potentially noise-affected neighbours about the nature of construction stages and noise reduction measures. • Giving notice as early as possible for periods of noisier works such as excavation. Describing the activities and how long they are expected to take. Keeping affected neighbours informed of progress.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses from construction noise and vibration

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Appointing a principal contact person for community queries. • Providing 24-hour contact details through letters and site signage. Recording complaints and following a complaint response procedure suitable to the scale of works. • Within normal working hours, where it is reasonably practicable to do so: – scheduling noisy activities for less sensitive times, (for example, delay a rock-breaking task to the later morning or afternoon) – providing periods of respite from noisier works (for example, periodic breaks from jackhammer noise). • The weekend/evening work hours in the schedule (including Saturday afternoon or Sunday) are more sensitive times and noisy work will be avoided. Out of hours works must be justified in accordance with EPA Publication 1834. The weekend/evening periods are important for community rest and recreation and will provide respite when noisy work has been conducted throughout the week. Accordingly, noisy work will not be scheduled during these times. • Using the lowest-noise work practices and equipment that meet the requirements of the job. • Maintaining equipment and vehicles according to manufacturer instructions • Locating site buildings, access roads and plant such that the minimum disturbance occurs to the locality. • Limiting times of operation of noisy equipment, vehicles and operations to reduce noise and vibration impacts. • Installing broadband reversing alarms on construction vehicles and machinery in preference to 'beeper' reversing alarms. The site will also be planned to minimise the need for reversing of vehicles. • Turning off plant and vehicles when not being used. • Taking care not to drop spoil and construction materials that cause peak noise events. • All mechanical plant is to be silenced by the best practical means using current technology.				

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Mechanical plant, including noise-suppression devices, will be maintained to the manufacturer's specifications. Internal combustion engines are to be fitted with a suitable muffler in good repair. • Fit all pneumatic tools operated near a residential area with an effective silencer on their air exhaust port. • Only undertaking low-noise or managed-impact works during night hours • Appointing a suitably qualified HSE representative to manage and approve unavoidable night work (10:00 pm to 7:00 am) applications. This person is to be independent from the project. • Testing of emergency equipment such as warning sirens will be scheduled during day-time hours where possible. For works outside of normal working hours: • Plan quieter unavoidable work activities outside normal working hours. • Adopt low-noise or managed impact works. Avoid high noise impact works such as piling, concrete pours. • Schedule noisy unavoidable work when it is less likely to affect residents' sleep and for shorter periods, wherever possible. • Schedule respite periods if unavoidable work is near residents. Consult with residents who may be most affected about restricting the number of nights per week and/or per calendar month when works are being undertaken. • Stockpile material from unavoidable work activities that occur outside normal hours in, for example, an acoustic enclosure. Also restrict load-out to occur during normal working hours. • Train all workers regarding unavoidable work activities that occur outside normal working hours.				

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-NV02	**Construction noise mitigation measures** Where the construction works are required to occur outside of EPA normal working hours, all reasonably practicable mitigation measures will be implemented to minimise the impact on receivers, including implementation of the following onsite mitigation measures where required: • Limiting works in proximity to receivers to the arrival of staff on site and toolbox meetings between 6 am and 7 am. The use of loud equipment, generation of unnecessary noise and the movement of vehicles on the construction footprint will be avoided. • Providing respite periods by restricting the hours that very noisy activities can occur. • Undertaking low noise impact works only at Lascelles Wharf on Sundays. • Adopting engineering noise controls at the source (e.g., silencer, mufflers, enclosures) by the best practical means using current technology – Reduction is typically in the range of 10 to 15 dB. • Installing onsite barriers such as hoardings or temporary enclosures to provide a noise barrier between any particularly noisy construction works and the residences - Reduction is typically in the range of 5 to 10 dB.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses from construction noise and vibration Discomfort and reduced quality of sleep from work outside of normal hours
MM-NV03	**Vibration safe working distances** Additional management measures will be undertaken where occupancies, structures and assets are within the safe working distances derived using the values in the following standards: • British Standard BS 6472-1:2008 Guide to evaluation of human exposure to vibration in buildings. Vibration sources other than blasting – Table 1 Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings • German Standard DIN4150-3:2016-12: Table 1 – Guideline values for vibration velocity for evaluating the effects of short-term vibration on structures • German Standard DIN4150-3:2016-12: Table 3 – Guideline values for vibration velocity for evaluating the effects of short-term vibration on buried pipework • An asset owner's utility standards.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses from construction noise and vibration Discomfort caused by vibration Changes to the natural behaviour of animals

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-NV04	**Noise and vibration monitoring** Noise and vibration monitoring will be undertaken during construction at: • The nearest noise sensitive residential property or properties impacted by out-of-hours works to confirm the effective implementation of noise mitigation measures • The nearest building or assets that are within derived set back distances for human response or in response to a complaint • Where an asset owner's utility standards are at risk of being exceeded. Frequency and duration: • The measurement will be undertaken at the earliest stage (within the first 24 hours) for each construction activity identified to impact sensitive receiver locations during out of hours works. • The measurement duration will be adequate to represent a typical 15-minute period for the applicable evening or night period. • For onshore pipeline construction, where the noise sources will be transient, measurements will be required for works at each noise sensitive receiver area where noise has been identified as a risk. • Measurements will be undertaken in response to any community complaints, where noise emissions need to be verified to resolve the issue i.e., where the activity cannot simply be stopped or mitigated to avoid the risk due to noise. A response plan will be developed to manage potential impacts if nominated criteria are exceeded, including: • Actions taken to rectify the exceedance e.g., stop works until noise monitoring confirms the level or implement mitigation measures to manage impacts. • Actions to minimise risk of reoccurrence e.g., provide mitigation measures or alternative methods. • Name of person(s) responsible for undertaking the required actions. • The duration of the monitoring will be determined by a suitably qualified acoustic consultant.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses from construction noise Discomfort and reduced quality of sleep from work outside of normal hours Discomfort caused by vibration Changes to the natural behaviour of animals

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-NV05	**Cumulative operational noise controls** • Noise from the Project when operating near existing industry will be managed in accordance with the Environment Protection Regulations 2021. • Prepare an operational management plan to ensure all activities are correctly scheduled to minimise noise emissions. For example, during the night period, limit the number of activities operating concurrently. • Additional cumulative impact management strategies will be developed in consultation with the relevant stakeholders. • Operational noise monitoring will be undertaken within the first 3 months of operation to confirm operational noise levels and verify cumulative noise impacts. – The measurements will be adequate to represent a typical 30-minute period for the applicable day, evening or night period and undertake in accordance with the measurement procedure outlined in Part I, section B of the Noise Protocol. – Measurements are recommended for all operating scenarios to verify the noise emissions. – Measurements will be undertaken as part of the Environmental Management Plan in response to any community complaints. • Final operational plant selection process, manufacturers' data or noise measurement data is verified for all operational equipment to ensure that tonality is not present. This includes low frequency noise from the following items of plant: – FSRU vessels – Tugboat exhausts – Regasification boilers	Treatment facility FSRU	Incorporated document EPA Development Licence and Operating Licence	Operation	Amenity impacts surrounding land uses Discomfort and reduced quality of sleep from work outside of normal hours

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-NV06	**Construction noise mitigation measures – normal working hours** • A noise barrier will be installed to the site boundary at a height of 2.4 m. For example, the use of shipping containers or alternative screen to reduce noise emissions at the closest noise sensitive receivers. • Installation of enclosures or localised noise barriers around the construction equipment to provide a noise barrier between any particularly noisy construction works and the closest noise sensitive receivers. • Stationary equipment such as generators and pumps will be stored within shipping containers or suitable acoustic enclosures. • Where the construction works would occur for a number of consecutive days, consult with the affected residences and offer alternative accommodation or onsite noise mitigation measures for people that may require to work or study from home. **Construction noise mitigation measures - outside of normal working hours** Where the construction works are required to occur outside of EPA normal working hours, all reasonably practicable mitigation measures will be implemented to minimise the impact on receivers as per MM-NV01, including implementation of the following additional onsite mitigation measures where required: • When works are linear, schedule works to avoid the closest noise sensitive receiver locations during out of normal hours or avoid works during this period (e.g., avoid works on Saturday afternoons 1.30pm to 6pm at Locations 1 and 2). • Where feasible low-noise impact works may occur during this period. This will be subject to initial compliance noise monitoring to confirm the noise emissions at the closest noise sensitive receivers. • Schedule noisy unavoidable work when it is less likely to affect residents' amenity (e.g., avoid weekends) and for shorter periods, wherever possible. • Schedule respite periods if works outside of normal working hours is near to residents in Locations 1 and 2. Consult with residents who may be most affected about restricting the number of nights per week and/or per calendar month when works are to be undertaken.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses Discomfort and reduced quality of sleep from work outside of normal hours

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Installing onsite barriers such as hoardings or temporary enclosures to provide a noise barrier between any particularly noisy construction works and the residences – barriers that remove line of sight to receivers have a typical reduction of 5 to 10 dB at the receiver. • Where the construction works would occur for a number of consecutive days, consult with the affected residences and offer alternative accommodation or onsite noise mitigation measures for people that may require to work or study from home.				
MM-NV07	**Unavoidable works, Horizontal Directional Drilling – noise control** Onsite mitigation to reduce the residual noise impacts will be required to achieve a minimum 10 dB reduction at the nearest residential receivers. This will require a combination of mitigation measures detailed below. Adoption of noise reduction measures to be installed adjacent to the HDD entry and exit sites as follows: • A noise barrier will be installed to provide an envelope between the compound and the site boundary at a height of 2.4 m. • Any access gates will be solid and generally kept closed, especially at night. • Installation of enclosures or localised noise barriers around the HDD construction equipment to provide a noise barrier between any particularly noisy construction works and the residences. • Provide respite periods by restricting the hours that the very noisy activities can occur. • Stationary equipment such as bentonite treatment, generators and pumps will be stored within shipping containers or suitable acoustic enclosures. • Where the construction works will occur for a number of consecutive days, and particularly during the night period, consult with the affected residences and offer alternative accommodation or onsite noise mitigation measures for people that may require to work or study from home. The impacts and the design of site-specific mitigation will be determined prior to construction and confirmed during construction via onsite monitoring.	Pipeline	Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses Discomfort and reduced quality of sleep from work outside of normal hours

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	A qualified specialist (e.g., HSE specialist independent from the project.), with skills and expertise in risk and safety, will be appointed to review unavoidable night work (10:00 pm to 7:00 am) applications to ensure that noise impacts have been assessed, all reasonably practicable work practices have been considered and that community engagement has been undertaken.				
MM-NV08	**Unavoidable works, Hydrotesting – noise control** The Hydrotesting is to be undertaken at least 800 metres from the nearest noise sensitive receivers, therefore, short-term construction noise levels are unlikely to be noticeable or cause a significant impact. By adopting mitigation measures detailed below the residual impacts can be adequately managed to minimise the risk from noise at night-time: • A noise barrier is advised to provide an envelope around the hydrotesting site at a height of 2.4 m. • Any access gates will be solid and generally kept closed, especially at night. • Adopting engineering noise controls for ancillary equipment (e.g., silencer, mufflers, enclosures) by all practical means using current technology. • Selection of quieter equipment. • Stationary equipment such as bentonite treatment, generators and pumps will be stored within shipping containers or suitable acoustic enclosures. The impacts and the design of site-specific mitigation to reduce the noise emissions at source will be determined prior to construction and confirmed during construction via onsite monitoring. A qualified specialist (e.g., HSE specialist, independent from the project), with skills and expertise in risk and safety, will be appointed to review unavoidable night work (10:00 pm to 7:00 am) applications to ensure that noise impacts have been assessed, all feasible and reasonably practicable work practices have been considered and that community engagement has been undertaken.	All	Incorporated document Consent under the *Marine and Coastal Act 2018* Pipeline Licence	Construction	Temporary amenity impacts surrounding land uses Discomfort and reduced quality of sleep from work outside of normal hours

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Safety, hazard and risk EES evaluation objective: To provide for safe and cost-effective augmentation of Victoria's natural gas supply having regard to projected demand and supply in context of the State's energy needs and climate policy.					
MM-SHR01	**FSRU safety standards** The Floating Storage and Regasification Unit (FSRU) will be designed, constructed and operated to meet relevant safety standards. The FSRU will be designed, operated and maintained under the purview of DNV GL (or equivalent classification agency). It will comply with the Rules for Classification as required to retain its Class Notation. This will include requirements for inspection, maintenance and functionality of all on-board safety systems.	FSRU	MHF safety case for FSRU EPA Development Licence and Operating Licence	Design Construction Operation	Fire and explosions Cryogenic exposure Asphyxiation
MM-SHR02	**Pipeline standards** The pipeline will be designed, constructed and operated in accordance with AS2885 and consistent with a T1 (Residential) environment. This will include completion of a Safety Management Study with the identification of threats and appropriate mitigation measures including increased depth of burial, heavier duty piping and protective slabs.	Pipeline works	Pipeline Licence Gas safety case	Design Construction Operation	Fire and explosion
MM-SHR03	**Facility standards** The Refinery Pier No. 5 extension, the equipment installed on Refinery Pier No. 5, and the Treatment Facility will be designed, operated and maintained in accordance with relevant Australian and international standards.	Refinery Pier Treatment facility	Pipeline Licence Gas safety case Amendment to Refinery MHF safety case	Design Construction Operation	Fire and explosions Cryogenic exposure Asphyxiation

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-SHR04	**Automated systems – safety and process control** The operation of the FSRU, pipeline and Treatment Facility will be monitored using appropriately SIL rated process automation and shutdown systems. Abnormal conditions will alarm locally and remotely to fully attended control rooms. Operation out of the design / operation envelope has the potential to result in imminent loss of containment, which will result in an automatic shutdown of gas operations via closing of emergency shutdown valves with depressuring of inventory through vent stacks if and when required will to be initiated remotely by an operator in the control room to ensure safe release. The control, monitoring and shutdown systems will be fail-safe and be designed to best industry practices with redundancy.	Pipeline Treatment facility FSRU	Pipeline Licence Gas safety case Amendment to Refinery MHF safety case MHF safety case for FSRU EPA Development Licence and Operating Licence	Design Construction Operation	Fire and explosions Cryogenic exposure Asphyxiation
MM-SHR05	**Dangerous goods – storage and handling** Dangerous goods, as defined by the Australian Dangerous Goods Code, and flammable and combustible liquids will be stored and handled in accordance regulatory requirements (refer Table 31), EPA Victoria Publication 1698 – Liquid Storage and Handling Guidelines and all relevant Australian Standards – including but not limited to the requirements of: • AS1940 – The storage and handling of flammable and combustible liquids • AS1210 – Pressure vessels • AS4343 – Pressure equipment – hazard levels • AS3846 – The handling and transport of dangerous cargoes in port areas • AS2941 – Fixed fire protection installations – pumpset systems • AS/NZS60079 – Explosive atmospheres.	Treatment facility FSRU	Gas safety case Amendment to Refinery MHF safety case MHF safety case for FSRU EPA Development Licence and Operating Licence	Design Construction Operation	Fire and explosions Cryogenic exposure Asphyxiation

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-SHR06	**Monitoring of chemical and fuel storage facilities** Routine visual monitoring and recording of chemicals and fuel storage facilities will occur as part of routine operational practices.	Treatment facility FSRU	Gas safety case Amendment to Refinery MHF safety case MHF safety case for FSRU EPA Development Licence and Operating Licence	Construction Operation	Fire and explosions Cryogenic exposure Asphyxiation
MM-SHR07	**Emergency response plans** Emergency response plans, such as for spills, will be developed and implemented for both the construction and operations phases of the Project.	Pipeline Treatment facility FSRU	Pipeline Licence Gas safety case Amendment to Refinery MHF safety case MHF safety case for FSRU EPA Development Licence and Operating Licence	Construction Operation	Fire and explosions Cryogenic exposure Asphyxiation

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-SHR08	**Fire and gas protection** The FSRU or LNG carrier will be provided with their own onboard fire protection and suppression systems. This is a requirement of the DNVB GL (or other equivalent classification society) class notation. Active fire protection and suppression will be provided for liquid fires and gas fires on Refinery Pier in compliance with Australian Standards. The design fire case for fire systems is a jet fire in the MLA area. The required firewater cooling rate is for the ship/shore manifold area, which is defined as the MLAs and associated piping and valves as well as for FSRU hull cooling. The diesel fuel supply will be designed for six hours of firewater per pump. The existing refinery current design will be upgraded to provide 2×100% or 3×50% capacity fire water pumps to provide 50% of the required firewater with the remaining firewater to be provided by firefighting tugs located with the Port of Geelong. Fire and gas detection will be provided in key locations piping on Refinery Pier and within the Treatment Facility.	Pipeline Treatment facility Refinery Pier FSRU	Pipeline Licence Gas safety case Amendment to Refinery MHF safety case MHF safety case for FSRU EPA Development Licence and Operating Licence	Design Construction Operation	Fire and explosions
MM-SHR09	**Separation distance** The location of the FSRU provides sufficient separation distance from sensitive receptors (North Shore, Geelong Grammar School) to be outside impact zones for significant breach events. The refinery process area is located over 600m from the FSRU to minimise the potential for escalation of an incident from one facility to the other.	FSRU	MHF safety case for FSRU EPA Development Licence and Operating Licence	Design Operation	Potential offsite impacts and escalation risk
MM-SHR10	**Site safety advisor** A suitably competent person will be appointed as Site Safety Advisor during construction and will have on-site a set of the relevant safety data sheets (SDS) for hazardous and dangerous materials.	Pipeline works Treatment facility Refinery Pier	Pipeline Licence Gas safety case Amendment to Refinery MHF safety case	Construction	Public safety Workforce safety

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Social and business EES evaluation objective: To minimise potential adverse social, economic, amenity and land use effects at local and regional scales					
MM-SB01	**Consultative mechanism for information and enquiries** A consultative mechanism will be developed: • to make information on changes to the waterside exclusion zone available to the community and stakeholders (in particular recreational fishing and boating clubs) • to make details of construction schedule (in particular disruptions to the road network) available to the community and stakeholders • to make the results of environmental monitoring available to the community • to make information relating to potential risks to human health and safety available to the community and stakeholders as required • for residents to make enquires, lodge complaints etc. during construction and operation.	All	Incorporated document Pipeline Licence Consent under the *Marine and Coastal Act 2018*	Construction Operation	Social impacts related to reduced access to areas near Refinery Pier for recreational activities such as fishing and boating Social and business impacts related to temporary disruptions to access points and the road network, temporary amenity impacts on sensitive receptors, and perceived safety risks
MM-SB02	**Consultation and arrangements with Quantem** 'Business as Usual' arrangement between Viva Energy and Quantem will continue to minimise potential scheduling conflicts between the LNG carrier and ships at Berth 1 through clear communication, advanced notification and scheduling.	Refinery Pier	Incorporated document Consent under the *Marine and Coastal Act 2018*	Operation	Business impacts related to disruption to access to Berth 1

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-SB03	**Employment plan** An employment plan will be prepared and implemented with a commitment to prioritise employing locals from northern Geelong suburbs, Indigenous groups and individuals from disadvantaged or low socio-economic backgrounds to enhance the employment benefits to the local community, as appropriate.	All	Pipeline Licence Incorporated document	Construction Operation	Creation of employment opportunities
MM-SB04	**Social procurement plan** A social procurement plan will be prepared and implemented to focus on utilising local businesses as much as possible. Viva Energy will partner with local not-for-profit community groups to assist with social procurement and employment of locals (i.e., Northern Futures, Give Where you Live).	All	Pipeline Licence Incorporated document	Construction Operation	Creation of employment opportunities
Surface water EES evaluation objective: To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.					
MM-SW01	**Discharge water** Depending on rainfall, soil condition and the groundwater table, dewatering may be required particularly during pipeline trenching activities. The following mitigation measures are recommended for management of water from trenching activities: • Water collected from excavated areas will be recycled and reused for construction activities such as dust suppression. • Where discharge to waterbodies is unavoidable, water will be collected and treated if turbidity exceeds turbidity objectives prior to discharging. • Discharge to land will not occur within 50 metres of watercourses or be discharged directly into stormwater drains. • Construction activities to be in accordance with EPA Publication 1834, and the requirements of the *Environment Protection Act 2017* • Site management mitigation measures will include appropriate placement of material stockpiles and chemical storages, covered loads, street sweeping and water quality monitoring, where required.	Pipeline	Pipeline Licence	Construction	Water quality impacts from dewatering

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Discharge of water to land will avoid soil erosion or sedimentation of land or water. Sediment control devices such as silt fence to remove suspended solids and dissipate flow will be used where required. • Water will not be discharged to waterways, wetlands or into stormwater drains without approval from relevant authorities. • Water will be tested for pH and salinity prior to discharge to land. pH and salinity should not exceed acceptable limits in EPA guideline. • Water that cannot be treated to meet the relevant discharge criteria will be disposed to an EPA Victoria licensed facility. • Relevant landholder(s) and water authorities will be consulted, and permission obtained prior to discharge to land. • Discharge will be to low gradient, stable, grassed areas and be undertaken in accordance with landholder requirements and through "irrigation type" systems to prevent scour or erosion. Visual monitoring during land discharge will be undertaken to ensure water does not enter existing waterways and/or wetlands. Groundwater encountered during construction of the pipeline will be managed in accordance with the groundwater mitigation measures.				
MM-SW02	**Managing runoff** • Obstructions to flow will be removed. • Flow diversion banks will be placed upstream of spoil material if required. • An overflow spillway will be constructed to allow runoff from external catchments to pass over the spoil material at a controlled location without causing erosion. • During the works, sediment control devices such as bunding or silt fences will be set around stockpiled material, earthworks and disturbed areas to minimise loss of sediment to the receiving environment. • Temporary diversions will be provided to allow flow around the excavation area.	All	Pipeline Licence Incorporated document	Construction	Runoff from disturbed areas impacting water quality of receiving waterbodies

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-SW03	**Watercourse trenching** Where trenching is undertaken over a watercourse the following mitigation measures will be undertaken: • Undertake works in accordance with APGA guidelines. • Where practicable, the trenched watercourse crossing will be constructed during no flow conditions and reinstated as soon as possible. • Weather forecasts will be monitored to avoid having open trenches at the waterway when high rainfall events are expected. • Where the watercourse is trenched, all obstructions to flow will be removed as soon as practicable after the pipe is laid and backfilled. • Trenching on both sides of the waterway will be fully excavated and prepared prior to undertaking the final section of trenching over the waterway. • Waterway reinstatement will be carried out in consultation with the CCMA. • The exposed trench within the watercourse will be reinstated immediately following the installation of the pipeline, including providing suitable compaction and revegetation. • Waterway reinstatement will be designed to avoid future erosion. This may include the use of riprap made of stones and fabric mesh to stabilise the waterway. • If necessary, a geofabric will be provided to prevent erosion and scour until the vegetation has established. • Visual monitoring will be undertaken downstream of the trench during flow events if the trench has not been reinstated. • Sediment control devices such as silt fences will be used to remove suspended solids and dissipate flow where required.	Pipeline	Pipeline Licence	Construction	Water quality impacts from watercourse trenching
MM-SW04	**Capture and treat runoff from treatment facility** Runoff from the treatment facility after a rain event will be captured and managed by the controlled discharge facilities (CDF) in place at the refinery.	Treatment facility	Incorporated document	Operation	Runoff from the treatment facility impacting water quality of receiving waterbodies

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
Terrestrial ecology impact assessment EES evaluation objective: To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values. To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.					
MM-TE01	**Complete works within construction right of way** Construction works will be completed within the 15-20 m construction right of way and additional designated works areas to restrict impacts on retained native vegetation and habitat.	Pipeline	Pipeline Licence	Design Construction	Vegetation loss as a result of the underground pipeline construction
MM-TE02	**Establish No-Go Zones** • No-Go Zones (NGZs) will be established to protect retained areas of native vegetation and the area of NTGVVP beyond the construction footprint. • NGZs will be fenced with highly visible fencing designed to last the duration of construction works. Fencing will be appropriately signed. • NGZs and works are limits will be clearly marked on all maps and construction drawings prior to commencement of the works and now works will occur outside of the marked footprints. • Fencing will be regularly inspected and maintained throughout the construction phase to ensure continued integrity.	Pipeline	Pipeline Licence	Construction Operation	Native vegetation and NTGVVP loss as a result of the underground pipeline construction
MM-TE03	**Minimise soil erosion** All earthworks will be undertaken in a manner that minimises soil erosion and adhere to the Construction Techniques for Sediment Pollution Control (EPA, 1991).	Pipeline Treatment Facility	Pipeline Licence Incorporated document	Construction	Impacts to retained vegetation and habitat as well as aquatic environments as a result of erosion

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-TE07	**Minimise impacts to trees** Large-scale excavation at the margins of construction works will be minimised where trees occur within 15 m to avoid impacts on the root zones (e.g., Between School and Torresdale Roads)	Pipeline	Pipeline Licence	Design Construction	Impacts to tree root zones during underground pipeline construction
MM-TE08	**Conduct an arborist assessment** An arborist assessment will be conducted prior to construction to identify those trees that will not be adversely impacted by the works, those that may not be impacted if protection measures are implemented, and those where loss is unavoidable.	Pipeline	Pipeline Licence	Construction	Impacts to trees during underground pipeline construction
MM-TE09	**Minimise disturbance, injury or death of wildlife** • Any open pits or trenches will be managed to reduce potential for fauna entrapment. The following measures will be implemented: – Minimise the period trenches and other excavations are open – Design excavations with slopes less than 45o to provide exit ramps for fauna – Create 'ladders' to enable fauna to exit the excavations (e.g. branches, ropes, planks) – Ensure fauna are discouraged from work areas by erecting barriers where practicable. – A protocol included in the site induction around the procedure for finding trapped fauna. • Fencing required to define construction boundaries or to protect NGZs will be designed in accordance with relevant DELWP guidelines to limit fauna strike. • The number, type and layout of lights for lighting (if required) for night works or for security purposes will be selected and designed to minimise light spill and to only light up the construction area with reference to the National Light Pollution Guidelines for Wildlife including marine turtles, seabirds and migratory shorebirds (DoEE, 2020). The design will: – keep lights close to the ground	Pipeline	Pipeline Licence	Design Construction	Injury to sensitive and native fauna Night lighting disturbing native fauna

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	– direct and shield lights to avoid light spill beyond the workspace – use lowest intensity lighting appropriate for the specific purpose – use lights with reduced or filtered blue, violet and ultra-violet wavelengths – avoid the use of LEDs if possible. • Night-time works will be minimised to reduce impacts of noise and light on nocturnal animals. • Pre-clearing survey will be conducted at all sites where trees and shrubs being removed to assess presence of fauna. • A suitably qualified wildlife handler ('wildlife spotter'), holding a relevant and current authorisation under the Wildlife Act 1975, will be engaged to salvage any wildlife encountered during the construction program.				
MM-TE10	**Control spread and/or introduction of weeds and/or pathogens** • Hygiene measures will be implemented to ensure opportunities for the introduction and spread of weeds (importation of seeds and other vegetative material to the site) and pathogens are limited. This will include vehicle inspections and establishment of wash down facilities. • Fill that is clean and certified weed and contaminant free will be used, where possible. • High risk weeds from construction areas will be treated prior to works commencing. • Outbreaks of noxious and/or Weeds or National Environmental Significance (WoNS) within construction areas that occurs due to construction activity will be managed. Spread into adjacent land will be prevented. • All contract staff inductions will include details about the requirement for vehicles and equipment to be free of mud and plant material prior to entering work sites.	Pipeline Treatment Facility	Pipeline Licence Incorporated document	Construction	Introduction and spread of weeds and disease during construction from vehicle movements

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-TE11	**Reduce erosion, sedimentation and contamination risk to retained vegetation and habitat** Measures to manage erosion and sedimentation, address the management, handling, and storage of hazardous chemicals, and manage dust will be implemented to minimise impacts on retained vegetation and habitat and aquatic environments.	Pipeline Treatment Facility	Pipeline Licence Incorporated document	Construction	Impacts to retained vegetation and habitat as well as aquatic environments as a result of erosion
MM-TE12	**Contractor/personnel awareness of ecological values** All contract staff will be inducted on the presence and location of ecological values and informed of all relevant protective measures and obligations while undertaking construction activities.	Pipeline Treatment Facility	Pipeline Licence Incorporated document	Construction	Impacts to retained vegetation and habitat
Transport EES evaluation objective: To minimise potential adverse social, economic, amenity and land use effects at local and regional scales					
MM-TP01	**Ongoing stakeholder consultation** A community, business and relevant authority stakeholder and communications plan will be developed for transport with ongoing stakeholder consultation to be undertaken during the lifecycle of the project. This will consider findings from the Technical Report K: *Transport Impact Assessment* and from the Traffic Management Plan developed for the project. Stakeholder consultation, including, but not limited to DoT, CoGG and GeelongPort will be undertaken. Key notifications and agreements may include: • Pre-construction stage: – TMP agreement – Dilapidation surveys • Construction, operation and decommission or re-power stages – TMP measures and controls – Construction traffic monitoring	All	Pipeline Licence Incorporated document	Pre-construction Construction Decommissioning	Intersection capacity Potential road closures Disruption to public transport Disruption to other road and site users General construction heavy vehicle road use Over-dimensional loads road use

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	– Road network monitoring, remediation protocols and maintenance requirements. • Prior to operation – Construction close-out meeting, infrastructure hand-back criteria				Site access points upgrades Amenity impacts on the road network Disruption to emergency vehicle access Road conditions and maintenance Road section upgrades
MM-TP02	**Traffic Management Plan** Prior to the commencement of construction (excluding preparatory works), TMP(s) will be developed and implemented to minimise disruption (to the extent practicable) to affected local land uses, traffic, car parking, on-road public transport, pedestrian and bicycle movements and existing public facilities during all stages of construction. The TMP will be developed in consultation with the relevant road management authorities and be informed and supported by an appropriate level of transport analysis including measures outlined in the Transport Impact Assessment. The TMP will include: • any required regulatory approvals conditions resulting from the EES process and other secondary approvals. • A review of relevant policy, regulatory and protocol requirements which have informed the TMP. • Existing conditions review undertaken at the time of TMP development to verify conditions. Those provided as part of the Transport Impact Assessment can be used as a baseline.	All	Pipeline Licence Incorporated document	Pre-construction Construction Decommissioning	Intersection capacity Potential road closures Disruption to public transport Disruption to other road and site users General construction heavy vehicle road use Over-dimensional loads road use

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Approved project scope as discussed in MM-TP01, including finalised details on construction extents, staging, vehicle types, final material sources, and peak construction impacts based on the refined detailed design and construction schedule • Consideration of cumulative impacts of other major projects operating concurrently in the local area, such as the traffic movements associated with the proposed relocation of the TTLine operations to Corio Quay. • Verification of final site access strategy, including access points and crossovers to the site. • Final nominated origins of any OD truck visitations for plant and equipment identified and final OD route assessments completed by the project transport contractor (see MM-TP08). • Mitigation measures outlined, including site access point requirements (e.g. vehicle size movements facilitated and Austroads intersection type requirements according to traffic demand warrants) and any requirements for OD delivery along derived transport routes. This may need to consider road section upgrades. Design drawings would need to be prepared for the above and sent for review and agreement with the relevant road authority at concept, functional and detailed design stages. • Following road condition and maintenance requirements considered: – Pre-condition (dilapidation survey) to provide an existing survey of public roads that may be used for access and designated for construction vehicle routes. – Consultation with road asset owners to agree on the extent of pre-condition (dilapidation survey) survey extents and survey requirements (specialist vehicle condition or photographic), road maintenance criteria, treatments and response timeframes, and post construction survey and asset hand-back agreements. – Depending on stakeholder requirements, other requirements may include specific traffic monitoring (maximum daily truck volumes), and specific bond payments for remedial works.				Site access points upgrades Amenity impacts on the road network Disruption to emergency vehicle access Road conditions and maintenance Road section upgrades

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• TMP control measures outlined, covering the following aspects: – Roles and responsibilities, including project management, co-ordination, public consultation, advertising and complaint procedures. – Road authority notification requirements. – Training and site induction requirements. – Contractor liaison protocol. – Roadside native vegetation requirements, including identification protocols and approvals (if required). – Vehicle access measures • Access requirements by vehicle type, including any regulator or stakeholder permits. • Road closure requirements. Management of any temporary or partial closure of roads and traffic lanes to maintain existing connectivity for local access, pedestrians and cyclists, in accordance with relevant road design standards and in consultation with landholders and any other relevant third parties. Traffic counts may need to be conducted to investigate suitable times for road and lane closures. Road closures to occur in off-peak periods when demands are low where possible (notably for OD vehicle deliveries). Minimise the number and duration of road closures. • Development of suitable measures to ensure emergency service access is not inhibited due to project construction activities in consultation with emergency services, especially regarding any road closures on the public road network (see MM-TP05). • Construction staging and car parking requirements to ensure no car parking occurs outside of the project boundary and affects local land use or accessibility. If required car share or shuttle bus provisions will be considered to reduce the need for single vehicle worker occupancy. • Signage requirements with reference to Australian Standard AS 1742. Notably for this project this would include notification of: – Movement of trucks from site access points to/from major road connections.				

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	– No-truck access signage to ensure vehicles do not access restricted areas and to aid with wayfinding • Speed limits set for construction stage. Notably review of existing speeds along Shell Parade and near nominated site access points to consider safe system principles. • Verify operating and working hours during construction. These will need to be agreed with key stakeholders with a remit for the construction contractor to verify local bus routes/timings to ensure no conflicts occur. • Environmental measures considered such as (see also MM-TP07): – Management of dust / sedimentation – Noise and vibration. • Monitoring, inspection and auditing requirements detailed with regards to the TMP, including: – Addendum TMP triggers – Monitoring and inspection protocols outlined to ensure the integrity of the TMP given it will be viewed as a live document for the duration of the projects construction period. Reviews are typically undertaken on monthly basis with relevant stakeholders informed of any significant changes. – Auditing can include compliance and road safety audits. The TMP would be an overarching document to inform subsequent specific work site TMPs developed by works contractors. In addition, there may be a need for other specific TMPs, such as for the delivery of components via OD vehicles.				

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-TP03	**Road safety audits** Road safety audits (RSA), at various stages of project development, indicatively suggested at: Existing condition and site access audits Detailed design stage RSA's will be completed by a pre-qualified VicRoads RSA auditor and be independent to the project and notable the design team.	All	Pipeline Licence Incorporated document	Pre-construction Construction Decommissioning	Site access points upgrades
MM-TP04	**Emergency access and evacuation plan** A contractor emergency evacuation plan will be developed outside the TMP report but reference to its production and Viva emergency evacuation protocols to be made. It will be produced in tandem between the developer, works contractor, local business and CFA.	All	Pipeline Licence Incorporated document Refinery MHF safety case amendment	Pre-construction Construction Operational Decommissioning	Disruption to emergency vehicle access
MM-TP05	**Sub TMPs** Sub TMPs will be completed by the relevant contractors, including for specific work activities (Worksite Traffic Management Plans). These will all consider and reference back to the overarching project TMP outlined previously. The sub TMPs will also outline more specific protocols and works contacts, for example: • Roles and responsibilities • Training • Incident and emergency procedures • Documentation and communication procedures	All	Pipeline Licence Incorporated document	Pre-construction Construction Decommissioning	Disruption to public transport Amenity impacts on the road network Disruption to emergency vehicle access

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
MM-TP06	**OD transport route assessments** Formal OD transport route assessments will be completed by the project transport contractor from the nominated origin(s) along with all necessary mitigation measures and stakeholder approvals. Following this assessment, final routes options will be verified, and any impacts identified along with relevant stakeholders who may need to be contacted to facilitate the safe delivery of materials to the project sites. Potential impacts include clearance to potential obstructions, such as wires, structures (bridges and culverts), trees, and rail crossing infrastructure for OD vehicles.	All	Pipeline Licence Incorporated document	Pre-construction Construction	Over-dimensional loads road use
MM-TP07	**Operational transport plan** An operational transport plan will be developed. This plan will include identifying the suitable route(s) to accommodate the projected heavy vehicle movements, management measures at key intersections and permit requirements for access to roads that are not approved B-Double routes along the anticipated routes from each facility to the Refinery. Consideration to the safety and amenity impacts of proposed heavy vehicle routes during operation will be given where possible. Relevant road authorities will be consulted during the development of the Operational Transport Plan. As required, the Operational Transport Plan may be used to assess impacts to road assets and assist in any potential compensation to relevant road authorities should impacts occur.	Treatment facility	Incorporated document	Operation	Road network infrastructure Site access disruptions Safety impacts
Underwater noise EES evaluation objective: To minimise adverse effects on water (in particular wetland, estuarine, intertidal, and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.					
MM-UN01	**Minimise underwater noise impacts** Choose the quietest operational technique possible and reduce the number or duration of sound exposure periods to the absolute minimum necessary to achieve the construction targets: • Reduce the rate of penetration and the number of piles installed per day (hammer strikes).	Dredging Refinery Pier FSRU	Incorporated document Consent under the *Marine and Coastal Act*	Construction Operation	Impacts on marine mammals during piling operations or other noisy aspects of jetty

MM ID	Mitigation measure	Project component	Statutory implementation	Project timing	Potential impact
	• Use noise dampening technologies at the source to reduce the initial sound production (primary noise mitigation) or placed in the path of propagating sound to reduce intensity (secondary noise mitigation).		*2018*		construction or FSRU operation
MM-UN02	**Deter marine animals from construction area** Implement procedures to deter marine animals from the construction vicinity, including methods such as: • Using Acoustic Harassment Devices (AHDs) during (noise-) critical activities such as the onset of impact pile driving • Implementing a safety zone around loud sound sources by visual monitoring of the surrounding area prior to commencing loud activities and implement activity delays of 20 minutes based on time of last sighting • Using soft-start or ramp-up procedures.	Dredging Refinery Pier	Incorporated document Consent under the *Marine and Coastal Act 2018*	Construction	Impacts on marine mammals during piling operations or other noisy aspects of jetty construction
MM-UN03	**Noise awareness training** Train construction workers to understand potential for underwater noise impacts and endorse measures to reduce emissions (e.g., switching off machinery or equipment not required on a vessel while moored).	Dredging Refinery Pier FSRU	Incorporated document Consent under the *Marine and Coastal Act 2018*	Construction Operation	Impacts on marine mammals during piling operations or other noisy aspects of jetty construction or FSRU operation

14.8 Environmental management documentation

The statutory approvals and consents that are required for the project to proceed will be implemented through a series of plans that will be required as conditions of approval. The plans will be required to implement and achieve compliance with relevant standards, guidelines and statutory approval obligations for the statutory approvals and consents outlined in **Section 14.3** and to reflect the mitigation measures outlined in **Section 14.7**. Contractors will be responsible for reporting compliance to Viva Energy, who will be responsible for compliance and associated reporting to relevant regulators as required.

All contractor documents prepared for the project will be required to align with the documents and mitigation measures referenced in the statutory approvals and consents where relevant, as they detail mandatory conditions and contingency measures to protect environmental and social values throughout the life of the project.

Table 14-5 outlines the environmental management documentation that Viva Energy and their contractors will prepare and implement.

Table 14-5 Environmental management documentation

Documentation	Description
Project proponent	
Environmental Management Framework	This document sets out how the environmental aspects as described in this EES for the design, construction and operation phases of the project will be managed. This EMF identifies mitigation measures that will define the environmental outcomes that must be achieved during design construction and operation of the project and will be incorporated into the required statutory approvals and consents.
Decision and Approvals	Minister's assessment of EES to inform the conditions of the statutory approvals.
Viva Energy	
Decision and Approvals	• EPA Victoria Development Licences and Operating Licences Planning scheme amendment and incorporated document • EPBC Act approval • CHMP approval • Pipeline Licence for construction and operation • Marine and Coastal Act consent • MHF Safety case • Safety case for the gas pipeline

Documentation	Description
Environmental Management Plan (EMP)	An EMP will be prepared in accordance with the conditions stipulated in the incorporated document for the project. It is anticipated that the incorporated document will require the preparation of an EMP, which will include: • Mitigation measures related to the project as developed in the EES and identified in the Minister's Assessment of the EES • Set out the process and timing for development of a CEMP and OEMP, as well as other plans and procedures required by the mitigation measures. The CEMP will include detailed management protocols for the management of: • Air quality • Hazardous substances management • Noise and vibration • Sediment, erosion and water quality (including surface water and groundwater) • Traffic and transport • Contaminated soil and groundwater and acid sulfate soil. The OEMP will include detailed management protocols for the management of: • Air quality • Hazardous substances management • Noise and vibration • Sediment, erosion and water quality (including surface water and groundwater) • Marine monitoring • Native vegetation offset management • Traffic and transport.
Construction Environment Management Plan (CEMP) – pipeline	A CEMP has been prepared in accordance with the Pipelines Act 2005 Part 9 Division 3 Section 133 to accompany the Pipeline Licence application for approval by the Minister for Energy, Environment and Climate Change prior to commencing construction. The CEMP addresses the requirements of the Pipelines Act and Regulations and includes the pipeline related mitigation measures described in the EES. The CEMP includes protocols for the management of: • Noise and vibration during construction • Acid sulfate soils management • Surface water discharge management • Wildlife management • Groundwater management • Air quality management.
Construction Safety Management Plan (CSMP) – pipeline	A CSMP has been prepared in accordance with the Pipelines Act 2005 Part 9 Division 2 Section 126 and Pipeline Regulations to accompany the Pipeline Licence for approval by Energy Safe Victoria, prior to commencing any pipeline construction.
Consultation Plan	A consultation plan will be prepared to describe the consultation approach during each of the stages of the project construction.
Cultural Heritage Management Plan (CHMP)	A CHMP will be prepared for the project work and is required to be approved by the Wadawurrung Traditional Owners Aboriginal Corporation as the registered Aboriginal Party.

Documentation	Description
Gas Safety Case	A safety case will be prepared in accordance with the Gas Safety (Safety Case) Regulations 2018, which will describe threats to safety that are posed by the project, define how these threats are controlled and demonstrate that the controls are suitable.
FSRU Safety Case	The FSRU would be classified as a MHF under Part 5.2 of the Occupational Health and Safety Regulations 2017 when in port and would require preparation of a safety case to be approved by WSV.
Operational Environmental Management Plan (OEMP) – pipeline	The OEMP will detail Viva Energy's environmental management framework which seeks to mitigate the impact of pipeline operation on the environment. The OEMP will be prepared in accordance with Part 7 of the Pipeline Regulations 2017 and submitted to the Minister for Energy, Environment and Climate Change for acceptance.
Health, Safety and Environment System	Viva Energy has existing robust health, safety and environment management processes and procedures in place to comply with all relevant industry standards and government regulation which will be used and implemented for the project.

14.9 Change management

The CEMP(s) and OEMP(s) that are conditions of statutory approval will be controlled documents that will be subject to a revision and approvals process. Documents will be developed, approved, implemented and revised as necessary throughout the life of the project.

All contractor plans and documentation will be prepared and then approved by Viva Energy prior to any works commencing. Where required, contractor management plans will also be subject to regulatory approval from relevant government agencies.

Proponent and contractor documentation may require revisions and amendments based on:

- Continuous improvement due to changes in design and work practices
- Monitoring results
- Changes to legislation
- Risks, or as a result of findings from internal or external audits
- Incidents
- Complaints
- Other compliance obligations voluntarily taken by Viva Energy.

Contractors will be required to submit all major revisions of environmental documentation to Viva Energy for review and approval. Major documentation revisions are considered to be changes that affect work and construction practices, roles and responsibilities, social and environmental risks and overall project delivery.

14.10 Assessing environmental compliance

Approvals for the project will include compliance requirements for Viva Energy and contractors. To monitor compliance, Viva Energy and contractors will be required to develop and implement a compliance system, undertake environmental monitoring as required and report to the project proponent and relevant regulators and when required under the statutory approvals. Environmental compliance requirements will be included in all management plans.

The environmental compliance system to be adopted for the project may include the following:

- Defining non-conformance(s)
- Developing and maintaining a register of non-conformance(s)
- Defining responsibilities and timelines for addressing non-conformance(s)
- Monitoring, auditing and reporting requirements.

Implementing this compliance approach will inform the continuous improvement of the project's environmental performance. A complaints management procedure in accordance with AS/NZS 10002:2014 'Guidelines for Complaints Management in Organisations' will also be implemented (refer to **Section 14.14**).

14.11 Monitoring

A range of monitoring programs will be specified in the contractor management plans as relevant to monitor environmental compliance with the required mitigation measures and statutory approvals conditions. Monitoring frequency and monitoring parameters will be informed by regulatory requirements and scale of environmental risk. Monitoring may include periodic inspections of construction work areas and the operation of project elements constructed. The proposed monitoring to be undertaken for the project is summarised in Table 14-6.

Contractors will be required to implement monitoring programs in accordance with environmental documentation to verify that:

- The monitoring frequency is sufficient to identify non-conformance(s) with the mitigation measures, statutory approvals conditions, management documents and applicable legislation
- The range of parameters being monitored is adequate (this is particularly relevant if an activity has led to an incident or complaint)
- Changes to approved construction and operational activities are adequately covered by the monitoring programs.

Any proposed changes to a monitoring program will be subject to statutory decisions before implementation. Viva Energy will ensure the changes satisfy compliance with all relevant mitigation measures. The contractor will be responsible for the ongoing management of baseline and monitoring data.

Viva Energy will be responsible for verifying that all baseline and monitoring data meet the specified monitoring requirements as well as ensuring that all datasets are maintained and accessible to the relevant regulatory authorities.

Table 14-6 Monitoring requirements for the project

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
Air quality EES evaluation objective: To minimise potential adverse social, economic, amenity and land use effects at local and regional scales					
MM-AQ06	Pipeline Treatment facility	Construction	Weather monitoring to determine if extreme heat and/or wind events require construction works to be modified to minimise dust impacts.	Weather conditions would be monitored for extreme heat and/or wind events using systems such as the Bureau of Meteorology forecasts and works will be modified if conditions are likely to result in air quality impacts at sensitive receptors. The project would use existing Refinery weather monitoring processes where appropriate.	Daily during construction
MM-AQ07	Pipeline Treatment facility	Construction	Observational monitoring of dust along the construction right of way (ROW) and at the treatment facility would be undertaken.	If dust is observed to be causing a hazard, then MM-AQ01 would be implemented. If dust levels cannot be contained works would be modified or stopped until the dust hazard is reduced to a manageable level.	Daily during construction

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
MM-AQ11	FSRU	Operation	An air quality monitoring program would be designed and implemented to monitor FSRU emissions and confirm FSRU emission rates comply with design specifications.	Stack testing would be conducted when the engines are being run on gas fuel. The concentration of the following pollutants would be sampled: • NO2 • CO • Total VOC • Formaldehyde.	Annual
Contamination and acid sulfate soils (onshore) EES evaluation objective: To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site. To minimise generation of wastes by or resulting from the project during construction and operation, including dredging and accounting for direct and indirect greenhouse gas emissions.					
MM-CO05	Pipeline Treatment facility	Construction	An acid sulfate soils monitoring program would be developed as part of the CEMP in accordance with the CASS BPMG (2010) to measure the effectiveness of the acid sulfate soils management strategy and to provide an early warning of any environmental degradation or impact to surface water, groundwater and soils.	The monitoring program would measure the effectiveness of the management strategy for potential ASS risks ('Medium' ASS hazard) (CASS BPMG, 2010) in accordance with: • Industrial Waste Management Policy (Waste Acid Sulfate Soils) 1999, or subsequent publication • EPA Victoria Publication IWRG655.1: Acid Sulfate Soil and Rock, or subsequent publication • Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils (CASS BPMG, 2010), or subsequent publication • National Acid Sulfate Soils Guidance (series of documents) 2018, or subsequent publication.	As per monitoring program

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
Marine ecology and water quality EES evaluation objective: To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values. To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.					
MM-ME05	Dredging	Construction	Monitor turbidity and light attenuation during dredging, with threshold limits, to confirm that turbidity increases are not consistently elevated and that there is not regular transport of turbidity from barge disposal into shallow water near Point Wilson.	Turbidity would be monitored during the dredging program continuously at six sites – four sites in north Corio Bay, with three sites along the 3 m depth contour at the offshore boundary of the main seagrass beds and one near the refinery intake; and at two sites 600 m inshore of the spoil disposal ground at Point Wilson DMG. Light attenuation would be monitored at the same six sites. The extent of plumes would be monitored visually during dredging to provide real time feedback to project managers. The following limits are proposed as thresholds for action to restrict turbidity releases: • 12-hour concentration above 15 NTU (trigger warning) • 24-hour concentration above 12 NTU (action required) Actions that would be taken would most likely involve reducing the period of overflow from barges to zero and slowing the dredging cycle of the backhoe.	Continuous monitoring during dredging, commencing 2 months prior and extending for 2 months after dredging has been completed
MM-ME06	Dredging	Construction and operation	Seabed biota monitoring in dredged area and Point Wilson DMG to detect any significant changes to infauna communities and recovery	Two baseline surveys will be made with a 3-month gap prior to dredging, and four post-commissioning surveys in the same locations of benthic fauna abundance, diversity and composition in the dredged area and Point Wilson.	Every 3 months for 2 years

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
MM-ME07	Dredging	Construction	Monitoring of plankton during and after dredging to identify toxic phytoplankton blooms	Plankton populations will be monitored at four sites in north Corio Bay (as used in the 2020-2021 plankton surveys) before, during and after the dredging period, at two weekly intervals. The purpose is to identify if there is a bloom of toxic phytoplankton as a result of release of nitrogen or toxic algal spores during dredging. The standard notifications to EPA and aquaculture will be made in the event that there is a bloom.	2 weekly intervals commencing 4 weeks before dredging, and continuing for 8 weeks after dredging has been completed
MM-ME17	FSRU	Operation	Monitoring of seawater discharges	Monitoring and recording of the flow rate, temperature and residual chlorine concentration of all discharges from the FSRU (excluding fire water, water curtain and ballast water) either from the refinery or directly into Corio Bay will be conducted. Monitoring will be conducted to keep a record of all discharges, confirm that the discharge rate, temperature and chlorine concentration are within the values stipulated in the licence conditions of the refinery Operating Licence and FSRU Operating Licence and, if not, provide the trigger for remedial action.	All seawater discharges

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
Noise and vibration EES evaluation objective: To minimise potential adverse social, economic, amenity and land use effects at local and regional scales.					
MM-NV04	Pipeline	Construction	Construction noise and vibration monitoring	Noise and vibration monitoring will be undertaken during construction at: • The nearest noise sensitive residential property or properties impacted by out-of-hours works to confirm the effective implementation of noise mitigation measures • The nearest building or assets that are within derived set back distances for human response or in response to a complaint • Where an asset owner's utility standards are at risk of being exceeded. Frequency and duration: • The measurement will be undertaken at the earliest stage (within the first 24 hours) for each construction activity identified to impact sensitive receiver locations during out of hours works. • The measurement duration will be adequate to represent a typical 15-minute period for the applicable evening or night period. • For onshore pipeline construction, where the noise sources will be transient, measurements will be required for works at each noise sensitive receiver area where noise has been identified as a risk. • Measurements will be undertaken in response to any community complaints, where noise emissions need to be verified to resolve the issue i.e., where the activity cannot simply be stopped	Within the first 24 hours of each construction activity identified to impact sensitive receiver locations during out of hours work In response to complaints

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
				or mitigated to avoid the risk due to noise. A response plan will be developed to manage potential impacts if nominated criteria are exceeded, including: • Actions taken to rectify the exceedance e.g., stop works until noise monitoring confirms the level or implement mitigation measures to manage impacts. • Actions to minimise risk of reoccurrence e.g., provide mitigation measures or alternative methods. • Name of person(s) responsible for undertaking the required actions. The duration of the monitoring will be determined by a suitably qualified acoustic consultant.	
MM-NV05	FSRU	Operation	Verification noise monitoring should be conducted on noise produced by the FSRU within 3 months of commencement to confirm noise emission and the schedule of activities.	Noise measurements should be undertaken in accordance with current Victorian EPA requirements to verify operational noise levels and verify cumulative noise impacts at Geelong Grammar, Biddlecombe Avenue and School Road dwellings (north-east). • The measurements should be adequate to be represent a typical 30-minute period for the applicable day, evening or night period and undertake in accordance with the measurement procedure outlined in Part I, section B of the Noise Protocol. • Measurements are recommended for all operating scenarios to verify the noise emissions. • Measurements should be undertaken as part of the Environmental Management Plan in response to any community complaints.	Once within 3 months of commencing commercial operation

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
Safety, hazard and risk EES evaluation objective: To provide for safe and cost-effective augmentation of Victoria's natural gas supply having regard to projected demand and supply in context of the State's energy needs and climate policy.					
MM-SHR04	Pipeline Treatment facility FSRU	Operation	The operation of the FSRU, pipeline and Treatment Facility will be monitored using appropriately SIL rated process automation and shutdown systems. The control, monitoring and shutdown systems will be fail-safe and be designed to best industry practices with redundancy.	Abnormal conditions will alarm locally and remotely to fully attended control rooms. Operation out of the design / operation envelope has the potential to result in imminent loss of containment, which will result in an automatic shutdown of gas operations via closing of emergency shutdown valves with depressuring of inventory through vent stacks if and when required will to be initiated remotely by an operator in the control room to ensure safe release.	Continuous automated
MM-SHR06	Treatment facility FSRU	Operation	Monitoring of chemical and fuel storage facilities to prevent leaks/ spills.	Routine visual monitoring and recording of chemicals and fuel storage facilities will occur as part of routine operational practices.	As per OEMP

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
Surface water EES evaluation objective: To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.					
MM-SW01	Pipeline	Construction	Monitoring of discharge water from construction areas to ensure water quality does not exceed acceptable limits in EPA guidelines and that water does not enter existing waterways and/or wetlands.	Site management mitigation measures would include appropriate placement of material stockpiles and chemical storages, covered loads, street sweeping and water quality monitoring, where required. Water would be tested for pH and salinity prior to discharge to land. pH and salinity should not exceed acceptable limits in EPA guideline. Discharge would be to low gradient, stable, grassed areas and be undertaken in accordance with landholder requirements and through "irrigation type" systems to prevent scour or erosion. Visual monitoring during land discharge would be undertaken to ensure water does not enter existing waterways and/or wetlands.	Prior and during discharge of water from site
MM-SW03	Pipeline	Construction	Monitoring of watercourse trenching to avoid impacts to downstream waterbodies	Weather forecasts would be monitored to avoid having open trenches at the waterway when high rainfall events are expected. Visual monitoring would be undertaken downstream of the trench during flow events if the trench has not been reinstated.	Daily weather forecast monitoring in the week leading up to trenching of the watercourse Twice daily visual monitoring if there are flow events in the watercourse

Relevant MM ID	Project component	Project phase	Description	Monitoring method and parameters	Monitoring frequency
Underwater noise EES evaluation objective: To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values.					
MM-UN02	Dredging Refinery Pier extension	Construction	Visual monitoring for marine animals to deter them from entering construction area where they may be adversely impacted by underwater noise.	Implement a safety zone around loud sound sources by visual monitoring of the surrounding area prior to commencing loud activities and implement activity delays of 20 minutes based on time of last sighting of marine mammals.	Prior to commence-ment of loud sound sources

14.12 Environmental reporting

Viva Energy will be responsible for reporting compliance with mitigation measures and statutory approvals conditions to regulators. Reporting and external notification requirements will be outlined in detail within the contractor management plans including which matters require reporting, to which party and the timeframe within which the reporting should occur. Reporting will depend upon the terms of the statutory approvals, but may include:

- Monitoring results
- Compliance with requirements
- Non-conformances and corrective actions
- Complaints register and responses
- Notifications to the registered Aboriginal party and First Nations – State Relations, if a potential Aboriginal site or artefact is identified
- Notification to Heritage Victoria and the Department of Environment, Land, Water and Planning (DELWP) if a heritage artefact is discovered
- Environmental incident notifications, including if contamination is encountered.

14.13 Audits

A suitably qualified professional will conduct independent audits at agreed intervals to monitor compliance with the mitigation measures, management systems obligations, statutory approvals conditions and relevant legislation and guidelines throughout all phases of the project. Specific details of the audit schedule will be included in Viva Energy's EMP, CEMP and OEMP. Audit regimes will be informed by the regulatory approval requirements applying to the FSRU and pipeline components of the project.

Audits would evaluate:

- Compliance with all relevant mitigation measures contained in the EMP, CEMP and OEMP
- Compliance with statutory approvals conditions issued for the project
- Conformance with any other relevant environmental management documentation
- Responses to non-conformances, complaints and incidents
- Compliance with safety requirements
- Implementation of monitoring programs.

Conformance and compliance will be assessed through a range of inspections, observations of project works, consultations with proponent, operators and contractors, reviews of records and meeting minutes as agreed between Viva Energy and the auditor. Viva Energy will make publicly available a summary of the independent audits and Viva Energy's response to the recommendations in the audits.

14.14 Complaints management

Stakeholders and members of the community will be able to raise issues or submit complaints about the proposed project. Through the complaints management process Viva Energy would seek to:

- Clarify and understand any concerns or complaints raised
- Consider and investigate concerns or complaints in a timely manner
- Communicate outcomes of reviews and investigations
- Commit to apply learnings from concerns or complaints

The project has established a toll free phone number (1800 515 093) to receive any feedbacks or complaints. All contact received through this channel would be lodged and responded to.

14.15 Contingency measures

Viva Energy and their contractors will have in place contingency measures to facilitate an efficient and effective response to unexpected environmental events that could arise during project construction and operation. While it is difficult to predict where contingency measures may be required during the construction and operational phases of the project, Viva Energy is committed to delivering on the mitigation measures outlined in the EES and to ensuring compliance with regulatory requirements. In the event that unexpected issues arise, or non-compliance becomes evident during construction or operation, contingency plans would be developed and implemented to address the issue.

Events for which contingency measures will be prepared include (but are not limited to):

- The discovery of previously unidentified Aboriginal cultural heritage (see MM-AH01) or historic heritage objects or places (see MM-HH01 and MM-HH02)
- Emergency shutdown of abnormal operation conditions (see MM-SHR04)
- Hazardous chemicals, fuel or waste spills (see MM-SHR07)
- Liquid fires and gas fires (see MM-SHR08)
- Construction work outside of EPA normal working hours (see MM-NV02)
- The discovery of unexpected legacy contaminated material(s) (see MM-CO04).

For issues such as air quality and noise emissions, where regulatory requirements are well understood, monitoring of performance during both construction and project operation will be a central element of Construction Environmental Management Plans (CEMP) and Operational Environmental Management Plans (OEMP).

While Viva Energy is unable to assess at this point where contingency measures may be required, some examples of the types of measures which could be adopted if needed include:

14.15.1 Marine discharges

Viva Energy would undertake verification monitoring of marine discharges from the project in accordance with current Victorian EPA requirements and would actively monitor the proposed dredging program to enable contingency measures to be adopted where required.

Chlorine

The current discharges of cooling water from the Geelong Refinery are well understood in relation to residual chlorine and temperature after more than 60 years of ongoing discharge and regular water quality monitoring. The preferred mode of operation of the FSRU involves reuse of the cool FSRU discharge into the refinery cooling water process and would result in the same discharge rates and chlorine concentrations as has occurred over the last 60 years. As residual chlorine remains the same, it is not envisaged that water quality monitoring will result in the need for contingency measures.

Notwithstanding, the following contingency measures would be available for managing chlorine in the project discharges:

- Continue the present daily monitoring and trimming of the chlorine addition to seawater entering the refinery. The same process will be continued when the FSRU is operating and delivering seawater with residual chlorine to the refinery intake. The refinery will add extra chlorine to achieve the existing intake level and continue the daily monitoring and trimming of the chlorine addition.
- In the event that higher residual chlorine was detected in the discharges during monitoring after project inception, the refinery would use its existing procedure to control for chlorine dosing and maintain the discharge chlorine concentration within licenced levels.
- It is anticipated that chlorine analysis technology will improve over time enabling Viva Energy to optimise, and potentially further reduce, chlorine dosing rates.

- In the event that the FSRU discharged cool water into Corio Bay via the proposed diffuser located on Refinery Pier (for example, if the refinery ceased operation in the future and the cooling water reuse option was not available), and higher residual chlorine levels than expected were detected, the chlorine addition to seawater on the FSRU could be adjusted downward.
- In the event that there was a longer period where chlorine levels from the diffuser discharge were higher than predicted, the diffuser could be modified (with additional smaller discharge ports to achieve extra dilution).

Temperature

The existing refinery discharges cooling waters at approximately 9 degrees above ambient temperatures in Corio Bay. The proposed reuse of the cool water discharge from the FSRU in the refinery for cooling water would result in a cooler discharge from the refinery after reuse of approximately 2 degrees above ambient when the FSRU is operating at peak production rates and 4 degrees above ambient when the FSRU is operating at average production rates. The temperature in the refinery discharges would be a function of how much water the FSRU is discharging at different production rates. As such, the proposed discharge would be within an approximate range of 2 - 9 degrees above ambient and would be compliant with the current refinery discharge licence.

As the temperature of the current refinery discharge plumes will be improved as a result of the project (closer to ambient) than that currently permitted under the existing refinery licence, and will meet the existing licence conditions, it is not envisaged that water quality monitoring will result in the need for contingency measures when the FSRU discharge is being reused as refinery cooling water.

In the event that the FSRU discharged cool water into Corio Bay via the proposed diffuser located on Refinery Pier (for example, if the refinery ceased operation in the future and the cooling water reuse option was not available), and monitoring indicated that the cold water plume from the FSRU was more extensive than predicted, the contingency measure to ensure compliance with conditions for the mixing zone under this mode of operation would be to:

- Modify the diffuser by adding additional discharge ports to create further mixing and dilution of the cold-water discharge.

Dredging

Viva Energy would undertake verification monitoring of turbidity and light attenuation at six locations - four sites in north Corio Bay and two sites inshore of the spoil disposal site throughout the dredging program and for a period before and afterward. In the event that turbidity monitoring during the dredging program showed higher turbidity levels or light attenuation than predicted, contingency measures could include:

- Reducing the period of overflow from the barges receiving the dredged material back to zero
- Slowing the dredging cycle of the backhoe dredge
- Installation of a further silt curtain (in addition to that recommended)

14.15.2 Air emissions

Viva Energy would undertake verification monitoring of air emissions produced by the FSRU within 3 months of commencement in accordance with current Victorian EPA requirements. Should verification monitoring detect unacceptable levels of air emissions, additional measures would be implemented to minimise emissions which could include:

- Alteration of discharge exhaust parameters to increase air dispersion, such as
  - vertical outlet orientation (instead of being tilted 45° aftwards)
  - increasing height of exhaust emission points
  - change to exhaust flow rate or temperature
- Operating FSRU engines when meteorology conditions (particularly wind direction and speed) are favourable
- Reducing the load and number of engines operating at any one time.

14.15.3 Noise emissions

Viva Energy would undertake verification monitoring of noise produced by the FSRU within 3 months of commencement in accordance with current Victorian EPA requirements. It is expected that the FSRU and associated equipment (tugboats, LNG carrier etc.) will comply with EPA requirements. Should verification monitoring detect unacceptable levels of noise emissions, additional measures could be implemented to minimise noise emissions which could include:

- FSRU, Tugboat and LNG Carrier source mitigation
  - Exhaust attenuators, mufflers or elbows
  - Substituting tugboats for quieter alternatives
  - Noise walls/enclosures constructed for noisy individual pieces of equipment
  - Reducing the load or number of engines operating at one time
- Activity scheduling
  - Restricting noisy activities such as mooring, closed loop FSRU operation and truck movements to daytime only
  - Scheduling noisy FSRU, Tugboat and LNG Carrier activities to commence when nitrogen unloading is not taking place
- Noise monitoring
  - Undertake additional attended noise monitoring to verify the noise emissions at sensitive receptors areas for operations during the Day, Evening and Night periods.
  - Setup permanent unattended noise monitors in areas of concern with notification triggers when noise levels are approaching compliance levels. Where compliance levels are exceeded, investigate the issue accordingly to identify the noise source and verify the noise emissions. Where required, implement mitigation measures to eliminate or reduce the noise emissions.
  - Monitor wind conditions (e.g., speed and direction) to evaluate noise emissions under various weather conditions including worst case noise propagation conditions (i.e., prevailing wind direction from source to receiver).

As outlined above, it is not possible to identify where construction and operational contingency plans may be required at this stage of the project. However, this section has provided some examples of the types of measures which could be adopted in response to non-compliance or amenity concerns which could arise over the life of the project. Viva Energy is committed to minimising impacts on the environment, its neighbours and the wider community and would implement contingency measures as required.

Appendix E

Marine ecology and water quality impact assessment

Viva Energy Gas Terminal Project

Technical Report A
Marine Ecology and Water Quality Impact Assessment



February 2022

Consulting Environmental Engineers

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1 Introduction

This technical report presents the marine ecology and water quality impact assessment conducted to support the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a gas terminal using a ship known as a floating storage and regasification unit (FSRU), which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas to the south-east Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU) and would convert the LNG back to a gaseous state by heating the LNG using seawater (a process known as regasification). A 7 km pipeline would transfer the gas from the FSRU to the existing Victorian gas transmission system at Lara.

The project would be situated adjacent to, and on, Viva Energy's Geelong Refinery, within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. Co-locating the project with the existing Geelong Refinery offers an opportunity to transfer the cold seawater from the FSRU to the refinery for reuse as cooling water. This would mean no additional extraction of seawater from Corio Bay is required for the project and the temperature of the cooling water currently discharged from the refinery to Corio Bay would be reduced to near-ambient temperature.

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the Environment Effects Act 1978 (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic and transport as well as visual amenity. This report assesses the impact on marine ecology while separate reports will cover the other potential effects.

In January 2021 the project was also determined to require assessment and approval under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) due to the potential for the project to have a significant impact on wetlands of international importance, listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

1.1 Purpose of Marine Impact Assessment

This marine ecology and water quality impact assessment identifies, assesses and characterises potential environmental impacts on the marine environment associated with the construction and operation of the project to inform the preparation of the EES required for the project.

This report identifies and recommends mitigation measures to avoid, minimise and manage potential impacts and will inform the development of an Environmental

Management Framework (EMF). The mitigation measures listed in the EMF would be implemented through the approvals and management plans for the project.

1.2 Why Understanding Marine Ecology and Water Quality Impacts is Important

Project activities have the potential to impact the surrounding marine environment during the construction and operation of the project. The potential impacts may include:

- Direct impacts on biota;
- Changes to the chemical or physical attributes of the environment; and
- Indirect effects on habitat conditions, biota and the ecological character of the Bay including the Point Wilson/Limeburners Bay section of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsular Ramsar site.

Understanding how the project could impact the marine environment is an important step in developing effective and appropriate measures to avoid or mitigate impacts.

The assessment of marine impacts addresses the potential for impacts on intertidal and subtidal habitats. This informs the assessment of potential indirect impacts on terrestrial fauna that use the intertidal habitats for foraging at low tide, particularly migratory shorebirds.

1.3 Project Area

The project would be located adjacent to, and on, the Geelong Refinery and Refinery Pier in the City of Greater Geelong, 75 kilometres (km) south-west of Melbourne. The project area is within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. The Geelong central business district is located approximately 7 km south of the project.

Corio Bay is the largest internal bay in the south-west corner of Port Phillip Bay and is a sheltered, shallow basin at the western end of the Geelong Arm, with an area of 4,300 hectares (ha). The Point Wilson/Limeburners Bay section of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site is located along the northern shoreline of Corio Bay approximately 1 km to the north-east of the project.

The Port of Geelong has been in operation for over 150 years and is the largest industrial bulk cargo port in Victoria attracting over 600 ship visits and handling more than 14 million tonnes of product annually. Geelong's shipping channels extend 18 nautical miles (33 km) from Point Richards through Corio Bay to Refinery Pier. Ports Victoria manages commercial navigation in the port waters in and around Geelong and is responsible for the safe and efficient movement of shipping, and for maintaining shipping channels and navigation aids. The channels are man-made having been deepened and widened through periodic dredging to support port trade development.

Refinery Pier is the principal location within the Port of Geelong for movement of bulk liquids. Vessels up to 265 m in length use the four berths at Refinery Pier which serve Viva Energy refinery operations. The majority of ship visits to the port are to Refinery Pier, with Viva Energy accounting for over half of the trade through the Port of Geelong.

The Geelong Refinery has been operating since 1954 (i.e., for over 60 years) and both the refinery and the co-located Lyondell Basell plant are licensed Major Hazard Facilities (MHFs). A range of industrial activities are situated in the Port environs including wood fibre processing and chemical, fertiliser and cement manufacture.

To the north of the Geelong Refinery, along the proposed underground pipeline corridor, the area is predominantly rural. There are several other existing Viva Energy-owned underground pipelines running between the refinery and the connection point to the South West Pipeline (SWP) at Lara. The proposed pipeline route follows already disturbed pipeline corridors, where possible, through a mix of land uses.

The project area is shown in Figure 1-1.

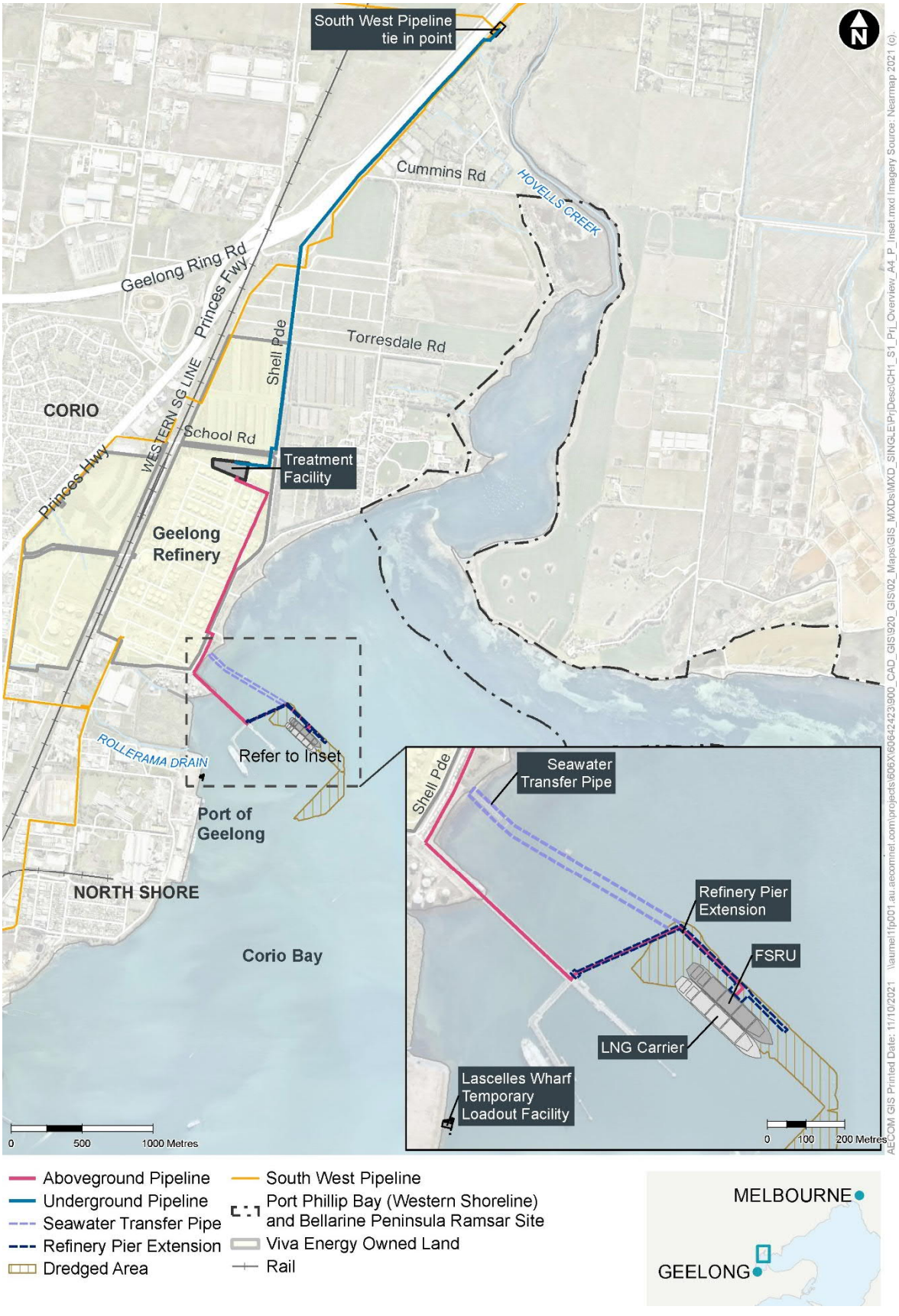


Figure 1-1. Project Location Overview

1.4 Project Description

This section summarises the project as described in EES Chapter 4: *Project description*. Key components of the project include:

- extension of the existing Refinery Pier with an approximately 570 metre (m) long angled pier arm, new berth and ancillary pier infrastructure including high pressure gas marine loading arms (MLAs) and a transfer line connecting the seawater discharge points on the FSRU to the refinery seawater intake
- continuous mooring of an FSRU at the new Refinery Pier berth to store and convert LNG into natural gas. LNG carriers would moor alongside the FSRU and unload the LNG
- construction and operation of approximately 3 km of aboveground gas pipeline on the pier and within the refinery site connecting the FSRU to the new treatment facility
- construction and operation of a treatment facility on refinery premises including injection of nitrogen and odorant (if required)
- construction and operation of an underground gas transmission pipeline, approximately 4km in length, connecting to the SWP at Lara.

The Refinery Pier extension would be located to the north-east of Refinery Pier No. 1. The new pier arm would be positioned to allow for sufficient clearance between an LNG carrier berthed alongside the FSRU and a vessel berthed at the existing Refinery Pier berth No. 1. Dredging of approximately 490,000 cubic metres of seabed sediment would be required to allow for the new berth pocket and swing basin.

The FSRU vessel would be up to 300 m in length and 50 m in breadth, with the capacity to store approximately 170 000 m^3 of LNG. The FSRU would receive LNG from visiting LNG carriers and store it on board in cryogenic storage tanks at about –160 °C.

The FSRU would receive up to 160 PJ per annum (approximately 45 LNG carriers) depending on demand. The number of LNG carriers would also depend on their storage capacity, which could vary from 140,000 m^3 to 170,000 m^3.

When gas supply is needed, the FSRU would convert the LNG back into a gaseous state via a heat transfer system using seawater (a process known as regasification). The natural gas would then be transferred through the aboveground pipeline from the FSRU to the treatment facility where odorant and nitrogen would be added, where required, to meet Victorian Transmission System (VTS) gas quality specifications.

Nitrogen injection would occur when any given gas cargo needs to be adjusted (diluted) to meet local specifications. Odorant is added as a safety requirement so that the normally odourless gas can be smelt when in use. From the treatment facility, the underground section of the pipeline would transfer the natural gas to the tie-in point at Lara.

1.4.1 Key Construction Activities

Construction of the project would occur over a period of up to 18 months. The key construction activities relate to:

- localised dredging of seabed sediments to enable the FSRU and LNG carriers to berth at Refinery Pier and excavation of a shallow trench for the seawater transfer pipe
- construction of a temporary loadout facility at Lascelles Wharf
- construction of the new pier arm and berthing infrastructure, and aboveground pipeline along Refinery Pier and through the refinery
- construction of the treatment facility on a laydown area at the northern boundary of the refinery site
- construction of the buried pipeline
- construction at the tie-in point to the SWP at Lara

There are no construction activities required for the FSRU component of the project. The vessel would be built, commissioned and all production and safety systems verified prior to being brought to site.

An estimated 490,000 cubic metres (m^3) of dredging would be required, over an area of approximately 12 hectares (ha), adjacent to the existing shipping channel to provide sufficient water depth at the new berth and within the swing basin for visiting LNG carriers to turn. Dredging within the new berth would be undertaken to a depth of 13.1 metres and the swing basin would be dredged to a depth of 12.7 metres. The dredging footprint is shown in Figure 1-2. It is planned to deposit the dredged material within the existing dredged material ground (DMG) in Port Phillip Bay (shown in Figure 1-3) to the east of Point Wilson, approximately 26 km from Refinery Pier. The seabed material to be dredged is mostly clay and silt and would be removed using a backhoe dredge and transported by barges to the disposal site.

Shallow trenching, involving excavation of approximately 8,000 m^3 of sediment, would be required to install the seawater transfer pipe. The excavated sediment would be placed next to the trench. The pipe would be assembled onshore and towed into the trench. Once installed, the pipe would be covered with the excavated sediment.

The temporary loadout facility at Lascelles Wharf would be the first construction activity to take place in order to facilitate the Refinery Pier extension. This would involve the installation of 10 piles using hydraulic hammers.

Construction of the pier arm would be carried out once dredging was complete, primarily from the water using barge-mounted cranes. Steel piles would be driven into the seabed by cranes mounted on floating barges and pre-cast concrete and prefabricated steel components would be transported to site by barge and lifted into position. The installation of pier infrastructure such as the marine loading arms (MLAs), piping from the FSRU to the existing refinery seawater intake (SWI) and aboveground pipeline would also be undertaken from the water using barge-mounted cranes and construction support boats.

The dredging is expected to take approximately 5 to 10 weeks, depending on the size of the dredge. The pier arm construction, and diffuser and seawater transfer pipe installation are expected to take approximately 12 months.

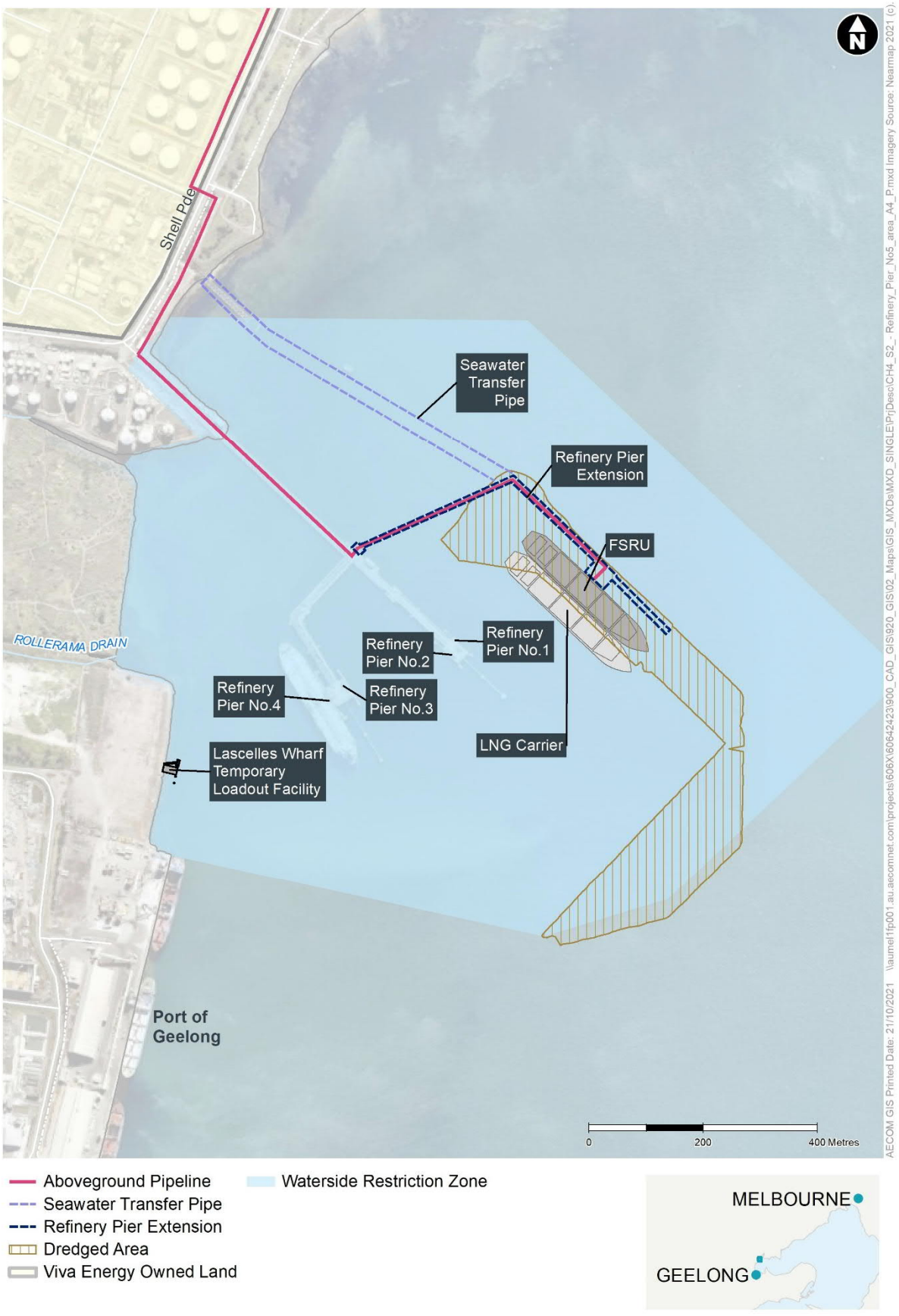


Figure 1-2. Dredging Footprint

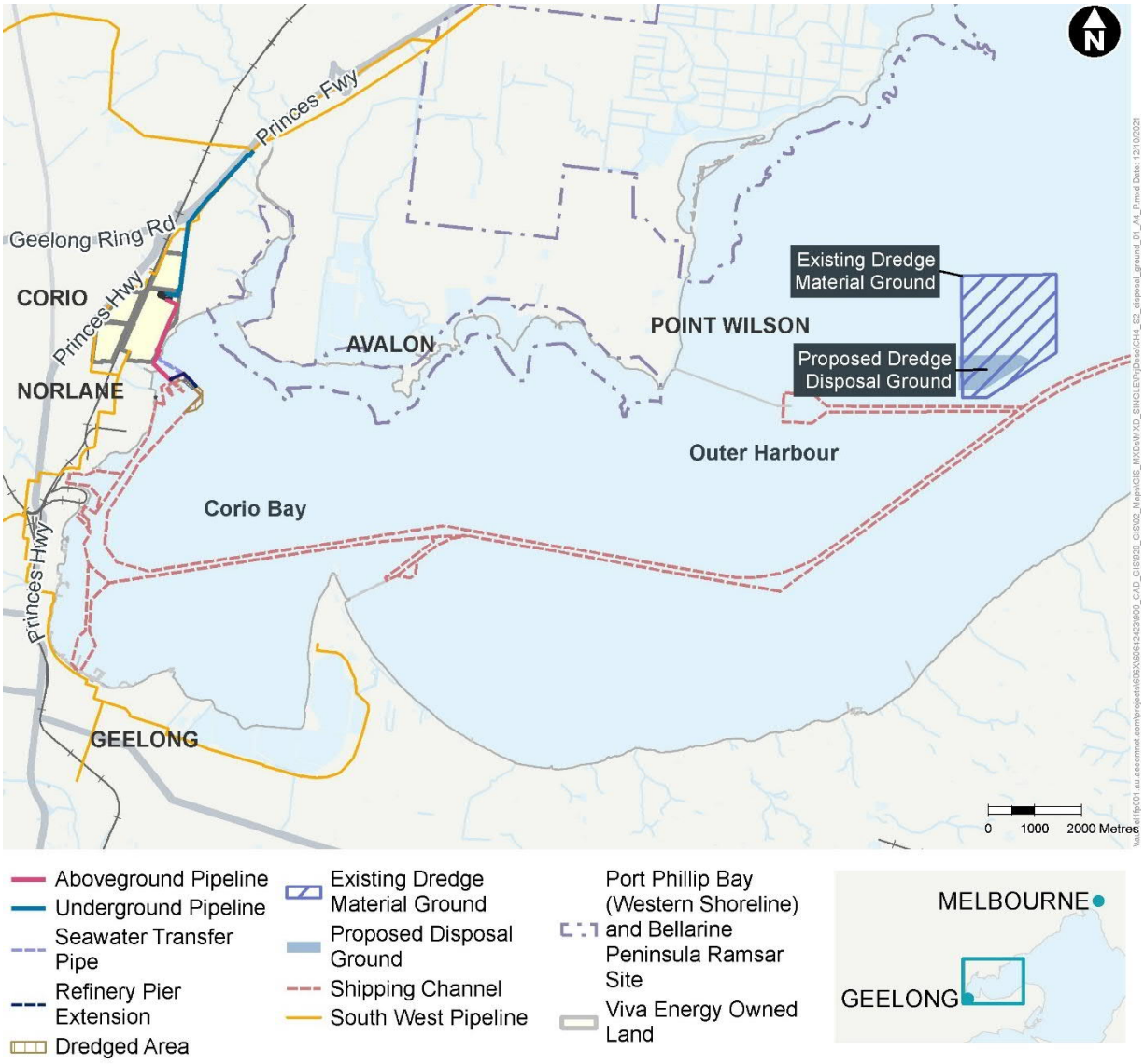


Figure 1-3. Proposed Dredge Material Disposal Ground

Selection of Dredge Spoil Disposal Site

Approximately 30 million m^3 of sediment has been dredged in Corio Bay over the last 150 years to make shipping channels. Much of this sediment has been deposited in the defined spoil disposal site to the east of Point Wilson. It has assumed that the dredging spoil from this project also would be deposited in the Point Wilson site unless there is an environmental constraint or there is a better disposal option.

Sediments throughout Corio Bay are slightly contaminated with metals, some reflecting elevated natural concentrations (e.g., arsenic, nickel) and some from urban and industrial sources (e.g., cadmium, chromium, copper, zinc) along the western shore. Metal inputs from the northern catchment via Hovells Creek also are apparent (e.g., cadmium, cobalt and vanadium) in Corio Bay sediments.

Sediments previously placed in the Point Wilson spoil disposal site have the same level of contamination as the proposed dredged material (as demonstrated in the 2020-2021 sampling program). The most recent material placed in the spoil disposal

site came from dredging near Refinery Pier No. 4 and the eastern side of Corio Channel – total of 400,000 m^3 of dredged sediment, which is a similar volume to the 490,000 m^3 proposed in the project with a similar metal composition. Thus, adding new sediment will not change the situation in the spoil disposal site.

Extensive sampling and testing of sediments from the proposed dredging area and the spoil disposal site were conducted as part of Technical Report B: *Dredged sediment disposal options assessment (*analyses are summarised in Section 7-14). The results identified no potential adverse impacts on ecological receptors at either the dredging site or the spoil disposal site (AECOM, 2021) On the basis of the sediment quality assessment undertaken by AECOM in accordance with the National Assessment Guidelines for Dredging (2009), it was concluded that the sediments proposed to be dredged are suitable for offshore disposal at the Point Wilson Disposal Ground.

Other spoil disposal sites are possibly available in Port Phillip Bay. However, travelling further would use more fuel, generate more GHG, and prolong the dredging period, for no environmental benefit. Containment of Corio Bay sediments in the Point Wilson spoil disposal site has not been used previously and is not indicated as required. Containment under a clay cover has been used for disposal of more contaminated sediments from Hobsons Bay and the Port of Melbourne.

Disposal on land is an option but the Ramsar Site precludes use of the northern coast and urbanisation precludes use of the western and southern coasts. Filling the seabed (sometimes termed land reclamation) to create new land on the coast of Corio Bay is not favoured. There is no nearby location identified for land reclamation.

In summary, as the extensive testing and risk assessments did not identify adverse impacts to ecological receptors at either the dredging site or the spoil disposal site, the Point Wilson site was adopted as the preferred spoil disposal site.

1.4.2 Key Operation Activities

The project is expected to be in operation for approximately 20 years. Key activities relating to project operation include:

- Delivery of LNG in up to 45 LNG carriers each year at Refinery Pier – the number and frequency of LNG carriers arriving each year would depend on their storage capacity and gas demand;
- Regasification of LNG onboard the FSRU using seawater as a heat source. The cooler seawater from the FSRU would then be reused within the refinery as cooling water, which would heat it back to near ambient temperature;
- Injection of nitrogen and odorant into the gas prior to distribution via the Victorian Transmission System (VTS); and
- Monitoring and maintenance of the pipeline easement.

The first two activities have implications for the marine environment.

LNG carriers would moor next to the FSRU to transfer LNG from the carriers to storage tanks on the FSRU. The transfer would take from 1 to 2 days. The number of LNG carriers is anticipated to be up to 45 per year depending on gas demand, and the carrier capacity.

The heat required to return the LNG (liquid) to a gas would be obtained from seawater passing through heat exchangers onboard the FSRU. The seawater would be drawn from Corio Bay into the FSRU through sea chests or dedicated water inlets in the hull and circulated through heat exchangers where the liquid LNG would vaporise to a gas. The daily seawater intake would depend on gas production, and would range from 148 ML/d (million litres per day) to 300 ML/d with a maximum day of 350 ML/d. The Geelong Refinery currently uses up to 350 ML/d of seawater for cooling purposes. Cooled seawater (7 °C below ambient seawater temperature) from the FSRU regasification system would be transferred by pipe to the refinery seawater intake for reuse within the refinery and would replace the seawater currently pumped in by the refinery.

To prevent marine growth in the heat exchangers, the seawater drawn into the FSRU would be chlorinated using an electrolysis process. Seawater discharged from the FSRU to the refinery after it has been used in the regasification process would contain short-lived residual chlorine. The refinery has for many years chlorinated the seawater extracted from Corio Bay for use in the cooling water system. Thus, the residual chlorine in the seawater transferred from the FSRU would reduce the need for the addition of chlorine at the refinery. There would be no change in the chlorine concentration in the refinery discharges to Corio Bay.

Any seawater from the FSRU regasification system that exceeds the intake requirements for the refinery (e.g., if parts of the refinery are shut for maintenance) would be discharged to Corio Bay through a diffuser located under the new pier arm. As an indication of planned future operations, it is expected that under current refinery operations there would be full reuse of the seawater from the FSRU on about 344 days per year (94 % of the time) and partial to full reuse on about 21 days per year (6 % of the time).

Operating Modes

The usual operating mode, or regasification mode, of the FSRU for this project would involve open loop operation with the transfer of seawater from the FSRU by a pipe to the refinery intake as described in the previous section.

With the project, the FSRU discharge would replace all or some of the existing seawater intake requirements of the refinery from Corio Bay, the amount of replacement being determined by the production rate of the FSRU at any given time. For example, there would be days where seawater discharge from the FSRU is lower than the normal approximate 350 ML intake requirements of the refinery (e.g., when the production rate for the FSRU is low due to reduced gas demand). In this situation, the refinery would draw the remaining volume of seawater required for cooling through the existing refinery seawater intake, as is done at present.

The refinery cooling water would be discharged from the existing refinery discharge points with the same residual chlorine content as the current refinery discharge but at a lower temperature, closer to ambient temperature conditions in Corio Bay than the current warm refinery discharge.

Backup Discharge Arrangement

The **backup discharge arrangement** for the project would involve direct discharge of some, or all, of the FSRU discharge water into Corio Bay via a diffuser located under the Refinery Pier extension. The diffuser would be used during refinery maintenance

periods when the rate of FSRU discharge could exceed the refinery demand for seawater.

The project assessed in this EES provides for open loop operation with discharge of FSRU water through the refinery or via the diffuser. The impacts of both of these discharge modes have been assessed, and both form part of the project put forward for regulatory approvals subject to the outcomes of the EES.

The refinery conducts significant maintenance shutdowns every second year where up to half of the refinery is taken offline for 2 to 3 months. During these periods, cooling water is still required for the operational part of the refinery and is in the range of 200 to 250 ML/day. Based on the projected seasonal FSRU production rates shown in Table 1-1 below, the FSRU would still be the principal source of cooling water for the refinery during refinery maintenance. Discharge via the diffuser would also be used in the event that the refinery was permanently decommissioned in the future and the option for reuse of the FSRU discharge water in the refinery was no longer available.

In summary, the potential impacts associated with discharge of FSRU water through the refinery and via the diffuser on the pier extension have been assessed in this EES.

Backup FSRU Operating Arrangement

The project assessed in the EES also includes the use of the FSRU in closed loop mode. Closed loop operating mode would only be used in the event that the FSRU was unable to transfer seawater through the transfer pipe to the refinery, for example, during FSRU maintenance or due to a pump or pipe failure. Closed loop is not preferred to the usual open loop operation as it uses up to 2.5% of the LNG cargo to heat the LNG and has higher greenhouse gas emissions than open loop operation. Notwithstanding this, closed loop operation also forms part of the project being put forward for regulatory approval. The potential impacts associated with the closed loop regasification mode have been assessed in this EES.

In summary, the project being assessed in this EES provides for open loop and closed loop operations, both of which would be used at times during project operation.

Gas Production Profile

The estimated gas production profile for the project is shown in Table 1-1. This indicative profile is based on typical gas demand rates throughout the year. The FSRU is anticipated to produce a maximum of 500 TJ/day of gas which would require about 300 ML/d of seawater for the regasification process. On a limited number of peak demand days, the gas production rate would fluctuate throughout the day, but the maximum daily flowrate of seawater would be 350 ML/day.

Table 1-1. Indicative Gas Production Profile

Season	Estimated gas production (TJ/day)	Seawater use (ML/day)
Summer (Dec – Feb)	250	148
Autumn (Mar – May)	350	208
Winter (Jun – Aug)	500	300
Spring (Sept – Nov)	350	208

Based on the production rates shown in Table 1-1, there would be few times in the year when FSRU water would be discharged through the diffuser. The winter period (Jun – Aug) is the only time when the FSRU discharge could exceed the refinery intake. The major, planned Refinery shutdowns are generally conducted during spring or autumn.

In all cases, the seawater use, and the associated seawater discharge would be no more than 350 ML/day which is the worst-case scenario adopted for the marine water quality modelling and environmental impact assessment, and consistent with the current discharge and operating licence for the refinery.

Base Case

The base case, which is the “no project alternative”, would involve continued operation of the refinery drawing in 350 ML/d of seawater from Corio Bay through the existing intake channel, and discharge of 350 ML/d through the four existing licensed discharge points along the shore of Corio Bay.

The assessment of impacts generally examines the change in impacts between the project and the base case. For the usual proposed mode of operation, this would involve no change in the seawater withdrawal rate of 350 ML/d, no change in the discharge rate of 350 ML/d, no change in the chlorine concentration at the four existing discharge points and a reduction in the temperature rise of the discharge plumes.

Backup Discharge Arrangements

As described above, there are backup discharge arrangements included in the proposal, and these have been assessed in the EES as though operational for a full year.

In practice, Viva Energy will seek to maximise use of open loop operation with transfer of the cooled FSRU water to the refinery intake as, in addition to the environmental benefit described in the Base Case, this arrangement would increase the heat transfer efficiency of the cooling water system in the refinery, with an economic benefit to the refinery. Viva Energy will seek to minimise closed loop operations.

Seawater Use

The seawater use involved in operating the project is as follows:

- Extraction of seawater for regasification and refinery operations will be limited to 350 ML/d;
- Discharge of seawater for regasification and refinery operations will be limited to 350 ML/d;
- Periodically, extra seawater will be used for ballast water and firefighting exercises and discharged to Corio Bay;
- The refinery intake of seawater will always exceed the FSRU transfer of seawater, so there will be no discharge of excess seawater to Corio Bay through the refinery intake channel.

1.4.3 Key Decommissioning Activities

The FSRU, which continues to be an ocean-going vessel throughout the operation of the project, would leave Corio Bay on completion of the project life to be used elsewhere.

It is anticipated that the Refinery Pier berth and facilities would be retained for other port related uses. The underground pipeline would likely remain in situ subject to landholder agreements and either decommissioned completely or placed into care and maintenance arrangements.

Decommissioning activities may be subject to change, subject to legislative requirements at the time and potential repurposing of the infrastructure at the end of the project.

1.5 Project Activities Relevant to the Assessment

The following project activities are relevant to this marine ecology and water quality impact assessment:

- Dredging of 490,000 m^3 of sediment for the new berth and swing basin, and excavation of a shallow trench for the seawater transfer pipe;
- Construction of the temporary loadout facility at Lascelles Wharf;
- Construction of the new pier arm and ancillary infrastructure, a diffuser under the new pier arm and pipeline along Refinery Pier;
- Construction of the seawater transfer pipe;
- Up to 45 LNG carriers visiting Refinery Pier each year to supply the FSRU; and
- Regasification of LNG onboard the FSRU using seawater as a heat source, which would then be reused within the refinery as cooling water;
- Continued discharge from the four existing refinery outlets at the same chlorine concentrations as now.
- Continued discharge from the four existing refinery outlets, generally with lower temperatures as now, unless the FSRU is not operating;
- Periodic discharge of cooler seawater from the FSRU via the proposed diffuser under the new pier arm, at times when the refinery is not operating, up to a maximum of 350 ML/d;
- Occasional discharge of warmer seawater from the ports on the FSRU if it needs to operate in closed loop mode, up to a maximum of 350 ML/d; and

- Discharge of ballast water from the FSRU when it loads LNG.

1.6 Stakeholder and Community Engagement

Stakeholders and the community were consulted to support the preparation of the project's EES and to inform the development of the project and understanding of its potential impacts.

Meetings were held with the EPA, Ports Victoria, Greater Geelong City Council, DELWP and other agencies at an early stage of the project to seek information about existing conditions and data and concerning environmental values that could potentially be impacted by the project.

Recreational fishers in Corio Bay were also interviewed during the marine monitoring program to develop an understanding of their thoughts around the marine environment.

In accordance with the scoping requirements, a Technical Reference Group (TRG) was convened and chaired by DELWP on behalf of the Minister for Planning. The TRG provided input throughout the EES process. EES Chapter 6: *Stakeholder and community engagement* provides a summary of the project's key engagement activities.

2 Scoping Requirements

2.1 Schedule of Scoping Requirements

The scoping requirements for the EES set out the specific environmental matters to be investigated in the EES. The scoping requirements include a set of evaluation objectives. These objectives identify the desired outcomes to be achieved in managing the potential impacts of constructing and operating the project.

The following draft evaluation objectives relevant to the marine ecology and water quality impact assessment:

- *Biodiversity - To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values.*
- *Water and catchment values – To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and on the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site.*

The scoping requirements of relevance to this marine ecology and water quality impact assessment and where they are addressed in the report are shown in Table 2-1.

Table 2-1. Register of Scoping Requirements for the Project

Aspect	Scoping Requirement	Section Addressed
Biodiversity - To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values.		
Key Issues	Potential for adverse effects on the ecological character and biodiversity values of *the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site* including, but not limited to, the listed threatened species and terrestrial and marine conservation reserves.	12
	Potential for indirect effects on biodiversity values including but not limited to those effects associated with changes in hydrodynamics and coastal processes, water quality (i.e. on water dependent ecosystems). Potential for significant short and long-term impacts on marine biota due to entrainment of organisms in seawater for regasification or due to variable water temperature discharges and other pollutants, including chlorine, after use for regasification, including impacts resulting from reduced availability of food for other species, resultant hydrodynamic changes and other impacts such as long-term changes to populations and distribution.	7, 8. 9, 10, 11
	Potential for adverse effects on the marine environment from dredging and sediment mobilisation, including increased turbidity and contaminant disturbance.	7

Aspect	Scoping Requirement	Section Addressed
Biodiversity - To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values.		
	Potential for impacts resulting from increased shipping activity on marine species, including acoustic impacts and potential collisions.	11
	Potential for significant impacts on the marine environment resulting from accidental or unintended leaks or spills arising from construction works or operational activities, including unintended introduction of exotic species (e.g., through ballast water).	11
Existing Environment	Characterise the distribution and quality of native vegetation and terrestrial, aquatic, intertidal and marine habitat and any wildlife movement in the area that could be impacted by the project or associated works. This must include the quality and type of habitat impacted and quantification of the total impact area and areas indirectly impacted from the proposed action and must be informed as appropriate by targeted surveys undertaken in accordance with the appropriate Commonwealth or DELWP survey guidelines	5
	Identify the existing or likely presence of any protected species, and especially species listed under the Flora and Fauna Guarantee Act 1988 and DELWP advisory lists, as well as environmental weeds, pathogens and pest animals.	5
	Characterise the listed threatened and migratory species, other protected species, ecological communities and potentially threatening processes that are likely to be present, in the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site* or in other wetlands nearby. This characterisation is to be informed by the literature and suitable available data (especially, where relevant, data <5 years old) and supported by seasonal or targeted surveys where necessary. Details of the scope, timing and method for studies or surveys used to provide information on the ecological values at the site (and in other areas that may be impacted by the project) should be outlined. Records and other data from local sources should also be gathered and considered as appropriate.	5 and separate report on migratory birds in Technical Report D: *Terrestrial ecology impact assessment*
	As appropriate, identify the different uses which significant species may make of different habitat areas that could be affected by the project at different times or life-cycle stages.	11
	Identify the marine or intertidal fauna and flora that could be affected directly or indirectly by the FSRU, including but not limited to entrainment through pumping system, susceptibility to changed water temperature or susceptibility to discharges containing chlorine or other pollutants.	10
	Identify exotic marine organisms that are already present or established near the project.	5
	Identify flora and fauna that could be affected by the project's potential effects on air quality, noise or vibration, or could be disoriented or otherwise impacted by project lighting.	11
	Describe the biodiversity values that could be affected by the project, including: • native vegetation and any ecological communities listed under the EPBC Act or Flora and Fauna Guarantee Act; • presence of, or suitable habitats for, native flora and fauna species, especially those listed under the EPBC Act, Flora and Fauna Guarantee Act, and DELWP advisory lists; and • use of the site and its environs for movement by EPBC Act, Flora and Fauna Guarantee Act, and DELWP advisory list listed fauna species, including migratory species, and other protected species.	5, 12

Aspect	Scoping Requirement	Section Addressed
Biodiversity - To avoid, minimise or offset potential adverse effects on native flora and fauna and their habitats, especially listed threatened or migratory species and listed threatened communities as well as on the marine environment, including intertidal and marine species and habitat values.		
	Describe the existing threats present to biodiversity values, including: • direct removal of individuals or destruction of habitat; or disturbance or alteration of habitat conditions (e.g., habitat fragmentation, changes to water quantity or quality, fire hazards, etc.); • threats of mortality of listed threatened fauna; • presence of or risk of introduction of any declared weeds, pathogens and pest animals within and near the project area; and initiating or exacerbating potentially threatening processes under the EPBC Act or Flora and Fauna Guarantee Act.	5, 12
Likely Effects	Assess likely direct and indirect effects of the project and alternatives on native vegetation, ecological communities and habitats for protected fauna and flora species, known or likely to occur in or adjacent to the project works, in particular any species listed under the EPBC Act, Flora and Fauna Guarantee Act or DELWP advisory lists.	7, 8, 9, 10
	Assess likely direct and indirect effects of the project on marine environment through the introduction of exotic marine organisms	12
	Indirect loss of vegetation or habitat quality, that may support any listed species or other protected fauna, resulting from changes to the local hydrology (terrestrial) or hydrodynamics (marine), edge effects, habitat fragmentation, loss of connectivity, or other disturbance impacts arising from construction or operation, including noise, vibration and lights.	8, 9
	Assess likely direct and indirect effects of the project on the ecological character and habitat values of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site*, including but not limited to effects of entrainment, dredging and sediment mobilisation, potential introduction of exotic organisms, wastewater discharges, other waste streams, noise, vibration and light.	12
	Assess likely direct and indirect effects of the project and alternatives on protected fauna and their habitat, including threatened or migratory species listed under the EPBC Act, Flora and Fauna Guarantee Act or DELWP advisory lists, relative to existing hazards and risks and with regard to conservation or listing advices, action statements, recovery plans and threat abatement plans	12
	Assess likely cumulative effects on biodiversity-related values that might result from the project in combination with other projects or actions taking place or proposed nearby.	13
Mitigation	Identify potential and proposed design options and measures that could avoid, minimise, mitigate or manage significant direct and indirect effects on native vegetation and any listed ecological communities or flora and fauna species and their habitat including the ecological character of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site* and habitat values within or adjacent to the pipeline alignment.	14
	Best practice guidelines and standards must be considered when designing mitigations.	14

Aspect	Scoping Requirement	Section Addressed
Water and Catchment Values - To minimise adverse effects on water (in particular wetland, estuarine, intertidal and marine) quality and movement, and the ecological character of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site*		
Key Issues	The potential for adverse effects on the functions, environmental values and the ecological character of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site*.	12
	The potential for adverse impacts on water quality and environmental values due to dredging and sediment mobilisation, spills or other incidents during construction or operation.	7
Existing Environment	Describe marine, estuarine, intertidal waters and their environmental values that could be affected from changed water quality, sediment or water movement, due to the project.	5
	Describe the ecological character of the Ramsar Site, and related hydrological and environmental values protected under the EPBC Act, including their acceptable limits for change.	5 12
	Characterise the interaction between surface water and marine waters within the project and broader area.	5 and Technical Report E: *Surface water impact assessment*
	Characterise the area's hydrodynamics and coastal processes and modelling techniques utilised to do so.	5, 6
Likely Effects	Identify and evaluate effects of the project on wetlands near the project works, including the likely extent, magnitude and duration (short and long term) of changes to water quality, water level, temperature or flow paths during construction and operation, considering appropriate climate change scenarios and possible cumulative effects resulting in combination with other existing or proposed projects of actions	7, 8, 9, 10
	Identify and evaluate effects of the project on wetlands near the project works, including the likely extent, magnitude and duration (short and long term) of changes to water quality, water level, temperature or flow paths during construction and operation, considering appropriate climate change scenarios and possible cumulative effects resulting in combination with other existing or proposed projects of actions	11
	Assess the impacts of the construction and operation of the project on the Ramsar Site, particularly potential substantial and/or measurable changes to the hydrological regime, in the context of ecological character description and acceptable limits for change. Ensure a systems-based assessment with marine water quality, hydrodynamics and marine ecology studies undertaken together.	11
Mitigation	Identify and evaluate aspects of project works and operations, and proposed design refinement options or measures, that could avoid or minimise significant effects on water, wetlands and marine environments.	14

2.2 Project Alternatives

This report provides the assessment of potential impacts on marine water quality and marine biota and ecosystems. It includes a detailed description of:

- a description of the proposal that is assessed in this report;
- the existing conditions, based on information from previous studies and monitoring programs,
- the procedures and results of additional field studies carried out as part of this EES;
- hydrodynamic modelling of the plumes from the various discharges to the marine environment, plus a regional hydrodynamic model to assess larger scale movement and dilution of the discharge;
- modelling of the rate of transformation and decay of chlorine in the marine environment, and the exchange of heat between the waters of Corio Bay and the atmosphere;
- an assessment of the potential effects of the proposal in terms of temperature changes, chlorine concentrations and turbidity due to dredging;
- an assessment of the potential effects on marine biota including seagrass, plankton populations and the Ramsar site in the north of the bay.

Alternatives to the proposal are addressed in Chapter 3 of the EES document.

This report addresses:

- alternative discharge locations (via existing refinery outlets or a new diffuser);
- alternative chlorine decay rates;
- alternative chlorine discharge concentrations; and
- open and closed loop operation of the FSRU.

The proposal involves transferring the discharge from the FSRU to the refinery, for reuse in the refinery. An alternative of collecting and transferring the refinery discharges to the FSRU was suggested by a reviewer and was considered. The main benefit would be to transfer the diluted plume from the refinery shoreline, where it has been for the last 60 years or more, to a deeper location on the seabed within the port. The main disadvantages would be that the requirement by the FSRU for seawater is normally well under the rate of discharge from the refinery, so some shoreline discharges would occur in any event. Other considerations are the extra complexity of piping and pumping the four existing, and widely spaced, discharges to the FSRU and to need to design for intermittent refinery closure.

Studies have shown that the impacts of the existing shoreline discharges are minimal, and the chlorine plume does not reach the Ramsar site, so there was not a strong reason to adopt this alternative.

2.3 Associated Reports

As stated above, this report focusses on marine water quality and marine biota and ecosystems. There are separate reports addressing the following aspects:

- Noise in the marine environment from dredging, construction and operations (refer to Appendix A-3: Underwater noise impact assessment);
- Terrestrial ecology, including the study of migratory birds using the Ramsar site (refer to Technical Report D: *Terrestrial ecology impact assessment*);
- Detailed description of structure and predictions of hydrodynamic model;
- Procedures and results from phytoplankton surveys in Corio Bay;
- Procedures and results from zooplankton surveys in Corio Bay;
- Procedures and results from ichthyoplankton surveys in Corio Bay; and
- Technical report on benthic habitat.

There are no interactions between the marine components of the proposal and freshwater.

3 Legislation, Policies and Guidelines

Table 3-1 summarises the key environmental legislation and policies that apply to the project in the context of this marine ecology and water quality impact assessment, as well as the implications for the project and the required approvals (if any).

Table 3-1. Register of Relevant Legislation and Policies

Description	Implications for the Project	Approval required
International standards / commitments		
The Convention on Wetlands of International Importance was the first modern treaty between nations aimed at conserving natural resources. The Convention became known as the Ramsar Convention in 1971 when it was signed in Ramsar, Iran. With the goal of stopping worldwide loss of wetlands and promoting conservation, the Convention requires international cooperation and relevant policy making. Wetlands of International Importance are designated sites containing representative, rare or unique wetlands or wetlands that are considered important in conserving biological diversity. Australia currently has 66 Wetlands of International Importance listed under the Ramsar Convention, which cover approximately 8.3 million hectares.	The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site is located approximately one kilometre to the north-east of the project. The Minister considered the project to be a controlled action due to potential significant impact on the Port Phillip bay (Western Shoreline) and Bellarine Peninsula Ramsar wetland, listed threatened species and ecological communities and listed migratory species.	Approval of controlled action required under the EPBC Act
Commonwealth		
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).		
The EPBC Act is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage Matters of National Environmental Significance (MNES) including, but not limited to, World Heritage Properties, National Heritage Places, Ramsar sites, nationally listed threatened species and ecological communities and listed migratory species. The EPBC Act states that 'controlled' actions i.e. actions that are determined as likely to have a significant impact on a MNES are subject to assessment and approval under the EPBC Act.	On 21 January 2021, the delegate for the Commonwealth Minister for the Environment determined the project to be a controlled action due to potential significant impact on the Port Phillip Bay (Western Shoreline) and Bellarine Peninsular Ramsar site, and listed threatened species and ecological communities and listed migratory species. The EES process is accredited to assess impacts on MNES under the EPBC Act through the Bilateral Assessment Agreement between the Commonwealth and the State of Victoria. Therefore, the Project will be assessed under the bilateral agreement.	Approval of controlled action required

Description	Implications for the Project	Approval required
Biosecurity Act 2015 (Biosecurity Act)		
The *Biosecurity Act 2015* sets out the legal framework for managing biosecurity threats (pests, weeds and diseases) to plant, animal and human health, and the environment.	This Biosecurity Act prescribes how ballast water should be managed within Australian seas, establishing obligations for vessels to: • manage ballast water prior to arrival in Australian seas, and between Australian ports • carry a ballast water management plan, ballast water management certificate, and maintain ballast water records. • All vessels associated with the project, including the FSRU and LNG carriers, would need to comply with the requirements of this Act.	No approvals required.
State		
Environment Protection Act 2017 (Environment Protection Act)		
The Environment Protection Act aims to protect Victoria's air, water and land by adopting a 'general environment duty' (GED) which imposes a broad obligation on entities and individuals to take proactive steps to minimise risks of harm to human health and the environment from pollution or waste. The Environment Protection Authority administers the Environment Protection Act and subordinate legislation	The Environment Protection Act regulates discharges to land, surface water or groundwater by a system of development and operating licences. Any discharge into a waterway or groundwater during the construction or operation of the project must be in accordance with the requirements of the Environment Protection Act. The GED requires all reasonably practicable steps be taken to minimise impacts from the construction and operation of the project.	The FSRU component of the project would require a development and operating licence. The refinery would also require a development licence, or exemption, and the current refinery operating licence would also need to be modified for the new activity.
Pipelines Act 2005 (Pipelines Act)		
This is the primary act governing the construction and operation of pipelines in Victoria. The Pipelines Act covers 'high transmission' pipelines for the conveyance of gas, oil and other substances. DELWP and Energy Safe Victoria (ESV) are responsible for administering the Pipelines Act and the Pipelines Regulations 2017.	The project requires a pipeline licence under the Pipelines Act for the construction and operation of the pipeline.	Pipeline licence required
Flora and Fauna Guarantee Act 1988 (FFG Act)		
The FFG Act is the primary Victorian legislation for the conservation	The FFG Act established the process for identifying, listing and managing	The FFG Act requires

Description	Implications for the Project	Approval required
and management of threatened species and communities, with the objective to 'guarantee' the future of Victoria's flora and fauna.	threatened species that must be considered in the impact assessments prepared as part of the EES for the project.	a permit for 'taking' of any FFG Act listed fish species by the operation of the FSRU
Fisheries Act 1995		
The *Fisheries Act 1995* Provides the framework for the regulation, management and conservation of Victorian fisheries including aquatic habitats.	This Act requires the protection of declared protected aquatic biota and fish and aquatic invertebrates listed under the FFG Act, some of which may occur within the project area.	The Fisheries Act requires a permit to take any declared Protected Aquatic Biota.
Environment Reference Standard		
The *Environment Reference Standard* (ERS) is made under Section 93 of the Environment Protection Act. It sets out the environmental values of the ambient air, ambient sound, land and water environments that are sought to be achieved or maintained in Victoria and standards to support those values. Environmental values are the uses, attributes and functions of the environment that Victorians value. Standards for the environmental values are comprised of objectives for supporting different uses of the environment and indicators that can be measured to determine whether those objectives are being met.	The project would seek to minimise the potential for impacts on surface water quality to ensure that existing environmental values are protected, with priority given to maintaining environmental values of areas of high conservation value (Ramsar sites). The project would seek to meet environmental quality objectives and indicators to ensure that pollutants into receiving waters are at a level that supports the maintenance or improvement of the current condition within the bounds of natural variations.	No approvals required
Marine and Coastal Act 2018 (MACA)		
The primary objective of the MACA is to protect Victoria's marine and coastal environment. It provides an integrated and coordinated approach to planning and managing the Victorian marine and coastal environment by protecting the coastline and addressing the long-term challenges of climate change, population growth and ageing coastal structures.	Any use or development of the Victorian marine area or coastal Crown land within 200 metres inland of the high-water mark requires Ministerial consent under the MACA. The project requires consent under the MACA for the components of the project to which this Act applies, namely to 'use or develop, or undertake works on, marine and coastal Crown land'. Dredging works associated with the project will require consent as this requires the project to 'undertake works on marine and coastal Crown land'. Consent will also be required for the 'use and development of marine and coastal Crown land' through the installation of the FSRU and construction of the new pier arm, aboveground pipeline and piping from the FSRU to the existing refinery cooling water intake.	Ministerial consent for the use, development or works on marine and coastal Crown land.

Description	Implications for the Project	Approval required
Marine and Coastal Policy		
The Policy guides decision makers in the planning, management and sustainable use of our coastal and marine environment. It provides direction to decision makers including local councils and land managers on a range of issues such as dealing with the impacts of climate change, population growth and ageing coastal structures. The Policy includes a Marine Spatial Planning Framework (MSP Framework) which guides long term planning and management of Victoria's marine environment in an integrated and coordinated way. The Policy came into operation in March 2020, superseding the 'policy for decision making' parts of the *Victorian Coastal Strategy (VCS)* 2014. The "actions" in the VCS 2014 will remain valid until such time as a Marine and Coastal Strategy is made	The project would need to align with the strategic directions and provisions of the Marine and Coastal Policy. Policies and plans developed under the MACA will inform the Minister's decision on whether or not to consent to use, development or works on Crown land under the MACA.	No approvals required
Planning and Environment Act 1987 (P&E Act)		
The P&E Act establishes a framework for planning the use, development and protection of land in Victoria. The P&E Act provides for the preparation of planning schemes in each municipality consistent with the Victoria Planning Provisions and procedures by which planning schemes may be amended and planning permits obtained to govern land use and development.	For works not covered under the Pipelines Act such as the pier extension and ancillary pier infrastructure, FSRU and treatment facility planning approval will be required.	Planning Scheme Amendment to the Greater Geelong Planning Scheme

3.1 Guidelines

3.1.1 Commonwealth Guidelines

National Water Quality Management Strategy – Australia and New Zealand Guidelines for Fresh and Marine Water Quality

The National Water Quality Management Strategy (ANZG) – Australia and New Zealand Guidelines for Fresh and Marine Water Quality sets the water quality objectives required to sustain current environmental values for natural or semi-natural water resources in Australia and New Zealand. The document identifies limits to acceptable change in water quality that would continue to protect the associated environmental value. Meeting the guidelines would provide a level of certainty that there would be no impact on waterways or environmental values.

The National Assessment Guidelines for Dredging (NAGD)

The NAGD provides guidance on the assessment and management of dredged material to protect and preserve the marine environment from pollution related to dumping at sea.

Australian Ballast Water Management Requirements

The Australian Ballast Water Management Requirements provide guidance on how vessel operators should manage ballast water when operating within Australian seas in order to comply with the Biosecurity Act 2015. They also align to the International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004 (the Ballast Water Management Convention), which entered into force internationally on 8 September 2017.

National biofouling management guidelines for commercial vessels

This guideline outlines operational procedures and provides information for operators of commercial vessels to follow to assist in the prevention of marine pest introductions and translocations.

The vessels encompassed by these guidelines are primarily commercial trading ships, which include bulk carriers, container vessels, oil and gas tankers, livestock carriers and general cargo ships. However, cruise vessels and other passenger ships are also included because their size, operational activity and maintenance regimes are similar to commercial trading ships.

3.1.2 State Guidelines

Victorian Coastal Strategy 2014

The Victorian Coastal Strategy is established under the *Coastal Management Act 1995*. The Strategy gives guidance on the protection of significant environmental and cultural values, integrated planning and direction for the future, sustainable use of coastal resources, and suitable development on the coast. The strategy establishes sea level rise planning benchmarks. The project should consider implications of projected sea level rise on facilities and set design criteria accordingly.

The Minister for Energy, Environment and Climate Change launched the draft *Marine and Coastal Strategy*. This strategy has been made under the MACA.

3.1.3 Other Guidelines

The following guidelines apply to the Sampling Analysis and Quality Plan (SAQP):

- ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra, ACT.
- HEPA, 2020. PFAS National Environmental Management Plan 2.0, February 2020. Heads of EPA Australian and New Zealand (HEPA). • NAGD (2009) National Assessment Guidelines for Dredging, Commonwealth of Australia, Canberra, ACT.
- NEPC (2013) National Environment Protection (Assessment of Site Contamination) Measure 1999, as amended in 2013. National Environment Protection Council.
- Simpson SL and Batley GE (2016) Sediment Quality Assessment: A Practical Guide, Second Edition. CSIRO.
- Simpson et al (2018) National Acid Sulfate Soils Guidance: Guidelines for the dredging of acid sulfate soil sediments and associated dredge spoil management. Department of Agriculture and Water Resources, Canberra ACT. June 2018.

3.2 Technical Criteria

Liquid Storage and Handling Guidelines. EPA 2018

This guide outlines the principles for preventing harm to the environment and human health when storing and handling liquid substances. This guide refers to bulk storage as well as smaller containers or packaged storage of liquid substances, and to liquids that are considered raw materials, product or waste.

Code of Practice: The Storage and Handling of Dangerous Goods

The code of practice provides practical guidance on how to comply with your obligations under Victoria’s occupational health and safety legislation for the safe storage and handling of dangerous goods.

4 Methodology for Marine Impact Assessment

This section describes how the marine ecology and water quality impact assessment was conducted to describe the existing environment and potential adverse effects on the marine environment.

A summary of the methodology for the marine ecology and water quality impact assessment is provided below:

1. Identify the factors influencing the characteristics of the existing marine ecosystem in Corio Bay;
2. Conduct an environment, social and economic issues risk screening to prioritise and focus the proposed investigations and impact assessment.
3. Identify the relevant project activities during construction, operation and decommissioning that have the potential to affect the marine environment
4. Identify the potential receptors, or aspects of the marine environment that could be impacted by the project and carry out targeted environmental investigations to develop an understanding of the existing conditions
5. Assess the potential impacts of the project activities on receptors by describing impacts in terms of the spatial extent, duration and magnitude of effect
6. Evaluate the vulnerability of marine biotopes (habitats), features and species to the project in accordance with the Feature Activity Sensitivity Tool (*FeAST*) described in the *Marine and Coastal Knowledge Framework (MACKF)* published by DELWP in 2021
7. Identify and recommend mitigation measures to avoid, minimise and manage potential impacts
8. After all feasible management and mitigation measures have been defined, assess the residual impact.

4.1 Feature Activity Sensitivity Tool Methodology

In May 2021, the Biodiversity Division of DELWP published a new marine risk assessment methodology called the Feature Activity Sensitivity Tool (FeAST). The FeAST methodology evaluates the vulnerability of marine biotopes (habitats), features and species to proposed developments and activities. Use of FeAST is intended to meet the objectives of the Marine and Coastal Act 2018 and Marine and Coastal Policy 2020, Environmental Effects Act 1978, Environment Protection Act 2017, Flora and Fauna Guarantee Act 1978, Wildlife Act 1975 and Environment Protection and Biodiversity Conservation Act 1999; as well as statutory plans such as the Port Phillip Bay Environmental Management Plan 2012-2027. The FeAST methodology is described in the Marine and Coastal Knowledge Framework (MACKF) published by DELWP in 2021.

The MACKF was developed to meet the recommendation of the Commissioner for Environmental Sustainability in the State of the Bays 2016 Report for assessing environmental outcomes of proposed activities in Western Port and Port Phillip Bays. In the State of Environment Report 2018, the Commissioner further recommended the MACKF be expanded to include all marine and coastal

environments. A summary of the procedures in FeAST, and the associated Biotope Classification Scheme (CBiCS) is presented in this Section.

4.1.1 Marine Food Chain

The basic cycle of life on earth begins when plants and algae (in aquatic environments and on land) produce cellular material using solar energy, carbon, nutrients and water. This plant material provides energy and nutrients for animals and they produce their own tissues. The food chain continues upwards, typically with larger animals being higher in the food chain than smaller animals: hence, the larger animals often consume the smaller ones.

In the end, all plants and animals die, and their remains are converted by micro-organisms (bacteria and fungi) back to nutrients that can be used by plants, hence restarting at the bottom of the chain.

The same basic cycle occurs in the aquatic environment. Figure 4-1 shows a simplified marine food chain (excluding the decay steps). As discussed, the simplified food chain diagram depicts dominant species, such as sharks, at the top with primary producers, such as phytoplankton, at the bottom. In practice, the marine food chain, and the multi- dimensional marine food web, have thousands of components, connections, interactions and synergies that can be incorporated. Even so, useful conclusions for this study were drawn from consideration of the marine food chain.

4.1.2 Factors Influencing Characteristics of the Marine Ecosystem

The factors that influence the characteristics of the marine ecosystem in Corio Bay can be considered in three groups:

1. Physical and hydrodynamic factors;
2. Chemical factors; and
3. Biological factors.

It should be noted that the *Biotope Classification Scheme* has a similar arrangement, where there are five levels, based on the same factors, as listed below.

Level 1 – Environment - the European Nature Information System (EUNIS) list of major environments such as marine (including estuarine), coastal, inland surface waters and constructed environments

Level 2 – Broad Habitat – where broad habitats are segregated by habitat zones and substratum type (sediment, coral reef, rock and other hard substrata). Zones are defined following standard zonation of coastal and marine environments

Level 3 – Habitat Complex - rock and other hard substrata are segregated on the basis of energy levels while sediments are segregated on the basis of grain size.

Level 4 – Biotope Complex - At this level of the hierarchy, biotopes are grouped into sets with similar physical and biological characteristics. This grouping usually has spatial consistency that can be mapped using remote sensing products. At the biotope complex level, there is predictability in biological assemblages and abiotic parameters.

Level 5 – Biotope - Biotopes are segregated on the basis of community

composition and/or diagnostic species. Diagnostic species could be dominant or in low abundance but frequently occurring and thus are ‘indicative’ of a specific biotope.

A range of estuarine and marine sediment beds in estuarine and marine environments have been classified using this method, which provides a standard nomenclature through the cataloguing system.

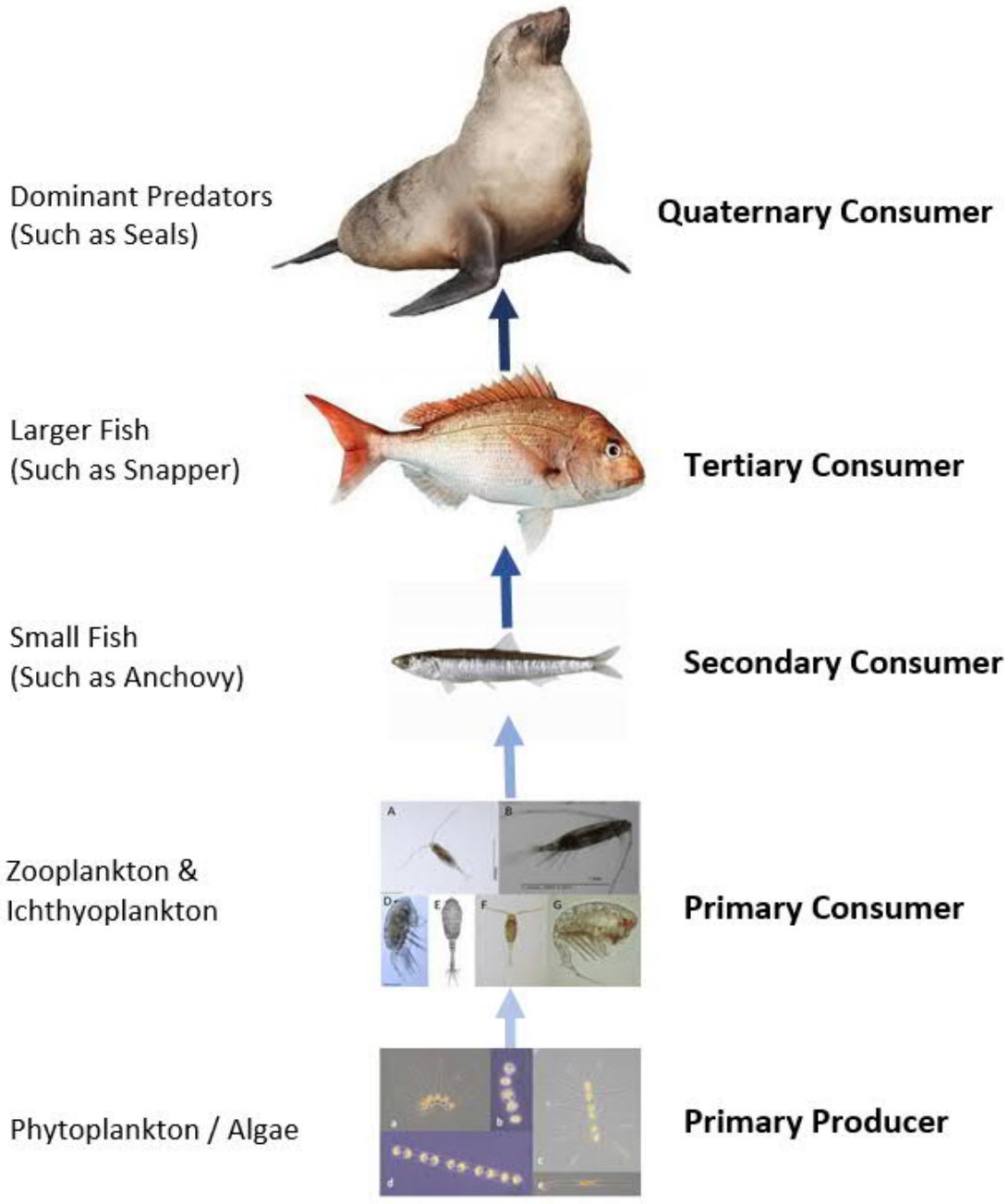


Figure 4-1. Simplified Marine Food Web Diagram

4.2 Physical and Hydrodynamic Factors

The **total aquatic habitat** for marine organisms in Corio Bay is *300 million m^3* which is the volume of water in Corio Bay (west of the line between Pt Lillias and Pt Henry).

The range between **high and low tide** (spring tide range of 1.0 m and neap tide range of only 0.2 m), coupled with the gradient of the intertidal zone, directly determines the area of the intertidal zone, and the duration that areas of the intertidal zone are exposed to submerged or atmospheric conditions. Tides are discussed in greater detail in Section 5.3 of the Environmental Context of Cori Bay Section.

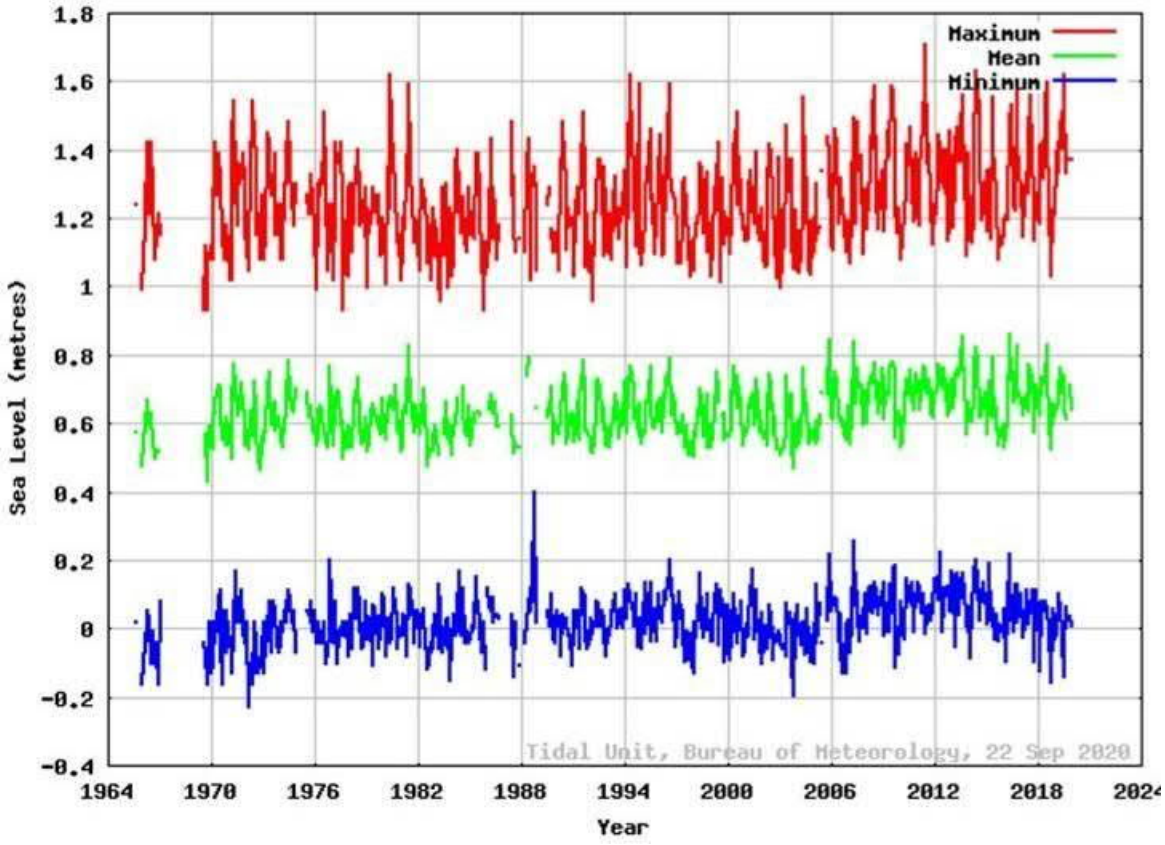


Figure 4-2. Monthly Minimum, Mean and Maximum Sea Level at Geelong

Figure 4-2 shows the minimum, mean and maximum monthly sea level measured at the Port of Geelong from 1965 to 2020. The variations in sea level are due to the tides and other factors such as atmospheric pressure variations, the effects of winds and currents in Bass Strait. The maximum water level in Corio Bay varies from 1.0 m to around 1.6 m (above lowest tide). Thus, plants and animals near the top of the water range have widely varying exposure to immersion or exposure to the atmosphere from hour to hour and day to day.

4.2.1 Sea level

Sea level in eastern Australia, including in Corio Bay, has been rising at a steady rate for a long period due to accelerated climate change. Records of tide levels from 1880 show that sea level has risen 220 mm over 140 years, at a rate averaging 1.6 mm/yr. Figure 4-3 shows the annual average sea level at Geelong for 1966 to 2020. The annual average sea level can vary by ± 0.12 m from year to year, but the long-term trend up to 2020 is an annual increase in sea level averaging 1.6 mm/yr.

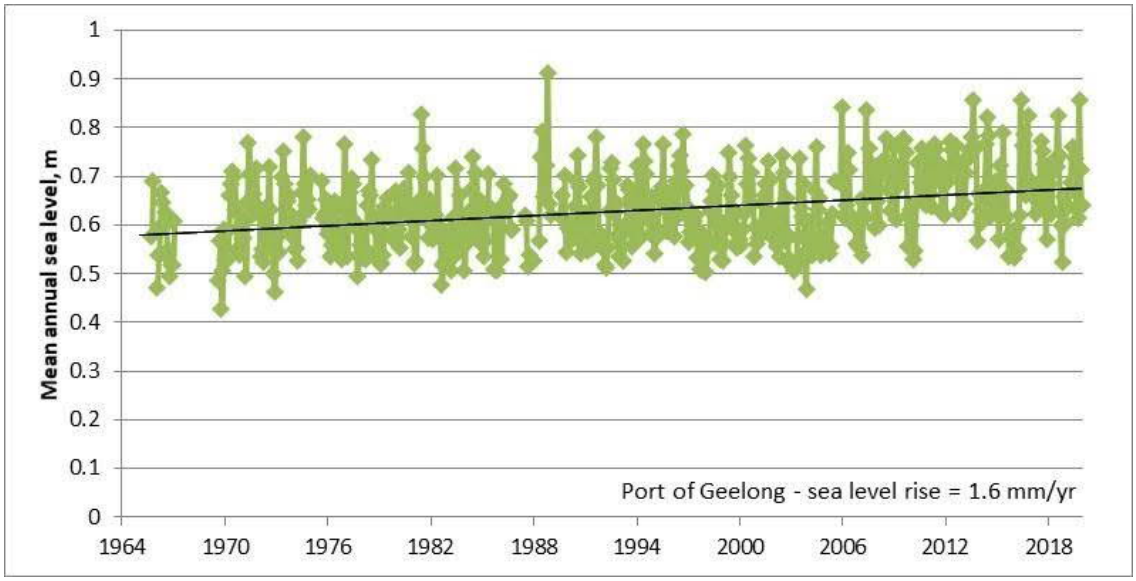


Figure 4-3. Change in Monthly Mean Sea Level at Geelong over Time

The waters of Corio Bay become slightly deeper each year. The **annual increase in sea level** adds about 69,000 m^3 of seawater (and marine habitat) to Corio Bay each year. This provides extra habitat for pelagic species.

Plants and animals that live around the periphery of Corio Bay, whose habitat is restricted by seawater level, need to adjust to the changing sea level. For a typical foreshore slope of 1 in 80, beds of plants (such as seagrass) need to move shoreward at a rate of about 1 m every 8 years. This example shows that the marine environment of Corio Bay adjusts each year due to sea level changes. However, due to the urbanisation and industrialisation around the shoreline of Corio Bay, in some places there is limited room for these habitats to recede.

Another factor that changes the volume of seawater in Corio Bay is the **dredging of channels.** In Corio Bay to the west of Point Henry, there is about 10 km of dredged channels (see Figure 4-4) that are 120 to 200 m wide and have a depth of 12.3 m at lowest tide. The seabed in the channels is 4 to 5 m below the natural seabed level, so that the volume of seawater in Corio Bay has been increased by *6,700,000 m^3* (about 3.2 %) due to dredging of channels.

Dredging of channels in Corio Bay has increased the available **deep-water habitat.** This is not inevitably a beneficial or detrimental impact, as there are a range of consequences that follow from more deep-water habitat, including the possibility of intrusion of cooler or more saline water, opportunities for species that are favoured by deep water or variations in water movement and circulation patterns, with related small or perhaps large changes in population distributions. These issues can be explored through an understanding of the marine food web in Corio Bay.

Other major hydrodynamic factors that influence environmental conditions in Corio Bay are the movement and exchange of water due to the tides, wind-induced currents, wave-induced mixing, sediment transport and freshwater inflows, each of which is discussed below.

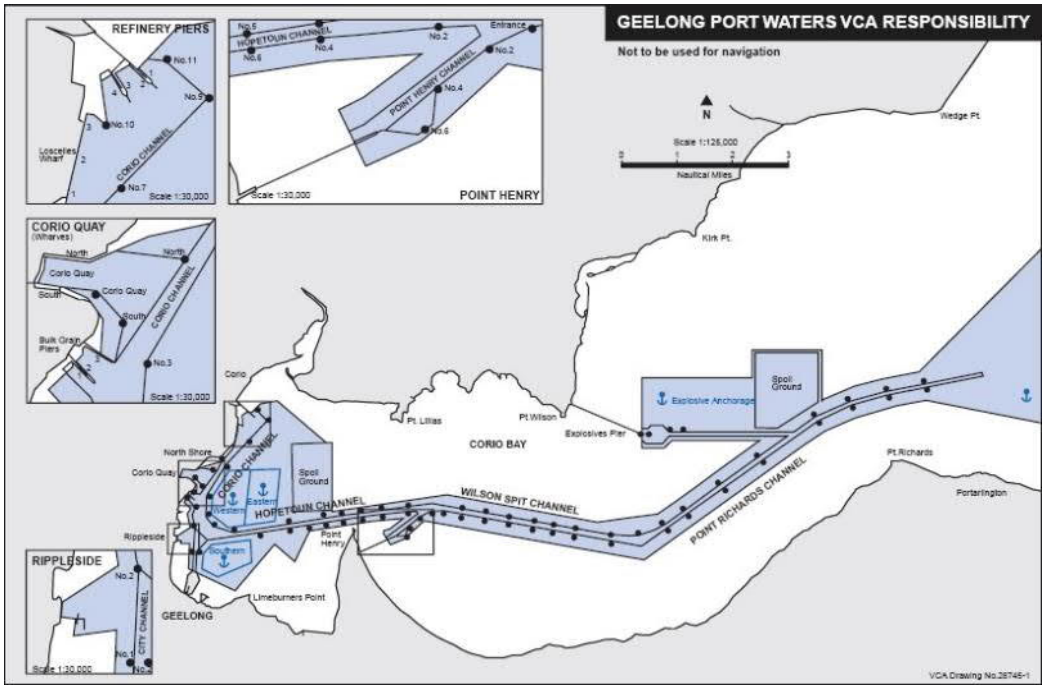


Figure 4-4. Dredged Channels in Inner Corio Bay and Outer Harbour

4.2.2 Tides

Corio Bay has an average depth of 8 m, and the **tidal range** averages 0.6 m (from low tide to high tide). There are larger spring tides and smaller neap tides, as explained in the previous section. The tides in Corio Bay are semi-diurnal, which means there are two high and two low tides each day. Tides are the most important factor influencing currents in Corio Bay and exchange of water with Port Phillip.

On average, from low tide to high tide, 26 million m^3 of seawater enters Corio Bay from the Outer Harbour, increasing the volume of seawater in Corio Bay by around 7.5%. The same volume leaves Corio Bay between high tide and low tide. These tidal flows means that there is a regular exchange and replacement of some of the waters in Corio Bay each day.

Port Phillip Bay has a volume of 25,000 million m^3 which is almost 80-times the Corio Bay volume of 300 million m^3. Thus, biological conditions in Port Phillip Bay have a dominating influence on conditions in Corio Bay.

4.2.3 Winds

The wind is the second-most important factor influencing currents in Corio Bay and a critical component for vertical mixing. Periods of strong winds generate vertical mixing and circulation patterns in Corio Bay that increase the rate of seawater exchange between Corio Bay and Port Phillip Bay. Figure 4-5 shows the wind roses for the 9 am and 3 pm wind patterns at Avalon Airport (which is close to Corio Bay). In the morning, winds from the west are dominant, but there are also frequent winds from the north and north-west, and occasionally winds from other directions. In the afternoon, winds from the south are dominant, but winds from the west remain frequent. The net effect is to cause a net clockwise circulation in Corio Bay. The dominant wind pushes Corio Bay water to the north with a corresponding outflow from the north-east sector and a corresponding inflow to the Bay in the deeper channels such as the Hopetown Channel.

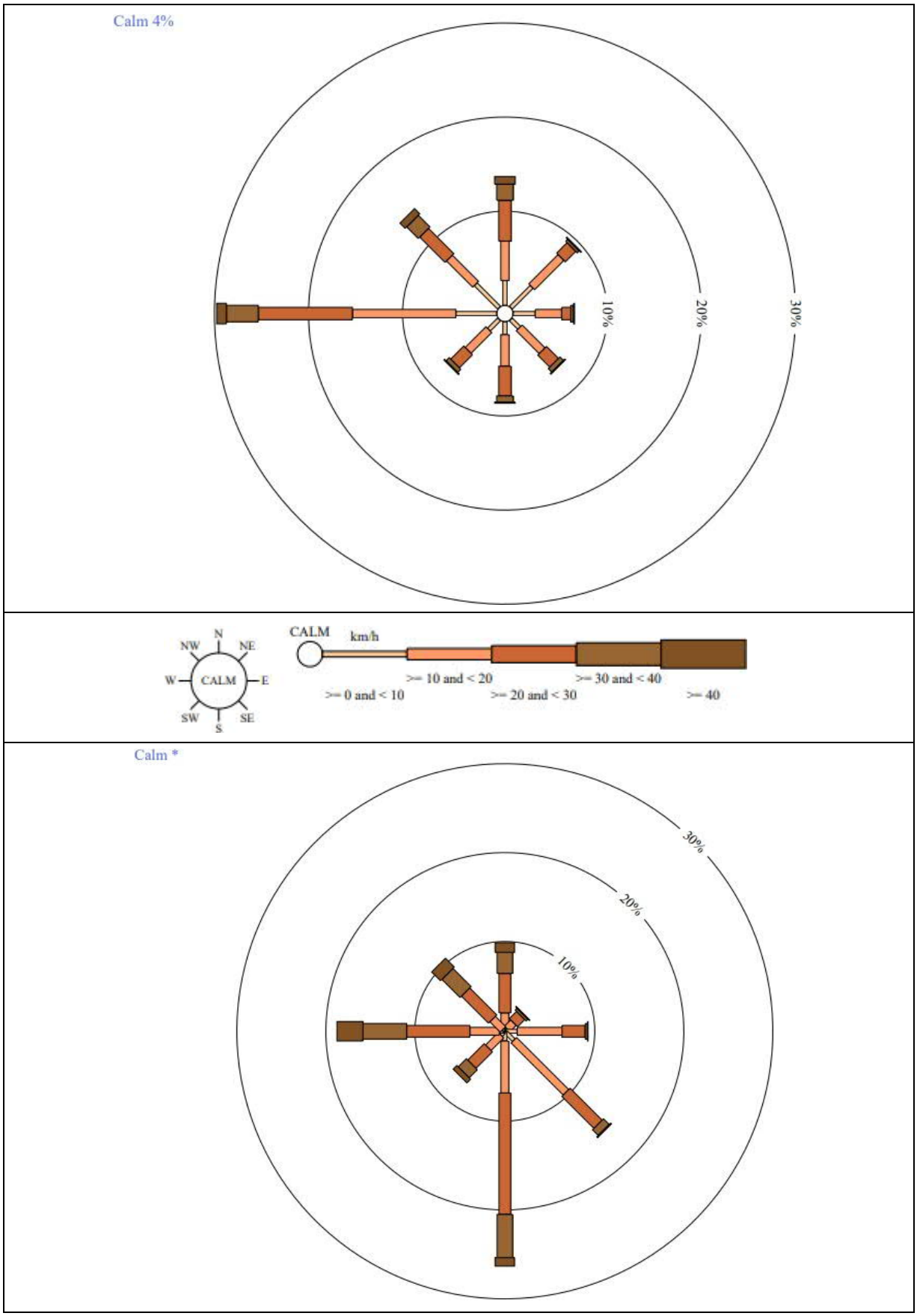


Figure 4-5. Annual 9 am and 3 pm Wind Patterns at Avalon Airport

4.2.4 Waves

Ocean swells cannot reach Corio Bay. Corio Bay has a short fetch and so wind-generated waves are seldom more than 1 m high. Waves break on the shores and shoals, and cause local mixing, erosion and sediment transport. There can be significant changes in sandy shorelines with large storms, or persistent sea breezes. Waves can create currents in shallow waters that carry water and contaminants (including sediments and seagrass) parallel to the shore.

4.2.5 Freshwater Inflows

Hovells Creek catchment extends around the north and west of Corio Bay. On average, the volume of freshwater runoff from this catchment is around 5 million m^3/yr, less than direct rainfall into Corio Bay averaging 21 million m^3/yr. Evaporation from Corio Bay is larger at 50 million m^3/yr.

As the loss of water due to evaporation exceeds rainfall and creek inputs, Corio Bay remains saline, sometimes slightly above the salinity of the waters in Port Phillip Bay and Bass Strait. As noted below, Corio Bay has a marine aquatic ecosystem.

4.2.6 Seabed Composition

The seabed composition has a major influence on the distribution of aquatic species. Some live only on rocky seabeds, others on sandy seabeds and yet others on muddy seabeds. Most of Corio Bay is classed as a muddy habitat, although there are narrow zones of sand near the coast. Areas of reef are very limited, and mostly found in shallow water around the coastline. Further details on the seabed composition are provided in the Section 5 Environmental Context of Corio Bay on the description of existing ecological conditions.

Note that the muddy or sandy seabeds in Corio Bay are heterogeneous, which provides the opportunity for a diversity of species to live in close proximity, and for competition between species on the seabed with similar characteristics.

4.2.7 Currents

Currents generated by tides, the wind and by wave action, influence the distribution of species. Some are favoured by strong currents and others by weak or stagnant currents. In general, currents in Corio Bay are considered weak, with a median current speed of around 0.04 m/s.

4.2.8 Turbulence

Turbulence, generated by currents and shear at the surface and seabed, influences the distribution of species. Some plankton species, for example, are favoured by strong turbulence while others may be damaged by them.

4.2.9 Light

Light transmission has a major influence on the distribution of species that require light for growth, or species that depend on others that need light for growth. As part of the assessment of the effects of dredging to extend to channel, measurements have been made of light transmission down through the waters of Corio Bay.

Photosynthesis can only occur when sufficient light penetrates down through the water column to support the needs of marine plants. The area with available light is called the photic zone. All primary productivity occurs in the photic zone, and as a result, most marine life lives in this upper zone.

Seaweeds and other plants have different sensitivities to light. Typically, brown algae

are found close to the surface, then green algae at around the middle of the photic zone and finally red algae at lower depths within the photic zone. Some animals have visual systems that see ultraviolet and polarized light (which people cannot).

Light makes it possible for aquatic predators to see their prey underwater. Artificial light alters the behaviour of fish. It is widely understood that artificial light will attract certain species of fish.

4.2.10 Noise

There is a noticeable level of noise underwater. Natural underwater noise is generated by waves, particularly breaking waves, wind shear, eddy turbulence, calls by mammals, clicking by shrimps, burrowing and other natural disturbances. Groups of whistling and echo-locating dolphins increase the noise level. Snapping shrimp are an important component of natural noise as well as fish. Many aquatic animals use sound to find prey, locate mates and offspring, avoid predators, guide their navigation, locate habitat, and to communicate with each other.

Over the last century, human activities such as shipping, recreational boating, construction, industrial activity and other activities have increased and created additional underwater noise.

4.2.11 Relationship to Biotope Descriptors

As discussed at the beginning of this section, the Level 2 – Broad Habitat descriptor for biotopes distinguishes ecosystems by water depth. The littoral zone consists of three subzones called the:

- supralittoral zone (above high tide line)
- intertidal zone (between high tide and low tide)
- sublittoral zone (low tide line down to where there is 1 % light intensity).

In Corio Bay, where the waters are often turbid, the seabed of the deeper mudflats and channels could be classed as the:

- circalittoral zone (seabed below the low tide line).

However, in FeAST this part of Corio Bay is classed as sublittoral sediment.

4.3 Chemical Factors

Chemical conditions impose limits on, and provide opportunities for, aquatic ecosystems.

The salinity of the water in Corio Bay is the factor responsible for Corio Bay having a marine aquatic ecology, and not an estuarine or freshwater ecology. The EPA monitoring of salinity in Corio Bay shows a regular seasonal cycle of salinity with a minimum of about 36.9 ppt in August to 37.4 ppt (parts per thousand) in March, due to the combined effects of rainfall, freshwater input and evaporation (as well as exchange with Port Phillip Bay). Thus, the salinity is always in a similar range to seawater.

4.3.1 Dissolved Oxygen

Dissolved oxygen is essential for most marine animals. Most dissolved oxygen in marine waters is a result of primary production by plants of various sizes (benthic microplankton, phytoplankton, seaweeds, seagrasses, kelp and mangroves) with a

smaller contribution from transfer of oxygen from the atmosphere to the water (re-aeration processes). The EPA monitoring of dissolved oxygen in Corio Bay shows there is abundant oxygen in solution in Bay waters (generally in the range of 93 % to 106 % saturation).

4.3.2 Water Temperature

The water temperature in Corio Bay varies diurnally in a small range and seasonally in a large range. As discussed in the previous section on the marine ecological context, the water temperature varies from around 10ºC (in late winter) to around 23°C (in late summer). The annual variation in Corio Bay water temperature corresponds to the annual variation in monthly average air temperature.

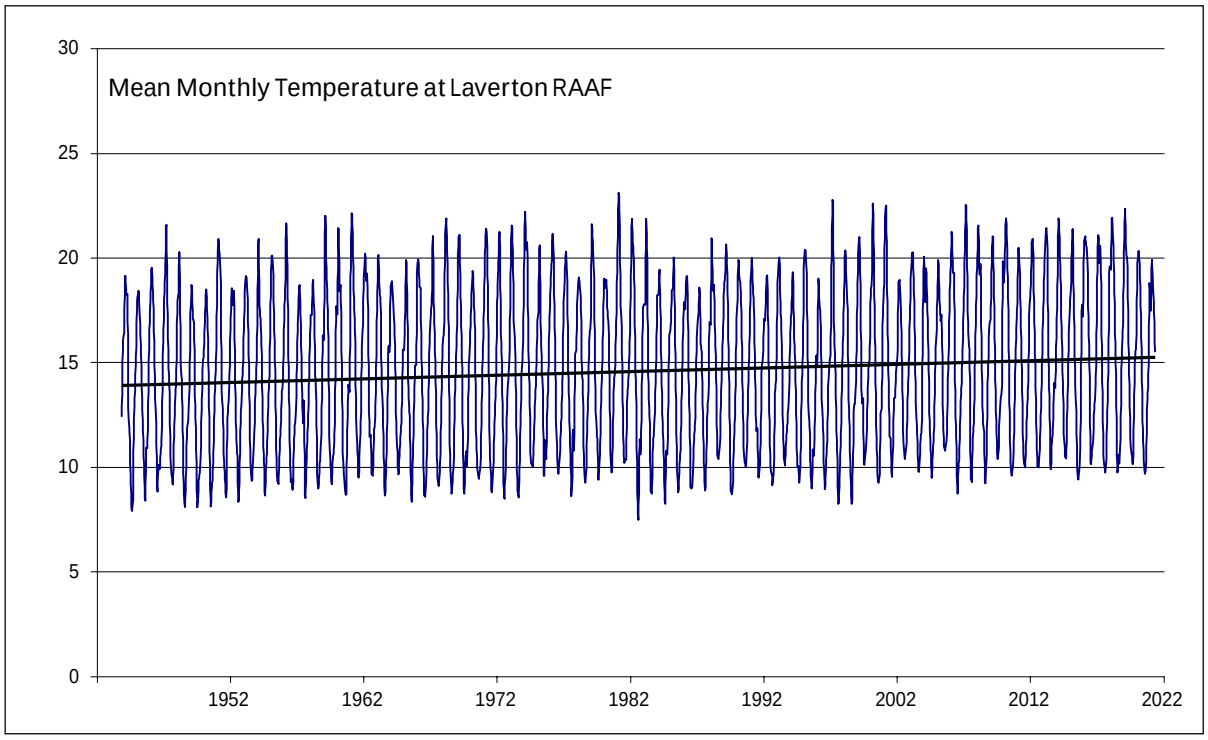


Figure 4-6. Annual Variation in Air Temperature at Laverton RAAF Site

Seawater temperature in Corio Bay has been rising at a steady rate in parallel to the rise in air temperature. There are no long-term records of seawater temperature for Corio Bay but air temperature at Laverton is considered to be a reasonable approximation. Figure 4-6 shows the annual average air temperature at Laverton for 1942 to 2021. During this 80-year period, there has been an increase in average annual temperature of approximately 1.5°C. Thus, aquatic biota in Corio Bay (and Port Phillip Bay) has been adjusting to a 1°C rise in water temperature approximately every 60 years.

Turbidity reduces light transmission through the water column and thus limits the depth range for growth of marine plants. High levels of turbidity also can be associated with excessive settlement of sediment with smothering of small organisms, shoreline erosion by waves, erosion of the shallow seabed, terrestrial runoff, plankton blooms and dredging.

4.3.3 Nutrients

Nutrients are essential for plant growth. Where there are more nutrients, there is

usually more plant growth, often of the species that can assimilate nutrients more rapidly than other species or have some other advantage to growth. In Port Phillip Bay, there is more plant growth (phytoplankton and large seaweeds) where the effluent from the Western Treatment Plant is discharged to the Bay.

The chemical form of nutrients and their availability over time (for example, the nitrogen in ammonia is more readily available to plants than the nitrogen in nitrate), and the combination of light and water temperature, directly influence marine plant growth. The total nitrogen concentration in Corio Bay averages 204 µg/L and the total phosphorus concentration averages 80 ug/L. There are sufficient nutrients for a productive marine system, with nitrogen as the limiting nutrient.

The ratio of available nutrients (particularly a high or low ratio of nitrogen to phosphorus) can provide an opportunity for some species and therefore directly influence the composition of the marine phytoplankton and algal communities. The operation of the Viva Energy re-gasification proposal does not involve the addition or removal of any nutrients, and therefore will not alter the nutrient composition of Corio Bay.

4.3.4 Metal Concentrations

Metal concentrations can be a constraint to growth (if too high or too low) or an opportunity (if available in the acceptable range). An inevitable consequence of human development (whether rural or urban or industrial) is that metal concentrations increase in marine waters downstream of the developments.

The sediments throughout Corio Bay have slightly elevated concentrations of metals – some occur naturally and other are a result of anthropogenic inputs. Other contaminant concentrations (such as dioxins or PFAS or micro-plastics) can be a constraint.

Bioaccumulation refers to the accumulation of a chemical in the tissue of a particular organism. Biomagnification refers to the increased concentration of a chemical in animals higher in the food chain. The process of biomagnification explains why mercury is naturally higher in large predators such as sharks and whales. It also demonstrates that releases of metals and chemicals that can bioaccumulate must be controlled and limited.

4.3.5 Oil Spills

Oil slicks form after a release or spill of liquid hydrocarbons into the environment. The oil is buoyant and spreads as a thin layer on the water surface, where it moves under the influence of wind and currents. A spill in the ocean leads to a much larger slick than the same spill on land.

Oil spills are particularly damaging to plants near the intertidal zone, as well as birds and mammals with fur. Oil spills can have disastrous consequences and spills cause intense community concern.

4.4 Biological Factors

As discussed in Section 4.2, the marine food chain is dependent on marine plants and algae which include phytoplankton, benthic microalgae, macroalgae and seagrass. Marine plants convert solar energy, water and carbon dioxide into glucose, which they use to grow tissue and reproduce. Phytoplankton do this very quickly – the life cycle of phytoplankton is typically one to three days and during this

time they can divide into two plankton organisms many times. In favourable conditions, a million plankton (contained in a few litres of seawater) can become two million plankton in a short period.

The composition of the plankton community in Corio Bay has been established by collecting seawater samples and counting the dominant species. Typically, there are about 360,000 phytoplankton cells in each litre of seawater, with the most common species being diatoms, although there is a range of other common species (see Figure 4-7). Phytoplankton generate about half the earth's oxygen and form the base of the marine food chain. Phytoplankton surveys are described in Section 5-9.

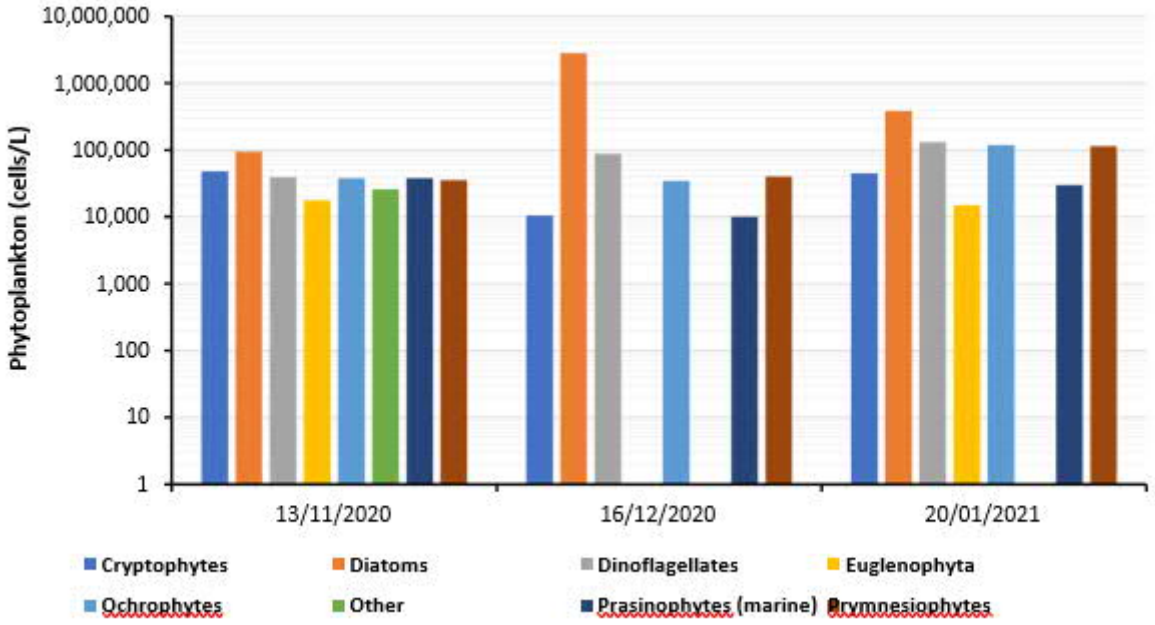


Figure 4-7. Phytoplankton Time Series in Corio Bay

There are billions of plankton competing for resources (space, sunlight, nutrients) in Corio Bay. Their numbers are limited by the availability of these resources and the pressure of predation by zooplankton and other filter feeders. Fish larval surveys are described in Section 5-12.

Zooplankton are the main predators of phytoplankton. Zooplankton are mostly very small invertebrate animals ranging in size from < 1 mm to a few millimetres that live in the water column. Some, like jelly fish and salps may be much larger. Zooplankton form the second rung in the food chain, feeding on phytoplankton and, in turn, being food for other zooplankton and small fish and invertebrates. Most zooplankton are filter feeders, using their appendages to strain phytoplankton, bacteria and other fine particles from the water. Others are predators, feeding on smaller zooplankton.

Zooplankton can reproduce rapidly, and populations can increase by about 30 % a day under favourable conditions. Zooplankton reach maturity quickly and live short but productive lives. Adult females can produce their body mass in eggs every two to three days and live for about one month depending on the species. Studies of copepods have found they can produce an average of 100 eggs/day.

The main competitive pressure faced by zooplankton is the competition for resources with their siblings. Each day, more than 99.9 % of the offspring of a

copepod must be eaten or lose in the competition for food and resources for a stable ecosystem.

At lower levels of the food chain, nature produces a great excess of offspring, of which only a tiny proportion can survive. But the large number of competitors provides the insurance that there will be a survivor, as one individual will not be eaten, find suitable resources and go on to reproduce the next generation.

Zooplankton are classified by size (picoplankton measure less than 2 µm; nanoplankton between 2 to 20 µm; microplankton between 20 to 200 µm; mesoplankton between 0.2-20 mm and macroplankton between 20 to 200 mm.

Holoplankton remain zooplankton for their entire life cycle and include pteropods, chaetognaths, larvaceans, siphonophores, and copepods. Meroplankton are actually larvae that eventually change into worms, molluscs, crustaceans, coral, echinoderms or fish. Further information on the common zooplankton species in Corio Bay is provided in Section 5 on field studies.

Zooplankton also include nanoplanktonic flagellates that eat bacteria. They are characterized by a long tail used for swimming (flagellates) or by hair-like structures called cilia (ciliates). Some dinoflagellates have a net-like structure called a protoplasmic net which is used to capture and eat prey that are larger than bacteria. Some dinoflagellate species are responsible for harmful fish kills and the infamous red tides.

All species of zooplankton have developed adaptations to float in the water column including spines to resist sinking by increasing the surface area of their bodies while minimizing the volume. Zooplankton also have mechanisms to deter fish (their heaviest predator) including transparent bodies, bright colours (hence red tides) and bad tastes.

4.4.1 Benthic Filter Feeders

While most zooplankton are filter feeders, there are also benthic filter feeders which reside on the seabed, such as mud clams and several species of worms. These species are not as effective at clearing the water column compared to zooplankton, although it is estimated that benthic filter feeders can clear the water column every 16 days (Wilson et al, 1993) (Melbourne Water, 1997). Infauna surveys are described in Section 5-16.

4.4.2 Fish

Small Fish form the next level of the food chain. The most common small fish in Corio Bay are gobies and anchovies (which together make up half the biomass of small fish). Anchovies spawn in Port Phillip Bay and Corio Bay and are an important food source for predators such as squid, fish and seabirds (including little penguins). Port Phillip Bay supported the largest commercial anchovy fishery in Victoria, before commercial fishing for anchovies was phased out in 2018.

Large Fish. As shown in Figure 4-1, small fish are eaten by large fish. Corio Bay and Port Phillip Bay were large commercial fisheries in the past. However, in 2016 the number of commercial fishing licences was reduced from 43 to 10 under the Government policy to remove netting from Port Phillip Bay by 2022. Commercial netting ceased in Corio Bay in 2018. Thus, Corio Bay now has only recreational fishing and aquaculture.

Important recreational fishing species in Corio Bay include King George whiting, snapper, flathead, Australian salmon, Australian anchovy, pilchards, yellowtail kingfish, silver trevally, garfish and gummy sharks (further details are in Section 5-11).

Commercial net fishing ended in 2018 after the phasing out of net fishing in the Bay in 2016. Nine commercial licence holders remain in Port Phillip Bay and continue to fish under strict catch limits (Victorian Fisheries Authority, 2018). This means that recreation fishing is now responsible for catching more fish in Corio Bay than commercial fishing.

Fish numbers vary considerably from season to season. King George whiting show a long-term increasing trend since 1978–79. Snapper catches are variable (partly due to spawning occurring in South Australian waters). Sand flathead numbers remain low compared with levels in the 1980s and 1990s. The abundance of other benthic fish species (including rays, stingarees and gurnards) declined substantially during the drought period, with the greatest declines occurring in the deeper parts of the bay.

Introduced Predators. Reductions in the abundance of some fish species has been attributed to competition with the numerous introduced species which have a similar diet to the native fish (Ref. State of the Bays Report, 2016).

Sea Urchins. Occasionally the marine food chain becomes out of balance. Purple sea urchins (*Heliocidaris erythrogramma*) are native to the Corio Bay and Port Phillip Bay. They feed on seaweed and seagrass. Urchin numbers and the cover of seaweeds and seagrass in Port Phillip Bay appear to vary over time in response to climate variation and nutrient inputs. However, over the last 30 years, there has been a sharp increase in the number of sea urchins in northern and western Port Phillip Bay and Corio Bay and a concomitant decrease in the cover of seaweeds on reefs. Little is known about changes to cover of algae on sand (attached or drift), though seagrass also varies markedly with climate. Deakin University is leading a program to cull sea urchins with support from the University of Melbourne and DELWP.

Large numbers of sea urchins grazing on the seagrass beds in Corio Bay have been observed by CEE biologist-divers causing significant damage to seagrass beds.

Decomposition. This brief analysis of biological factors has focussed on the upward section of the food chain. There is an equally important decomposition or downward section, which mostly involves bacteria and small filter-feeding animals living in the sediments, as well as detritus feeders, such as crabs, shrimps and snails. The decomposers return nutrients to the base of the food chain.

4.5 Risk Screening

A risk-based screening approach was used for the EES assessment in accordance with the requirements outlined in the ‘Ministerial guidelines for assessment of Environmental Effects under the Environment Effects Act 1978’ (page 14). The risk screening was undertaken to ensure that the level of investigation conducted in each technical study was adequate to inform an assessment of the significance and acceptability of the project’s potential environmental impacts.

An environmental, social and economic issues risk screening tool was used to prioritise and focus the proposed investigations, assessments and approaches to

avoiding, minimising or managing potential impacts. The issue screening process involved an evaluation of the potential environmental, social and economic issues associated with the project based on the information collected through a series of initial assessments undertaken into the potential effects of the project.

A risk workshop convened by a qualified risk practitioner and comprising technical specialists from the proponent, project design team and EES team conducted the initial risk screening. The risk screening process utilised knowledge of the project infrastructure and design, existing environment and land use setting to assess potential risks based on the specialised knowledge of the technical experts. This discussion of the hydrodynamic, chemical and biological factors that influence the characteristics of the marine ecosystem in Corio Bay provided the background for the risk-based screening. Technical experts in the risk screening were required to have a general understanding of these characteristics as well as a specialist understanding of a specific aspect of the proposed project or environment. This process ensured the risk screening was based on informed views and understanding of the impact pathways and receptors.

The purpose of the issues screening approach was to assist in identifying:

- Significant issues, uncertainties and/or potential impacts that require more detailed characterisation and/or assessment within the EES
- Matters or potential impacts considered to be already well understood or less significant.

A high, medium, or low screening value was assigned to potential issues to determine the level of assessment required to identify and investigate impacts.

Each potential issue was given a score (1, 2 or 3) against the categories of:

- Community and stakeholder interest
- Significance of assets, values and uses
- Potential impact (spatial, temporal and severity).

The scores were added together, or the highest score across the three contributing categories were used, to give a ‘screening value’ of high, medium or low, which gives an indication of the level of impact assessment that is required. Issues that were assigned a screening value of high or medium required detailed assessment in the EES at a level commensurate with them being considered primary level issues.

Issues that were assigned a screening value of low were proposed to be documented and managed with some investigation and assessment in the EES at a level commensurate with them being considered secondary level issues.

4.5.1 Criteria and consequence rating

Risks, issues, and potential impact pathways were identified for both construction and operation of the project. Table 4-1 defines the criteria and consequence ratings for each of the three categories that were used to inform the issues screening. The sum of the scores against each of the three categories gives the ‘screening value’.

Table 4-1. Issues screening criteria and consequence ratings

Rating	***Community and stakeholder interest***	***Significance of assets, values and uses***	***Potential impact (spatial, temporal and severity)***
1	Low interest and perceived impact	Locally significant asset, value or use	Potential for localised, temporary impact
2	Some interest and targeted perceived impacts	Regionally significant asset, value or use	Potential for significant temporary, or localised permanent impact
3	Broad community and stakeholder interest or impacts	State or nationally significant asset, value or use	Potential for significant permanent impact

The screening values are then used to determine the level of assessment required as shown in Table 4-2.

Table 4-2. Issue investigation categories

Significance Rating	***Screening value***	***Potential consequences***	***Complexity of mitigation***	**Level of assessment**
7, 8 or 9 or the highest rating across any one of the three contributing categories is 3	High	Potential for elevated, longer-term impacts, significant assets or values may be affected with enduring changes. Considers both impacts and benefits, or Issue may not be well defined and insufficient information is available for the impact assessment, or High level of community interest.	Stringent management measures may be required	Detailed assessment required
4, 5 or 6 or the highest rating across any one of the three contributing categories is 2	Medium	Potential for moderate level impacts, significant assets or values may be affected over an extended time frame with some resultant changes. Considers both impacts and benefits, or Issue may be moderately understood, and some information is available, however more is required for	Standard management measures are available that can be adopted with some modification	Moderate assessment required

Significance Rating	*Screening value*	*Potential consequences*	*Complexity of mitigation*	**Level of assessment**
		the impact assessment, or Medium level of community interest.		
3 or the highest rating across any one of the three contributing categories is 1	Low	Potential for short term and localised impact. Asset or values may be temporarily affected but recovery expected, or Issue is well understood and there is enough information available for the impact assessment, or Low level of community interest.	Standard management measures are available.	Some assessment required

4.5.2 Risk screening results

Table 4-3 Risk screening results

Aspect	Issue	Community & stakeholder perceived impacts	Significance of assets, values & uses	Potential impact (spatial, temporal & severity)	Screening Score	Screening Value
Construction						
Marine ecology and water quality	Potential impacts on marine habitat and water quality from mobilisation of sediments and contaminants	3	3	3	9	High
Marine ecology	Destruction of marine habitat from dredging activities	3	3	3	9	High
Marine ecology	Plumes of turbid water generated during dredging and disposal impact environmentally sensitive areas within and beyond Corio Bay e.g. seagrass, Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site	3	3	3	9	High

Aspect	Issue	Community & stakeholder perceived impacts	Significance of assets, values & uses	Potential impact (spatial, temporal & severity)	Screening Score	Screening Value
Marine ecology	Potential impacts on marine fauna from underwater noise generated from piling and dredging activities	1	1	1	3	Low
Operation						
Marine ecology	Discharge of ballast water from the FSRU and LNGC	2	1	1	4	Medium
Marine ecology and water quality	Warm water and chlorine discharge impacts on marine environment and water quality (if FSRU discharge reused in refinery via connection with intake)	2	3	2	7	High
Marine ecology and water quality	Cold water and chlorine discharge impacts on marine environment and water quality (if FSRU discharge direct to Corio Bay)	3	3	3	9	High
Marine ecology and water quality	Warm water and chlorine discharge impacts on marine environment and water quality (if FSRU operated in 'closed loop')	3	3	2	8	High
Marine ecology	Entrainment of plankton and larvae into FSRU	3	3	3	9	High
Marine ecology	Operational activities (including noise, vibration and lighting) impact on marine fauna	2	2	2	6	Medium
Marine ecology	Introduction of marine pests	1	2	2	5	Medium
Marine ecology	LNG carriers collide with large marine fauna (e.g. whales)	3	2	1	6	High
Marine ecology	Underwater noise generated by operation of the FSRU and visiting LNG carriers impacts marine fauna	2	2	2	6	Medium

4.6 Potential Impacts During Construction

The construction activities in the marine environment that the project would entail are as listed below.

- localised dredging over an area of 12 ha adjacent to the shipping channel for a new berth and turning basin (12 ha)
- excavation of a shallow trench for the seawater transfer piping
- transportation of 490,000m^3 of excavated seabed sediment in barges for disposal at the existing dredged material ground east of Point Wilson
- construction of a 570 m long pier extension to the north of the existing Refinery Pier with ancillary jetty infrastructure including marine loading arms, and a pipeline along Refinery Pier;
- installation of seawater transfer piping between the FSRU and the existing seawater intake to the refinery;
- installation of a diffuser under the new pier arm to discharge seawater from the FSRU at times when the intake capacity of the refinery is insufficient for reuse

Dredging would take between 5 to 10 weeks while pier arm construction, and diffuser and pipeline installation would take approximately 12 months.

4.7 Potential Impacts During Operation

Operation of the facility is assumed to have effects on the marine environment as listed below. As the basis for the marine impact assessment, it is assumed that:

The FSRU will be in operation for approximately 20 years;

- Up to 45 LNG carriers would visit Refinery Pier each year.
- The intake of seawater at the FSRU would be a maximum of 350 ML/d. For most of the year (except winter months) the intake would average 250 ML/d.
- The refinery would be operating for about 95 % of the year when the seawater from the FSRU would be transferred by pipe to the refinery seawater intake. There would be no change in the volume of the refinery discharges. It has been assumed that the Refinery would shut-down for maintenance for 5% of the year. Complete shutdown of the refinery during maintenance has been assumed to model and understand the impacts of the worst-case scenario.
- During refinery shut-down for maintenance, the cooler seawater from the FSRU would be discharged from the diffuser under the new pier arm.

4.8 Potential Impacts During Decommissioning

As the basis for the marine impact assessment, it is assumed that decommissioning would involve:

- Emptying the FSRU of LNG to the gas transmission system;
- Decoupling the FSRU from the pier structures;
- FSRU leaving the berth with tug assistance;
- Removing the transfer piping from the FSRU to the refinery seawater intake; and

- Leaving the pier extension and ancillary infrastructure, the diffuser and pipeline along Refinery Pier in place for other uses.

Once empty, we are advised that the FSRU could leave the mooring within 24 hours. Removing the transfer piping could take 2 to 4 weeks. There are no extra or significant impacts in decommissioning that are not addressed already in construction or FSRU operations.

4.9 Potential Impacts Requiring Detailed Assessment

The following potential impacts, described in Table 4-4, were identified as requiring a more detailed assessment for the marine ecology and water quality impact assessment.

Table 4-4. Potential Impacts Requiring Detailed Investigation

#	*Characteristics –Potential Impact*	*Impact pathway*	*Magnitude of effect*	Rating
1	Release of contaminants	Dredging	8 weeks	8
2	Chlorine discharge from refinery	FSRU and refinery	Continuous	8
3	Turbidity reduces light	Dredging	8 weeks	7
4	Subtidal – in photic zone	Dredging	8 weeks	7
5	Seagrass and communities	Dredging	8 weeks	7
6	Entrainment current near FSRU	FSRU	350 ML/d	7
7	Chlorine discharge from FSRU	FSRU	5 % of year	7
8	Seagrass and communities	Warm discharge plumes	Continuous	7
9	Migratory waders	Warm discharge plumes	Continuous	7
10	Subtidal – in photic zone	Chlorine in plumes	Continuous	6
11	Capture by entrapment	FSRU	Continuous	6
12	Capture by entrainment	FSRU	Continuous	6
13	Introduced pests	All marine construction	12 months	6
14	Introduced pests	LNG carrier	30 per year	6
15	Discharge current near diffuser	Diffuser	350 ML/d	6
16	Intertidal	Warm discharge plumes	Continuous	6
17	Shell/rubble with H banksii	Warm discharge plumes	Continuous	6
18	Sediment accumulation	Dredging	~100 ha	5
19	Shell/rubble with H banksii	Dredging	8 weeks	5
20	Migratory waders	Dredging	8 weeks	5
21	Iconic species	Dredging	8 weeks	5
22	Spills during construction	All marine construction	12 months	5
23	Spills during operations	FSRU and LNG carrier	12 months	5
24	Organics released in discharge	FSRU	Continuous	5
25	Pelagic and demersal fish	Intake and discharge	Continuous	5

26	Reduced temperature in plumes	FSRU and diffuser	Continuous	5
27	Cold plume from diffuser	FSRU and refinery	5 % of year	5
28	Iconic species	Intake and discharge	Continuous	5
29	Noise and light impacts	FSRU, LNG carrier and pier	Continuous	4

4.10 Methodology for Detailed Assessment

The methodology devised and implemented to develop a more detailed assessment of the impacts listed in Table 4-4 was as follows:

1. Develop 3-D hydrodynamic model of currents in Corio Bay;
2. Install current meter and measure salinity/temperature profiles to calibrate the hydrodynamic model;
3. Conduct hydrographic survey to establish bathymetry of Corio Bay for incorporation in model;
4. Analyse freshwater input to Corio Bay from Hovells Creek catchment;
5. Analyse proposed dredging envelope to derive change in seabed depths due to dredging and increase in seabed elevation in spoil disposal area;
6. Develop chlorine module in associated water quality model;
7. Field studies and literature review to establish rate of chlorine decay;
8. Develop temperature module in associated water quality model;
9. Field studies and literature review to establish rate of temperature transfer;
10. Analyse refinery monitoring data to establish discharge rates, temperature rise and chlorine concentration in the discharges to Corio Bay;
11. Assess predicted discharge rates, chlorine levels and temperature change in direct discharges from FSRU via the diffuser;
12. Assess predicted discharge rates, chlorine levels and temperature change in ballast water and closed loop operation of the FSRU;
13. Biological survey of Corio Bay to establish extent of habitats and ecotones.
14. Biological survey of Ramsar zone in north Corio Bay;
15. Monthly surveys of phytoplankton at sites in Corio Bay;
16. Monthly surveys of zooplankton at sites in Corio Bay;
17. Monthly surveys of fish larvae at sites in Corio Bay;
18. Measure light transmission at edge of Ramsar zone;
19. Develop discharge scenarios for assessment including:
    a. Existing discharge from refinery (4 plumes totaling 350 ML/d);
    b. Average discharge from FSRU with refinery operating;
    c. Peak discharge from FSRU with refinery operating;
    d. Average discharge from FSRU via diffuser (refinery not operating);
    e. Peak discharge from FSRU via diffuser (refinery not operating);
    f. Closed loop and ballast water discharge from FSRU.
20. Predict and assess chlorine levels for various discharge scenarios;
21. Predict and assess temperature changes for various discharge scenarios;
22. Assess potential impacts/effects on characteristics of the Ramsar zone including migratory waders;
23. Develop management measures to minimise the potential to introduce pests;
24. Develop management measures to minimise spills, and clean-up methods, for construction and long-term operations;
25. Assess entrapment impacts and develop management measures;

26. Assess entrainment impacts and develop management measures;
27. Assess implications of organics released in discharge plumes;
28. Develop turbidity and sediment settlement module in water quality model;
29. Assess changes in light transmission in Corio Bay and near spoil grounds; and
30. Assess physical and biological implications of proposed dredging

Baseline for Assessment

The refinery has been discharging warm chlorinated seawater on the shore of north Corio Bay for over 60 years. A key component of the proposal is that, by reusing the FSRU discharge in the refinery to replace the current seawater extraction, there will be no change in the rate of seawater extraction or discharge, and no change in the rate of chlorine discharge. As a result, there is no change from the impacts that have existed, are licenced and have been accepted for the last 60 years.

As the FSRU discharge is cooler, reusing it in the seawater circuit of the refinery will decrease the temperature of the discharge plumes by 5 to 7 ^{o}C, and make the temperature of the discharges closer to the natural ambient temperature. A change from elevated temperature towards natural conditions could be considered to be a positive impact. The assessment is provided in Section 8.

In the event that the refinery ceased to operate at some point in the future and reuse of FSRU water in the refinery was no longer an option, the FSRU would discharge to Corio Bay via a diffuser located on the proposed Refinery Pier extension and not via the four existing refinery discharge points. The diffuser, which would have numerous discharge points along its length, would facilitate rapid mixing of the cool water and residual chlorine with the plume being localised the area around the FSRU and berthing area for visiting LNG carriers. The potential impacts of discharge from the FSRU via the diffuser are discussed in Sections 8 and 9 of this report.

It is appreciated that there does appear to be a different baseline for assessment of impacts for discharge of chlorine and temperature. This is addressed by providing predictions of the chlorine and temperature conditions for existing and future conditions.

4.11 DELWP Methodology to Assess Environmental Risk

As requested by DELWP, the assessment of environmental risk in this project will following the sequence of steps defined in the FeAST documentation provided by DELWP in July 2021. The methodology involves the four stages shown in Figure 4-8 and outlined below.

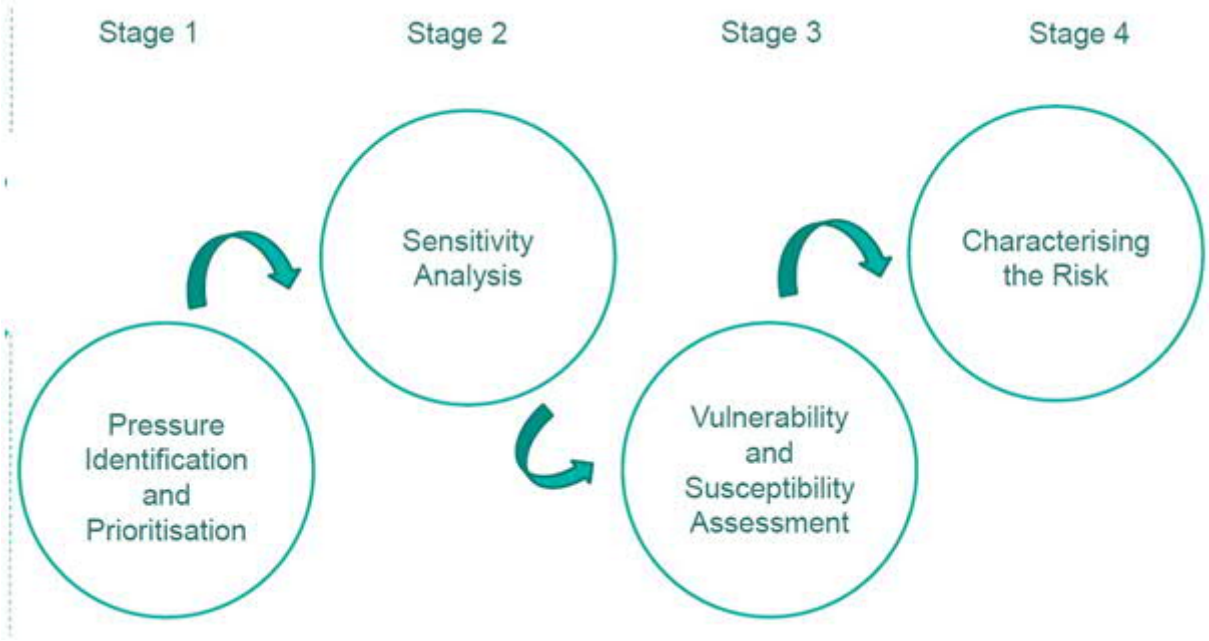


Figure 4-8. Four States in Feast Environmental Risk Assessment

4.11.1 Pressure Identification and Prioritisation

Pressures are factors or processes that stress marine ecosystems. The pressures listed below have been identified as those which pose a threat to marine ecosystems. The benchmark intensity of each pressure is identified, as well as the temporal extent and thus the magnitude of each pressure can be established.

- Abrasion
- Air noise
- By-Catch
- Collision Above
- Collision Below
- Electromagnetic
- Hydrocarbons
- Invasive Species
- Light Input
- Movement Barrier
- Nutrients
- Organics
- Organometals
- Radionuclides
- Seabed Loss
- Seabed Type Change
- Sediment Type Change
- Siltation Heavy
- Siltation Light
- Substrate Subtraction
- Substances
- Suspended Solids
- Synthetics
- Underwater Noise
- Vibration
- Visual Disturbance
- Water Flow

Table 4-5 shows the magnitude matrix used for establishing the magnitude of each pressure based on the intensity and frequency.

Table 4-5. Pressure Magnitude matrix

Magnitude of Pressure		Frequency			
		Persistent	Frequent	Regular	Occasional
		>3 times/yr	2-3 times/yr	1 time/yr	<1 time/yr
Intensity	High (3)	High	High	Moderate	Moderate
	Medium (2)	High	Moderate	Moderate	Low
	Low (1)	Moderate	Moderate	Low	Very Low
	Very Low (0)	Moderate	Low	Very Low	Very Low

4.11.2 Sensitivity Analysis

The next stage in the risk assessment process is to establish the sensitivity that each feature, species, ecosystem, biotope or habitat by establishing the likelihood of a negative change when a pressure is applied. This is derived through a sensitivity matrix for each pressure. The sensitivity matrix is shown below in Table 4-6.

Table 4-6. Pressure Sensitivity matrix

Sensitivity to Pressure		Resistance			
		Very Low (2)	Low (3)	Medium (4)	High (5)
		>75%	25-75%	25%	No Effect
Recovery	Very Low (2) >25 years	High (5)	High (5)	Moderate (4)	Low (3)
	Low (3) 10-25 years	High (5)	High (5)	Moderate (4)	Low (3)
	medium (4) 2-10 years	Moderate (4)	Moderate (4)	Moderate (4)	Low (3)
	High (5) <2 years	Moderate (4)	Low (3)	Low (3)	Very Low (2)

This step is evaluating the consequence of potential impacts for each pressure as having a magnitude greater than 3 on the following natural resources:

1. Natural, environmental and biodiversity features;
2. Habitats and biotope communities;
3. Matters of National Environmental Significance (MNES) as protected by the EPBC Act.

Once each relevant pressure is given a sensitivity score for each feature, species, ecosystem, biotope or habitat, the scores are averaged for a final aggregated weighed sensitivity score (%) with a single sensitivity value for each feature, species, ecosystem, biotope or habitat.

4.11.3 Characterising the Risk

The risk is determined from the risk matrix provided by DELWP and shown in Table 4-7.

The sensitivity score is applied on the vertical axis, and the exposure score on the other axis. For the example highlighted in Figure 4-9, a medium sensitivity (corresponding to 70 to 86 % sensitivity) and a high exposure (corresponding to more than 0.5 % of the biotope area potentially affected) results in a HIGH RISK.

The exposure levels are defined by the proportion (%) of the feature, species, ecosystem, biotope or habitat within a define\d area which is spatially impacted by the pressure resulting from the activity.

The scale of exposure has been assessed by understanding the area of spatial impact to habitats that occur within a marine bioregional distinct unit referred to as a biounit. The proposed area is inside the Port Phillip Bay biounit and therefore the exposure level to the habitat has been assessed using the distribution data available within the biounit. This has been combined with the sensitivity analysis on the biotopes.

Table 4-7. DELWP Environmental Risk Assessment Matrix

Environmental Risk		Exposure			
		None	Low	Medium	High
		None	<0.25%	0.25-0.49%	>0.5%
Weighted Sensitivity	Very Low (2) <55%	No Risk	Low Risk	Low Risk	Low Risk
	Low (3) 55-70%	No Risk	Low Risk	Low Risk	Low Risk
	medium (4) 70-80%	No Risk	Low Risk	Medium Risk	High Risk
	High (5) 85-100%	No Risk	Medium Risk	High Risk	High Risk

5 Environmental Context of Corio Bay

5.1 Introduction to Corio Bay

Corio Bay is a small bay in the western corner of Port Phillip Bay (see location map in Figure 5-1) that extends for 8.7 km north/south and 5.6 km east/west. The area of Corio Bay is 4,300 ha. Before the settlement of Geelong, a sandbar across the eastern side of the bay from Point Lillias to Point Henry (see Figure 5-2) prevented ships from entering Corio Bay. Channels were dredged through the sand bar between 1853 and 1893, allowing the development of the Port of Geelong and the shoreline for urban Geelong.

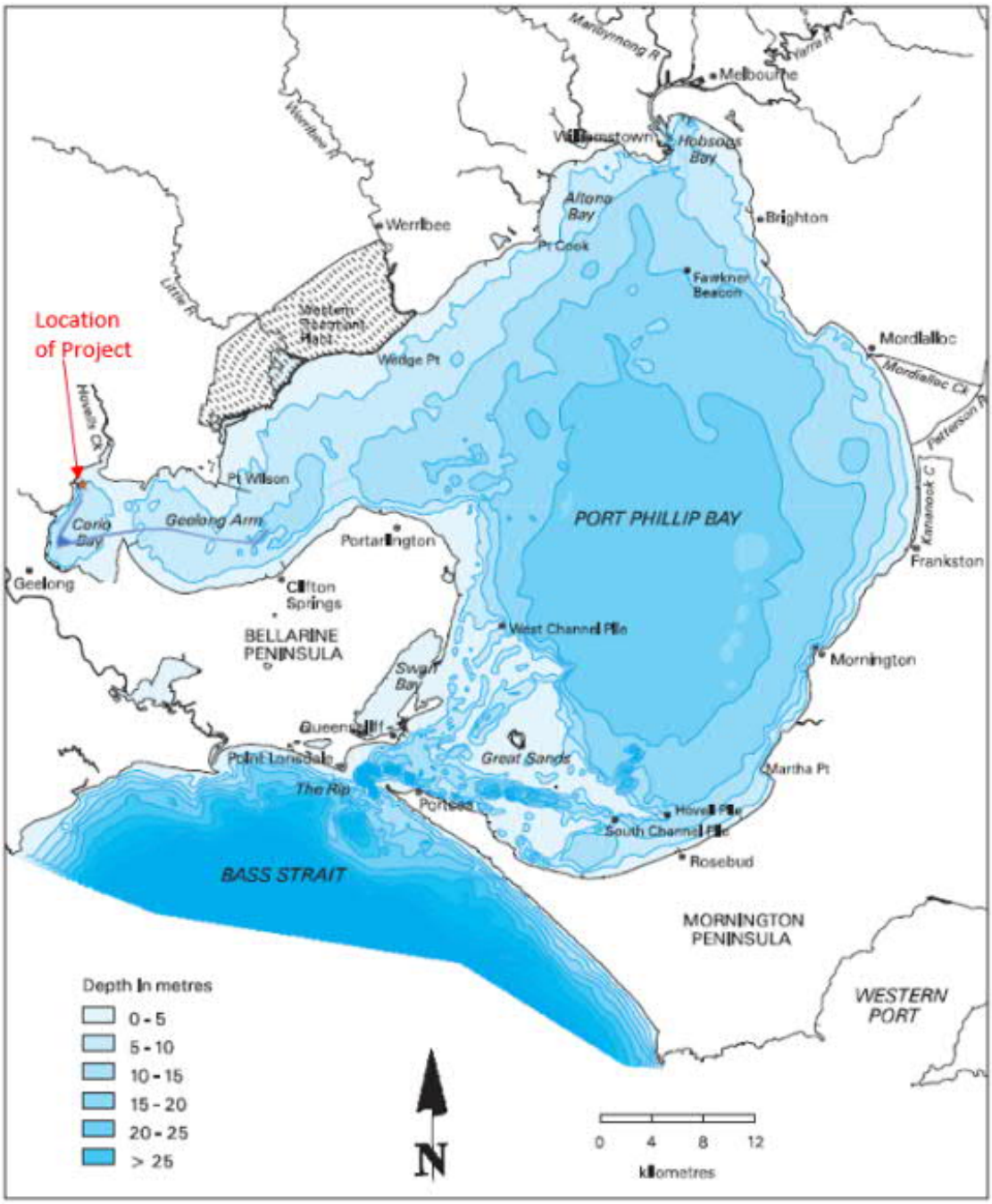


Figure 5-1. Port Phillip Bay, Corio Bay and Location of Project

5.2 Bathymetry of Corio Bay

The bathymetry of Corio Bay is characterised by a shallow perimeter and a deeper section over the centre of the Bay. Figure 5-2 shows bathymetric contours in the Bay. The north shore has shallow water, of less than 5 m, that extends up to 900 m from the shoreline. This area has dominant seagrass beds and small rocky reefs.

A sand bar runs across the east entrance of the Bay between Point Lillias and Point Henry with water of 2 to 5 m depth. The Hopetown Channel has been dredged through this sandbar from Port Phillip Bay to the jetties along the western shore. The channel is approximately 140 m wide and is maintained to a depth of 12.3 m (below LAT). The Corio Channel extends north from the Hopetown Channel and includes several turning basins for ships. There is a smaller channel maintained to a depth of 9.7 m which runs south from Hopetown Channel to the south port at Geelong.

In the south-east corner of the Bay, the 5 m depth contour is around 3 km offshore from the edge of the former Cheetham Salt Works, creating a large shallow area with extensive seagrass. The south-west corner has a much steeper gradient compared to the rest of the bay with the 5 m contour being only 300 m from the shore.

The central section of the bay is a broad and mostly flat zone with depths of 6 to 9 m. The average depth of Corio Bay is 7 m and the volume at mean sea level (MSL) is approximately 300 million m^3.

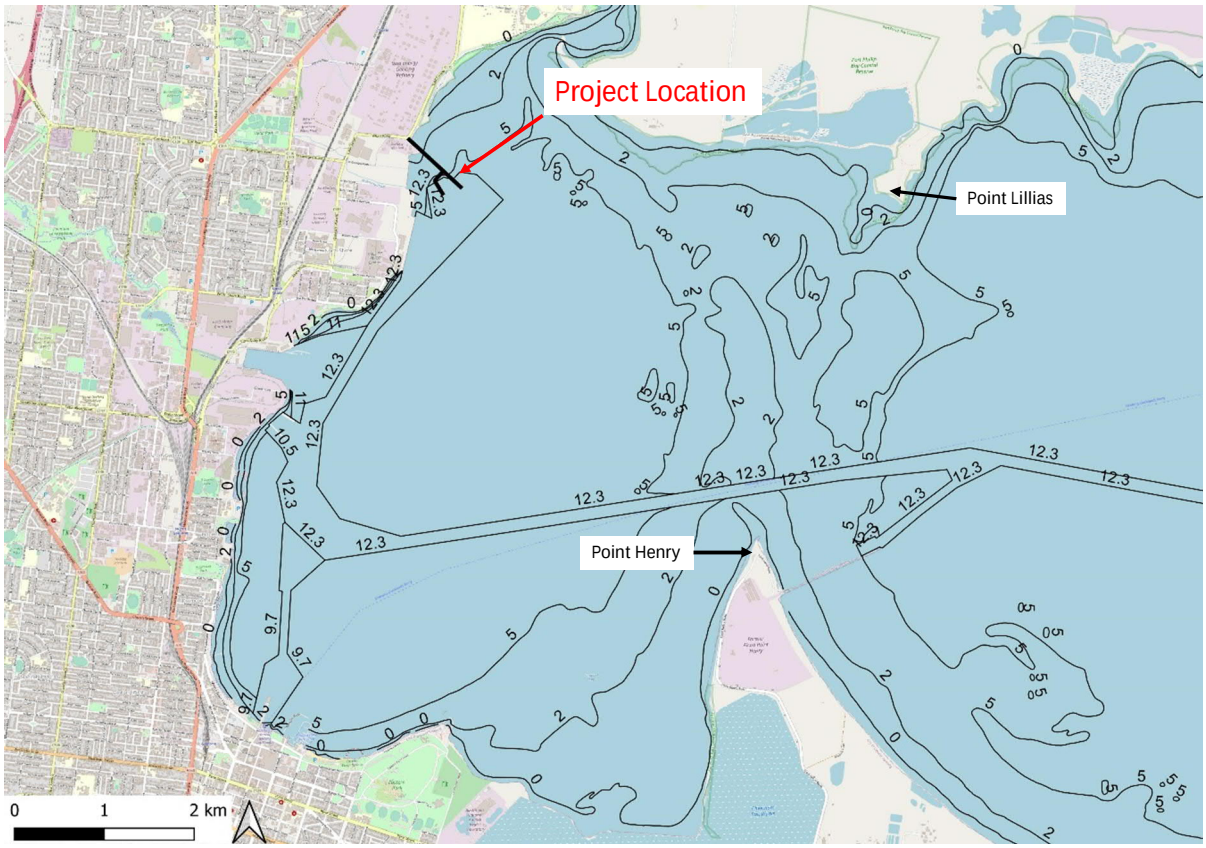


Figure 5-2. Bathymetry of Corio Bay

5.3 Tides of Corio Bay

The astronomical tides in Corio Bay are semi-diurnal with a diurnal inequality, meaning there are approximately two tidal cycles each day: with one having a larger range than the other. Corio Bay has a small tidal range, particularly for neap tides.

The tides at Corio Bay range from 0.58 m below mean sea level (MSL) at the lowest astronomical tide (LAT) to 0.66 m above MSL at the highest astronomical tide (HAT). Table 5-1 shows the tidal level at Corio Bay from the Australian National Tide Tables (2008). The spring tide range is 1.0 m, and the neap tide range is only 0.2 m. There is a large difference between the spring and neap tide ranges.

Table 5-1. Tide Ranges at Port of Geelong

Level	**Height (m)**	
HAT	0.66	
MHWS	0.5	Spring Tide = 1.0 m
MHWN	0.1	Neap Tide = 0.2 m
MSL	**0.0**	
MLWN	- 0.1	
MLWS	-0.5	
LAT	-0.58	

The seawater volume entering and leaving Corio Bay on a spring tide is 43 million m^3 which is about 14 % of the volume of seawater in Corio Bay. Thus, there is a significant daily exchange of water through the shipping channel between Corio Bay and the Outer Harbour, on the western side of Port Phillip Bay.

The tidal water movement generates turbulence which causes mixing over the depth and horizontally. Thus, the tides allow species to spread throughout the bay, even though they have very limited ability to swim. The daily rise and fall of the tides refresh the marine flora and fauna in the intertidal zone.

Because Corio Bay is distant from Bass Strait, the seawater stays more than a year in Corio Bay, on average, before it is replaced by new ocean seawater. As a consequence, the aquatic marine ecosystems in Corio Bay are largely self-contained with an emphasis on recycling nutrients within the Bay.

On the other hand, there also are a range of visitors, from migratory birds coming to the coastal wetlands, schools of fish (e.g. King George whiting, snapper, flathead) from Port Phillip Bay traversing through Corio Bay, ships using channels and jetties, introduced marine pests (species hitching a ride on vessel hulls and in ballast water) and, of course, recreational sailers and fishers.

Limeburners Bay, which is at the northern end of Corio Bay at the mouth of Hovells Creek, experiences the same tides as the rest of Corio Bay.

5.4 Currents in Corio Bay

5.4.1 Current Speed and Direction - Summer

Tidal currents in Corio Bay are small because of the small dimensions of the Bay and the small tidal range – the seawater does not have far to travel between high and low tide. As is apparent in Figure 5-2, the distance from the shipping channel at Point Henry to the north, west or south perimeter of the Bay is only 3 to 4 km. Water movement is 14 % of this distance (corresponding to the percentage of tidal exchange) so the tidal excursion is about 0.5 km or 500 m. This corresponds to an average tidal current of around 4 cm/s. Stronger currents will be experienced in channels during spring tides, and weaker currents in shallow areas and during neap tides.

As part of this project, two current meter deployments have been completed to measure currents in the project area. The first current meter deployment (summer deployment) was for approximately 56 days between 17 December 2019 and 11 February 2020 with current speed and direction being recorded every 15 minutes in 0.2 m increments above the seabed. This meter was installed in Corio Bay at a location north of Refinery Pier and 100 m offshore from the refinery cooling water inlet.

The second current meter deployment (autumn deployment) was for 30 days from 18 April to 18 May 2021, at a deeper site near Refinery Pier, to obtain current records in a different season (autumn rather than summer).

5.4.2 Summer Current Meter Measurements

Table 5-2 shows the current speed and direction (in percentages) for the seawater layer at 0.6 m above the seabed for the summer deployment. The table shows that the recorded currents are dominated by south-west to west currents, with very little flow to the east. Currents to the north were more frequent than currents to the south.

The median current speed was 0.044 m/s. The highest current speed recorded was 0.16 m/s to the south-west.

Table 5-2. Current Speed and Direction at 0.6 m from Seabed (Summer)

Direction	Degrees	Current Speeds (m/s)									Total (%)
		0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	
N	338 - 23	2.0	3.5	3.5	2.9	1.3	0.4	0.2	0.1		14
NE	23 - 68	1.2	2.7	1.6	1.0	0.3	0.1				7
E	68 - 113	1.6	2.1	1.5	0.7	0.2	0.1				6
SE	113 - 158	1.2	1.9	1.5	0.7	0.3	0.1	0.1			6
S	158 - 203	2.0	3.4	3.2	1.7	1.1	0.6	0.3	0.1		12
SW	203 - 248	1.8	4.8	4.7	3.1	1.8	0.7	0.2	0.2		17
W	248 - 293	2.6	5.4	5.8	3.3	1.9	0.7	0.2	0.1		20
NW	293 - 338	1.2	4.5	5.2	3.6	2.0	0.6	0.1			17
Total		13.5	28.3	27.2	17.1	8.8	3.3	1.1	0.5	0.0	100

Table 5-3 shows the current speed and direction (in percentages) for a second seawater layer at 2.2 m above the seabed. The current directions are mostly to the south-west or west which is towards shore at the current meter location. It is possible that the current directions were influenced by the inflow of seawater into the nearby refinery intake, which could explain the consistent flow to the west.

The median current speed was 0.045 m/s. The highest current speed recorded was 0.18 m/s to the south-west.

Table 5-3. Current Speed and Direction at 2.2 m above Seabed (Summer)

Direction	Degrees	Current Speeds (m/s)									
		0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	Total (%)
N	338 - 23	2.0	3.8	3.9	2.4	1.3	0.3	0.2	0.1		14
NE	23 - 68	1.3	2.0	1.4	0.8	0.2	0.1				6
E	68 - 113	1.4	1.9	0.7	0.4	0.1	0.1				5
SE	113 - 158	1.4	1.9	0.9	0.4	0.1	0.1				5
S	158 - 203	2.0	3.0	2.6	1.2	0.6	0.4	0.2	0.1		10
SW	203 - 248	1.8	4.6	5.0	3.5	1.6	1.0	0.4	0.2	0.1	18
W	248 - 293	2.3	6.5	7.0	4.4	1.5	0.5	0.1	0.1		22
NW	293 - 338	2.0	5.5	6.3	3.8	1.8	0.7	0.2			20
Total		14.2	29.1	27.9	16.9	7.1	3.1	1.0	0.5	0.1	100

5.4.3 Water Movement in Summer Deployment

Figure 5-3 shows the daily east-west water movement calculated from the summer current speed and direction readings. The current meter was located about 120 m offshore from the existing refinery seawater inlet, and the daily water movement at this site was mostly to the west (into the seawater inlet). Daily water movement to the west was 1.5 to 2.5 km/d (corresponding to an average current of 2 to 3 cm/s).

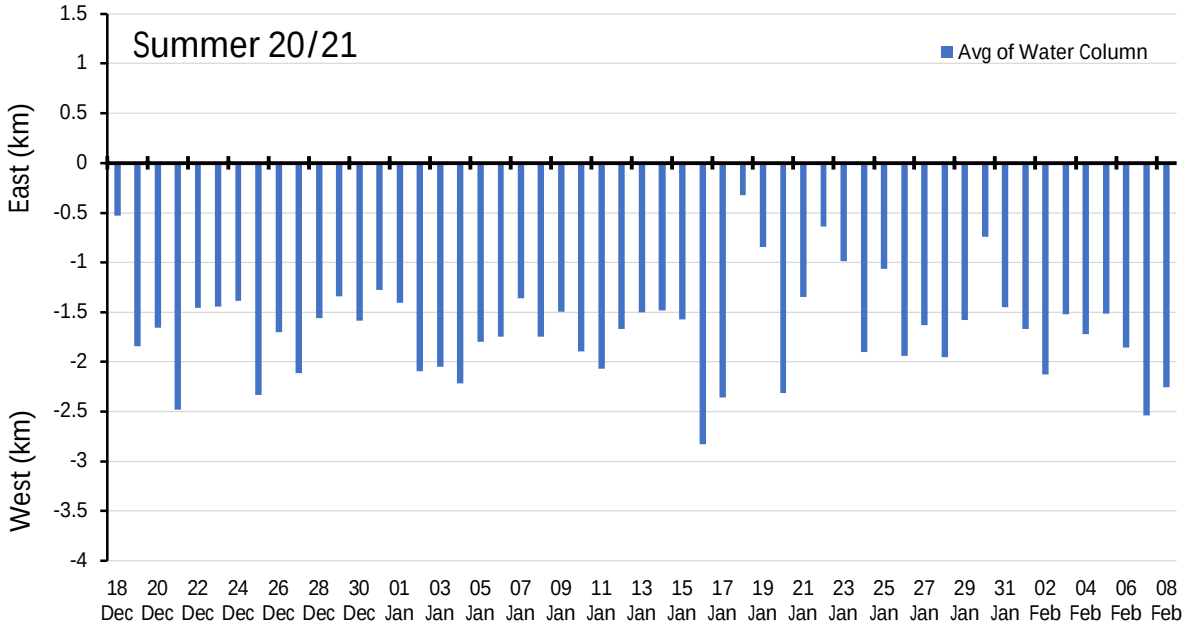


Figure 5-3. Corio Bay East–West Water Movement

Figure 5-4 shows the daily north-south water movement calculated from the current speed and direction readings. The plot shows both north and south water movement, data is split north and south, although there is an overall movement to the north. The periods of larger water travel correspond to prolonged winds in particular directions. The overall average water movement in a day was 0.4 km to the north, corresponding to less than 1 cm/s.

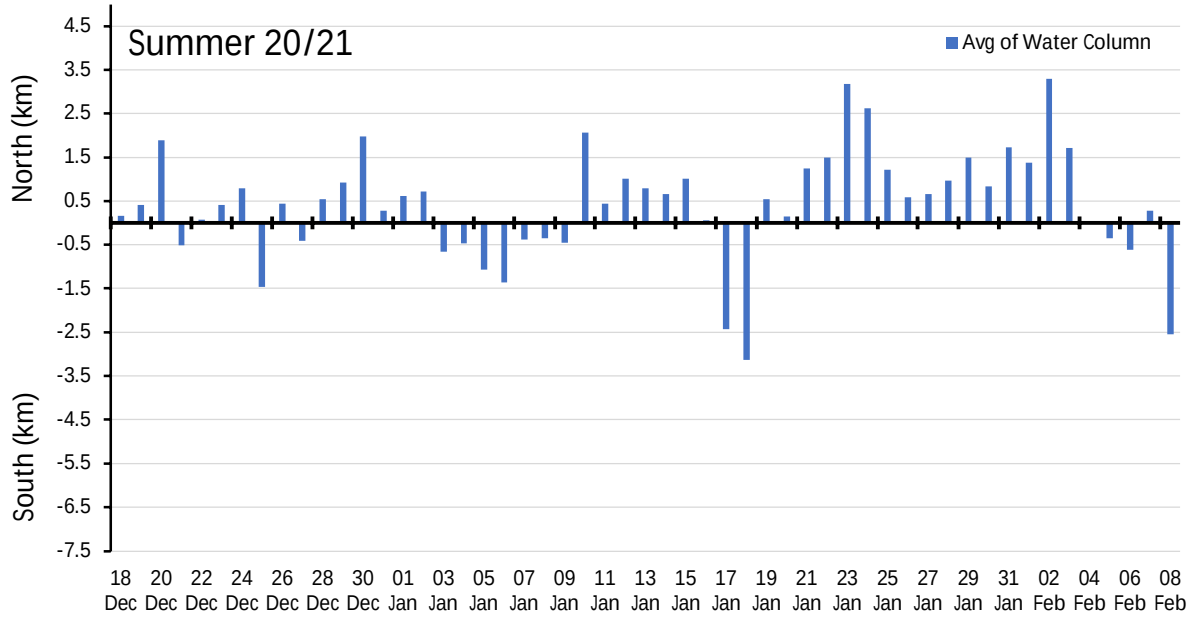


Figure 5-4. Corio Bay North-South Water Movement

5.4.4 Current Speed and Direction - Autumn

CEE carried out a second current meter deployment in autumn, from 18 April to 18 May 2021, at a deeper site near Refinery Pier, to obtain current records in a different season (autumn rather than summer).

The acoustic doppler current meter ADCP was deployed to the north of Refinery Pier in water that was approximately 5 m deep at mean sea level. Figure 5-5 shows the installed ADCP in the second deployment (refer to technical report (CEE, 2021g).

The recorded data was extracted from the instrument after its deployment and was sorted into bins at 1 m intervals from the seafloor up to 4 m above the seabed. The measurements at 2 m and 3 m above the seabed were analysed in detail. The data collected near the seabed showed weaker and more variable currents while the data collected near the surface showed stronger currents and the effects of wave-induced currents and wind shear.

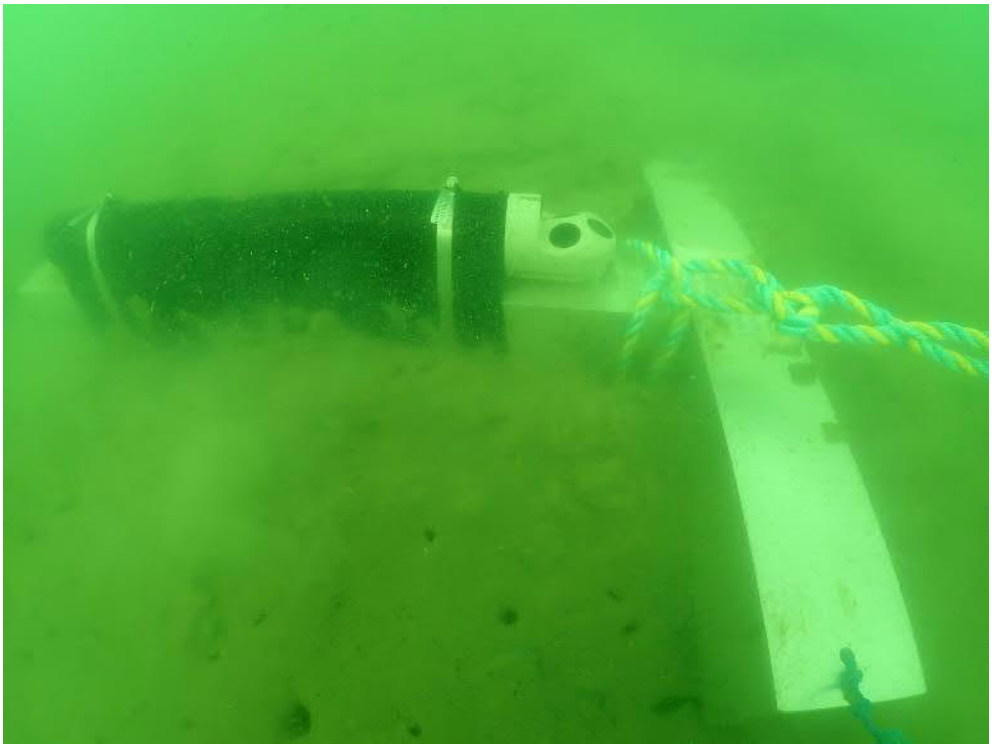


Figure 5-5. ADCP Deployed in Corio Bay in April 2021

The data from the ADCP deployed by CEE shows a regular tidal pattern with periodic ebb and flood tidal currents, and occasional bursts of stronger currents at times of strong winds. Figure 5-6 shows a time series of the current speed at 2 m above the seabed over a seven-day period in April 2021. The plot shows the current speed increasing and decreasing during the tide cycles, with the lowest speeds occurring at slack water between the tides.

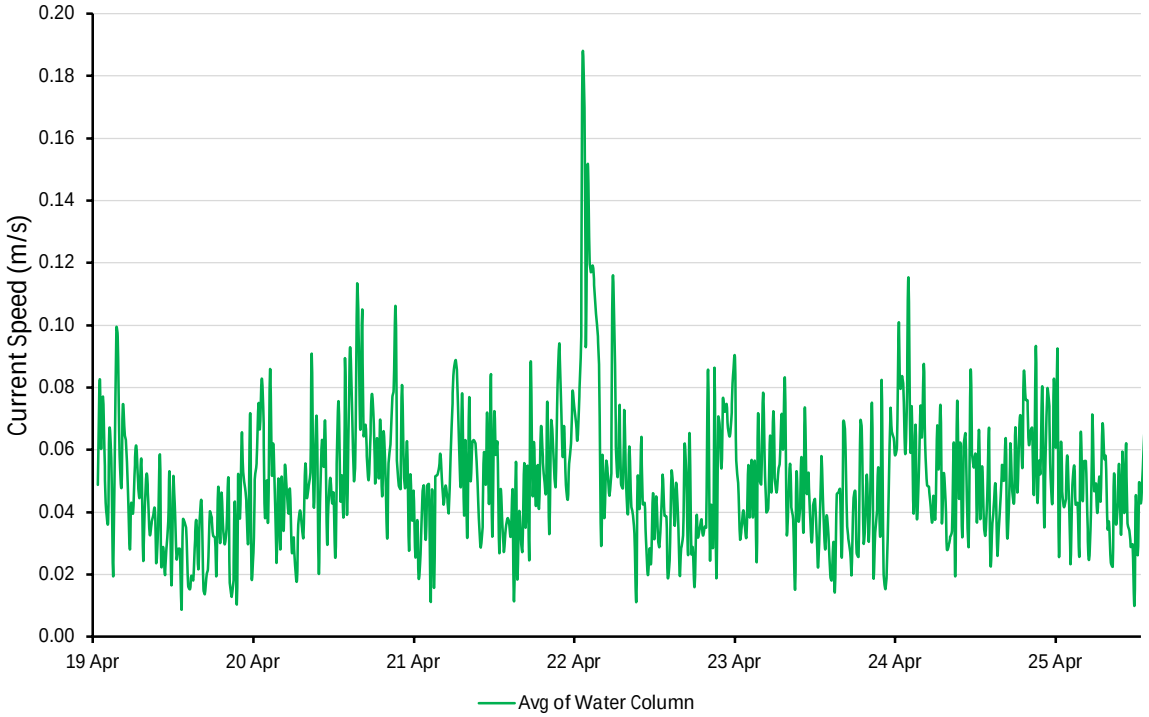


Figure 5-6. Current Speed vs Time During Autumn ADCP Deployment

Table 5-4 shows the average current speed as well as several percentiles for layers at 2 m and 3 m above the seabed, as well as the average of the two layers. It can be seen that the speeds in both layers are the same, apart from a minor difference in the 99th percentile current speed. The median for all layers was 0.04 m/s and the mean speed was 0.05 m/s.

Table 5-4. Current Speed and Direction at 2 m and 3 m above Seabed

Current speed in m/s	2 m above Seabed	3 m above Seabed	Over water column
99th Percentile	0.12	0.13	0.12
90th Percentile	0.09	0.09	0.09
70th Percentile	0.06	0.06	0.05
Average	0.05	0.05	0.05
50th Percentile	0.04	0.04	0.04
10th Percentile	0.02	0.02	0.02
5th Percentile	0.01	0.01	0.02

Figure 5-7 shows the frequency distribution of the current speeds measured in the two mid-water layers. Both layers have a very similar pattern, with low speeds of 0.01 m/s, median speeds of 0.04 m/s and maximum current speeds of 0.14 m/s.

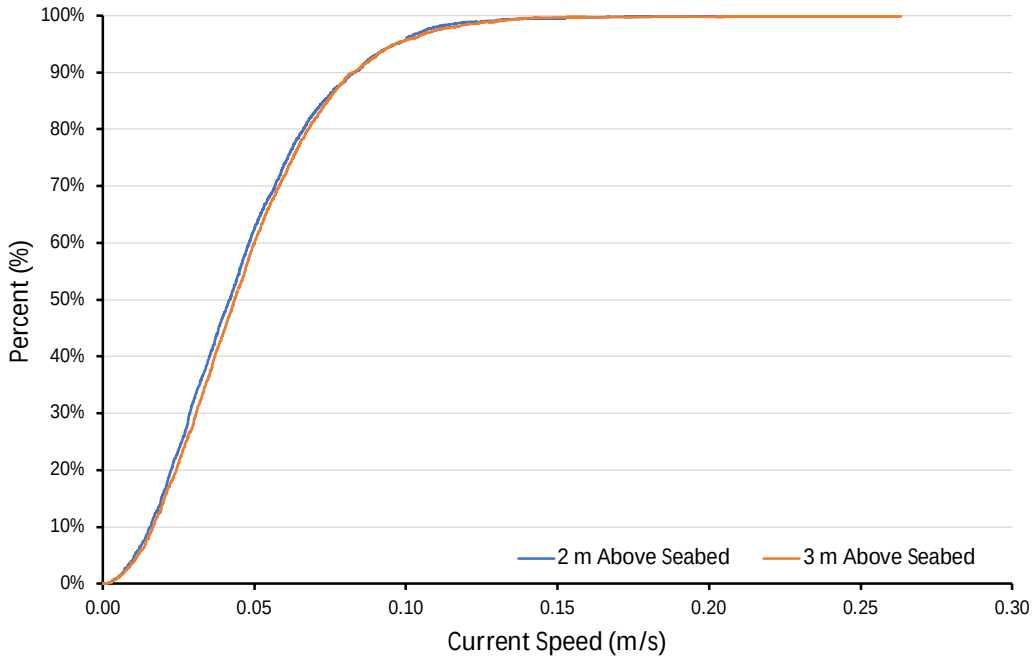


Figure 5-7. Frequency Distribution of Current Speed During Autumn

The current measurements that are summarised in Table 5-4 and Figure 5-7 demonstrate that Corio Bay has weak current speeds for most of the time. The implications of this are that water movement will be relatively small each day and discharged plumes will tend to mix in the locality of the point of discharge, before being carried away in the net water movement.

Table 5-5 shows the distribution of current speeds and directions for the mid-water layer at 2 m above the seabed. The most frequent currents are from the north and north-east while there are also frequent currents from the south and south-west. There were only a small percentage of currents from the east to south-east.

Table 5-5. Current Speed and Direction at 2 m above Seabed (Autumn)

Direction	Degrees	Current Speeds (m/s)											Total (%)
		0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.24	
N	338 - 23	2.8	6.7	6.3	4.3	2.9	1.3	0.2		0.1			25
NE	23 - 68	1.7	4.3	3.2	2.1	0.8	0.3	0.2	0.1				13
E	68 - 113	1.8	2.9	1.8	0.7	0.3	0.1			0.1			8
SE	113 - 158	1.9	2.5	1.7	0.7	0.3	0.1					0.03	7
S	158 - 203	1.8	2.8	2.4	1.1	0.8	0.2	0.1					9
SW	203 - 248	2.1	2.7	2.3	0.9	0.5	0.3	0.1					9
W	248 - 293	2.3	4.0	3.3	1.5	0.4	0.2	0.1					12
NW	293 - 338	1.9	5.7	5.3	3.3	1.2	0.5	0.1					18
Total		16.1	31.6	26.3	14.6	7.2	3.0	0.7	0.1	0.1	0.0	0.0	100

Table 5-6 shows the distribution of current speeds and directions for the water layer at 3 m above the seabed. There are more frequent north currents and less frequent south currents. The dominant current speed was 0.04 m/s.

Table 5-6. Current Speed and Direction at 0.6 m from Seabed (Autumn)

Direction	Degrees	Current Speeds (m/s)												Total (%)
		0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.24	0.28	
N	338 - 23	2.1	6.0	6.8	4.2	1.4	0.8	0.2	0.03					21
NE	23 - 68	2.0	5.1	4.9	4.6	2.0	0.9	0.3	0.07			0.03		20
E	68 - 113	2.0	3.3	2.3	1.6	0.7	0.1	0.2		0.03				10
SE	113 - 158	1.6	2.2	1.9	0.8	0.3	0.1	0.1					0.03	7
S	158 - 203	1.9	3.1	2.9	1.1	0.5	0.1	0.1				0.03		10
SW	203 - 248	1.3	2.8	2.3	1.1	0.6	0.3	0.2		0.03				9
W	248 - 293	1.8	3.1	2.2	1.4	0.4	0.2	0.1	0.07			0.03		9
NW	293 - 338	2.0	4.2	3.9	2.0	0.8	0.1	0.03						13
Total		14.7	29.9	27.2	16.8	6.6	2.7	1.2	0.2	0.1	0.0	0.1	0.0	100

5.4.5 Water Movement in Autumn Deployment

Figure 5-8 shows the daily east-west water movement calculated from the autumn current speed and direction readings in the two layers and is a projection of the water movement based on the current speed and direction at the point of measurement. Positive values on the plot indicate movement to the east while negative values represent movement to the west.

The plot shows daily water movement was mostly to the east, at up to 0.5 km/d, but with an average of 0.18 km/day. This small distance of 180 m indicates that is not a large net current but mostly a regular back and forth movement of water with the tides, interspersed by larger water travel in periods with strong winds.

The north section of Corio Bay generally has a clockwise circulation driven by regular winds from the south-west and the inflow of water in the shipping channel (MMBW, 1973). The clockwise circulation in Corio Bay mimics the clockwise circulation in Port Phillip Bay (CSIRO, 1996). The particle tracking simulations in Section 10 of this report clearly illustrate the clockwise circulation in Corio Bay.

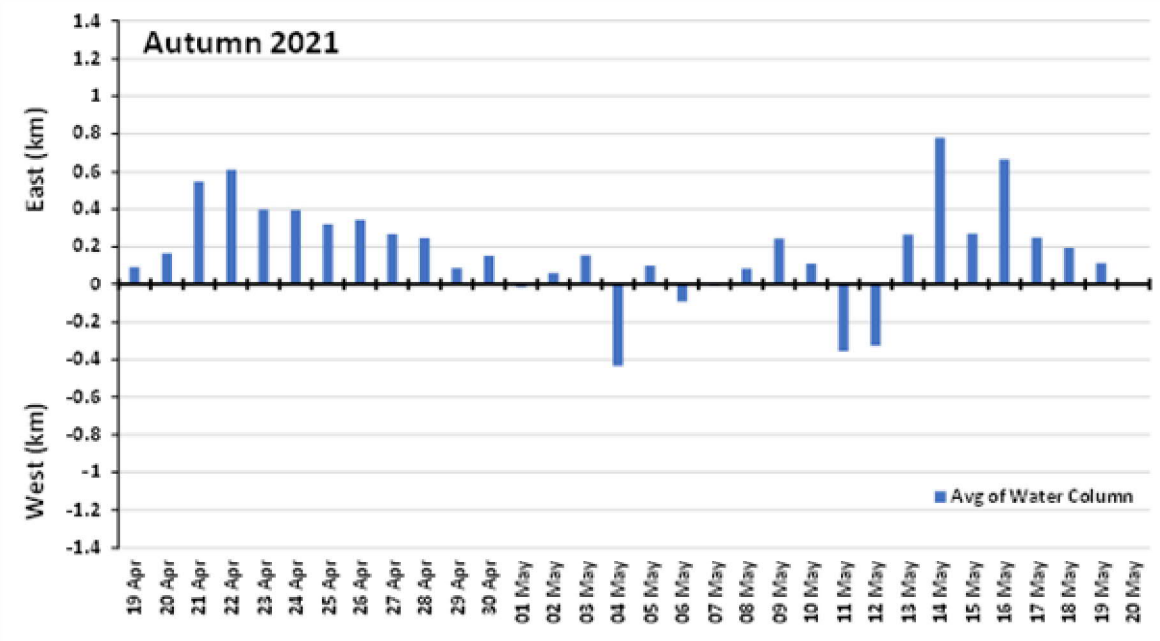


Figure 5-8. Corio Bay East-West Water Movement During Autumn

Figure 5-9 shows the daily north-south water movement and is a projection of water movement based on the current speed and direction at the point of measurement. Positive values on the plot indicate movement to the north while negative values

represent movement to the south. The movement is dominated by northerly currents which support the clockwise current circulation in Corio Bay where water enters through the deep channels, such as the Hopetoun Channel, and then circulates in a clockwise fashion to return to Port Phillip Bay in the north-east of Corio Bay, near Point Lillias. The plot shows that water can move up to 1 km north in a day, but typically only moves a smaller distance.

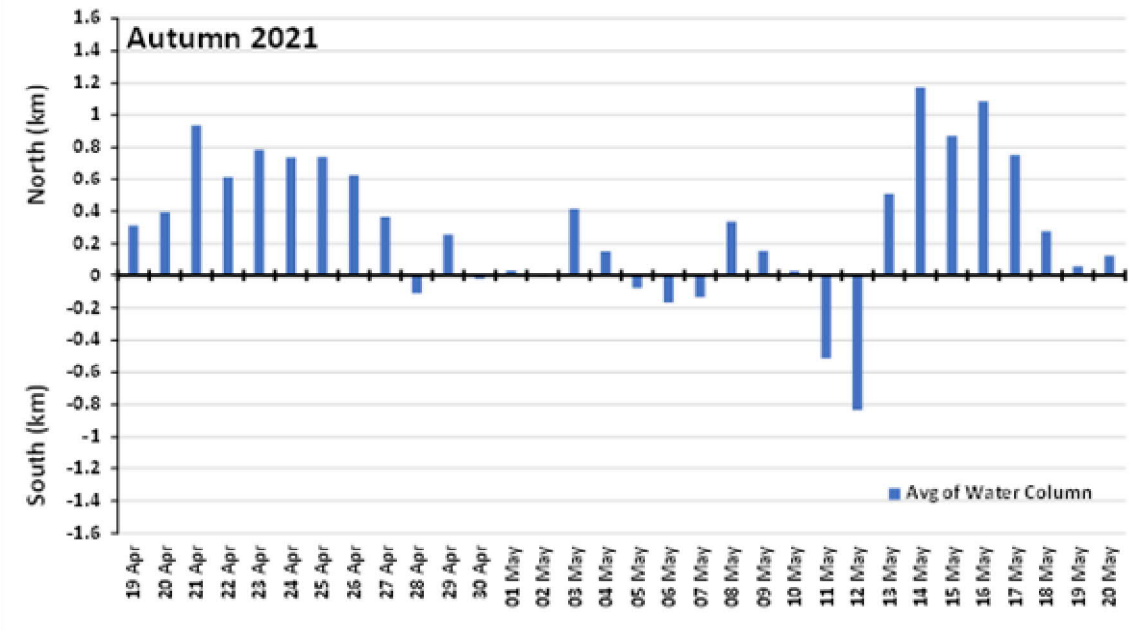


Figure 5-9. Corio Bay North-South Water Movement During Autumn

5.5 Water Quality

Water quality is sampled by EPA Victoria (EPA) at several points through Port Phillip Bay on a monthly basis. The sites sampled are:

- Werribee;
- North East Segment;
- Central Segment;
- South East Segment;
- Corio Bay;
- Hobson Bay;
- Newport Power Station, and
- Popes Eye (near mouth of Port Phillip Bay).

The EPA monitoring data was assessed to establish the annual and seasonal water quality in the study area. Additional data gathered by CEE field studies are used to extend the data gathered by EPA to more sites in Corio Bay.

5.5.1 Water Quality Index

EPA releases annual report cards which summarise the environmental water quality using key indicators. The overall score is used to classify the water quality on a scale of *very poor*, *poor, fair, good* and *very good*.

The most recent annual report card for Port Phillip Bay was compiled by the EPA, Melbourne Water and DELWP for June 2019 to June 2020 for 6 monitoring sites in Port Phillip Bay and one in Corio Bay. The overall water quality index (WQI) for Port Phillip Bay in the 2019/20 period was rated as *good*. Above average rainfall that year resulted in increased runoff and river flows which caused an increased discharge of pollutants to the Bay, including nutrients, sediments and heavy metals. Thus, the score was under '*very good*'.

Figure 5-10 shows the 2019-20 WQI graph, extracted from the EPA 2019/20 report card. The figure shows the overall WQI as well as the individual indicators which contribute to it. It can be seen that the Bay was *very good* in terms of dissolved oxygen and algae, *good* in terms of salinity, but only *fair* in terms of nutrients and water clarity.

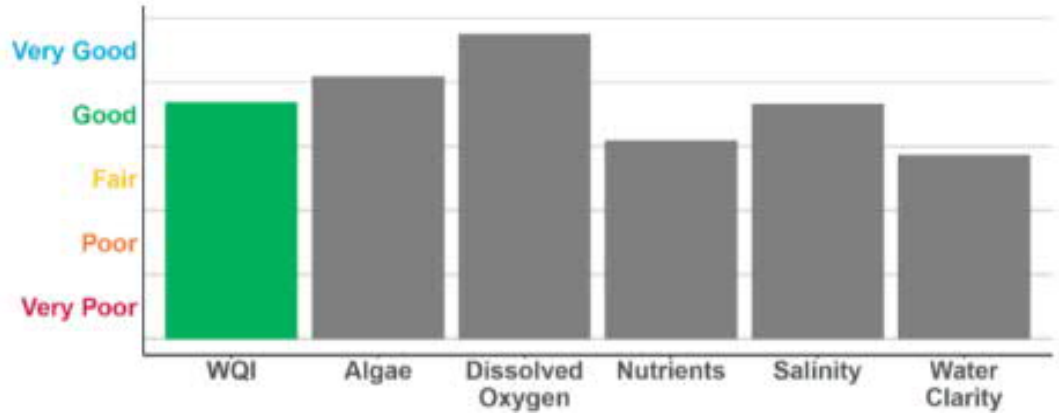


Figure 5-10. Water Quality Index for Port Phillip Bay 2019/20

5.5.2 Toxicants

The Port Phillip Bay Environmental Study (CSIRO, 1996) reported that most of the sediments of Port Phillip Bay contain metal concentrations well below hazardous levels. They reported that "Study results show that the overall toxicant levels are continuing to decline, and that the toxicants entering (Port Phillip) Bay are largely locked up in the sediments".

Cores taken in the 1992-1996 study in Corio Bay showed surface enrichment with copper, lead, zinc and cadmium due to anthropogenic input. The distribution of organic toxicants was similar to that of metals. Cadmium contamination in Corio Bay was traced to an industrial effluent which was closed. After that, cadmium levels in Corio Bay mussels decreased to below the National Health and Medical Research Council (NHMRC) limits. Levels of metals in the sediments such as copper and zinc were never above NHMRC limits.

Sediment sampling conducted in Corio Bay as part of the EES for this project to inform development of a dredged spoil disposal strategy (Coffey, 2020) and (AECOM, 2021) indicated that, with a small number of exceptions, contaminant levels were below guideline limits.

Section 7 presents a detailed analysis of the degree of sediment contamination in the area that would be dredged.

5.5.3 Salinity in Corio Bay

The salinity data from the EPA monitoring site in Corio Bay has been analysed over a 10-year period from 2010 to 2020 and the results are shown below in Figure 5-11. The plot indicates that salinity in Corio Bay has been consistent over the decade, with an average salinity of 37 psu and a range from around 35 psu to 38 psu. These salinities are typical of seawater and are within the water quality objective from the *Environment Reference Standard* (EPA, 2021) for Geelong Arm of a 25th – 75th percentile range of 35 to 38 psu.

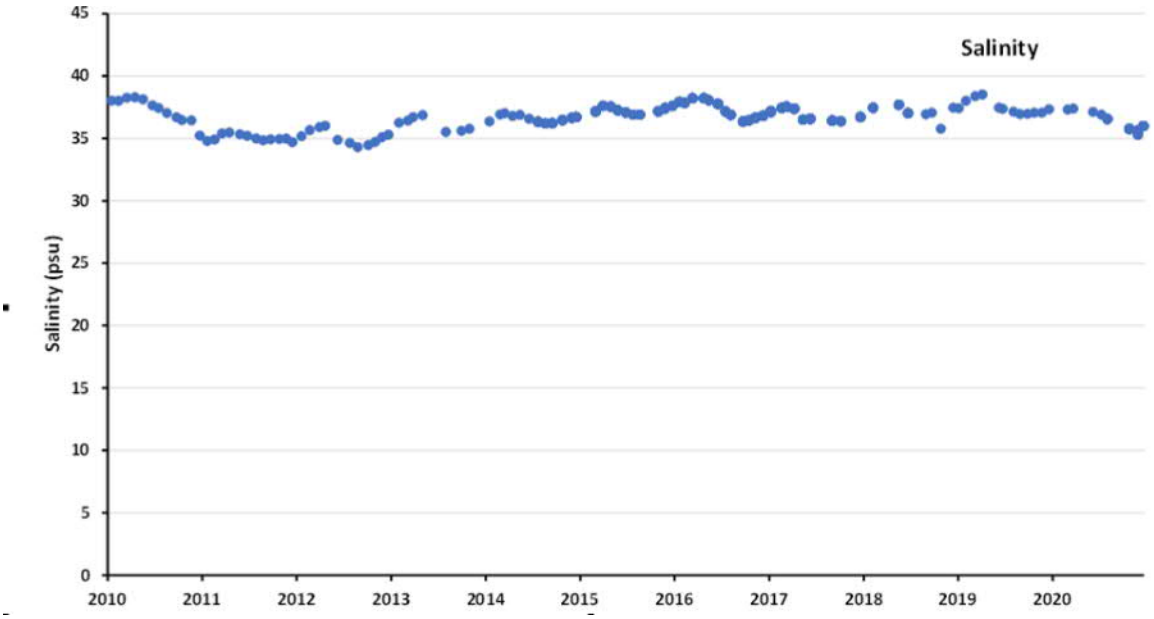


Figure 5-11. Corio Bay Salinity (2010 – 2020)

Figure 5-12 shows the 2019/20 vertical profiles of salinity at the Corio Bay site from the water surface to the seabed at about 9 m below the surface. The results show that the salinity is consistent through the water column.

Figure 5-11 and Figure 5-12 both show a seasonal variation in salinity with higher salinity from December to March and lower salinity from July to August. This change reflects the balance of rainfall, runoff and evaporation.

Given the tidal water exchange rate between Corio Bay and Limeburners Bay, it is estimated that the salinity is much the same the same in Limeburners Bay as in Corio Bay, except when there are large freshwater flows in Hovells Creek. Generally, Hovells Creek has small flows and thus, Limeburners Bay is mostly saline.

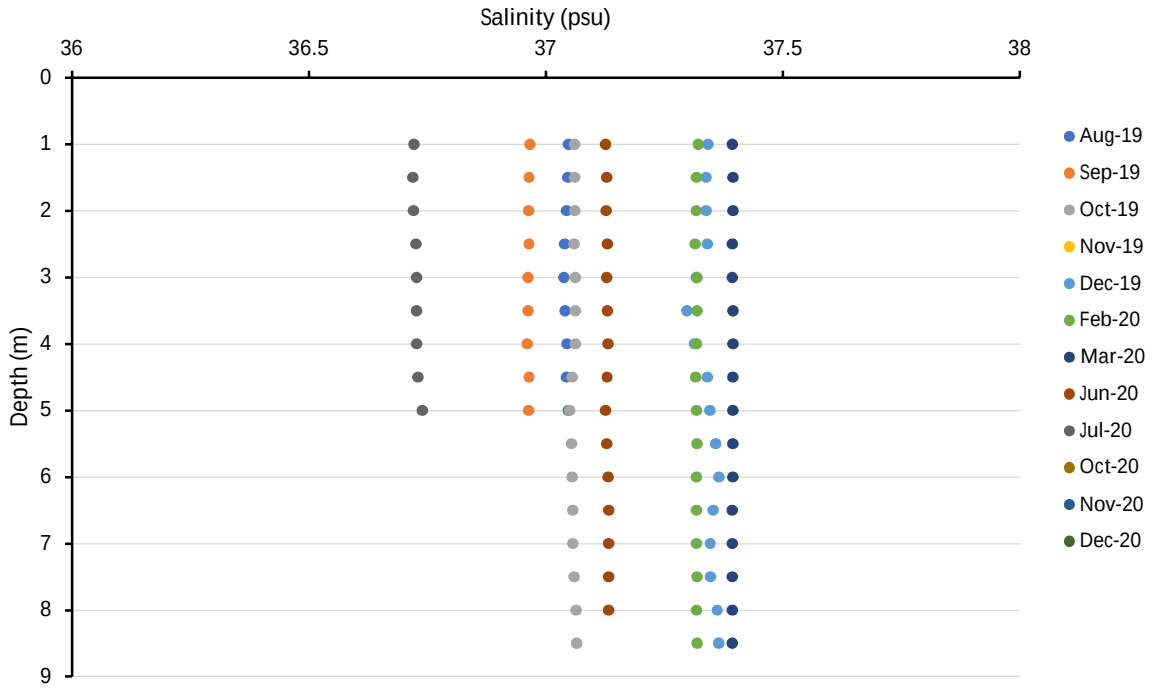


Figure 5-12. Corio Bay Salinity Profile (2019/2020)

5.5.4 Suspended Solids in Corio Bay

The suspended solids (SS) data from the EPA has been analysed over a 10-year period from 2010 to 2020 and the results are shown in Figure 5-13. The plot indicates that SS concentrations range from around 1 mg/L to 14 mg/L, with an average SS concentration of 2.6 mg/L. The 75th percentile concentration is 3.1 mg/L which meets the EPA water quality objective for SS of a 75th percentile concentration below 5 mg/L. The EPA monitoring station is in central Corio Bay and there are higher suspended solids levels where waves disturb sediments on the shore. Average SS at shallower sites is typically 5 mg/L.

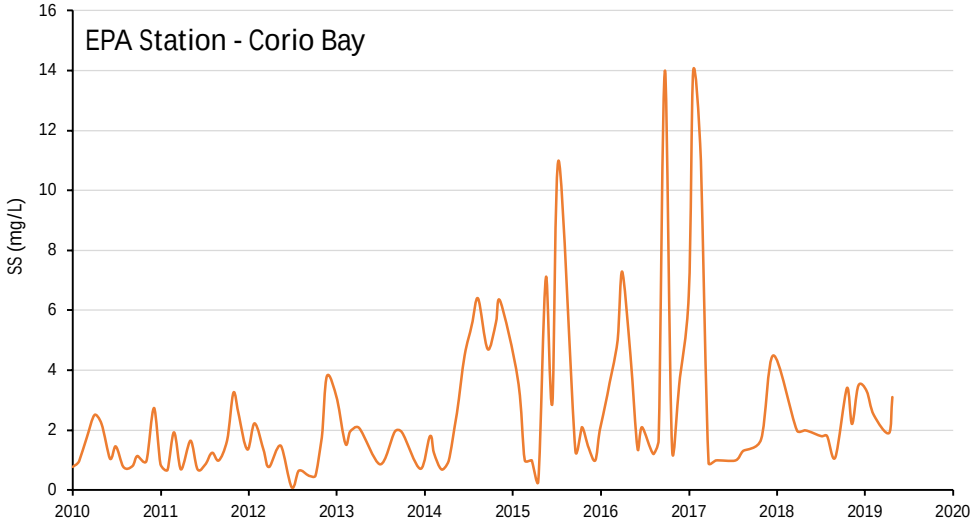


Figure 5-13. Corio Bay Suspended Solids (2010 – 2020)

This study involved an extensive series of video tows and diving to deploy and retrieve instruments (current meters, light meters, temperature loggers). The video and diving activities were constrained by events with high suspended solids, which limited visibility in Corio Bay, particularly near the seabed.

5.5.5 Dissolved Oxygen in Corio Bay

The dissolved oxygen data from the EPA has been analysed over a 10-year period from 2010 to 2020 and the results are shown in Figure 5-14. The plot shows that dissolved oxygen (DO) is at very satisfactory levels, with the DO generally between 90 and 110 % saturation. There are no events of low DO.

The water quality objective for DO in the Geelong Arm from the *Environment Reference Standard* (EPA, 2021) is a 25th percentile of 95 % and a maximum of 130 %. The monitoring results show that this objective is met.

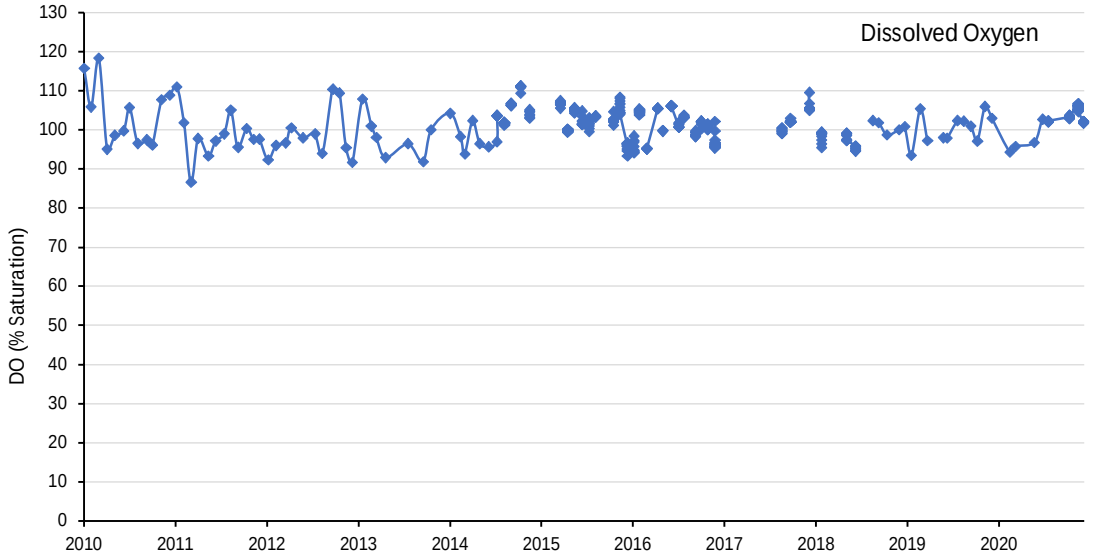


Figure 5-14. Corio Bay Dissolved Oxygen (2010 – 2020)

5.5.6 Temperature

EPA Data

Figure 5-15 shows the monthly temperature in Corio Bay compared to the temperature in the central segment of Port Phillip Bay from March 2015 to August of 2020. The data is collected on a monthly basis by the EPA and was provided to CEE for this assessment. The average monthly temperature over the period was 16℃ in Corio Bay and also 16°C in central Port Phillip Bay.

However, Corio Bay has a slightly larger temperature range than the central segment with a summer maximum about 0.6°C higher and a winter minimum about 1°C lower. The larger range reflects the limited water movement in Corio Bay compared to Port Phillip Bay.

Note that the EPA monitoring site in Corio Bay is in 9 m water depth. There will be larger monthly temperature variations in shallower water.

In intertidal zones, the organisms experience the water temperature at high tide and the air temperature at low tide. Over a day, the variation in temperature in the intertidal zone can range from around 14°C to 24°C depending on the season.

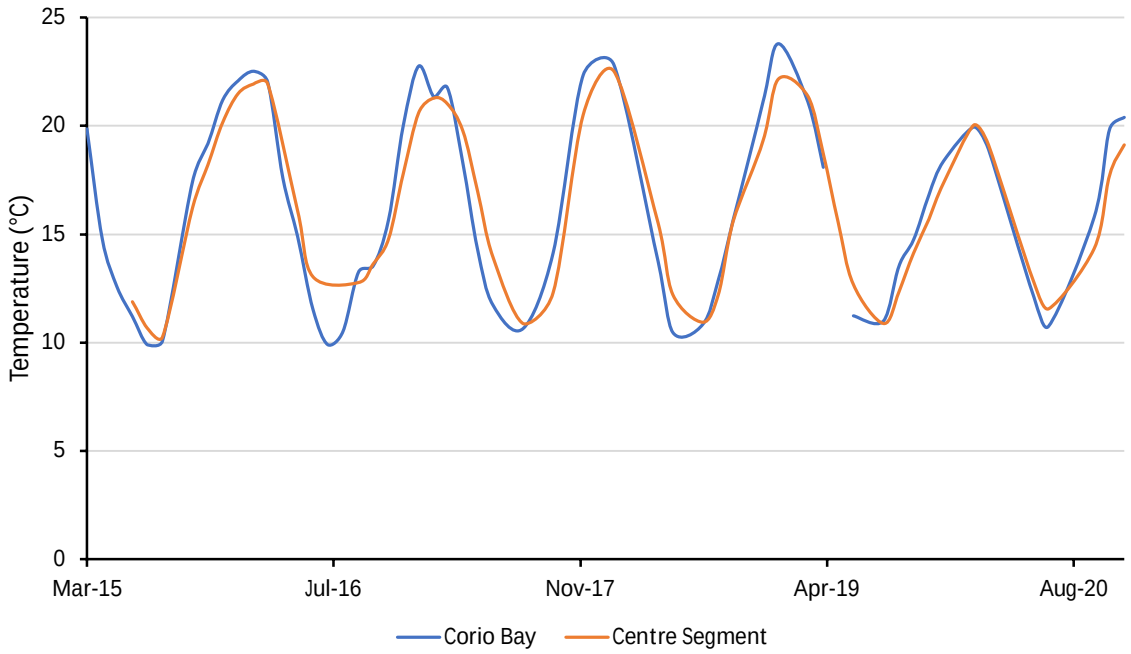


Figure 5-15. Corio Bay and Centre Segment Water Temperature (2015 – 2020)

Figure 5-16 shows average monthly temperature data in Corio Bay from August 2019 to December 2020 through the water column and was provided to CEE by the EPA. There is a large seasonal variation in water temperature – from around 11°C in July to around 20.5°C in December 2020.

The water temperature is generally consistent through the water column to 9 m depth although a small thermocline is apparent in October to December in some years.

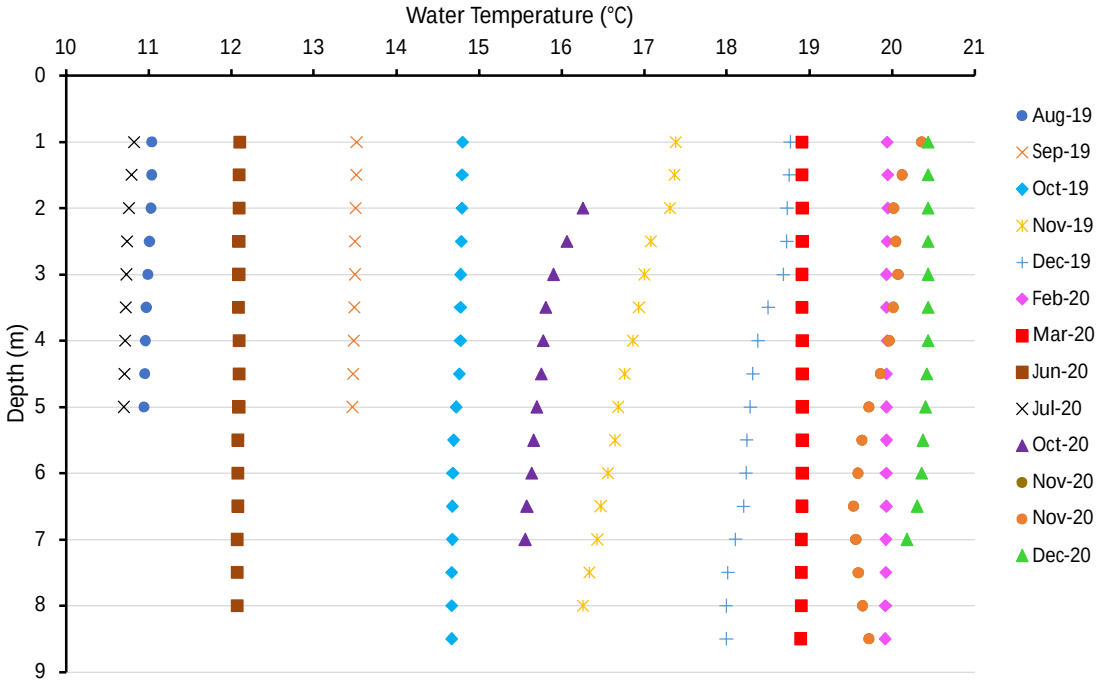


Figure 5-16. Corio Bay Water Temperature Profiles (2019 – 2020)

CEE Data

CEE conducted a water temperature monitoring program with the aim of assessing temperature variations in shallow and mid depths. CEE used HOBO U24-002-C loggers which were permanently placed in a protective housing. The loggers recorded a single point water temperature reading every 10 minutes and the data was collected monthly. A more detailed description of the CEE temperature results can be found in the CEE technical report for temperature and salinity (CEE, 2021d).

One logger was positioned at the refinery inlet at a depth of around 2 m. A second logger was placed off Refinery Pier in water of a depth of around 5 m.

Figure 5-17 shows measured records of seawater temperature at two sites in Corio Bay from November 2020 to mid-June 2021. The blue line (refinery inlet) shows the temperature for the logger in the refinery inlet which was positioned in water around 1 – 2 m in depth, which is typical of water in the intertidal zone of the shallow Bay. This logger showed a larger degree of variation compared with the logger at the pier (orange line) which was positioned at a depth of around 5 m. The inlet had daily variations of up to 5°C and a median of 2.85°C, due to the large amount of heating and cooling by solar radiation. Due to greater depth, the logger at Refinery Pier had less variation with a maximum variation of 4.5°C and a median variation of 0.6°C.

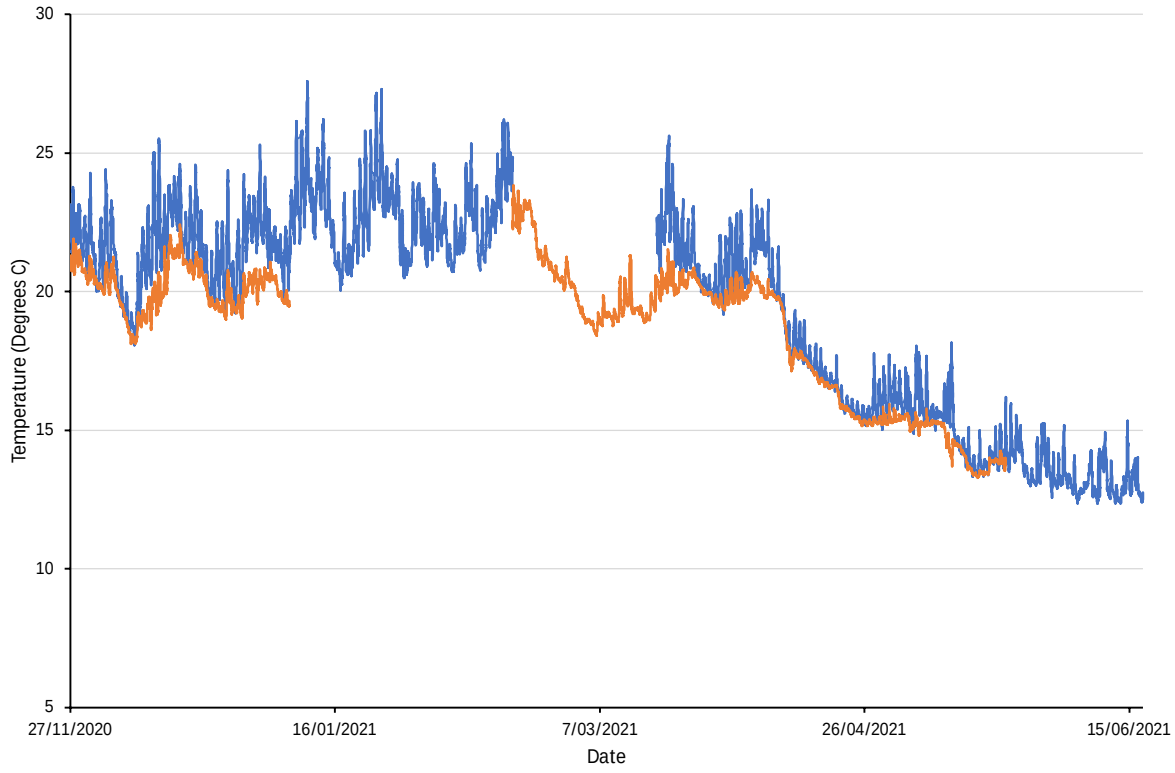


Figure 5-17. Recorded Seawater Temperature in Corio Bay

5.5.7 Nutrients in Corio Bay

Total nitrogen (TN) and total phosphorus (TP) data from Corio Bay have been collected by the EPA over a 10-year period from 2010 to 2020 and the results are shown below in Figure 5-18. The figure shows the historical plot of TN (blue line) and TP (red line).

The plot shows the TN has a wide range – from 150 µg/L to 300 µg/L, with no particular seasonal pattern. Between 2010 and 2016, TN averaged of 204 µg/L. However, the average increases to 225 µg/L with the inclusion of 2016 to 2020 data.

TP has a more consistent concentration over the decade in the range of 60 to 100 µg/L. There is a seasonal pattern with lower TP in spring and higher TP in autumn. Over the decade, the average TP was 80 µg/L. There is no trend of increasing TP concentration.

Plant growth in Port Phillip Bay is nitrogen-limited (Harris et al. 1996). Nitrogen as ammonia and nitrate are the most critical nutrients. Phosphorus is of less interest because it is present in excess in Port Phillip Bay compared to inorganic nitrogen. The organic forms of nitrogen and phosphorus are also of less concern, as they are generally not readily available for uptake by plants.

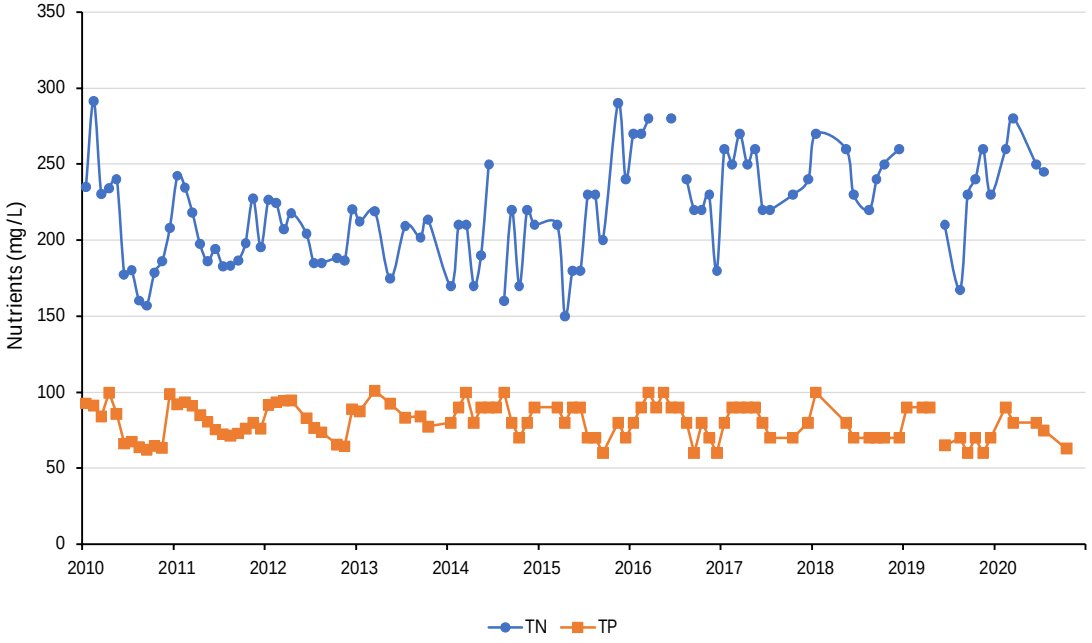


Figure 5-18. Corio Bay Nutrients (2010 – 2020)

The TN to TP ratio is only 3:1, which is low and indicates that nitrogen is usually the limiting nutrient for algal growth. According to the *Port Phillip Bay Environmental Report (Melbourne Water, 1996),* nutrient levels and chlorophyll levels (a measure of the algae present) are low to moderate compared to other estuaries surrounded by urban development in Europe and North America. Despite increasing population around the Bay there has been no indication of any increase in nitrogen or chlorophyll concentrations in the water over the last decade (to 1996 – this is reviewed above with more recent data). Nutrients are not, however, a critical issue for this project as it does not involve any addition to or removal of TN and TP from Corio Bay.

5.5.8 Chlorophyll-a in Corio Bay

Figure 5-19 shows chlorophyll-a concentrations in Corio Bay in µg/L measured by the EPA from 2000 to 2020. The plot shows that there was an increase in chlorophyll-a from 2003, reaching a peak in the summer of 2012. After that, the concentration decreased, mostly to less than 1 µg/L with occasional spikes.

The water quality objective for chlorophyll-a in the Geelong Arm from the *Environment Reference Standard* (EPA, 2021) is a 75 percentile of 3 µg/L. The monitoring results show that this objective is met.

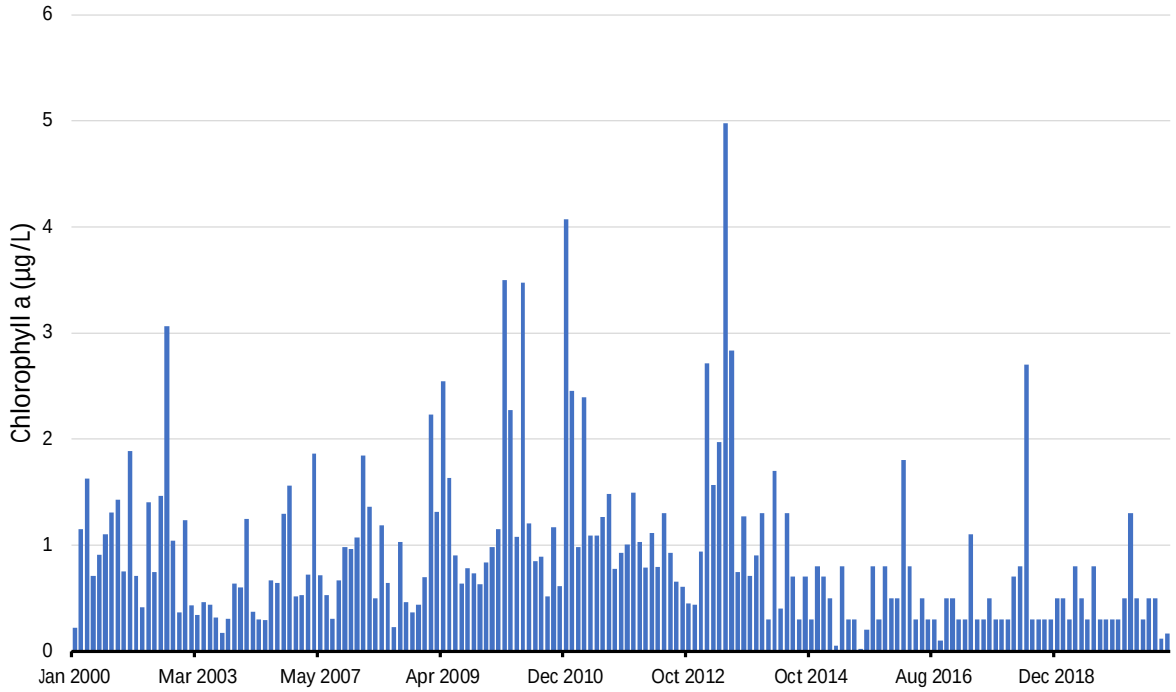


Figure 5-19. Chlorophyll-a in Corio Bay from 2000 to 2020

Table 5-7 shows the seasonal variation in chlorophyll-a from 2000 to 2020. The highest concentrations are observed in summer and autumn with lower concentrations in winter and spring.

The seasonal cycle involves an increase in phytoplankton populations commencing in spring and reaching a peak in summer and early autumn, when there is warmer water and longer days – both favourable to phytoplankton growth. There is a decline in late autumn and winter, with cooler water and shorter days, so the cycle can start again into the next summer.

Table 5-7. Chlorophyll-a Seasonal Abundance (µg/L)

Percentile	Summer	Autumn	Winter	Spring
Average	1.1	1.4	0.7	0.7
5%	0.3	0.3	0.2	0.3
50%	1.0	1.1	0.6	0.7
99%	3.8	5.6	2.2	1.5

5.5.9 Turbidity

Turbidity is a measure of water clarity. High turbidity results in lower clarity and less transmission of light through the water column. Alternatively, low turbidity results in better clarity and more transmission of light. The growth of seagrass and seaweeds on the seabed in Corio Bay requires sufficient light to reach the plants to enable growth.

Turbidity has been measured by the EPA at one site in mid-Corio Bay and several sites in Port Phillip Bay since 2014. Figure 5-20 shows the measured turbidity in Corio Bay and the Werribee site in Port Phillip Bay from January 2014 to December 2020. The plot shows that there was a large spike in turbidity in summer 2015 with some smaller spikes in early 2016 and 2019-2020.

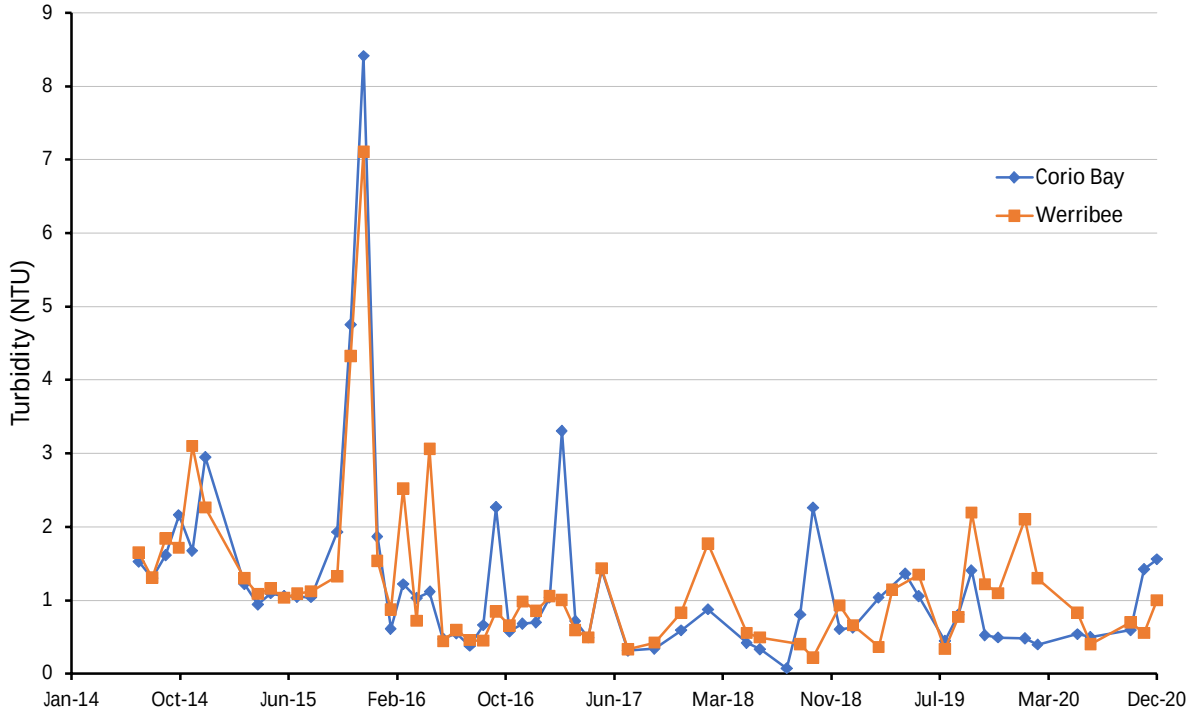


Figure 5-20. Turbidity Time Series for Corio Bay

In the period measured, the turbidity has averaged around 1.2 NTU at both sites, with a recorded peak of 8.5 NTU in Corio Bay and 8.7 NTU at Werribee. Turbidity peaks can result from storms or from phytoplankton blooms. The combination of fine sediments and wave action can at times generate high turbidity, particularly in coastal waters which will limit seagrass growth.

There is no limit for turbidity listed for Port Phillip Bay in the *Environmental Reference Standard*. However, there is a limit for turbidity of 75 % < 10 NTU for other estuaries. Using this as a guideline, the turbidity in Corio Bay is low and satisfactory.

The waters near the seabed in Corio Bay are much more turbid than the surface waters in the upper water column. This is a result of marine organic detritus and fine silts sinking to the seabed, forming a soft layer on the seabed about 10 to 20 mm deep.

Re-suspension of the fine silts and clays that make up the surface sediments and the organic material causes a high turbidity near the seabed. Figure 5-21 shows the turbidity readings for the period from 19 December 2019 to 3 January 2020. The turbidity was variable and ranged from around 4 NTU to 40 NTU. The median turbidity near the seabed was 12 NTU.

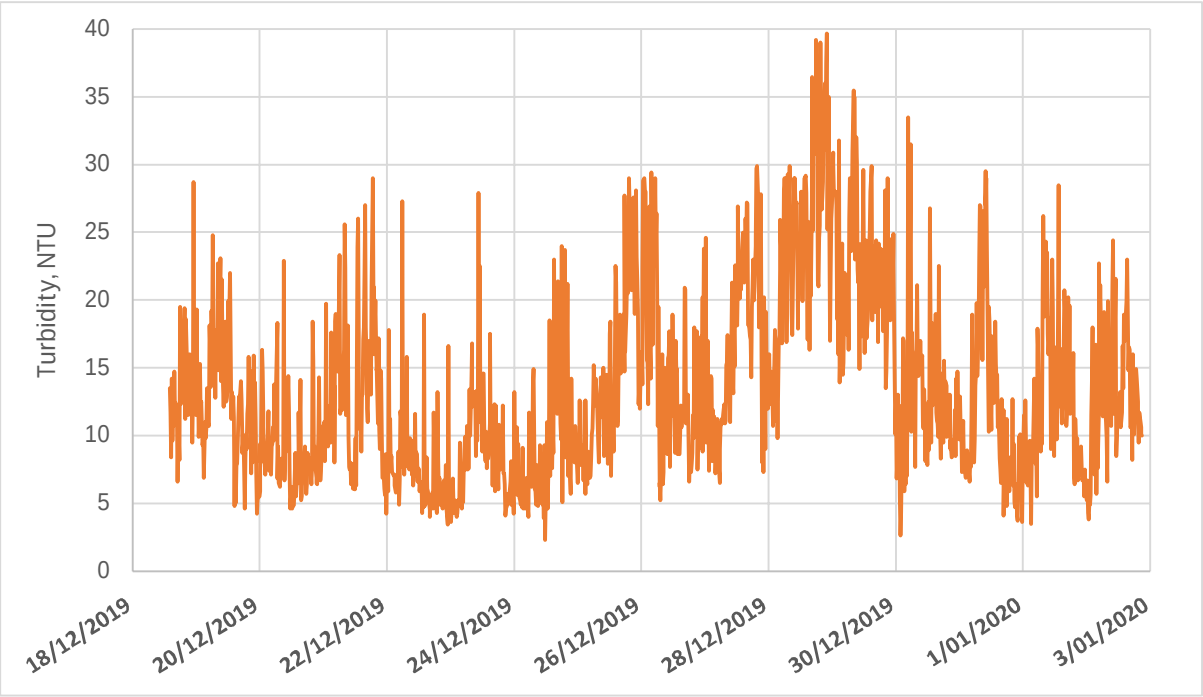


Figure 5-21. Measurements of Turbidity Near Seabed in Corio Bay

The increasing turbidity with depth provides a natural constraint on the extent to which seagrass and algae can grow in Corio Bay. As discussed later in this Section, dense *Zostera* seagrass beds extend from low water to 3.7 m depth. Dense *Halophilia* seagrass beds extend from 1 m to 4.3 m depth. This means that there usually is sufficient light reaching the shallow seabed of Corio Bay to enable the growth of seagrass and seaweeds.

5.5.10 Light Attenuation in Corio Bay

Light attenuation was measured in Corio Bay by using two Odyssey PAR sensors recording light simultaneously at two depths. The PAR sensors were deployed in Corio Bay near the Ramsar site in water which was 7 m deep. The two sensors were attached 2.3 m apart at depths of 4 m and 6.3 m, at MSL.

Solar radiance data was sourced from Avalon airport which provides the solar exposure at the surface as an average daily value from midnight to midnight each day. The data from Avalon was adjusted by calculating the sub-surface irradiance which takes into account the refraction and reflection of the solar rays on the water surface. This method uses the solar zenith and angular reflection of run ray which assumes a flat surface. Given the sheltered water of Corio Bay with low winds, and waves, this was considered appropriate. The underwater PAR data was averaged across each day to match the Avalon data and was then converted into the same units (from µmol/m^2/s to MJ/m^2/d). Therefore, an attenuation coefficient for each day could be calculated from just below the surface to 4 m depth and then from 4 m depth to 6.3 m depth.

The equation used for the attenuation calculation is described below.

$$K_d = -Log\left(\left(\frac{PAR_{Bottom}}{PAR_{Top}}\right)\frac{1}{z}\right)$$

PAR_{bottom} is the data recorded by the lower point while PAR_{top} is the data recorded by the upper point. *Z* represents the distance between the points. For the first calculation the *z* is 4 m and for the second calculation the *z* is 2.3 m. Figure 5-22 shows a plot of the calculated average light attenuation from 20 May 2021 to 6 June 2021. The graph shows that over the period, the average attenuation of light through the water column was around 0.75 m^{-1} ± 0.05 (SEM).

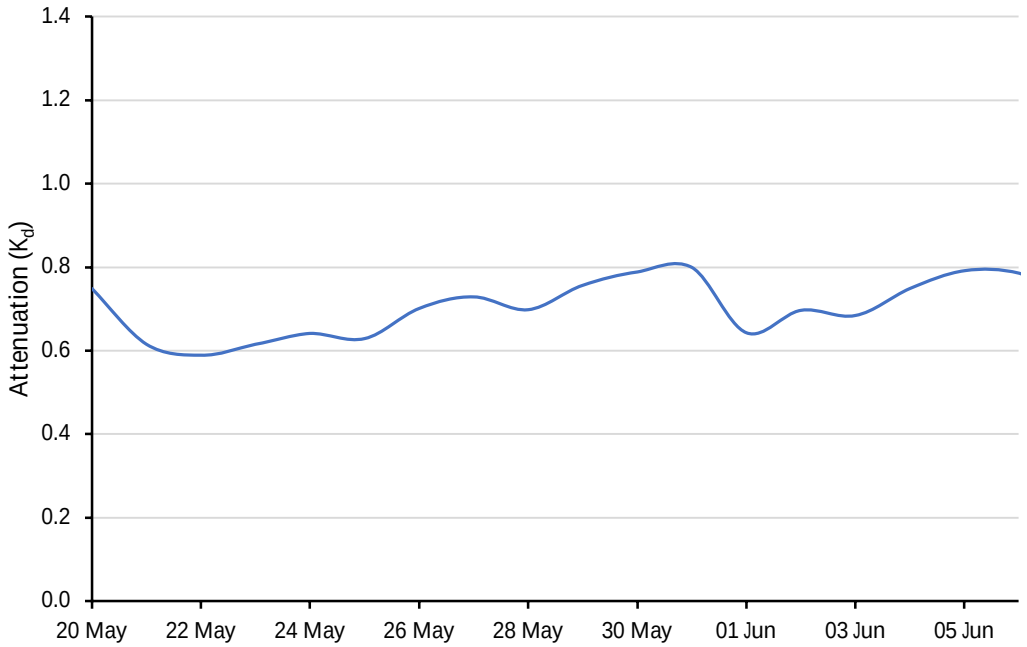


Figure 5-22. Light Attenuation Time Series (k_d)

For seagrass species such as *Zostera*, 5% of surface irradiance is required for survival though summer months. With a k_d value of around 0.75 m^{-1} the depth at which a 5% of light will be reached is around 4 m (Figure 5-23). This matches with observed seagrass in Corio Bay which is thickest at around the 2 m bathymetry contour and grows down to around 4 m in depth sparsely.

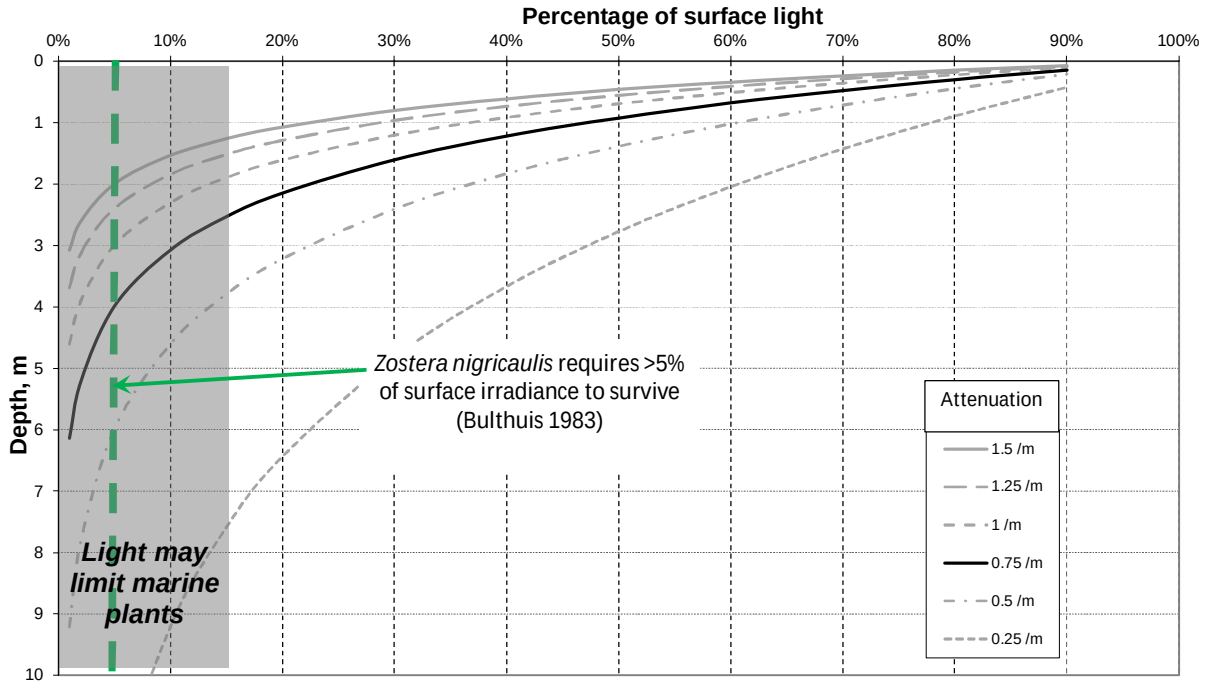


Figure 5-23. Light Loss Over Depth Respective to k_d

Lee (2015) measured light attenuation around Port Phillip Bay from 2008 – 2011 and in seagrass beds from 2008 to 2009. Figure 5-24 shows a time series plot of k_d for the year from October 2008 to September 2009 at Long Reef. The results are in a similar range to the data collected at Corio Bay in 2021.

The Long Reef data shows that light is significantly attenuated with only 6% of light reaching 5 m depth (Lee, 2015). The program also compared the PAR to turbidity which shows a relationship of K_d = 0.124 x TSS + 0.12. A k_d value of 0.75 m^{-1} corresponds to a TSS of 5 mg/L.

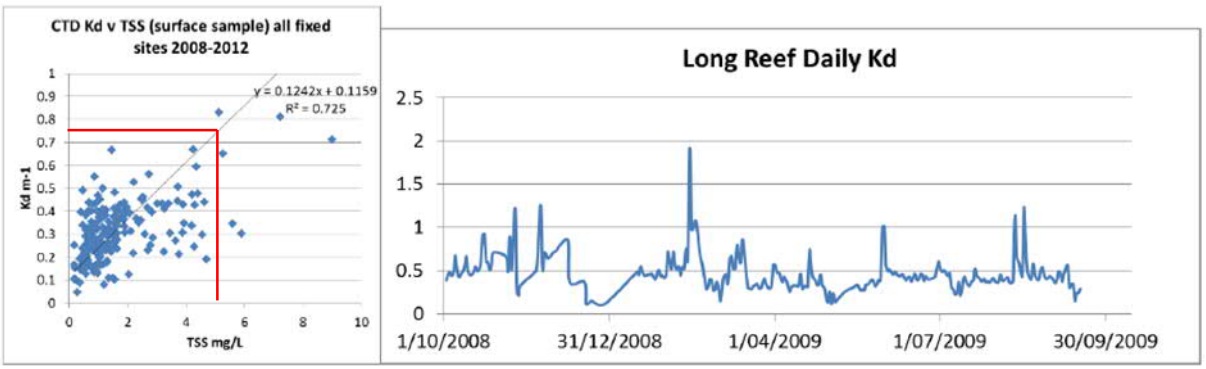


Figure 5-24. Long Reef k_d and k_d Vs Turbidity

Table 5-8 includes data from the DPI *Bayside Seagrass Monitoring Program - Milestone Report No. 1* (Hirst et al, 2008) which shows k_d values calculated from PAR measurements at 2 m and 5 m below the surface at various locations in Port Phillip Bay. The data show k_d values typically ranged from 0.2 m^{-1} to 0.4 m^{-1} with much higher values in Swan Bay - attributed to problems with the loggers (Hirst et al, 2008).

Table 5-8. Background k_d in Port Phillip Bay (Hirst et al, 2008)

Region (light logger)	Lower logger depth (m)	Distance to shallow plot (km)	Distance to deep plot (km)	Mean daily Kd (m^{-1})	Mean % daily irradiance at 2 m	Mean % daily irradiance at 5 m	Total days
Point Richards (Aquaculture zone pile)	4.0	1.3	0.07	0.2	66	37	60
Kirk Point (Long Reef)	3.0	4.5	NA	0.3	55	NA	54
Blairgowrie (speed restriction pile)	2.7	0.7	0.08	0.2	65	36	47
Blairgowrie (Sorrento Channel No. 10)	5.4	0.7	0.5	0.2	67	38	55
Mud Islands (North West MNP pile)	3.2	1.2	5	0.2	63	33	61
Mud Islands (South East MNP pile)*	2.0	2.5	2.4	0.2	69	40	6
St. Leonards (Coles Channel No. 5)	5.0	0.8	0.4	0.4	51	23	66
Swan Bay (MNP pile south east of jetty)	1.3	0.5	NA	2.3	8	NA	66

This brief review shows the light attenuation coefficient ranges generally ranged from 0.2 m^{-1} to 1.0 m^{-1} in Port Phillip Bay and ranged from 0.6 m^{-1} to 0.8 m^{-1} in Corio Bay, which has higher turbidity than Port Phillip Bay. The average k_d value of 0.75 m^{-1} in north Corio Bay corresponds to a TSS of 5 mg/L, based on the relationship derived by Lee (2018).

5.6 Aquatic Plants

All marine plants use light energy from the sun to transform carbon dioxide, water and nutrients into organic matter, while releasing oxygen (the process of photosynthesis). There are four main groups of aquatic plants living in Corio Bay. These are:

1. Phytoplankton;
2. Seagrasses;
3. Macroalgae; and
4. Microphytobenthos.

Phytoplankton are tiny single-cell algae that live in the water and are moved about by currents. The Bay contains more than 300 species of phytoplankton, ranging in size from a few thousandths to a few tenths of a millimetre across. The two main categories are diatoms and dinoflagellates.

Diatoms have an intricate silica skeleton and try to keep close to the surface. They are usually most numerous in summer. Dinoflagellates have two flagella, or threads, which can be used to steer them through the water. They have a versatile lifestyle, some being able to live on organic matter dissolved in water, while others are carnivorous and eat smaller algae, bacteria and protozoa.

Seagrasses are marine flowering plants that reproduce by vegetative growth or from seed fertilised by pollen. They usually grow on sandy or muddy surfaces, using rhizomes and roots for anchorage. Seagrasses obtain some nutrients from the sediment through their roots, while the leaves take up nutrients directly from the

water. The rhizome systems of seagrasses stabilise sediments and reduce erosion by wave action. Seagrass beds are areas of high biological productivity and provide food and shelter for many marine animals. Most of the seagrasses in Corio Bay occur in intertidal and shallow waters less than 5 m deep. There are extensive seagrass beds along the shore in front of the refinery, and along the northern coast (in the declared Ramsar site – see Section 5-17).

Macroalgae are large marine plants commonly known as “seaweeds”. Some grow on rocks, shells or firm sand and are anchored by roots (rhizome or holdfasts). Others drift around the Bay with the currents. Over 60 species of green algae, approximately 100 species of brown algae and approximately 260 species of red algae have been recorded in Port Phillip Bay, and most of them would be present in Corio Bay. Macroalgae obtain nutrients from the water through their fronds and stems. They need light to survive, so they can only grow in shallow water where there is sufficient sunlight. The most dense stands occur in the shallower waters of Corio Bay, mainly between 2 and 8 m water depth.

Microphytobenthos are microscopic algae that live in a thin layer on the seafloor. They are also referred to as benthic algal mats because the algae grow on the surface of the sediment. There are dense mats in southern Corio Bay and moderately dense patches in the entrance to Geelong Arm. Almost all microphytobenthos consist of small diatoms, although occasionally dinoflagellates, green algae and even some blue-green algae can be present. They convert organic matter falling to the seabed. They grow at a slow rate (as they exist in low light levels).

5.7 CEE Fieldwork

Over the previous 12 months, CEE has conducted various technical fieldwork operations to better understand the existing marine conditions in Corio Bay. These studies have been aimed at developing a localised knowledge of the marine habitats, flora, fauna and production and quality over different times of the year and through various seasons. It was also important to develop knowledge on how the existing port operations impact the marine ecosystem to better understand potential impacts which may be introduced due to the construction and operation of the project.

Table 5-9 provides a list of the field studies undertaken by CEE over the 12 month period as well as where the results are addressed and a brief description of why the study was required.

Table 5-9. List of CEE Field Studies in 2020/21

Field Study	Reason for Study	Section Addressed
Plankton sampling (including phytoplankton, zooplankton and ichthyoplankton).	Plankton was sampled monthly to understand the abundances of plankton species over a year and how the communities change seasonally. The results provide evidence on production, grazing and mortality of plankton in the localised area of Corio Bay.	5.9, 5.10 & 5.12
Water quality sampling	Water quality was sampled monthly to see how temperature, salinity and dissolved oxygen change seasonally	5.5

Field Study	Reason for Study	Section Addressed
Water temperature recording	Water temperature was recorded via two temperature loggers at various depths. The water temperature was recorded to see how temperature changed hourly, daily and yearly and determine the temperature variations biota are normally exposed to under existing conditions.	5.5
Light attenuation recording	Two PAR loggers logged underwater light for a period of 3 months. The data was used to calculate light attenuation in the water column.	5.5
Current recording	Currents were recorded for 1 month by an ADCP to the north of Refinery Pier. Current data was used to calibrate the regional hydrodynamic model used to understand the hydrodynamics of the Bay and to track particle movement in the water column over time.	5.4
Seabed video tows	Video tows of the seabed were conducted at sites throughout Corio Bay focussing on the project area of north Corio Bay. The video tows assessed the seabed habitats and confirmed the boundaries of important biotopes.	5.15 & 5.17
Mussel sampling	Mussel sampling at several places in Corio Bay. The mussels were analysed for bromoform and tribromomethane.	9.12
Additional seabed video tows	Further video tows, focussing on the seagrass which dominates the shoreline by the refinery and into Limeburners Bay to assess the impact of the existing refinery plume on seagrasses.	9.10
Infauna sampling	Infauna sampling was conducted at several sites throughout the Bay using a ponar grab. The samples were analysed to assess the composition and richness of infauna communities.	5.16

5.8 Plankton Monitoring in Corio Bay

Phytoplankton abundance has been monitored by EPA at several sites in Port Phillip Bay and one site in Corio Bay in 2008-09 (*Baywide Water Quality Monitoring Program - Milestone Report No.5*, EPA March 2010) and then since 2012 on a monthly basis.

Phytoplankton is the most significant primary producer in Port Phillip Bay, accounting for the majority of net primary production (Beardall and Light 1997). The biomass is low compared to similar estuaries and bays within Australia and internationally (Harris et al. 1996). It was suggested by Beattie et al. (1997) that the phytoplankton biomass within Port Phillip Bay is maintained at these low levels by zooplankton grazing, providing a rapid flow of the products of photosynthesis into the food chain.

Phytoplankton monitoring shows a similar number and abundance of species at all monitoring sites throughout Port Phillip Bay, including Corio Bay, but a large variation in abundance at particular sites through the year, due to short blooms of a few species. For example, the 2009 surveys recorded summer algal blooms at Werribee, Hobsons Bay and Corio Bay. Even so, over the year, the median number of phytoplankton cells in Corio Bay were essentially the same as in central Port Phillip Bay.

A similar finding is apparent from the analysis of the EPA phytoplankton counts from 2012 to 2020. Over that period, the median number of phytoplankton cells in Corio Bay (330,000 cells/L) were essentially the same as in central Port Phillip Bay

(360,000 cells/L), but lower than near Werribee (430,000 cells/L) and higher than at Popes Eye, near the entrance of Port Phillip Bay (195,000 cells/L).

A detailed survey of plankton in Corio Bay was conducted by CEE commencing in October 2020 and extending into 2021. The sampling included collection and identification of phytoplankton, zooplankton and ichthyoplankton at up to 10 sites in Corio Bay. More intensive sampling was conducted in the seawater inlet to the refinery through October and monthly offshore sampling in Corio Bay commenced in November. The surveys continued for 12 months.

The inlet sampling started on 16 October 2020 and proceeded weekly until the end of the month. Through November and December 2020, the inlet was sampled fortnightly before transitioning to monthly from January 2021. For a better comparison to the continued monthly sampling in 2021, the weekly and fortnightly results have been standardised into monthly results which are shown in the sections below.

One sampling site was in the seawater inlet channel for the refinery. The other nine sites were distributed around Corio Bay and the Geelong Arm of Port Phillip Bay.

The nine sites used in the offshore sampling, are shown in Figure 5-25. The distribution of sites aimed to cover the different habitats in Corio Bay and the adjacent waters of Port Phillip Bay. Six of the sites are located with Corio Bay - one near the existing Refinery Pier, one to the north by the Ramsar zone, one at the EPA monitoring site in Corio Bay, and three in the south of the Bay.

Three of the sites are in the Geelong Arm of Port Phillip Bay. These were reference sites to compare the phytoplankton communities in Corio Bay with those in Port Phillip Bay.

Plankton samples were collected at all sites over summer, from November 2020 until January 2021. An analysis of the results show that the plankton distribution was well mixed through the Bay with no significant difference detected between plankton in North Corio, South Corio and the Geelong Arm. Thus, the monthly sampling in the Bay was reduced to the three offshore sites in Corio North.



Figure 5-25. CEE Plankton Sampling Sites in Corio Bay

For the offshore sampling, depth-integrated sampling methods appropriate for Corio Bay were used, similar to those used in the Victorian Marine Biotoxin Management Plan (e.g. Fisheries Victoria 2017; EPA *Victoria Marine Monitoring Program*).

Phytoplankton Sampling and Identification

Samples for phytoplankton analysis at the offshore sites were collected by a depth-integrating method using a 15 m long, 19 mm diameter clear PVC hose with valves on both ends and a 1.5 kg weight on one end. The hose was lowered slowly through the water so it filled with a column of water. The valves were closed, the hose was brought into the boat and the water emptied into a clean container and mixed. At the inlet, the shallow depth meant that a mixed representative sample could be taken. A 1 L water sample was collected in a bottle, and preserved with Lugol's potassium iodide solution at a concentration of approximately 0.5 % v/v.

Phytoplankton in samples were identified and enumerated by Microalgal Services, a NATA accredited specialist phytoplankton laboratory. Phytoplankton were concentrated using membrane filtration, and then samples were placed into Sedgewick-Rafter counting chambers and examined using light microscopy. Microalgal Services phytoplankton specialists advised on collection and preservation procedures. This is the same laboratory as used in the EPA monitoring.

Microalgal Services provided a master sheet on the ecology and temporal and spatial patterns of the phytoplankton of the samples collected during the program. Microalgal Services sheet is appended to this report. Phytoplankton species were identified to the lowest possible taxonomic level (usually genus or species) using morphological features and counted. Phytoplankton abundances were reported as cells per litre.

Zooplankton Sampling and Identification

Samples for zooplankton analysis were collected as an integrated sample over the water column (Melbourne Water, 1992-1997 & CSIRO, 1996). A 2 m long, 0.5 m diameter conical net made with 210 µm mesh and a 90 mm cod-end and weight attached to the bottom of the mouth was used to sample zooplankton offshore. Vertical hauls from just above the seabed to the water surface provided a depth-integrated sample over the water column (as recommended by Kimmerer and McKinnon 1985). The vertical distance of each haul was recorded, typically 12 m for central channel sites and 4 to 10 m for shallower sites.

The net was hauled steadily by hand at around 1 m/s. Any zooplankton adhering to the inside sides of the net were rinsed to the cod-end by washing gently but thoroughly from top to bottom and from the outside after each haul. Samples were concentrated by draining excess water through the side of the net and rinsing zooplankton back into the cod-end. One zooplankton sample was collected at each site as listed above. All samples were preserved in 2 % v/v buffered formalin and transported to the Institute of Marine and Antarctic Studies, University of Tasmania, for analysis of species abundance.

For zooplankton sampling in the inlet, the same conical net was hung in the water horizontally to catch zooplankton as it flowed along the channel and into the refinery. The net was held in place for 1 minute before being retrieved.

Ichthyoplankton Sampling and Identification

For ichthyoplankton sampling at the seawater inlet site, a 4 m long, 500 µm mesh net with a mouth of 0.8 m and weight attached to the bottom was used. The net was hung in the water horizontally to catch ichthyoplankton as it flowed through the inlet channel and into the refinery. The net was held in place for 20 minutes before being retrieved and the volume was calculated with the flow rate.

During the offshore sampling, the same net was towed behind the vessel. Tows covered a range of depths from approximately 1 m above the seabed to the surface which provided a depth integrated sample over the whole water column in steps. Each tow lasted for approximately 12 minutes over 400 to 500 m and collected ichthyoplankton from 200 m^3 of seawater.

Any ichthyoplankton adhering to the inside sides of the net were rinsed to the cod-end by washing gently but thoroughly from top to bottom and from the outside after each haul. Samples were concentrated by draining excess water through the side of the net and rinsing ichthyoplankton back into the cod-end. All samples were preserved in 5% v/v buffered formalin.

Fish eggs, fish larvae, syngnathids and cephalopods were sent to an ichthyoplankton specialist Dr A Miskiewicz at the Australian Museum for identification and archiving. Dr. Miskiewicz is an expert in larval fish taxonomy and is the co-author of the temperate fish larvae text, "*Larvae of temperate Australian fishes: laboratory guide for larval fish identification*" by F Neira, AG Miskiewicz and T Trnski (1998).

Larvae were identified to the lowest practical level, which was typically genus or species. Species for which larval characters are undescribed were differentiated into families with lower classification based on morphological characteristics. In some cases, the species of specimens for which larvae are described to family taxonomic level could be inferred based on the known distribution of species within that family.

The inlet sampling location was located at the edge of the seawater inlet channel at the shore. The seawater inlet channel is only a meter or so deep and varies with the stage of the tide. The water surface is 2 to 3 m below the edge of the railing that bounds the channel. The plankton nets were hung horizontally in the channel to filter plankton.



Figure 5-26. Inlet Plankton Sampling Location

In summary, the plankton communities that were sampled in Corio Bay comprise:

- Phytoplankton, which are the microscopic plants that can photosynthesize and one of the key sources of primary production in Corio Bay;
- Zooplankton, which are the small animals of various feeding groups that provide a source of food for other filter feeding animals including other plankton, invertebrates on the seabed, jellyfish, larval fish and small fish; and
- Ichthyoplankton which are fish eggs and fish larvae.

5.9 Phytoplankton

As noted above, phytoplankton are the microscopic plants that photosynthesize and are responsible for about half the primary production in Corio Bay. Most phytoplankton obtain their energy through photosynthesis (they are autotrophs), although some species of phytoplankton can obtain energy by also consuming other phytoplankton or bacteria (heterotrophs).

Phytoplankton are grazed on by zooplankton, the next level in the marine food chain. Zooplankton are tiny invertebrate species which range from microscopic to shrimp like creatures. The smallest zooplankton species graze on bacteria and phytoplankton while the larger zooplankton feed on phytoplankton and smaller zooplankton.

Phytoplankton also are eaten by a range of larval fish and benthic filter-feeding organisms as well as zooplankton. The primary productivity provided by the phytoplankton in Corio Bay is complementary to the primary productivity of seagrasses, macroalgae and benthic microalgae.

Phytoplankton have a limited capacity to swim in the water column. Therefore, due to their very small size, their ability to maintain position in tidal currents with vertical mixing is very limited. They drift with prevailing currents and mixing processes. Phytoplankton typically have rapid life-cycles (only hours to a few days) and can respond quickly to changes in the availability of light and nutrients.

Phytoplankton abundance and species richness in Port Phillip Bay and Corio Bay depends on several factors which include nutrient inputs, light, temperature, turbidity, nutrient availability, and grazing pressure.

Available nutrients, light and temperature are considered the most important factors influencing phytoplankton growth. Greater biomass generally occurs near Werribee and in Hobsons Bay where the Yarra River provides nutrients. Lower biomass is generally recorded in the south of Port Phillip Bay, reflecting the distribution of available nutrients. The phytoplankton biomass is generally higher during summer/autumn months than over winter, reflecting seasonal patterns of light and temperature (Beardall et al. 1997).

Corio Bay has similar abundance of phytoplankton as Port Phillip Bay, but lower abundance of phytoplankton than in other embayments around the country.

5.9.1 EPA Phytoplankton Monitoring in Corio Bay

Phytoplankton abundance has been monitored by EPA at one site in Corio Bay and several sites in Port Phillip Bay. Phytoplankton has been sampled in Corio Bay by the EPA since 2012 on a monthly basis.

Figure 5-27 shows a time series plot of total phytoplankton abundance in Corio Bay from 2012 to 2020. The data show that over that time the number of phytoplankton cells in Corio Bay averaged 643,000 cells/L with periodic large spikes. Higher abundances of phytoplankton occur in summer. Over the years, the typical or geometric mean number of phytoplankton cells was 354,000 cells/L.

The EPA phytoplankton data shows than Corio Bay has an active plankton community that is usually more abundant that in some areas of Port Phillip Bay (such as the central region or Popes Eye, near the Entrance), but less abundant than in other sites such as near Werribee (due to the input of nutrients from the Western Treatment Plant).

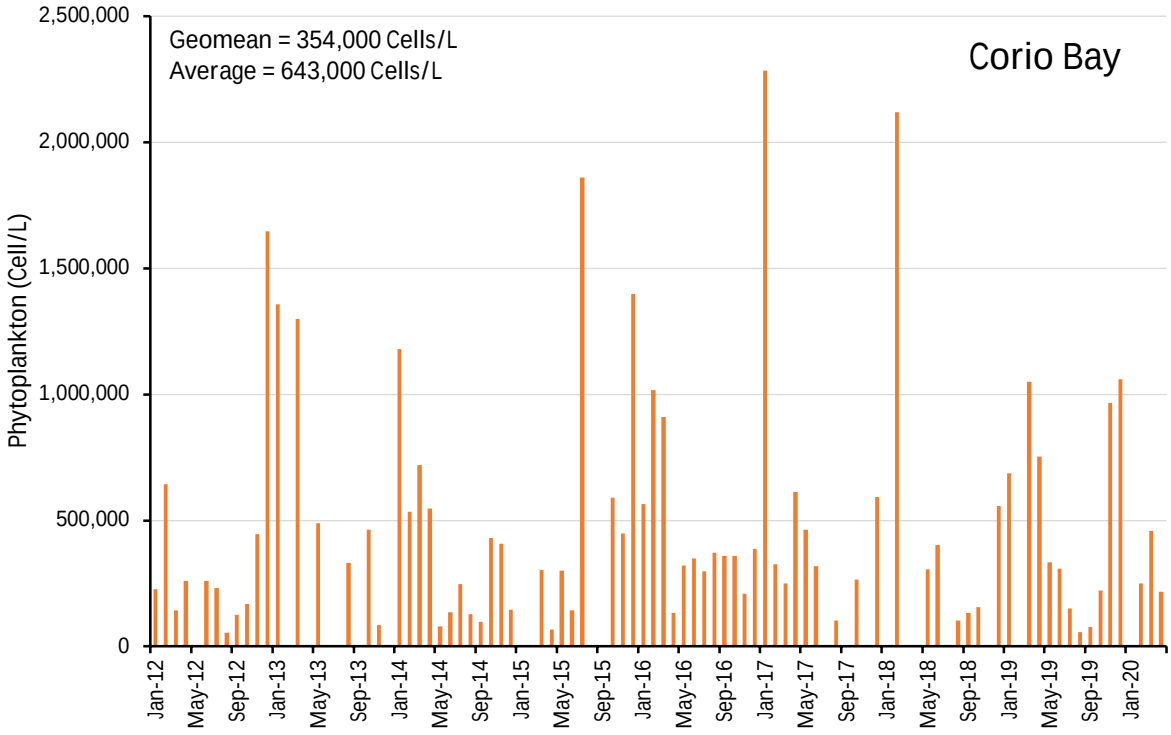


Figure 5-27. Phytoplankton in Corio Bay (2012 – 2020)

CEE carried out a more intensive phytoplankton and zooplankton sampling program in Corio Bay to assess the spatial distribution of plankton in Corio Bay and the effects of the circulation patterns, channel deepening and refinery use of seawater for cooling.

5.9.2 Phytoplankton Sampling Results

Abundance

Phytoplankton abundance and composition has been analysed for the samples collected at the seawater inlet site from October 2020 through to October 2021. Table 5-10 shows the average numbers of each of the phytoplankton classes which were captured at the north Corio Bay sites including Viva, Point Abeona and EPA, and at the Inlet site in units of 1000 cells/L. The results in the table show that diatoms were the most abundant phytoplankton class and made up around 45% of the total abundance over the year. The second most abundant class was dinoflagellates at around 22% of total abundance. Cryptophytes, prymnesiophytes, prasinophytes (marine) and euglenophyta each made up between 1% - 16% of the total abundance. The month with the highest phytoplankton abundance was December 2020 when a large spike in numbers was observed at all sites.

Table 5-10. Summary of Phytoplankton Species Abundance (1000 cells/L)

Date	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Total	
n (samples)	3	3	3	3	3	3	3	3	3	3	3	3	3	6	
Phytoplankton geomean	413	359	1726	737	577	641	518	291	185	305	250	278	227	323	
Phytoplankton Classes														Geo Mean	%
Diatoms	116.3	109.1	1425.2	430.1	294.4	316.0	102.5	101.4	49.0	108.6	54.8	67.6	74.0	144	44%
Dinoflagellates	47.8	60.0	133.4	117.7	106.7	76.5	150.9	60.3	29.2	49.8	76.5	66.1	51.1	71	22%
Cryptophytes	81.0	48.5	52.6	48.3	82.7	74.4	88.5	45.5	41.0	52.3	28.8	54.4	25.0	52	16%
Prymnesiophytes	52.8	35.1	36.3	48.3	20.5	46.8	42.0	24.5	16.3	22.8	23.4	34.0	14.0	30	9%
Prasinophytes (marine)	46.2	33.4	19.3	11.5	7.6	61.3	34.8	26.0	20.8	34.1	26.3	17.5	21.0	24	7%
Euglenophyta	10.3	14.7	5.9	7.5	1.0	19.3	20.5	9.5	8.8	9.5	4.3	2.5		2	1%
Chrysophytes						33.0	68.5	17.5	15.8	23.3	31.3	33.8	37.0	0.04	0.01%
Other	4.3	9.4				14.1		6.0	3.0	4.0	0.8	0.3	3.0	0.03	0.01%
Raphidophytes	0.2	4.9		0.1	0.1		0.4	0.1	0.3		0.1	0.8	0.5	0.02	0.01%
Ciliate	0.4						0.3	0.5	0.6	0.3	3.5		1.0	0.0013	0.0004%
Ochrophytes	53.3	38.7	52.3	74.0	62.5									0.0009	0.0003%
Dictyochophytes		5.3	1.2		1.5		10.0					0		0.0002	0.00005%
Cyanoprokaryota (freshwater)						0.1	0	0			0			0.00001	0.00000%
Chlorophytes (freshwater)											0.8	1.5		0.00001	0.00000%

< 25th Percentile = 4 (1000cells/L)	25th – 50th Percentile = 4 – 25 (1000cells/L)
50th – 75th Percentile = 25 – 53 (1000cells/L)	> 75th Percentile = 53 (1000cells/L)

Figure 5-28 shows a plot of the average abundance at each site (dashed lines) as well as the overall average abundance (red line). The dashed black trace shows the average monthly daylight hours for the same period. The graph shows the pattern which can also be observed in Table 5-10 with a large spike in abundance in December 2020 and then a steady decline at each site of the following months. The graph shows that peak phytoplankton abundance coincides with the longer daylight hours and thus, abundances are likely to increase in the later and warmer months of 2021.

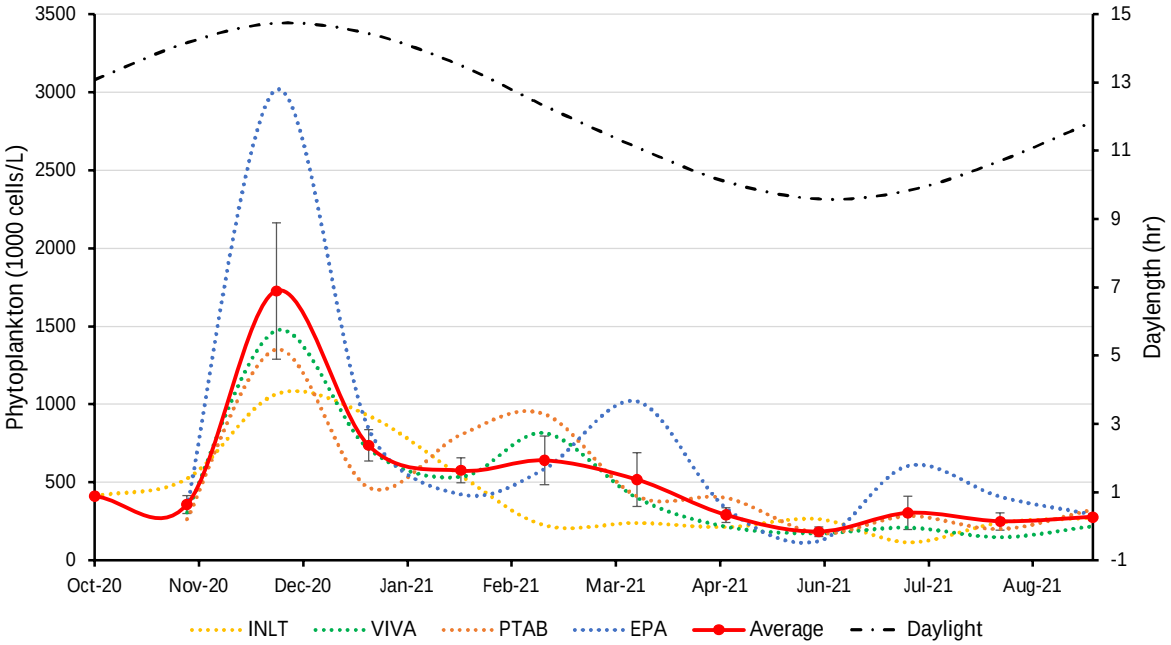


Figure 5-28. Time Series of Phytoplankton Abundance (Mean ±SEM)

Figure 5-29 is a plot of the phytoplankton abundance by site which includes the four sites in north Corio Bay. The average abundance for the four sites examined show that the Inlet, Point Abeona and Viva sites were all similar with values between 400 – 500 (1000 cells/L). However, the EPA site was slightly higher at over 700 (1000 cells/L). This is mostly due to the large bloom in December 2020, however the site also had increased total abundance compared to the other sites in April, July and August where numbers at the EPA site were close to double the others. The black bars indicate the standard error of the mean.

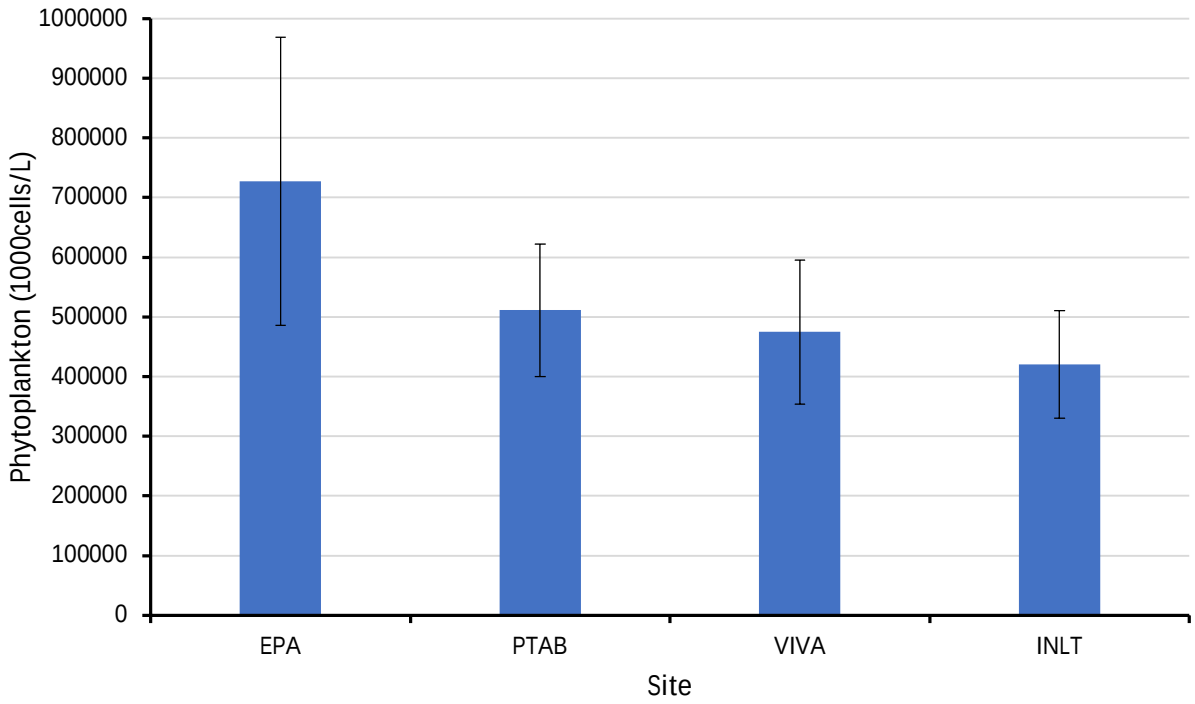


Figure 5-29. Phytoplankton Abundance per Site (Mean ±SEM)

Figure 5-30 shows time series plots of each of the major phytoplankton groups at each of the four sites being investigated. The plots are on a LOG scale due to the high abundances. Diatoms are the class with the highest abundance and have their peak in December 2020 with a large bloom. After December 2020 the abundance of diatoms steadily decreases. Dinoflagellates have more of a constant trend around 100 (k cells/L). The phytoplankton class does have some variations with a large spike at the EPA site in April 2021 and August 2021.

Cryptophytes have abundances which range between 10,000 – 200,000 cells/L. Unlike other classes, there were very low numbers of cryptophytes recorded in December 2020 particularly at the Viva and EPA sites. However, similar to dinoflagellates the EPA experienced small pikes in April and August 2021.

Prymnesiophytes started with concentrations between 10,000 and 100,000 cells/L but over the year, there were several months when some sites were below 10,000 cells/L. The highest concentrations of this site were recorded at the EPA site in January 2021 and September 2021, both with concentrations of around 100,000 cells/L.

Three tests were carried out on separate days to determine the percentage loss of viability in phytoplankton populations with passage through the refinery heat exchanger. The inlet counts were counted as 225,000, 227,000 and 272,000 cells/L (geometric mean of 240,000 cells/L). Seawater samples were collected from the W1 discharge 15 minutes later, and the geometric mean of the counts of the three outlet phytoplankton samples was 120,000 cells/L. Diatoms were the principal species.

The results show that 50 % of the discharged phytoplankton were living (i.e., viable). The W1 discharge flows usually north and reaches the inlet about 4 hours later, by which time the phytoplankton counts were the same as at the other refinery sites.

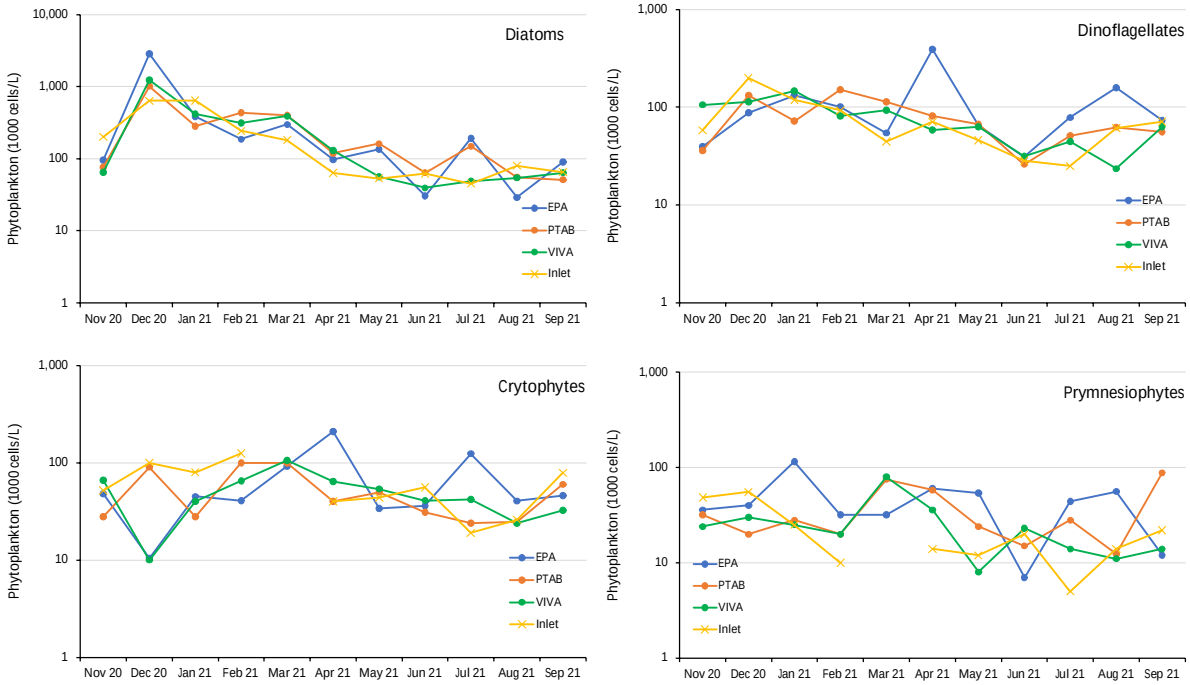


Figure 5-30. Time Series of Major phytoplankton Groups

Species Richness

Figure 5-31 shows a time series plot of the species richness at each of the four sites (dashed lines) as well as an overall average (black line). The bars on the black line represent the standard error of the mean. The plot shows that the inlet had a large number of species present in November 2020, but a sharp decline showed lower numbers at all sites in December 2020, January 2021 and February 2021. This is likely because of the large bloom in abundance which was dominated by the major phytoplankton classes allowing less species to develop. From March to September 2021 the richest was variable from site to site, although the general trend was stable between 20 – 50 species each month. A larger number of species was consistently observed at the Point Abeona site compared to the Inlet. This is likely because the Point Abeona site is close to the Ramsar site and the largest seagrass beds of Corio Bay while the Inlet site is close to the shoreline.

The dashed black line shows the average monthly daylength in hours. Interestingly richness was lower in the months with more daylight hours and then increased when the daylength became shorter. When abundance is high, phytoplankton are dominated by a few groups which limits the growth of other species. However, when the abundance drops in the cooler weather, a large number of species can develop.

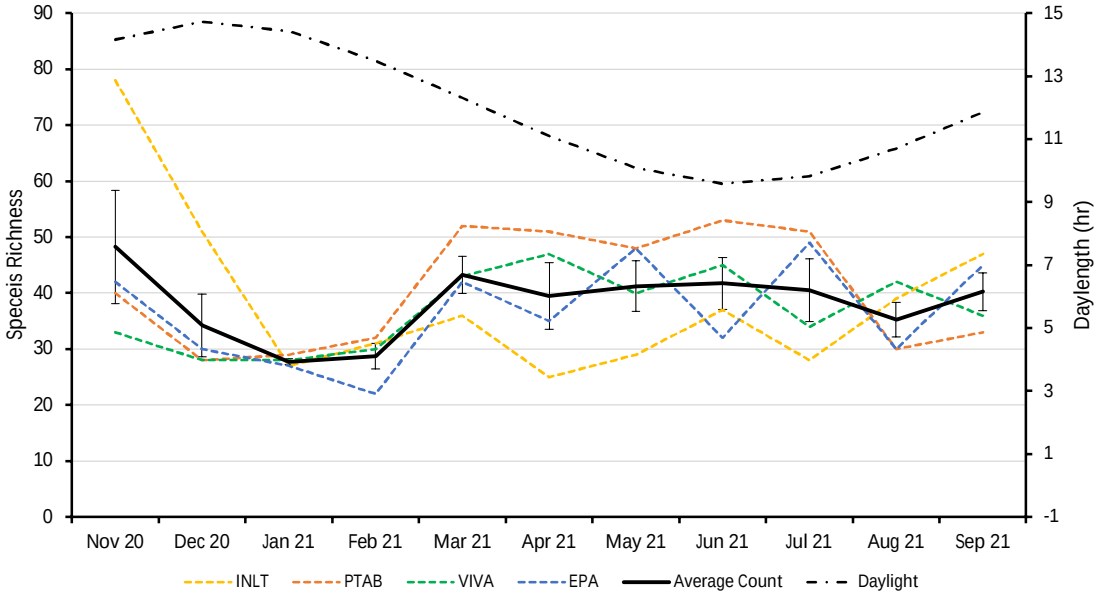


Figure 5-31. Time Series of Species Richness (Mean ±SEM)

Figure 5-32 shows the average species richness for each site over the whole survey period. The results show that the average species richness from site to site is very consistent and ranges from 36 at the EPA site to 40 at the Point Abeona site. The black bars represent the standard error of the mean.

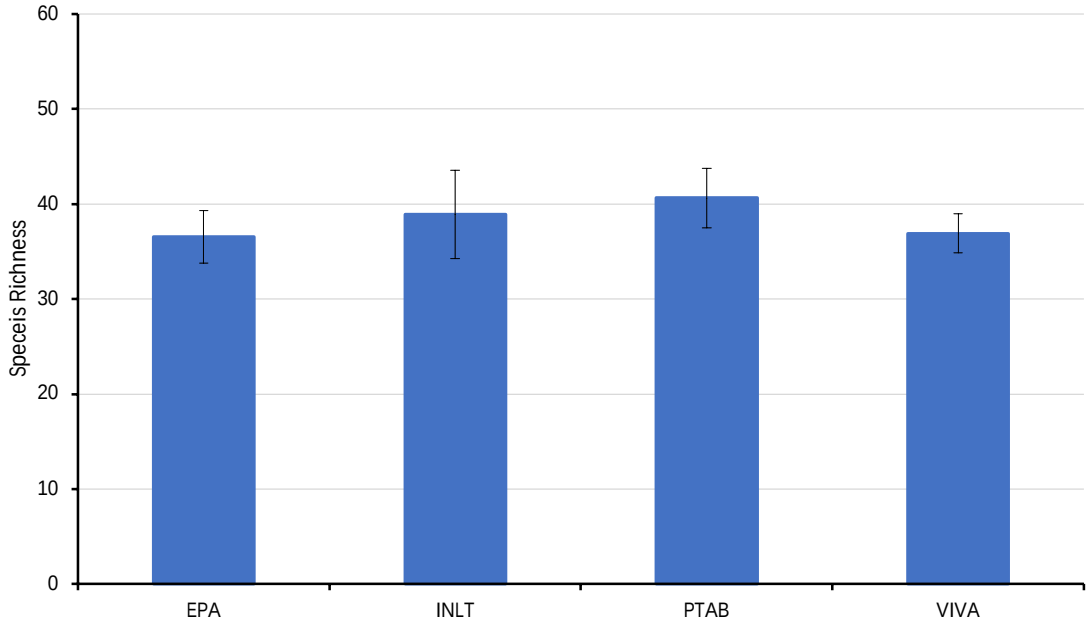


Figure 5-32. Species Richness Per Site (Mean ±SEM)

The conclusion drawn from the phytoplankton study is that the abundances are similar at the sites throughout Corio Bay, with diatoms being the dominant species.

Phytoplankton abundance at the refinery seawater inlet was the same as elsewhere in Corio Bay, which indicates that the passage of seawater through the refinery is not having a significant effect on phytoplankton populations.

5.10 Zooplankton

Zooplankton are small invertebrate animals which live throughout the Bay and feed on smaller species such as bacteria and phytoplankton. Zooplankton size can range from only a few thousandths of a millimetre in diameter to a few millimetres long. The majority of zooplankton are filter feeders. This means that they suck water in through their mouths and catch their food with small bristles or hairs. It is estimated that filter feeders can filter the entire volume of Port Phillip Bay in the period of around two weeks (Melbourne Water, 1992-1997).

According to a study by Kimmerer and McKinnon, 1985, about half of the zooplankton in Port Phillip Bay are copepods and another 23 % are *Cladocera* (crustaceans or water fleas). The abundance of zooplankton depends on the abundance of phytoplankton communities as the zooplankton feed on phytoplankton in the water column.

The smaller zooplankton, referred to as microzooplankton, are less than 0.05 mm in diameter. These typically include dinoflagellates and ciliates and they normally feed on small phytoplankton. These species have high growth and loss rates, with a life cycle of a week or so.

The larger zooplankton, are referred to as mesozooplankton, are more than 150 mm in size and typically have life cycles of a few weeks, feeding on the larger phytoplankton. There is also some feeding across size classes in that mesozooplankton feed on the microzooplankton. However, most plankton models (such as the *Port Phillip Bay Integrated Model*, 1997) assume that zooplankton feed only on the phytoplankton (Melbourne Water, 1992-1997 & CSIRO, 1996).

The loss rate for large zooplankton was estimated to be within the range of 2 % to 8 % per day, which reflects the dominance of smaller crustacea in Port Phillip Bay (Melbourne Water, 1992-1997 & CSIRO, 1996) and a life cycle of 2 to 7 weeks. While several studies into zooplankton have been conducted through Port Phillip Bay which includes Corio Bay, there has been little investigation of the zooplankton communities within Corio Bay itself. This report provides a description of the zooplankton community in Corio Bay based on sampling carried out from October 2020 to January 2021.

Most zooplankton are weak swimmers and are moved by ambient water currents. Some plankton can move vertically through the water column in response to time of day; others stay at a certain depth range, generally in waters that are stratified by temperature or salinity layers. Others may be associated with particular seabed habitats, such as seagrass or mudflats in shallow water and have strategies to maintain their position on, in or close to those habitats. Recognizing these behaviour patterns, samples for zooplankton analysis were collected as an integrated sample over the water column (Melbourne water, 1992-1997 & CSIRO, 1996).

Vertical hauls from just above the seabed to the water surface provided a depth-integrated sample over the water column (as recommended by Kimmerer and McKinnon 1985). The vertical distance of each haul was recorded, typically 12 m for central channel sites and 4 to 10 m for shallower sites.

5.10.1 Zooplankton Sampling Results

Table 5-11 shows a species distribution table for abundance based on the month to month sampling. The table includes data which was collected from the north Corio Bay sites and the Inlet site and is summaried to only include species which account for at least 1% of total abundance based on a geometric mean. Each value is an average of the four sites for each species at each month. The results show that *paracalanus indicus* was the most abundant species at 40% while *acartia* was the second most abundant at 30%. *Noctiluca scintillans* were the third most abundant species due to a large bloom in January 2021. However, this species became sparse in the mid months of the year, though began to come back in August 2021. Other dominant groups included *oikopleura, podon, gladioferens, evadne, obelia, leptomedusa* and *crab zoea*. These groups all made up 1 – 5% of total abundance.

Table 5-11. Zooplankton Abundance – Cells/m^3

Date	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Total	
n (samples)	3	3	3	3	3	3	3	3	3	3	41	
Zooplankton	6226	838	3096	3214	654	455	278	288	381	1340	296	
Species											Geo Mean	%
Paracalanus indicus	296.6	71.5	55.4	169.0	163.1	195.8	131.4	83.7	33.9	161.8	114.4	39%
Acartia sp.	2284.6	17.9	6.7	70.4	99.4	134.2	48.7	61.4	171.0	236.7	89.0	30%
Noctiluca scintillans	233.8	269.8	2801.6	2798.3	33.1	3.1		5.9	2.2	632.3	29.1	10%
Oikopleura sp.	345.8	4.6	3.0	36.1	55.0	9.7	12.8	8.3	3.3	19.9	15.2	5%
Podon sp.	2269.7	332.7	49.0	38.0	149.1		0.1	42.7	35.4	12.7	14.4	5%
Gladioferens sp.	680.4	0.8	0.2	4.2	8.1	16.6	20.9	9.0	34.7	161.3	12.2	4%
Evadne sp.	14.2	77.9	119.1	20.5	26.9	4.4		43.2	57.0	6.0	9.3	3%
Obelia sp.	2.3	19.7	6.1	12.0	4.1	1.3	3.3	7.3	3.4	22.2	5.6	2%
Leptomedusa	1.1	2.2	2.6	1.1		17.4	26.8	1.0	8.4	55.7	2.1	1%
Crab zoea	5.5	2.8	8.1	4.1	4.1	2.5	1.5	0.5	0.1	1.2	1.9	1%

< 25th Percentile = 0.4 (cells/m^3)	25th – 50th Percentile = 0.4 – 2.9(cells/m^3)
50th – 75th Percentile = 2.9 – 17.4 (cells/m^3)	> 75th Percentile = 17.4 (cells/m^3)

Zooplankton abundance has been analysed for all species across the three north Corio Bay sites and the Inlet site. The resuts are shown in Figure 5-33. The dotted lines show the average plankton abundance at each of the sites while the solid red line shows the overall average. Finally, the dotted black trace represents the average daylight hours for each month.

The plot shows a variable trend in overall plankton abundance. A large bloom was recorded in November 2020 resulting in high numbers of zooplankton at all of the sites, but especially at the inlet. Following the bloom, there is a significant decrease in abundance in December 2020 before another rise up to around 3,000 cells/m^3 in January and February 2021. When the daylight hours begin to reduce and the weather cools off in autumn and winter, the zooplanton abundance at all sites decreases to less than 1,000 cells/m^3.

Towards the end of the graph in August, it can be seen that as the daylight hours slowly began to increase once more, the overall abundance of zooplankton is starting to increase.

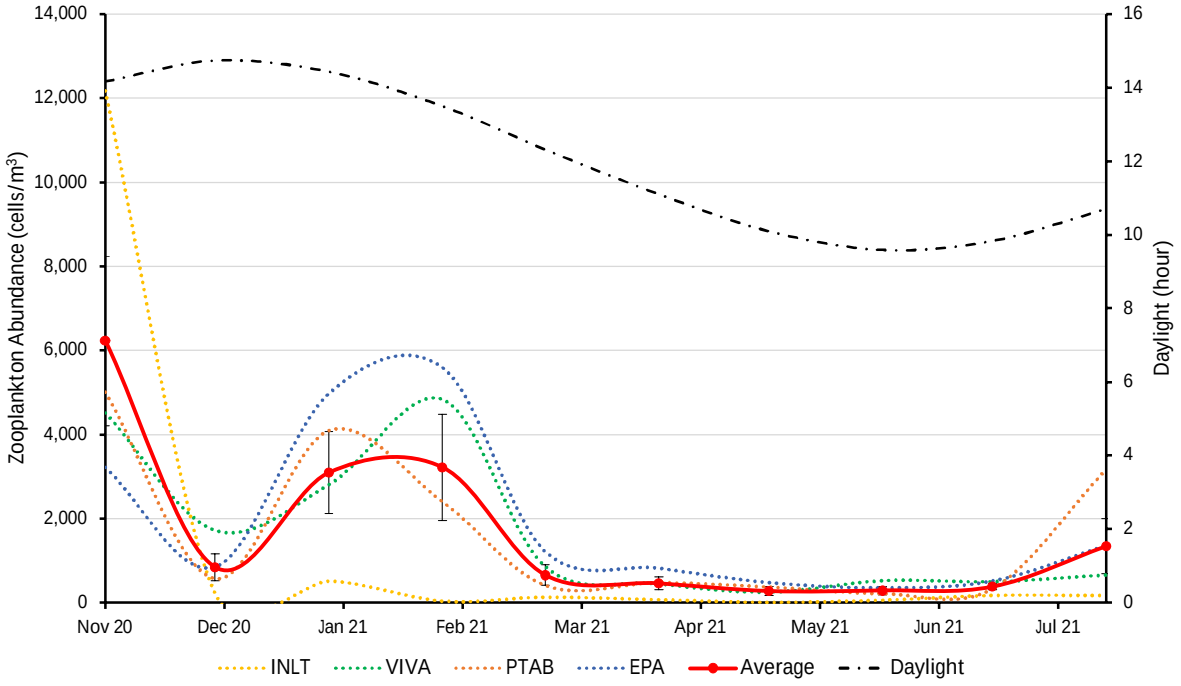


Figure 5-33. Zooplankton Abundance and Daylight Hours

(Mean ±SEM)

Figure 5-34 shows a plot of the zooplankton abundance at each of the north Corio Bay sites and the Inlet across the whole study period. The plot indicates that the inlet had the lowest abundance at around 1,300 cells/m^3 while the EPA site had the highest at 1,900 cells/m^3. Both the Viva and Point Abeona sites were very similar in average abundance at around 1,700 cells/m^3.

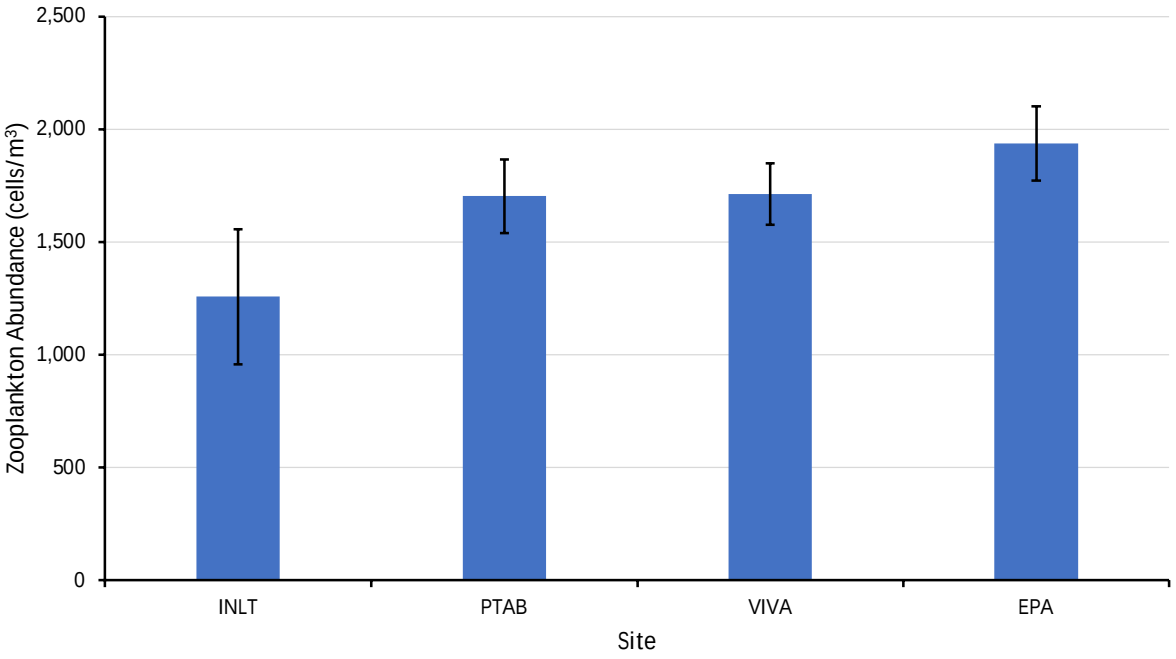


Figure 5-34. Zooplankton Abundance by Site

(Mean ±SEM)

Figure 5-35 shows the abundances of the major zooplankton groups from the three sites in north Corio Bay. The blue line represents data from the EPA site, the green line represents data from the Point Abeona site, the yellow line represents data from the Viva site and the orange line represents data from the Inlet site.

P*aracalanus indicus, acartia* and *Noctiluca scintillans* are the most abundance zooplankton groups making up around 40%, 30% and 10% respectively. Both P*aracalanus indicus* and *acartia* experienced large blooms in November. *Acartia* especially, had abundances at the offshore sites of over 3000 cells/m^3. P*aracalanus indicus* had varied numbers from site to site with the highest numbers typically at the EPA site which experienced a peak in February 2021. Each site had decreased numbers in winter with a low in July 2021, although numbers began increasing in August. Concentrations at the Inlet site remained consistently low over the year. For *acartia* abundances were below 500 cells/m^3 across the year after the large bloom in November. August showed a slight increase in abundances at the Point Abeona site as well as the EPA site. Numbers at the Inlet site and Viva sites remained low.

Noctiluca scintillans had low numbers in November and December 2020 but experienced a large spike at the offshore sites in January and February 2021 up to around 4,500 cells/m^3. By March 2021, the bloom came to an end and numbers decreased at all sites to less than 100 cells/m^3. August has shown an increase in numbers at several sites.

Other less abundant groups included *oikopleura, podon* and *gladioferens.* Concentrations of *oikopleura* had spikes at the EPA and Viva sites in summer months at over 100 cells/m^3, durign other months the concentrations were less than 50 cells/m^3. *Podon* experienced a very large spike in abundance at the Inlet site up to

9000 cells/m^3, however, all other months had concentrations less than 500 cells/m^3. Similar to other groups, *gladioferens* had a large spike in November 2020 and during the proceeding months had concentrations less than 60 cells/m^3 and an increase in July and August 2021.

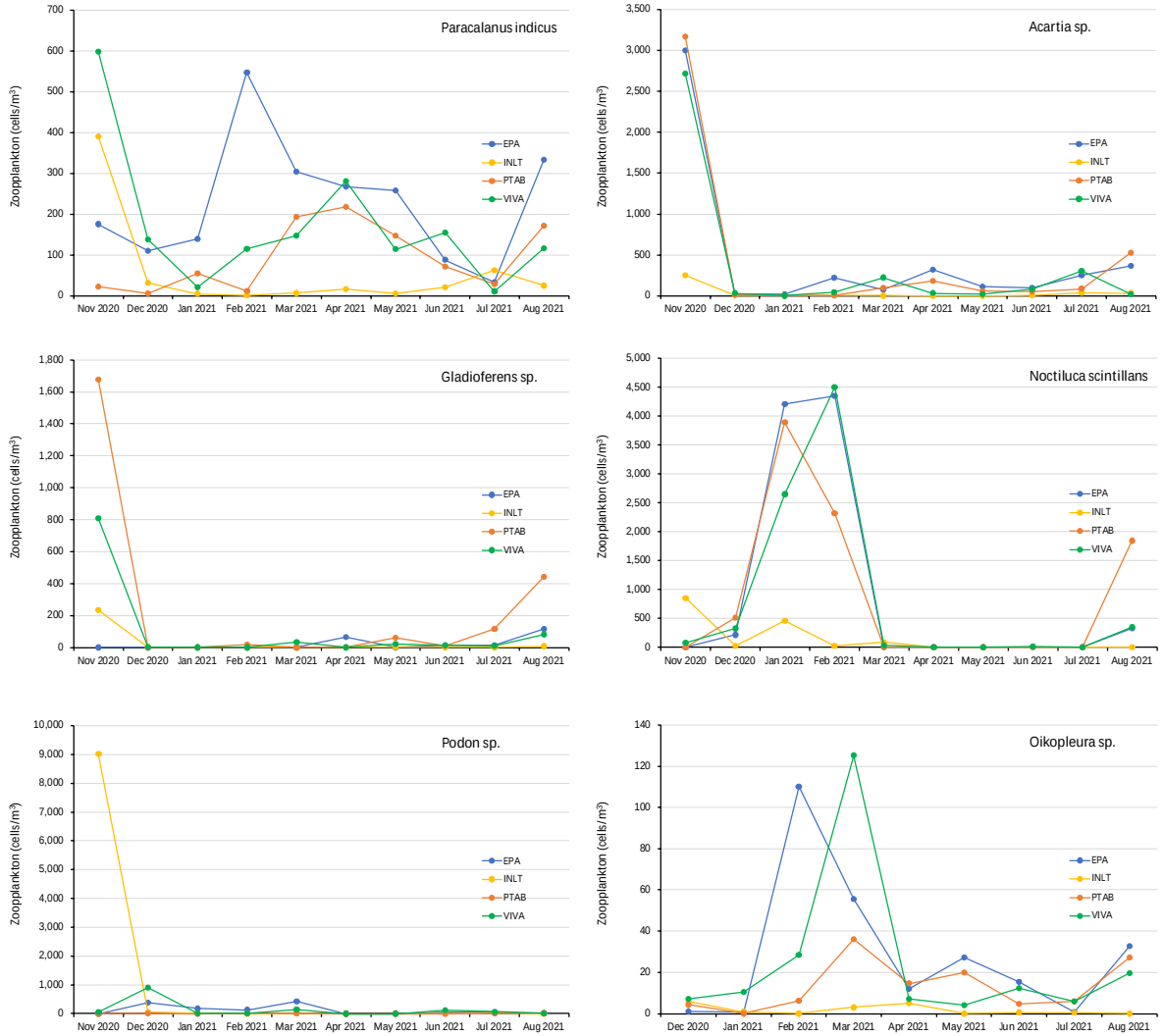


Figure 5-35. Major Zooplankton Classes in north Corio Bay

Species Richness

Figure 5-36 shows the species richness of each of the sites as well as the overall average richness and daylight hours. The species richness over the survey period has a steady declining trend starting with an average at around 21 species in November 2020 and declining to around 10 – 12 species in August 2021.

There is slight variation in richness from site to site (dashed lines). There is lower richness at most sites in November even though that month has higher overall abundance. This is because the high abundance is driven by very high numbers of several key zooplankton species such as *acartia* and *podon sp*. reducing the total number of species that are present. Based on the plot, there is no clear link between the species richness and daylight hours.

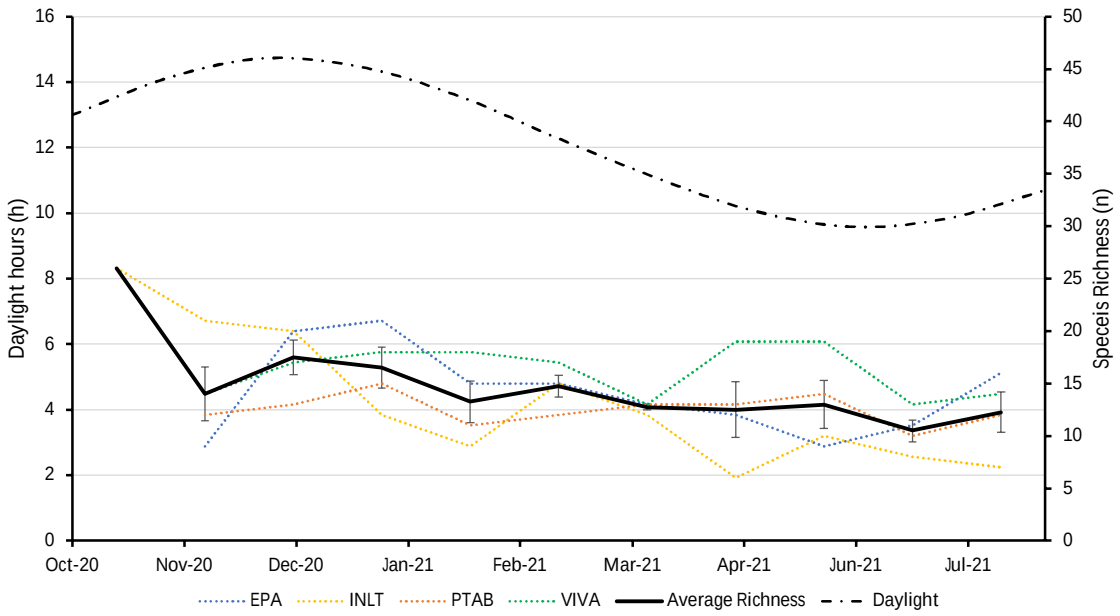


Figure 5-36. Species Richness Time Series

The conclusion drawn from the zooplankton sampling is that the major taxonomic groups are present most of the year, but the proportions of the zooplankton species vary considerably from month to month. There are similar temporal trends at the three widely spread sites in north Corio Bay. Thus, zooplankton appear to be responding to similar regional factors, such as an increase in phytoplankton numbers in Corio Bay.

5.11 Fish

5.11.1 Aquaculture

There is an aquaculture reserve and an onshore abalone farm near Bates Point to the east of Point Lillias (Ref: *CoastKit Base Map for Aquiculture*, 2021).

5.11.2 Fish Habitat

Corio Bay has a range of marine habitats, including seagrass, muddy seabed, mangroves, unvegetated sediments, biogenic reef, sandy beaches and man-made structures. Associated with these habitats is a diverse fish fauna that includes species of commercial, recreational, conservation and ecological importance.

There has been commercial fishing in Corio Bay since the 1850's. However, in 2018, commercial netting was banned in Corio Bay (VFA 2021b), essentially ending commercial fishing in the bay. Recreational fishing in Corio Bay continues from both land and boat and is very popular.

There are also conservation-listed fish species in Corio Bay, as well as ecologically important species that are key components of the marine food chain.

Most of the seabed in central Corio Bay is silt and muds. These support a range of fish species that feed on zooplankton, infauna and smaller fish.

Around the perimeter of the Bay are areas of seagrass. The seagrass, particularly in the intertidal and shallow subtidal areas such as Stingaree Bay, the Avalon coast and Limeburners Bay, provide attractive habitat for fish.

Intertidal seagrass is dominated by *Zostera muelleri* while the subtidal seagrass is dominated by *Zostera nigricaulis*. Deeper areas of the Inner Harbour have a sedimentary substrate but significant cover of the seagrass *Halophila australis* at intermediate depths where there is sufficient light penetration. The dynamics of seagrass habitat in Corio Bay is largely independent of the main area of Port Phillip Bay and is most similar to Swan Bay (Jenkins et al. 2015).

Limeburners Bay has mangrove, *Avicenna marina*, and saltmarsh zones that provide habitat for small and juvenile fish (Crinall and Hindell 2004; Hindell and Jenkins 2004).

The estuarine area of Limeburners Bay is likely to be a spawning habitat for Black Bream, *Acanthopagrus butcheri*, and also a migration pathway for the Southern Shortfin Eel, *Anguilla australis*.

Other fish habitats in Corio Bay include man-made structures such as piers, wharfs and breakwaters. Artificial reefs have recently been constructed in the St Helens area and seeded with oysters and mussels (VFA 2021a), and these will provide further habitat for fish.

5.11.3 Fish Community

Sampling of the fish community for research purposes in Corio Bay has been less intense than in other areas of Port Phillip Bay. However, there is sufficient data to give a broad overview of the species present. Further analysis of fish larvae and eggs was undertaken by CEE over a period of a year and the results are described later in Section 5.12.

The Port Phillip Bay Trawl Survey ran for two decades and included one site in the deeper, sedimentary area of Corio Bay (Parry et al. 1995; Hirst et al. 2011; Parry and Hirst 2016). The trawl net was weighted to catch fish on the seabed and hence tended to sample near-bottom (demersal) fish. The 10 most abundant fish species in trawl surveys conducted in Corio Bay from 1990 to 1994 (Parry et al. 1995) and 2008 to 2011 (Hirst et al. 2011) are shown in Table 5-12 and distinct differences can be seen in the most abundant fish from the two time periods.

In the earlier surveys, there were more species associated with seagrass or algae (e.g., Rock Whiting, Leatherjackets, Cardinal Fish). Studies of historical seagrass cover in Port Phillip Bay show that the extent was high in the 1990's but there was a major decline in seagrass cover in the 2000's (Ball et al. 2014), thought to be related to reduced nutrient inputs during the millennial drought (Jenkins et al. 2015; Hirst et al. 2016). However, studies by CEE show that the extent of seagrass in the north of the Bay varies from year to year (as described in Section 5.17.2). Table 5-12 lists the most abundant fish species in the two trawl surveys described above. Sand flathead, King George whiting, Yank flathead and red mullet were common in both periods.

Table 5-12. Most Abundant Fish Species from Trawl Surveys

1990-1994		2008-2011	
Common name	**Species**	**Common name**	**Species**
Little Rock Whiting	*Neoodax balteatus*	Snapper	*Chrysophrys auratus*
Toothbrush Leatherjacket	*Acanthaluteres vittiger*	Globefish	*Diodon nicthemerus*
Bridled Leatherjacket	*Acanthaluteres spilomelanurus*	Sand Flathead	*Platycephalus bassensis*
Sand Flathead	*Platycephalus bassensis*	Australian Anchovy	*Australian Anchovy*
King George Whiting	*Sillaginodes punctatus*	Yank Flathead	*Platycephalus speculator*
Southern Cardinal Fish	*Vincentia conspersa*	Sparsely-spotted Stingaree	*Urolophus paucimaculatus*
Yank Flathead	*Platycephalus speculator*	Southern Calamari	*Sepioteuthis australis*
Red Mullet	*Upeneichthys vlamingii*	Yellowtail Scad	*Trachurus novaezelandiae*
Eastern Shovelnose Stingaree	*Trygonoptera* sp.	King George Whiting	*Sillaginodes punctatus*
Greenback Flounder	*Rhombosolea taparina*	Red Mullet	*Upeneichthys vlamingii*

Snapper, a highly valued fishing species, was the dominant species in the later surveys but did not appear in the ten most abundant species in the earlier surveys. The early 2000's was characterised by a period with very high recruitment of young snapper in Port Phillip Bay compared to the 1990's, and this resulted in relatively high abundances of older snapper in the later surveys (Hamer et al. 2011; Black et al. 2016).

The bottom dwelling flatheads (Sand and Yank) ranked highly in both periods, as did another highly valued fish species, King George Whiting. The Australian Anchovy and the Yellowtail Scad, which were abundant in the second surveys, are important species from an ecosystem viewpoint, forming key prey species for many higher order predators.

The fish community associated with seagrass, and unvegetated sediment at the edge of seagrass, was studied at Eastern Beach Geelong in October 2010 and March 2011 using underwater stereo video. Habitats were sampled in two depth zones: "shallow" (0.4 to 1.1 m) and deep (2.2 to 7.7 m) (Jenkins et al. 2012). The effectiveness of this method at Eastern Beach was limited at Eastern Beach due to low water clarity (Jenkins et al. 2012). Species recorded on the video samples are shown in Table 5-13. These species are all commonly associated with seagrass habitats in Port Phillip Bay (Jenkins et al. 1997; Jenkins and Wheatley 1998).

Table 5-13. Fish Species Recorded at Eastern Beach in Seagrass Habitat

Common name	Species
Little Rock Whiting	*Neoodax balteatus*
King George Whiting	*Sillaginodes punctatus*
Bridled Leatherjacket	*Acanthaluteres spilomelanurus*
Hardyhead	Atherinnidae
Smooth Toadfish	*Tetractenos glaber*

Whiting

The population of King George Whiting, *Sillaginodes punctatus*, in Port Phillip Bay are juveniles up to approximately 4 years of age (Hamer et al. 2004). Older fish move out of Port Phillip to the open coastal waters where mature fish spawn, most likely in western Victoria and south-eastern South Australia (Jenkins et al. 2000; Jenkins et al. 2016). Spawning occurs from April to July, and eggs and larvae then drift from west to east in coastal waters for a period of 3 to 5 months (Jenkins et al. 2000; Jenkins et al. 2016). At the end of the larval period (September to November), post-larvae of approximately 20 mm length enter bays and inlets of central Victoria, including Port Phillip Bay, and settle near shallow seagrass beds (Jenkins et al. 2000).

An ongoing monitoring program for whiting post-larvae abundance has been established in Port Phillip Bay at eight seagrass sites, including one in Corio Bay (VFA, unpublished data). Sampling is conducted in spring each year (October and November) in shallow seagrass using a 10 m long, 1 mm mesh seine net. King George Whiting post-larvae show a high variation in abundance from year to year in Corio Bay (see Figure 5-37), which is consistent with Port Phillip Bay as a whole.

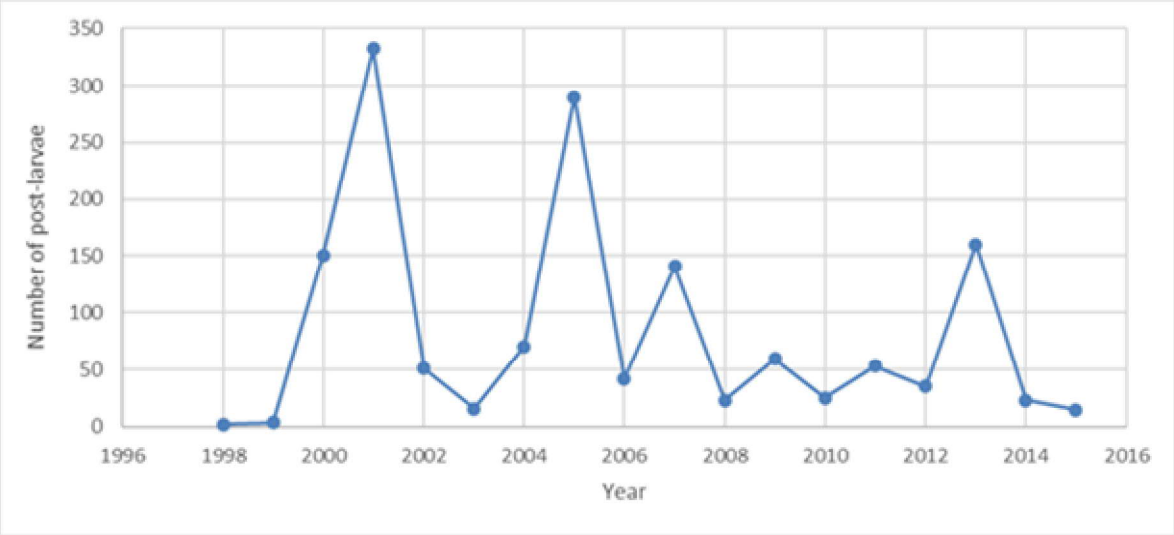


Figure 5-37. Annual Variability in King George Whiting Larvae Abundance

The variation in settlement of post-larvae Whiting is mainly due to factors affecting larvae in Bass Strait prior to their entry to Port Phillip Bay, particularly the strength of westerly winds that transport larvae to the bay (Jenkins 2005), and water temperature in Bass Strait which effects growth rate and larval survival (Jenkins and King 2006).

Ongoing monitoring of post-larval whiting abundance in Port Phillip Bay provides estimates of the number of young fish entering the fishery in 2 to 3 years' time. Recent monitoring (including in Corio Bay) has shown above-average post-larval Whiting settlement in 2017 and 2018 (P. Hamer, pers. comm.) and this has resulted in above-average whiting catches in recent years.

Snapper

The life stages of Snapper, *Chrysophrys auratus*, in Port Phillip Bay range from eggs to large, mature adults. The major spawning area for the west Victorian stock of Snapper (ranging from Wilsons Promontory to south-eastern South Australia) appears to be Port Phillip Bay (Hamer et al. 2005; 2011). Most spawning appears to occur in the north-eastern area of Port Phillip (Hamer et al. 2011; Hamer and Mills 2017), although the presence of larvae in the Geelong Arm indicates that spawning can also occur near there (Hamer et al. 2011). According to the distribution map for snapper in CoastKit, snapper do not breed in Corio Bay. Current sampling of fish larvae as part of the technical studies (see next section of this chapter) provides information on whether snapper spawning also occurs in Corio Bay.

Studies of snapper reproduction in Port Phillip Bay indicate that most of the spawning occurs from mid-November to mid-January (Hamer et al. 2011). Larval survival in Port Phillip is strongly related to the availability of preferred zooplankton prey (Murphy et al. 2012; 2013), which leads to high recruitment variability (Hamer and Jenkins 2004; Black et al. 2016) and the dominance of a few outstanding year-classes in the population (Hamer et al. 2011). These dominant year-classes also come to dominate the population of Snapper in the whole western stock as juveniles grow and migrate out of Port Phillip (Hamer et al. 2011).

The larval stage of snapper lasts for about 1 month (Sim-Smith et al. 2013) before the young juvenile fish settle onto deeper, generally sedimentary habitat (Hamer and Jenkins 2004). As they grow, juvenile snapper (pinkies) is often found associated with nearshore reefs, while adult snapper occurs in a variety of habitats.

Acoustic pinging tags and "listening" stations have been used to track snapper movement in Port Phillip Bay as well as between the bay and Bass Strait. Juvenile and adult snapper show large movements within Port Phillip Bay, including to and from Corio Bay (Hamer and Mills 2017). Adult fish also have a seasonal migration into Port Phillip from Bass Strait in September/October and many leave the bay again in either mid-December to February or April-May (Hamer and Mills 2017).

5.11.4 Commercial Fishing

The number of commercial fishing licences has declined in recent decades under a licence buyback scheme, and in 2018 a complete ban on commercial netting in Corio Bay was implemented (VFA 2021b). Commercial net fishing in the remainder of Port Phillip Bay is scheduled to be closed in 2022 (VFA 2021b). A small number of commercial licences will remain after then for non-net fishing methods (VFA 2021b).

Most of the past commercial fishing in Corio Bay in the past was based on netting methods (haul seining and mesh netting), with a very small amount of hook and line fishing taking place (see Figure 5-38). As netting is banned, almost all the commercial fishing in Corio Bay would have ceased in 2018.

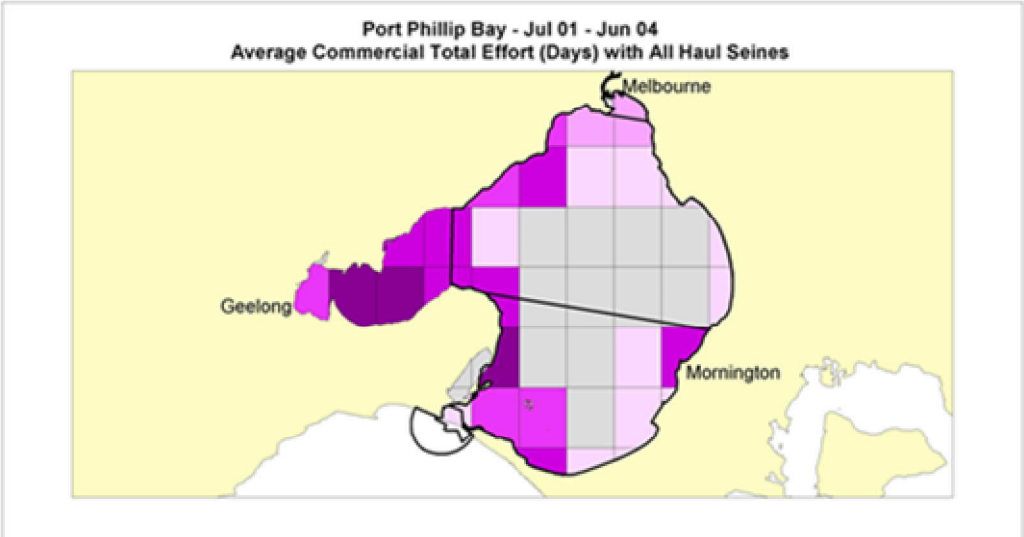


Figure 5-38. Distribution of Commercial Fishing 2001-2004

Over the period from July 2002 to June 2014, the ten species with the highest commercial catch by weight in Corio Bay are shown in Table 5-14 (Victorian Fisheries Authority, unpublished data). This ranking reflects high recruitment success of King George Whiting and Snapper in the 2000's, as well as their high commercial value. The vast majority of the catch would have been taken by netting methods (mesh net, haul seine, garfish seine) although a small proportion of the Calamari catch would have been taken by hook and line (jigging) methods.

Table 5-14. Top 10 Commercial Fish Species in Corio Bay (July 02 to June 14)

Common name	**Species**
King George Whiting	*Sillaginodes punctatus*
Rock Flathead	*Platycephalus laevigatus*
Snapper	*Chrysophrys auratus*
Yank Flathead	*Platycephalus speculator*
Pike	Unspecified
Southern Sea Garfish	*Hyporhamphus melanochir*
Black Bream	*Acanthopagrus butcheri*
Yellow-Eye Mullet	*Aldrichetta forsteri*
Australian Salmon	*Arripis* spp.
Southern Calamari	*Sepioteuthis australis*

5.11.5 Recreational Fishing

Recreational fishing from small boats and from jetties and the shore are popular in Corio Bay. Land-based recreational fishing is undertaken from jetties, piers and breakwaters, as well as from the shoreline. There are many boat ramps for small boats around the perimeter of Corio Bay.

Creel surveys of catches for fishers returning to Corio Bay boat ramps were recorded from 2009 to 2014 (Victorian Fisheries Authority, unpublished data). In Corio Bay,

flathead was the most common species, followed by King George Whiting and Snapper. Other species retained included Elephant Fish (*Callorhinchus milii), Yelllow-Eye Mullet (Aldrichetta forsteri),* Black bream (*Acanthopagrus butcheri*), and Grass Whiting (*Haletta semifasciata).* Fish that were commonly released included under legal minimum size Flathead, Snapper and King George Whiting, as well as bycatch species such as Southern Fiddler Ray (*Trygonorrhina fasciata),* Port Jackson Shark (*Heterodontus portusjacksoni)* and smooth Toadfish (*Tetractenos glaber)* as shown in Table 5-15. Southern Sea Garfish and Warehou were also commonly retained.

Other species retained included Elephant Fish, *Callorhinchus milii*, Yellow-Eye Mullet, *Aldrichetta forsteri*, Black Bream, *Acanthopagrus butcheri*, and Grass Whiting, *Haletta semifasciata.* Fish that were commonly released included under legal minimum size flathead, Snapper and King George Whiting, as well as bycatch species such as Southern Fiddler Ray, *Trygonorrhina fasciata*, Port Jackson Shark, *Heterodontus portusjacksoni* and smooth toadfish, *Tetractenos glaber*.

Table 5-15. Top 10 Recreational Fish Species

Common name	Species
Flathead	*Platycephalus* spp.
King George Whiting	*Sillaginodes punctatus*
Snapper	*Chrysophrys auratus*
Southern Sea Garfish	*Hyporhamphus melanochir*
Warehou	*Seriolella* spp.
Australian Salmon	*Arripis* spp.
Leatherjacket	Unspecified
Gummy Shark	*Mustelus antarcticus*
Silver Trevally	*Pseudocaranx georgianus*
Southern Calamari	*Sepioteuthis australis*

5.11.6 Species of Conservational Significance

Several fish species that occur, or perhaps may occur, in Corio Bay have been listed under various Acts or placed on internationally recognised lists of threatened species, including:

- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* ('EPBC Act');
- Victorian *Flora and Fauna Guarantee Act 1988* ('FFG Act');
- International Union for the Conservation of Nature and Natural Resources (IUCN) Red List 2003;
- Convention on the International Trade in Endangered Species (CITES); and
- Victorian *Fisheries Act 1995* (Fisheries Act).

There are 25 marine threatened, or migratory species listed under the EPBC Act and FFG Act that may occur in Corio Bay, as shown in Table 5-21 in Section 5-1. That section also addresses their likelihood of occurring within Corio Bay.

These species may include pipefish and seahorses, *Syngnathidae* (EPBC Act, CITES, IUCN Red List; Fisheries Act), and School Shark, *Galeorhinus galeus* (EPBC Act 'conservation dependent'; IUCN Red List).

Syngnathid (pipefish and seahorse) species are likely to be common in seagrass beds of Corio Bay, however, research sampling research sampling for *syngnathids* has not been successful. Extensive sampling with fine-mesh nets has, however, been carried out in Swan Bay, which is a seagrass system with similar characteristics to Corio Bay (Jenkins et al. 2015) recorded a significant number of *syngnathid* species (Jessop 1988; Jenkins et al. 1993; Jenkins et al. 1997; Saunders 1997).

The most abundant *syngnathid* species in subtidal seagrass, *Zostera nigricaulis* in Swan Bay are the two species belonging to the genus *Stigmatopora*, the Spotted Pipefish, *Stigmatopora argus*, and the Widebody Pipefish, *Stigmatopora nigra*. The most abundant *syngnathid* species in intertidal seagrass, *Zostera muelleri* beds in Swan Bay was the Hairy Pipefish, *Urocampus carinirostrus* (Jessop 1988; Jenkins et al. 1993; Jenkins et al. 1997; Saunders 1997).

Australian Mudfish

The Australian Mudfish, *Neochanna cleaveri*, is a small galaxiid fish that has been recorded in the Yarra River (Fulton et al. 2006). The Mudfish is a diadromous species with both freshwater and marine life stages. Adult Mudfish occur in swampy areas in the lower reaches of coastal streams, but larvae disperse to marine waters (Fulton et al. 2006). Spawning occurs in winter and juvenile Mudfish return upstream in the spring-early summer (Koster et al. 2019). Larvae may occur in Corio Bay from winter to early summer and this can be assessed from the ichthyoplankton surveys.

Australian Grayling

The Australian Grayling, *Prototroctes maraena*, is another diadromous species with both freshwater and marine life stages (Crook et al. 2006). Adult grayling live entirely in freshwater but they migrate to the lower reaches of rivers to spawn in the autumn, and larvae are transported to the sea where they reside until they transform into juveniles and migrate back to freshwater in the spring-early summer (O'Connor 2015). Spawning may be triggered by an increased freshwater flow and decreased water temperature (Koster and Dawson 2010).

There is a known population of Australian Grayling in the Yarra River and individuals have been recorded in the Werribee River (O'Connor 2015; Amtstaetter et al. 2021). The freshwater creek flowing to Corio Bay, Hovells Creek, is much smaller than the Yarra or Werribee Rivers, and grayling are not listed as an ecological value for the Point Wilson area of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan* (DELWP, 2020). Grayling are listed in the Barwon River in the Ecological Character Description for the *Port Phillip Bay (Western Shoreline) & Bellarine Peninsula Ramsar Site (*DELWP 2020) but not in the Point Wilson-Limeburners area.

While it is possible that, during the marine phase, larvae of grayling could visit Corio Bay from late autumn to early summer, the ichthyoplankton surveys did not identify any grayling in any sample. Grayling are unlikely to be present in Corio Bay except perhaps as isolated visitors.

School Shark

School Shark, *Galeorhinus galeus*, occur mainly in deeper offshore waters, although they move into shallow, protected coastal waters for breeding. In a survey of Port Phillip Bay, the Point Wilson area had a number of School Shark pups, indicating that the Geelong Arm may be a nursery for the species (Stevens and West 1997). It is possible that School Shark breeding could occur in Corio Bay, although no pups were recorded from sampling in Limeburners Bay (Stevens and West 1997).

Fish Eggs and Larvae

Sampling for fish eggs and larvae in Corio Bay has been relatively limited in the past, although CEE is carrying out monthly surveys at several sites in Corio Bay in 2020-2021 (results are in Section 4-11). The main species identified in spring-summer were *fish eggs* (99 %), Other species identified were rock kale, gobies and *Stigmatopora sp.*

Previous sampling in January 1979 identified *anchovy eggs* at 32 stations in Corio Bay with a mean concentration of 8,600 eggs per 100 m^3 (Arnott and McKinnon 1985). CEE surveys found an average of 300 eggs per 100 m^3 in monthly sampling of nine sites in Corio Bay from November 2020 to February 2021. These results indicates that Corio Bay may be an important spawning area for this species.

Anchovy eggs and larvae (over the summer spawning season) and goby larvae are the dominant ichthyoplankton in Port Phillip Bay (Jenkins 1986; Neira and Sporcic 2002). A small number of samples were collected in Corio Bay between March and August 1983 (Jenkins 1986), with pipefish (*Syngnathidae)*, goby (*Gobiidae*) and Greenback Flounder *Rhombosolea tapirina* larvae, and Longsnout Flounder *Ammotretis rostratus* eggs recorded

5.11.7 Fish in Ramsar Zone

The Ramsar zone in Corio Bay supports various fish species with have been identified and are listed in the Port Phillip Bay (Western Shoreline) & Bellarine Peninsula Ramsar Site Ecological Description (DELWP, 2021). The ecological description includes species such as the Tasmanian Blenny (*Parablennius tasmanianus*), common weedfish (*HeterocIinus adelaide*), Swan River goby (*Pseudogobius olorum*), anchovy (*Engraulis australis*), small- mouthed hardyhead, black bream *(Acanthopagrus butcheri*) and sandy sprat (*Hyperlophus vittatus*) (DELWP, 2021). The report also mentions other species which are more common in the seagrass beds which are prevalent around the Limeburners Bay section of the Ramsar site including pipefish (*Stigmatopora argus*), goby (*Favonigobius lateralis*) and bridled leather jacket (*Acanthaluteres spilomelanurus*) (DELWP, 2020).

The unvegetated sediments of the Bay are comprised with similar species but also include other such as banjo ray (*Trygonorrhina fasciata*), gummy sharks *(Mustelus antarcticus*), black bream and rock flathead (*Platycephalus laevigatus*) (DELWP, 2020).

5.11.8 Summary on Fish

Corio Bay has a range of marine habitats, including seagrass, muddy seabed, mangroves, unvegetated sediments, biogenic reef, sandy beaches and man-made structures. Associated with these habitats is a diverse fish fauna that includes species of commercial, recreational, conservation and ecological importance.

Based on trawl surveys, recreational target fish species in the deeper areas of Corio Bay are dominated by snapper, flathead and King George Whiting; ecologically important species such as Australian Anchovy and Yellowtail Scad; and species associated with vegetated habitats (seagrass, algae) such as Leatherjackets and Rock Whiting. Seagrass beds in Corio Bay are important habitat for small juvenile King George Whiting.

Commercial net fishing was prohibited in Corio Bay in 2018 and there will be no future commercial fishing in the bay. Prior to 2018, commercial catches in Corio Bay were dominated by King George Whiting, flathead and snapper.

Recreational fishing is very popular in Corio Bay both from land and boat. The most commonly retained species in Corio Bay are flathead, King George Whiting, Snapper and Southern Sea Garfish, as well as bycatch species such as sharks and rays.

The main species of conservation significance are the *syngnathids* (pipefish and seahorses), School Shark and possibly Australian Mudfish. There are no records to date of the marine larval phase of Australian Mudfish (or of Australian Grayling) in Corio Bay. Sampling for syngnathids in Corio Bay seagrass has not been conducted in Corio Bay but based on sampling similar seagrass habitats in Swan Bay, *syngnathid* species are likely to occur.

School Sharks breed in the Geelong Arm of Port Phillip Bay, with pups recorded from sampling near Point Wilson. School Sharks may also enter Corio Bay although none have been recorded from sampling to date.

Sampling of ichthyoplankton (fish eggs and larvae) has been very limited in Corio Bay in the past, although there is now a monthly survey over a year at several sites in Corio Bay. The collection of abundant Australian Anchovy eggs in Corio Bay over summer 2020-21 indicates that the Bay may be an important spawning area for this species.

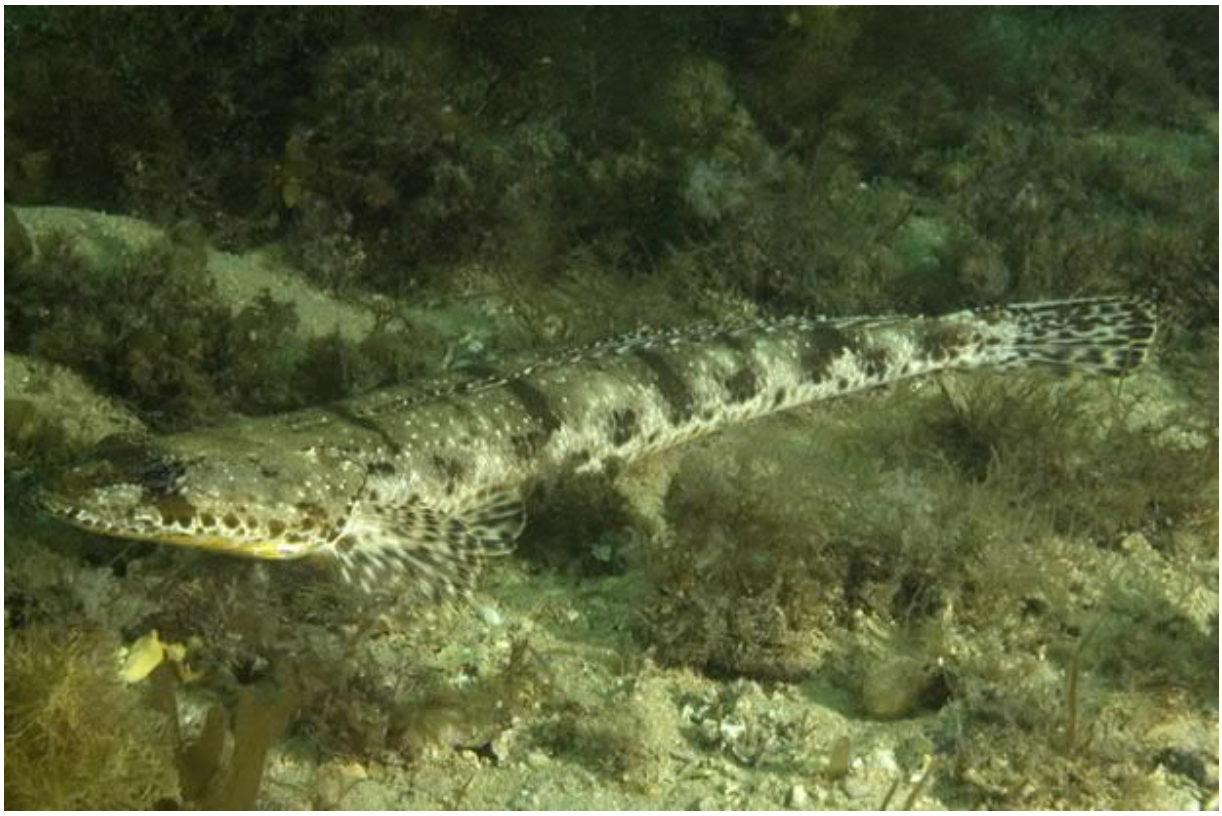


Figure 5-39. Sand Flathead on the seabed of Corio Bay

Recreational fishers in Corio Bay were interviewed and most considered that the Bay provided good fishing. The most common species of fish caught were reported to be flathead, snapper, whiting and bream.

According to local fishers, Corio Bay is fishable in most conditions except strong easterly winds. There are plenty of fish and easy access by small boats or fishing from piers and jetties.

Over the spring months, snapper become increasingly active in Corio Bay. Snapper move into the bay to feed on specific food items such as marine worms, small whiting and juvenile cuttlefish. Flathead are more common in spring while large King George whiting, large bream, trevally and squid are also prevalent.

Snapper can be caught all year round in Corio Bay, but the spring and summer months are prime times when the fish form small, tight schools. Although Corio Bay is mostly shallow, it has seagrass beds, jetties and other man-made structures that attract fish.

5.12 Ichthyoplankton

Seagrass is recognized as a nursery area for fish. Thus, a study was made of the abundance of ichthyoplankton (drifting eggs and larvae of fish) in north Corio Bay to establish the range of species that are present. Because many of the eggs are small, and have not developed recognizable features, it is not always possible to allocate the specimens to particular species, and these are listed as “fish eggs”. However, species have been listed for the specimens that could be identified under a microscope.

5.12.1 Ichthyoplankton Sampling Results

Table 5-16 shows the abundance of all the ichthyoplankton species collected at the four north Corio Bay sampling sites including Viva, Point Abeona, EPA and the refinery Inlet from October 2020 to October 2021. There was no data for the seawater inlet site in January 2021 as the sample was damaged in transit and thus could not be analysed.

Ichthyoplankton Abundance

The results of the sampling show that the ichthyoplankton is largely dominated by fish eggs which made up around 99% of the total abundance across the study period. Results show that some other species were also dominant around the end of 2020 such as the Australian Anchovy and Gobies. However, numbers for these species dropped away quickly after December 2020. The Table concludes that spring and summer months are when ichthyoplankton are at their most abundant with very little numbers in winter months.

Table 5-16. Ichthyoplankton Abundance

(Units are cells per 100 m^3)

Date	Oct 20	Nov 20	Dec 20	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Total	
n (samples)	4	4	4	3	4	4	4	4	4	4	4	41	
Zooplankton	817.1	1809.8	775.6	24.9	20.1	60.9	34.2	12.1	48.0	30.1	222.5	77	
Species												Geomean	%
Fish eggs	660.7	1049.5	581.6	20.5	17.7	52.2	30.5	7.7	47.4	29.3	220.6	7.68E+01	99%
Goby Type 1	0.7	6.8	25.4	0.5		6.5	0.1				1.1	1.17E-01	0.2%
Australian Anchovy	22.8	435.0	75.2	1.1		0.2	0.1					1.07E-01	0.1%

< 25th Percentile = 0.1 (cells/100m^3)	25th – 50th Percentile = 0.1 – 0.5 (cells/100m^3)
50th – 75th Percentile = 0.5 – 6 (cells/100m^3)	> 75th Percentile = 6 (cells/100m^3)

Figure 5-40 provides a time series graph of the north Corio Bay sites (dashed lines) as well as the overall average (red line). The back bars represent the standard error of the mean and the black dashed line represents average daylight hours per month. Similar to the table above, Figure 5-40 shows a large spike in ichthyoplankton abundance in November and December 2020 with very little numbers for the remainder of the year. Extremely high numbers were recorded at the Viva site in November 2020 with far lower numbers at the EPA site. By January 2021 the concentrations were very similar between the sites and abundance dropped to consistently below 100 cells/100m^3.

The graph shows a correlation between the abundance of ichthyoplankton and daylight hours with higher concentrations during months with longer days and lower concentrations during colder months when the average daylight hours are shorter.

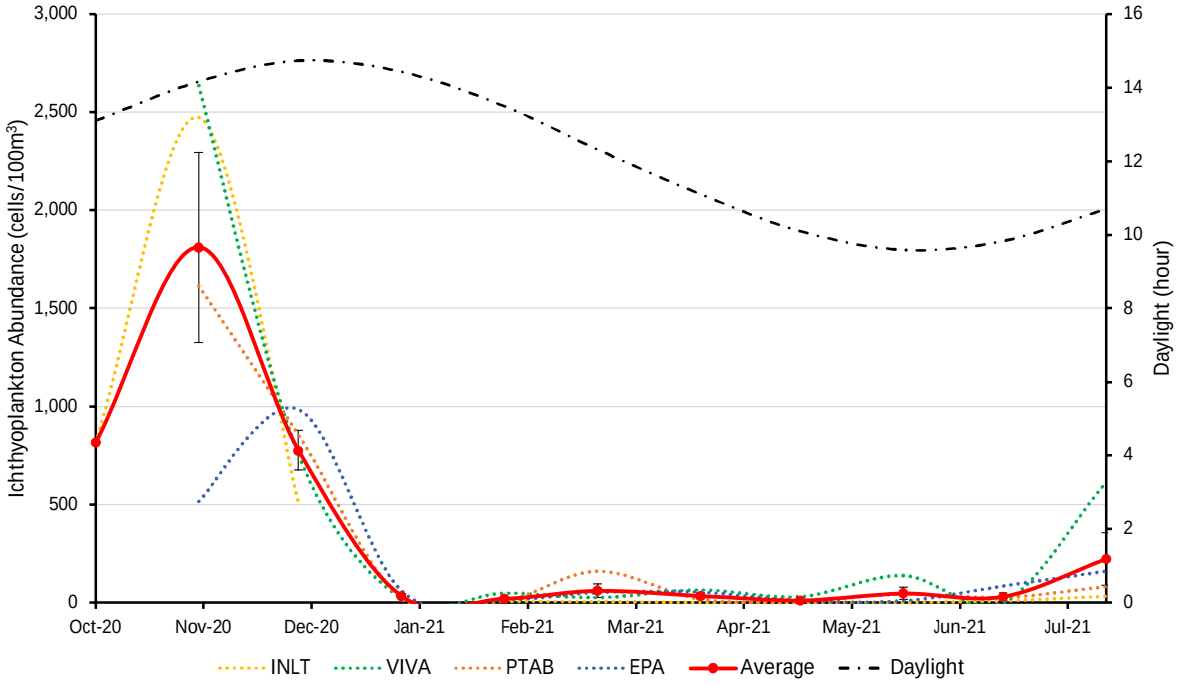


Figure 5-40. Ichthyoplankton Abundance in Corio Bay

Figure 5-41 shows time series plots of fish eggs and Australian Anchovies. Fish eggs are the most abundant group at around 99% total abundance. Fish eggs were highest in November and December 2020, but the plot clearly shows a decline in the cooler months. However, in August 2021, numbers at some sites are starting to increase again.

Australian Anchovies were a dominant species in the summer months of sampling as there were very high numbers measured at the Inlet site in November 2020. However, after this short bloom in abundance, number is Australian Anchovy larvae decline to mostly zero through the colder months of the year.

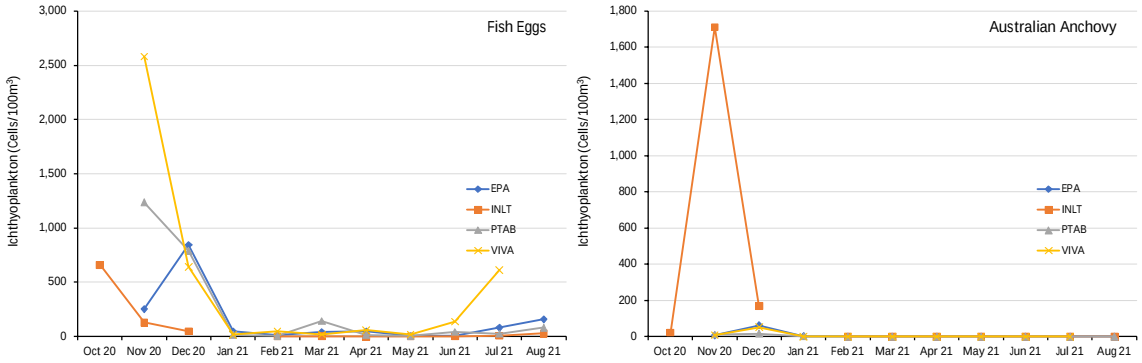


Figure 5-41. Abundance of Major Ichthyoplankton Species

Figure 5-42 shows an example of an Australian Anchovy which was in high abundance in November of 2021 at the refinery Inlet.



Figure 5-42. Example of Australian Anchovy *(Source: Fishes of Australia, 2021)*

Species Richness

Figure 5-43 is a time series of average species richness for ichthyoplankton at the four north Corio Bay sites over the study period. The dashed lines show the average richness per site and the solid black line is the overall average with the standard error of the mean. The dashed black line represents the average month daylight hours.

When abundance was high, there were many species in the samples. In November and December 2020 species richness ranged from an average 10 to 11 species per site. In 2021 the richness decreased to an average of 2 to 4 species per site for the remainder of the study period.

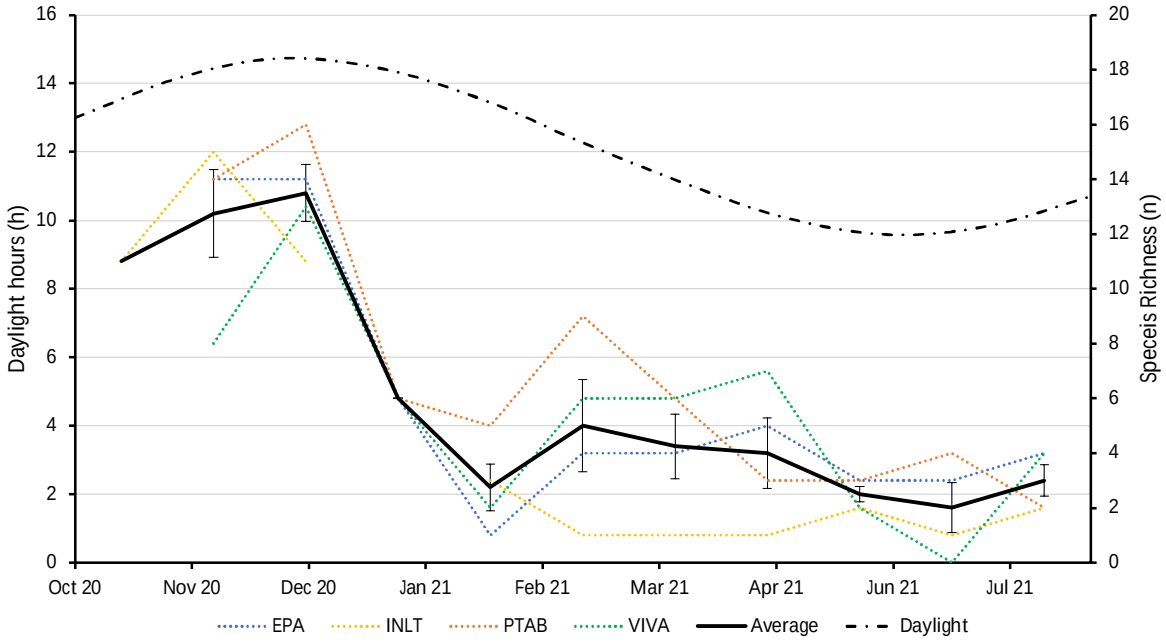


Figure 5-43. Species Richness of Ichthyoplankton in North Corio Bay

These ichthyoplankton survey results indicate that ichthyoplankton communities in Corio Bay are patchy and there is a variation of abundance between the different species and from month to month. Highest abundance appeared to occur in spring-early summer, which matches the expected seasonal breeding pattern. Abundance had become low by January 2021, with fish eggs being the only dominant species through the cooler months. There was a more than ten-fold decrease in the abundance of fish eggs between November 2020 and February 2021.

5.13 Seabed Composition

The physical and biological characteristics of the Port Phillip Bay seabed, including Corio Bay, have been documented in studies over the past 60 years. Large-scale multidisciplinary studies that provide integrated information on Port Phillip Bay are:

- Port Phillip Survey by the National Museum of Victoria (1957 to 1962);
- Environmental Study of Port Phillip Bay sponsored by Melbourne & Metropolitan Board of Works and the Fisheries and Wildlife Department of Victoria (MMBW, 1971) during 1969 to 1972;
- Port Phillip Bay Environmental Study during 1992 to 1996 (CSIRO,1996); and
- CoastKit marine and coastal knowledge web-mapping portal (DELWP, 2020).

The seabed of Corio Bay is predominantly unconsolidated sediments, with most of central Corio Bay comprising silt and clay (mud) with increasing proportions of sand around the margins as shown in Figure 5-44. The distribution of sediments in Port Phillip Bay including Corio Bay was mapped in 1966, 1972, 1987, 1995 and 2000.

The sediment particle size composition of the seabed is a key factor influencing the characteristics of the marine ecological communities inhabiting the seabed. Information on contaminants in the sediments of Corio Bay is presented in Section 7 – *Assessment of Dredging Impacts.*

The seabed habitat around specific area of interest in the project area such as the new temporary wharf and the permanent extension to Refinery Pier are described in Section 11.4.

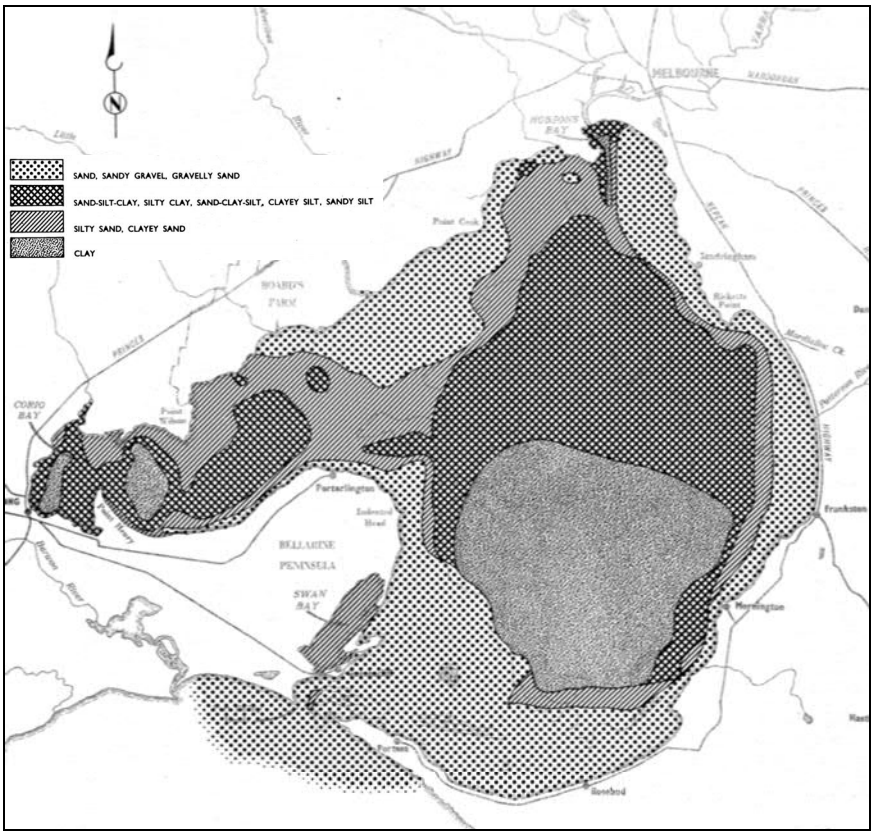


Figure 5-44. Port Phillip Bay Sediment Composition

5.14 DELWP CoastKit Maps of Biotopes

DELWP, in cooperation with the EPA, Melbourne Water, Victorian Fisheries Authority (VFA), Parks Victoria, Universities and the Victorian Marine and Coastal Council has developed a comprehensive marine biodiversity program and polices for Port Phillip Bay and Corio Bay. The main components of the *Marine Biodiversity Policy and Program* are:

- Marine and Coastal Knowledge Framework (includes CoastKit);
- Port Phillip Bay Environmental Management Plan and MERI Report for 2022;
- Victorian Coastal Monitoring Program;
- Marine Environmental Targeted Actions (Biodiversity Response Planning projects);
- LitterWatch Victoria https://www.litterwatchvictoria.org.au/;
- Coastal Wetland restoration to promote blue carbon, coastal protection, biodiversity and fish production opportunities (ecosystem benefits and services).

Figure 5-45 shows the broad distribution biotopes in Corio Bay as mapped by DELWP in CoastKit. The different colours denote different biotopes and seabed character, while the purple dots denote observation sites. Further details on the range of biotopes in Corio Bay is provided in Figure 5-46.

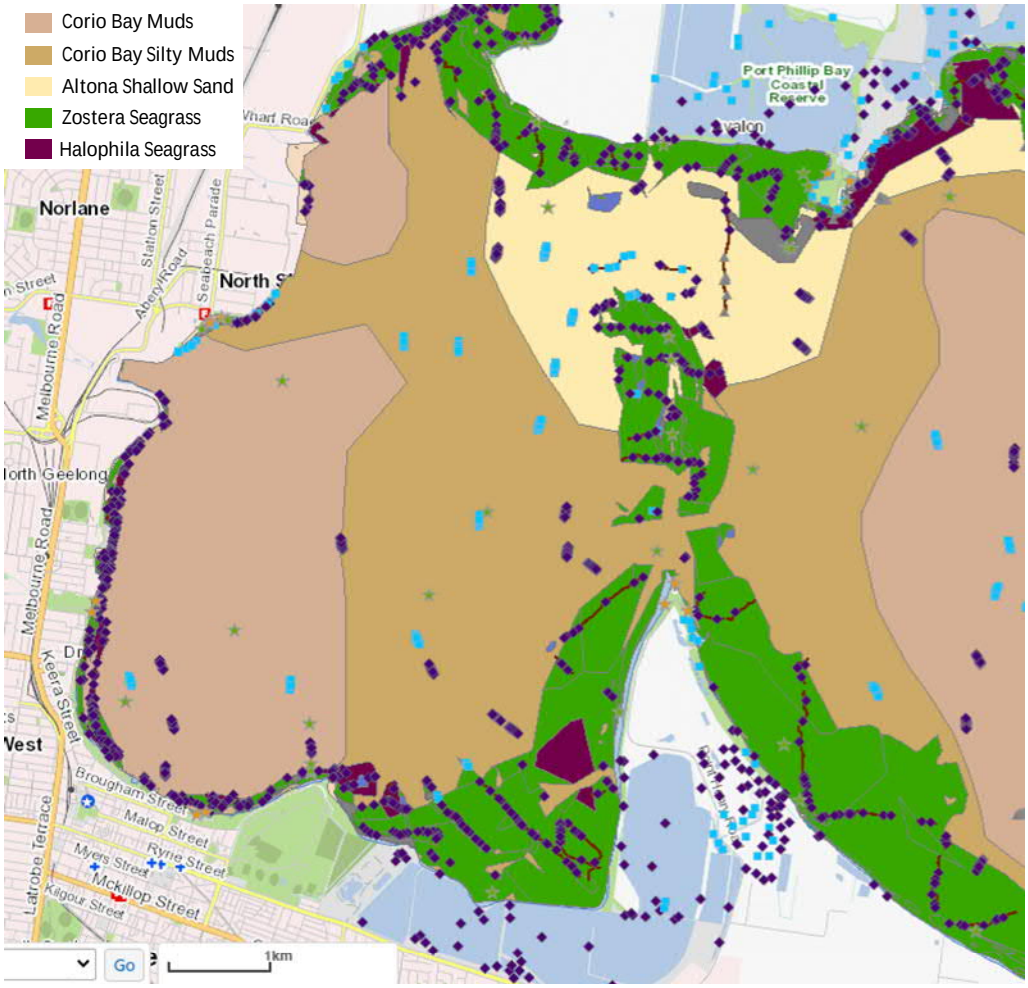
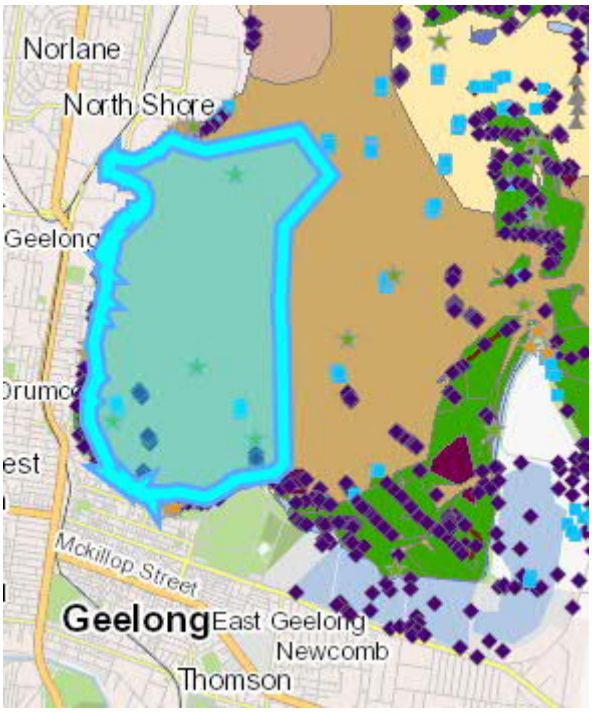
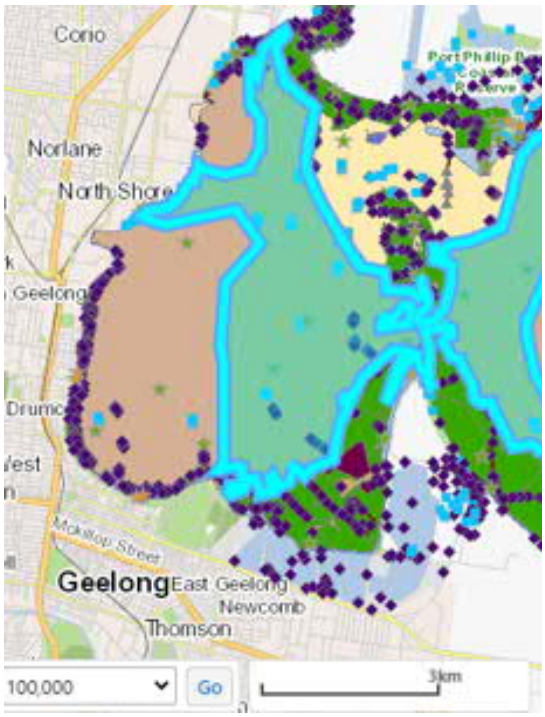


Figure 5-45. Port Phillip Bay Sediment Composition - 2020

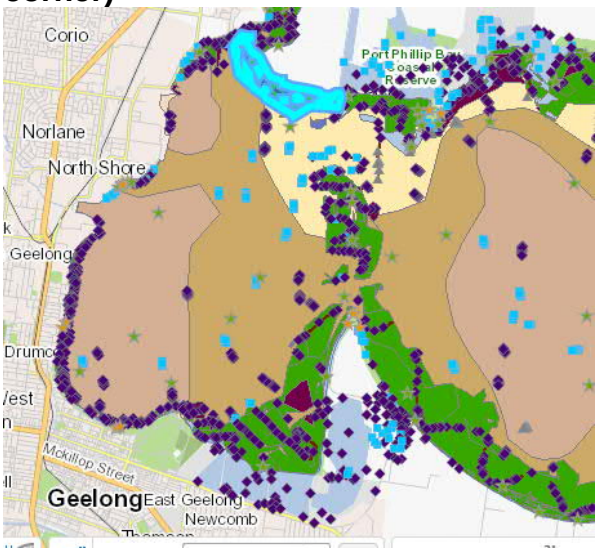
Corio Bay Muds



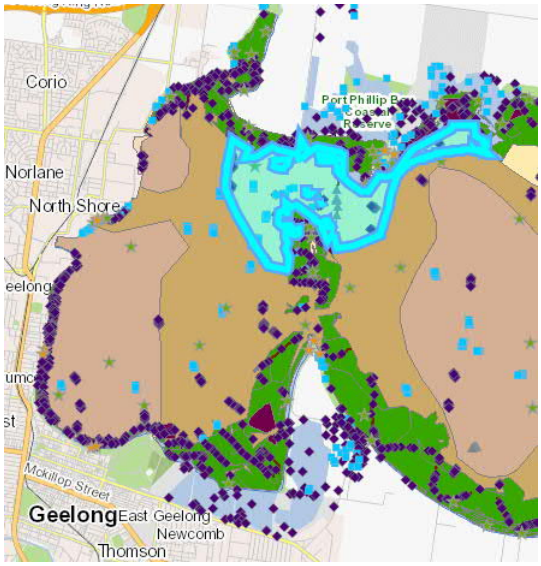
Silty Mud



Zostera and Ruppia (also in SE corner)



Shallow Sand



Zostera and Ruppia (SE corner)



Caulerpa beds

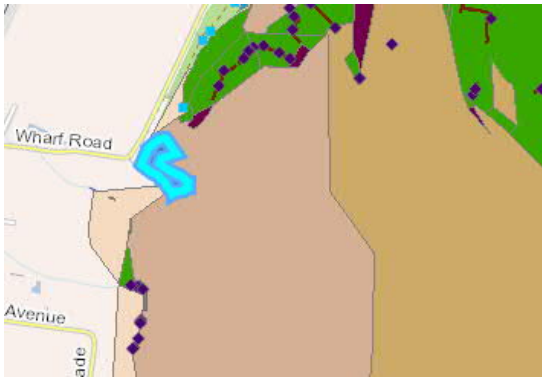


Figure 5-46. Outline of Key Biotopes in Corio Bay

5.15 Survey of Seabed Habitat in North Corio Bay

The CoastKit descriptions provide a good basis for assessing marine environmental impacts in Corio Bay as a whole. The principal biotopes are:

- Corio Bay muds;
- Corio Bay silty mud
- *Zostera* and *Rupia* beds;
- Shallow sand; and
- *Caulerpa* beds.

There is also a small area of mangroves (in Limeburners Bay), a small section of *Pyura* biogenic reef (just offshore from the seagrass beds in north Corio Bay), a small strip of *Halophila* beds on the west side of the channel into Limeburners Bay, and hard substrate (mostly man-made) along the western shore.

To obtain a more detailed understanding of the seabed characteristics in north Corio Bay near the project area, CEE surveyed the benthic habitat along 49 transects in north Corio Bay using HD underwater image. A total of 6,345 images were analysed, ranging from 32 to 449 images per transect. The observed habitat includes seagrasses with macroalgae on shallow soft seabed, and microalgae (microphytobenthos) and burrowing invertebrates (bioturbation) on deeper soft seabed.



Figure 5-47. Example of Thick Zostera Seagrass

The composition of the seabed observed in the towed transect paths was consistent with previous descriptions and mapped distributions. The central area of Corio Bay was generally muds (a mixture of clays and silts, with very low sand content), while the seabed around the perimeter was more variable with sandy muds, muddy sands and sand with shell.

The outcomes of the CEE 2021 benthic habitat survey are summarised below. The maps show the survey results overlayed on Port Phillip Bay Biotopes from Seamaps Australia (Lucieer et al. 2017) allowing an easy comparison with previous studies.

5.15.1 Microphytobenthos (MPB)

Microphytobenthos (MPB) is the general term used to define micro photosynthetic organisms (including unicellular green algae, diatoms, cyanobacteria and flagellates) that form a thin surface layer on marine and estuarine soft sediments. MPB can be distinguished by a green, golden or brownish layer growing on the sediment. They are often the only primary producers (plants) in deeper waters on fine sediments and play an important ecological role in the marine aquatic environments. Highest MPB densities were recorded on muddy seabed and lowest densities on dense seagrass patches, which shade the seabed.

Figure 5-48 shows a spatial map of microphytobenthos in the *Port Phillip Bay Channel Deepening Project Environmental Effects Statement* (2004). The plot shows the MPB biomass in surface sediments based on the CSIRO 1994 Port Phillip Environmental Study and other studies (Beardall and Light, 1996).

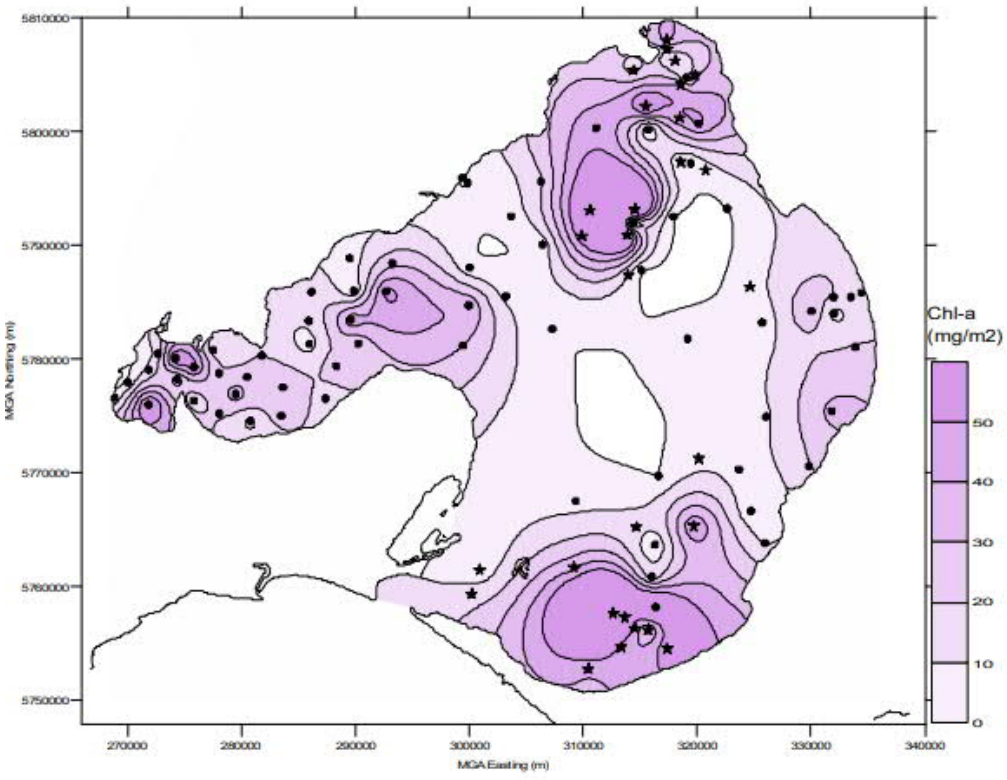


Figure 5-48. Distribution of MPB in Port Phillip Bay

Source: (Edmunds et al, 2004) Page 16

For Corio Bay, the map shows two main areas with a high density of MPB, these being in the southern region around Stingaree Bay and in the northern region near Point Lillias. These areas have a Chl-a concentration of over 50 mg/m^2. However, the rest of Corio Bay also has a consistent cover of MPB, excluding the areas of dense seagrass. In Port Phillip Bay, there is higher MPB cover of MPB in three areas (west, north and south) with the lowest concentrations in the central regions.

Figure 5-49 shows the extent of MPB on transects in Corio Bay as part of the 2021 surveys by CEE. MPB was found on much of the soft sediment seabed around the Refinery Pier and in water with depths between 4 to 8 m. Areas with no MPB were the areas where seagrass was present and areas shallower than 3 m in depth.

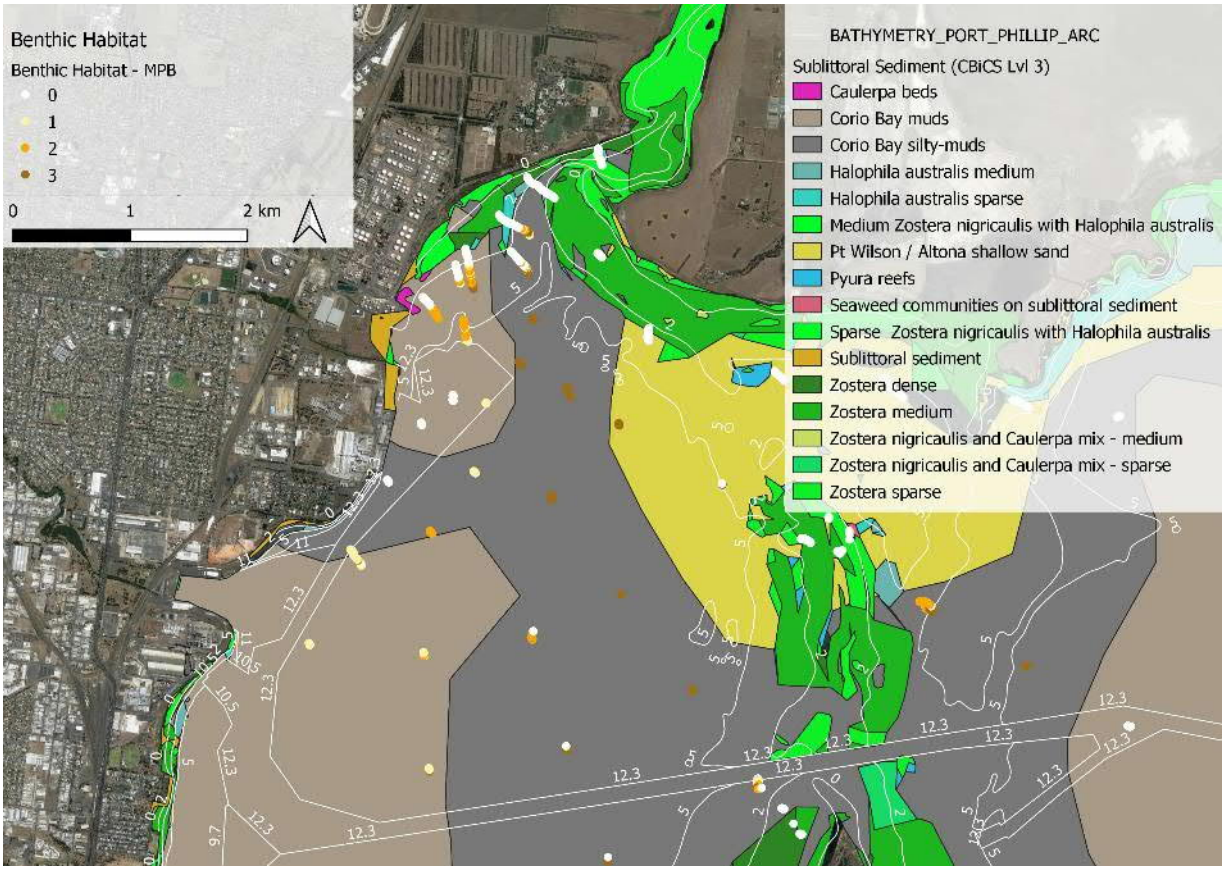


Figure 5-49. Distribution of MPB in Corio Bay

5.15.2 Bioturbation

Bioturbation is a term used to describe the disturbance of marine sediment by burrow-dwelling organisms, usually invertebrates such as polychaetes, crustaceans and echinoderms. The distribution of bioturbation activity was similar to the distribution of MPB. Sediment disturbance was recorded in all sections of the bay at sites without seagrass and macroalgae.

Figure 5-50 shows the extent of bioturbation on transects in northern Corio Bay. Higher levels of bioturbation were associated with greater depths. A consistent medium level of bioturbation was found at the deeper areas of both the north and centre sections of the Bay. Highest levels of bioturbation were seen at the deeper ends of transects just north of Refinery Pier (VIV 16) and also at 2 km south of the pier (VIV 46). Lowest bioturbation was observed around the shallower depth contours.

Some areas of high bioturbation were characterised by large burrows and were usually associated with medium to high levels of MPB.

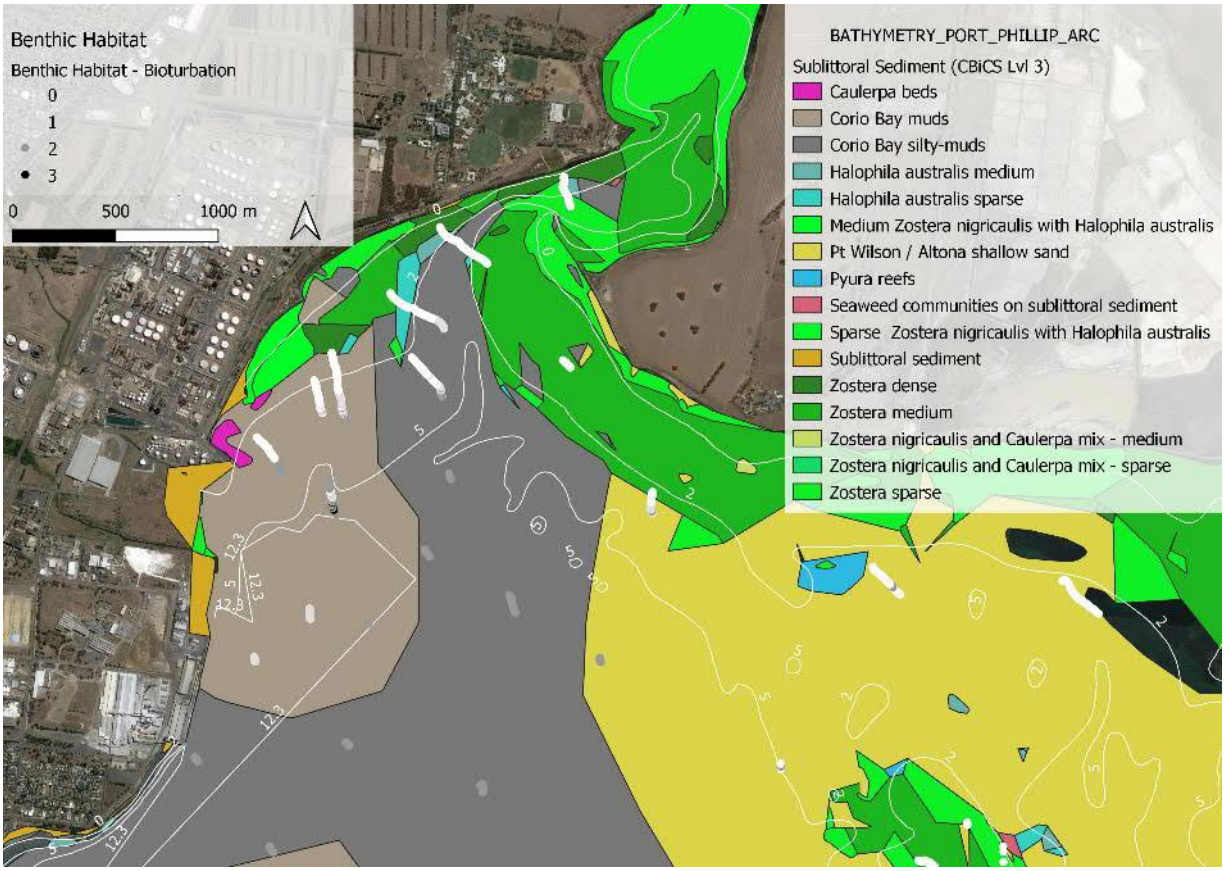


Figure 5-50. Bioturbation in North Corio Bay 2021

5.15.3 Biogenic Reef

Biogenic reef is sparse in Corio Bay. The Port Phillip Bay Biotopes (*Seamaps Australia)* show a small area of biogenic reef on the eastern side of the bay between Point Henry and Point Lillias.

CEE located another small area of biogenic reef at a similar depth further to the west (see Figure 5-51). The reef comprised a build up of shells and sand.

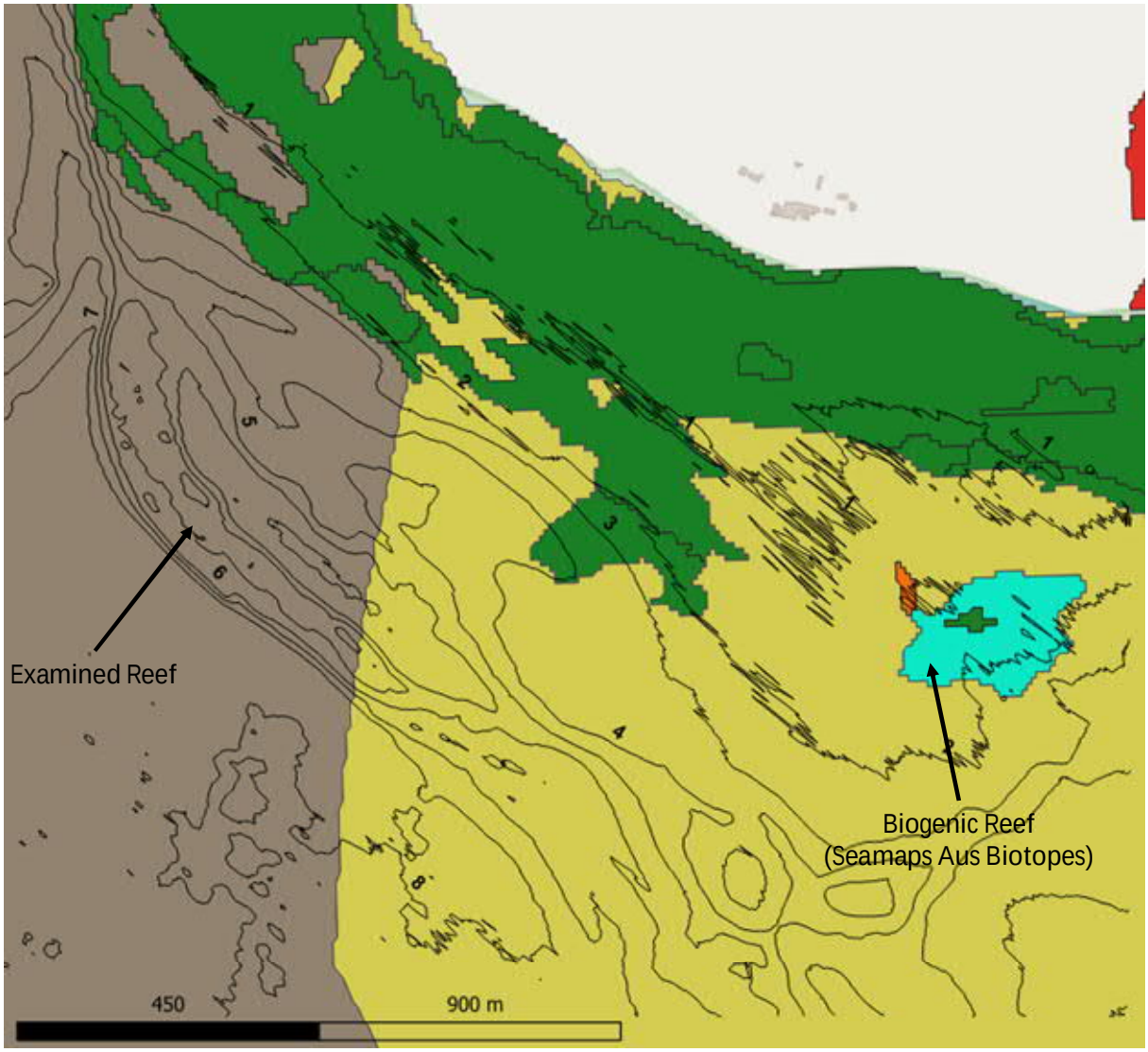


Figure 5-51. Map of Biogenic Reef in Corio Bay

5.16 Soft Seabed Invertebrate Fauna

The MMBW 1968-70 studies of soft seabed biota sampled burrowing invertebrates, or infauna, at 86 sites across Port Phillip Bay (Poore et al 1975) including one silty-clay location in Corio Bay (Figure 5-52). The same site was sampled again in the 1992-96 CSIRO Study (Wilson et al 1997). A considerable number of samples were collected from the 1968-70 program and data were progressively analysed and reported: MMBW 1971; Poore and Rainer 1974 (Figure 5-53); Poore et al 1975; Poore 1992 (Figure 5-54); Wilson et al 1997.

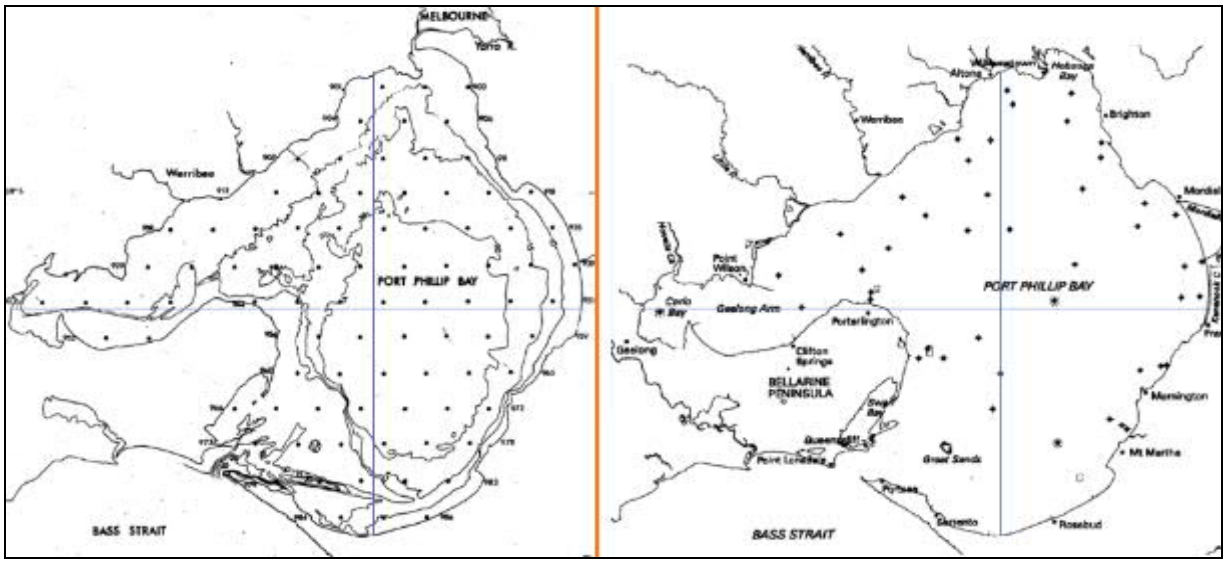


Figure 5-52. Corio Bay Infauna Sample Sites, MMBW (1969-72), CSIRO (1992-96)

(From Poore et al 1975, Wilson et al 1997)

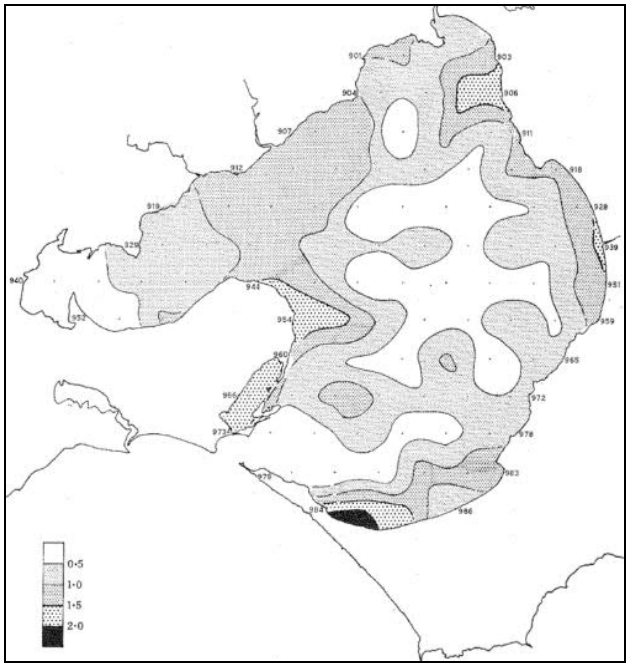


Figure 5-53. Port Phillip Benthic Mollusc Diversity Distribution 1969-72

(Poore and Rainer 1974)

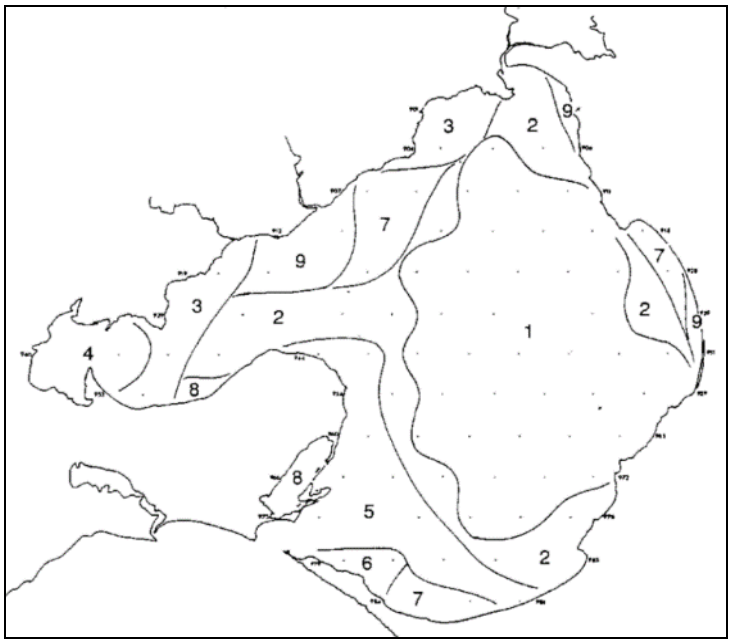


Figure 5-54. Port Phillip Benthic Community Hierarchy, Infauna Data 1969-72

(see text below for key to community descriptions, Poore 1992)

Figure 5-54 presents the distribution of infauna community distribution from an integrated analysis of all data collected from the representation of the 1969-72 sampling program. Nine infauna community groups based on species richness, seabed composition and water depth were identified in Port Phillip Bay:

1. The central basin of muddy sediments at depths greater than 15 m (a region of low species richness);
2. Intermediate stations surrounding the central basin plus an area at the entrance to the Geelong Arm (a region of high species richness);
3. Corio Bay entrance, shallow water north of Point Wilson, plus the Altona region (a region of high species richness);
4. Corio Bay muddy environments (a region of low species richness);
5. Region near entrance to Port Phillip Bay, coarse sands;
6. Southern sands, shallow tidal coarse sands;
7. Shallow water off Werribee and similar station on the east coast.
8. Swan Bay and Clifton Springs area, seagrass communities (very high species richness);
9. Offshore from Werribee region, Portarlington and other shallow environments (regions of very high species richness);

The muddy sediments of Corio Bay were identified by Poore (1992) as a region of low species richness (in the area shown as category 4 in Figure 5-54).

Soft seabed habitat epibiota and infauna in the Geelong Arm of Port Phillip and Corio Bay were surveyed at 6 locations in February-March 1992 as shown in Figure 5-55 (Carey and Watson 1992).

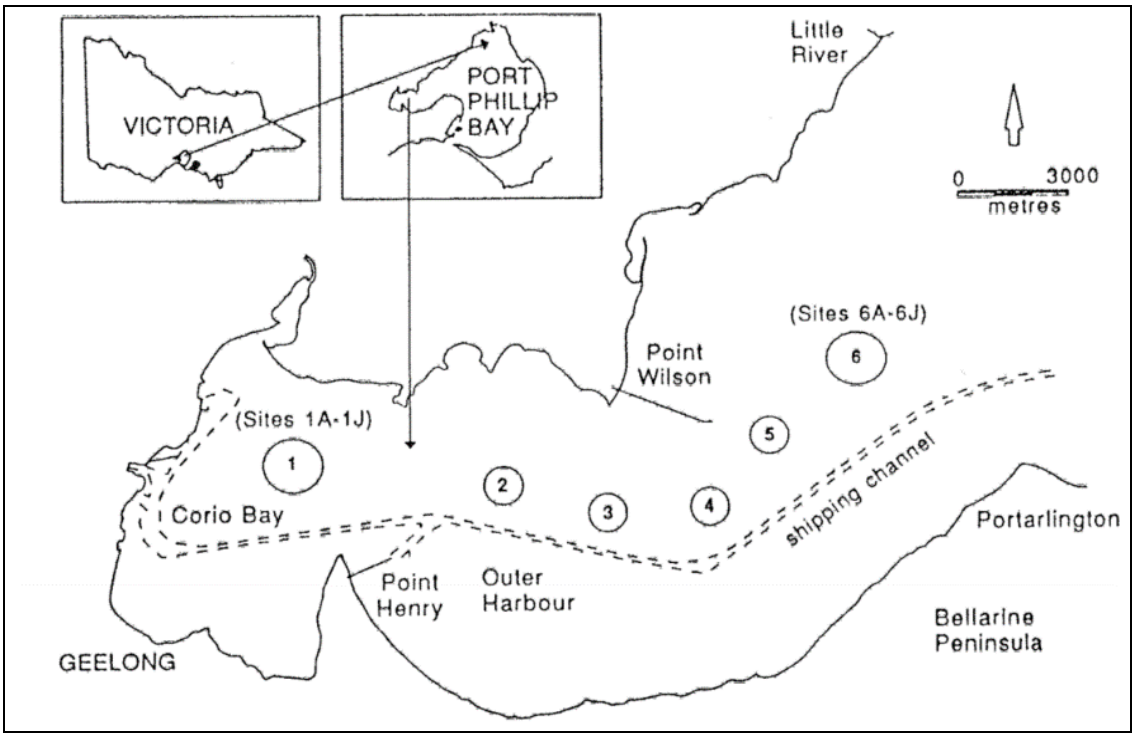


Figure 5-55. Geelong Arm and Corio Bay Soft Seabed Sample Locations, 1992

(Source: Carey and Watson 1992)

The seabed at all six locations was described as semi-compacted grey clay with varying quantity of aged and sub-fossil shell. Epibiota including fan solitary ascidians (*Pyura stolonifera*), fan worms (*Sabella spallanzanii*), seagrass (*Halophila australis*) and scallops (*Pectin alba*) were characterised along 10 transects. Infauna (burrowing invertebrates) were sampled at two sites at each location including a central location Corio Bay.

The main infauna were:

- **polychaete worms** (which the most common infauna group representing 44 % of total population by number);
- **small crustaceans** representing 27 % of the total population and;
- **small burrowing clams** (bivalve molluscs) representing 12 % of the population.

The survey documented a range of introduced epibiota and infauna species in Corio Bay, including records of the introduced sabellid fan worm *Sabella spallanzanii*.

Commercial scallops were recorded on diver-transects at locations 2, 4, 5 and 6. Scallops were abundant on all ten diver-transects at location 6 (offshore from Werribee) but were absent from all 10 transects in Corio Bay.

Sampling of Infauna

CEE sampled infauna at several sites through Corio Bay in June 2021. Infauna was sampled from five locations. *North Ref* was an area location in north Corio Bay to the north-east of Refinery Pier and represents infauna in the wider project area. *Dredge*

Area was the area where future dredging would occur and where seabed sediment removal would impact infauna communities. *Channel Ref* is an area in the existing channel to assess how infauna communities adapt to dredging activities. *Corio Ref* is a location in central Corio Bay and represents infauna communities in the rest of the Bay. Finally, *DMG* is the area of the spoil ground where the dredged sediments would be deposited. A detailed description of the sampling methods and results for the collection and analysis of infauna is provided in a separate report (CEE, 2021e).

Infauna analysis was conducted by Infauna Data Laboratory which is has expertise in expert in infauna identification and counting. The laboratory has been providing infauna analysis for museums, universities and private companies for decades and is widely respected in the marine science community for their work.

Table 5-17 provides the number of infauna individuals which were sampled in each area. It can be seen that four of the sites have similar results in the number in fauna collected, however the result from the existing channel (Channel Ref) is significantly lower with 140 individuals. The sites in mid Corio Bay (Corio Ref) were the second lowest with 188 and the spoil ground out near Point Henry (DMG) had the highest infauna count at 263.

The table also indicates that polychaetas were the most abundant group overall and were the most abundant at each site with the exception of the Corio Bay site which also had very similar numbers of ostracods.

Table 5-17. Infauna Individuals from Corio Bay (2021)

Infauna	North Ref	Dredge Area	Channel Ref	Corio Ref	DMG
Polychaeta - Capitellidae	19	12	1	10	9
Polychaeta - other	67	88	34	51	123
Amphipods	11	9	14	16	46
Ostracods	57	54.7	1	51.7	40
Bivalves	24	25	0	24	8
Holothuroidea	22	27	15	20	24
Nemertean	21	14	3	10	11
Actiniaria	8	8	2	5	2
Total number	**229**	**238**	**140**	**188**	**263**

Figure 5-56 shows the total average abundance of infauna at each site per grab. The spoil ground (DMG) site had the highest number per grab, as is expected given the higher total number in infauna recorded in Table 5-17. Similarly, the channel site (Channel Ref) has the lowest number per grab. The abundance of infauna in the area to be dredged (Dredge Area) is the same as elsewhere in north Corio Bay (North

Ref), and similar to the abundance in central Corio Bay (Corio Ref) and the spoil disposal ground (DMG).

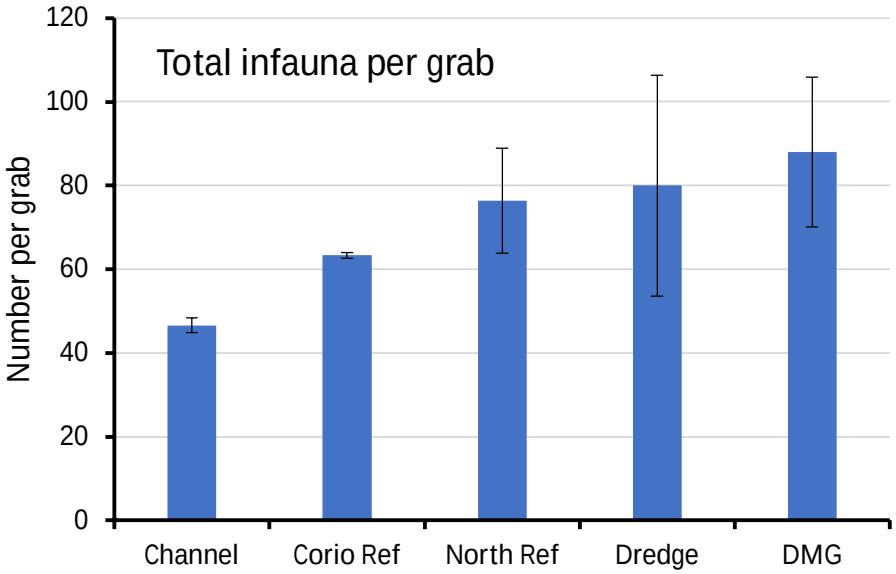


Figure 5-56. Infauna Per Grab

Figure 5-57 shows the average species richness of infauna communities around Corio Bay and including the spoil ground. The pattern of sites from lowest to highest species richness is the same as the total average number of infauna per sample. The plot shows that the sites in Corio Bay all have very similar species richness with the channel being slightly lower than the other sites. The Corio Ref and North Ref sites both had an average of 15 species across three samples while Channel Ref had an average of 12 species and Dredge Area had an average of 16 species. However, the DMG site had a much higher number of recorded species compared to the Corio Bay sites at around 27 different species.

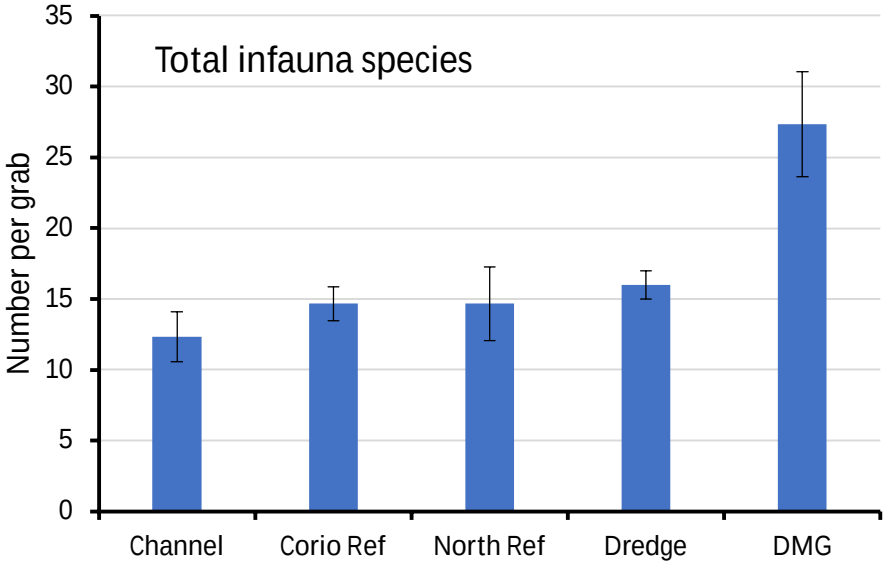


Figure 5-57. Infauna Species Richness

5.17 CEE Video Tow Transects

Underwater imaging was used by CEE to characterise the seabed habitat at 49 sites around Corio Bay. Transect site locations were selected to represent incremental distances from the Refinery Pier and benthic habitats found in Corio Bay.

Video tow site planning involved overlaying arcs with radius increments of either 500 m or 1,000 m from Refinery Pier over existing habitat maps. Video transect sites, represented as yellow dots in Figure 5-58 were located as the intersection of a radial line from Refinery Pier and the arcs. GPS coordinates for each site were used as the starting point for each transect.

Figure 5-59 shows the extent of the towed video transects used to characterise benthic habitats and biodiversity in Corio Bay. The map is divided into four areas: Corio Bay North (Area A), Corio Bay Centre (Area B), Corio Bay South (Area C) and Geelong Arm. The length of transects varied depending on habitat type from short (10 to 50 m, as a spot-check of habitat) to long (350 m, to identify transitions in habitat).

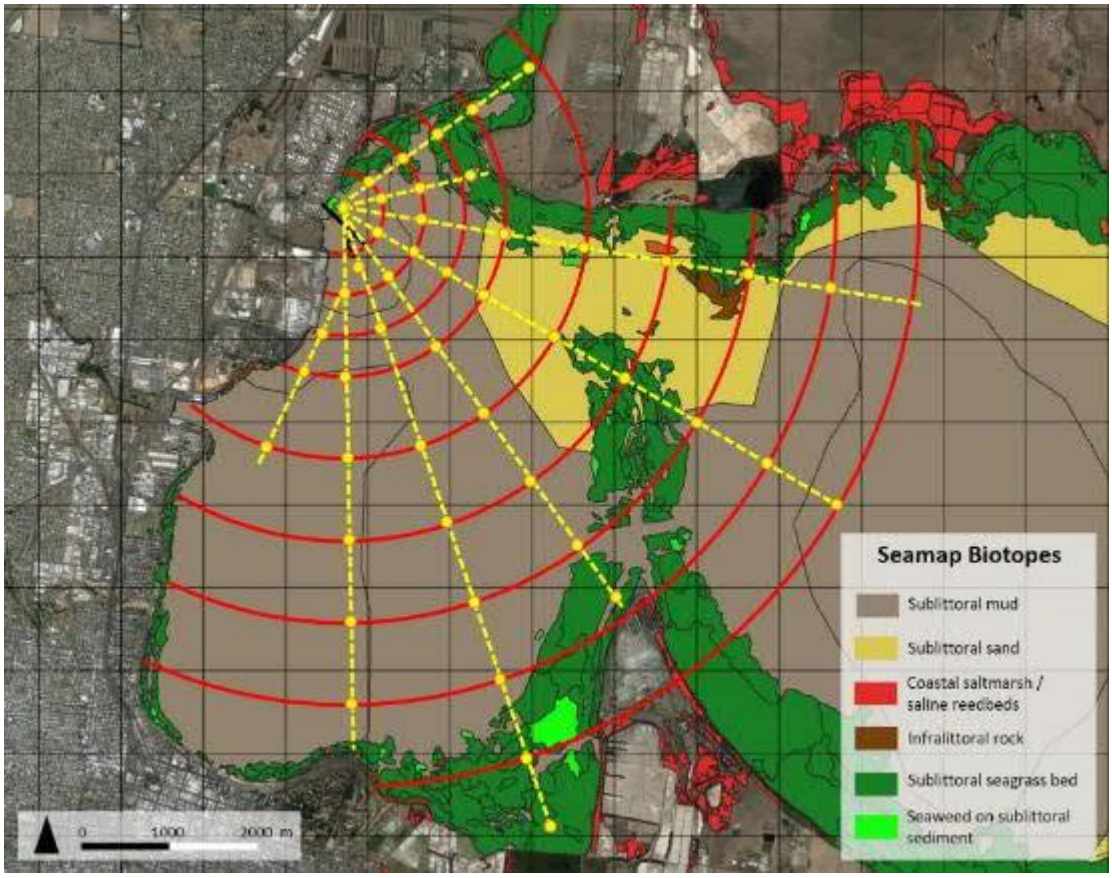


Figure 5-58. Video Tow Sampling Design

Benthic habitats and biodiversity were documented along 22 transects in Area A, near the refinery in northern Corio Bay. Five transects were conducted on sandy habitat, five over seagrass beds and twelve on seabed characterised by mud. Most of the biotopes described previously in Corio Bay were present in this area (Seamap Australia, Port Phillip biotopes).

Area B (Corio Bay Centre) was mostly characterised by a muddy seabed (Seamap Australia). A total of 17 transects were conducted in this area with five being associated with seagrass beds. Six transects were included from Area C (Corio Bay South) on both muddy and seagrass habitat (Seamap Australia). Four transects were located in the Geelong Arm.



Figure 5-59. Towed Underwater Video Transects in Corio Bay (CEE 2021)

The images recorded during each tow in Corio Bay were analysed for the abundance of biota usually associated with such seabed composition, namely seagrass, macroalgae, microphytobenthos and bioturbators.

Seagrass density was classified using 4 categories: ”Nil”, “Sparse”, “Medium” and “Dense” (Blake and Ball, 2001).

***Zostera* spp**. density categories were assigned as follows:

Nil:	Absent.
Sparse:	Plants are present but of a density where leaves from individual plants do not touch each other.
Medium:	Leaves touch but sediment discernible beneath.
Dense:	Leaf density sufficient to hide the sediment underneath from view.

***Halophila* sp**. density categories were assigned as follows:

Nil:	Absent.
Sparse:	Leaves do not touch, and individual plants clearly dispersed.
Medium:	Leaves do not touch although within proximity of each other
Dense:	Sediment visible but the leaves were within touching distance of each other.

The same procedure was used for the macroalgae (including “Macroalgae General”, “*Caulerpa* sp.”, “*Codium* sp.” “*Ulva* sp.” and “*Sargassum* sp.”) and “Filamentous Algae” categories. The results are summarised below and presented in the report on *Corio Bay Habitats* (CEE, 2021).

5.17.1 Sea Urchins

Sea urchins are native to Port Phillip Bay but populations of one particular species, *Heliocidaris erythrogramma* seem to have increased significantly in some areas in the last decade. Sea urchin overpopulation can result in overgrazing, leading to “urchin barrens”. Barrens are areas characterised by exclusion of large plants (macrophytes) and a corresponding decrease in biodiversity and habitat complexity.

While sea urchins can feed on kelp beds and other macrophytes with little effect on macrophyte abundance, high numbers with continued recruitment of juveniles creates barrens with high numbers of urchins and the absence of macrophytes and other plant species that would usually be expected in the habitat and water depth (Ling et al 2019).

Sites in Corio Bay with high sea urchin abundance were devoid of seagrass. Although *Zostera* has been previously reported at these sites (Lucieer et al 2017) the recent photographic transects (e.g., VIV 21.1 and VIV 37) show an absence of seagrass at these sites in 2021 and high sea urchin numbers. In the north of Corio Bay and by Limeburners Bay there was dense seagrass with limited sea urchins as shown in Figure 5-60. However, there, was a barren area close to discharge W5 from the refinery where sea urchins were present.

Figure 5-61 shows a recent photo of the offshore edge of the seagrass bed near the current refinery discharge point W5. The edge of the seagrass is in the photic zone but has no seagrass. It does, however, have large numbers of sea urchins.

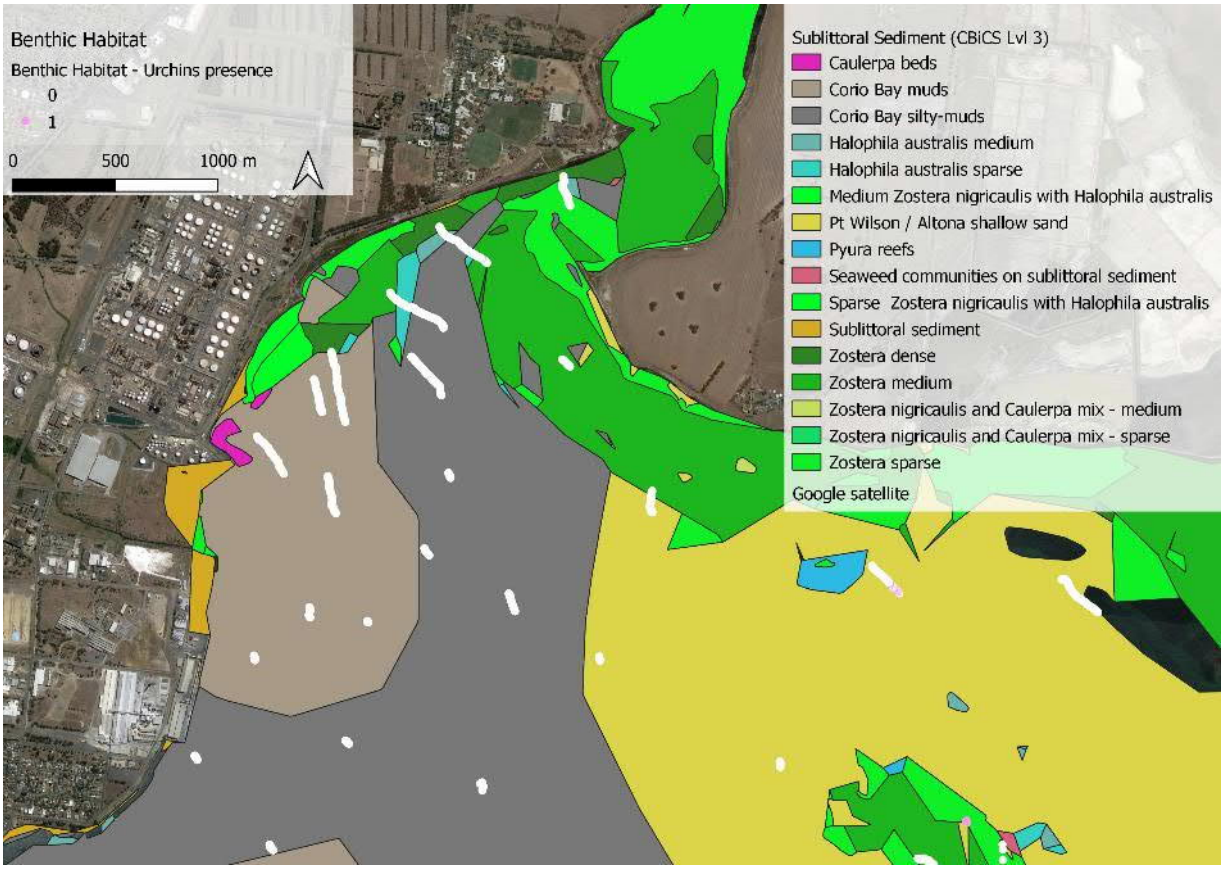


Figure 5-60. Sea Urchins in North Corio Bay 2021

Deakin University and Melbourne Water are funding a program to reduce sea urchin numbers in the western side of Port Phillip Bay using divers to damage the urchins. To retain the seagrass beds in Corio Bay, it may be necessary to extend the urchin depopulation program to Corio Bay.



Figure 5-61. Sea Urchins Near W5 Discharge Point

5.17.2 Seagrass

Benthic macrophytes such as seaweeds and seagrasses are important primary producers in marine ecosystems and provide habitat for algal and invertebrate epiphytes, invertebrates and fish (particularly small or juvenile fish).

Biological features of the intertidal and shallow subtidal segments of Port Phillip Bay marine ecosystem including Corio Bay have been mapped (Blake and Ball 2001, King et al 1972) and there have been a variety of studies on the fauna associated with intertidal seagrass habitats (Hindell et al 2000).

Dense seagrass meadows are widely recognised as providing important ecological services including: (1) primary production, directly by the seagrasses themselves but also through the many macroalgae and microalgae that attach to the seagrass leaves; (2) chemical processes including nutrient cycling by the seagrasses and associate microbiota; and (3) habitat for a diversity of other plants, invertebrates and fish.

For these reasons, seagrasses are often included as a key criterion and habitat descriptor in assessing the condition of Ramsar wetlands including the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site (DELWP 2020, Parks Victoria 2003).

Limeburners Bay in Corio Bay is one of three areas noted as an important component of the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site, the others being the Point Wilson area and Swan Bay (DELWP, 2020).

Table 5-18. Seabed biological categories mapped by Black and Ball 2001

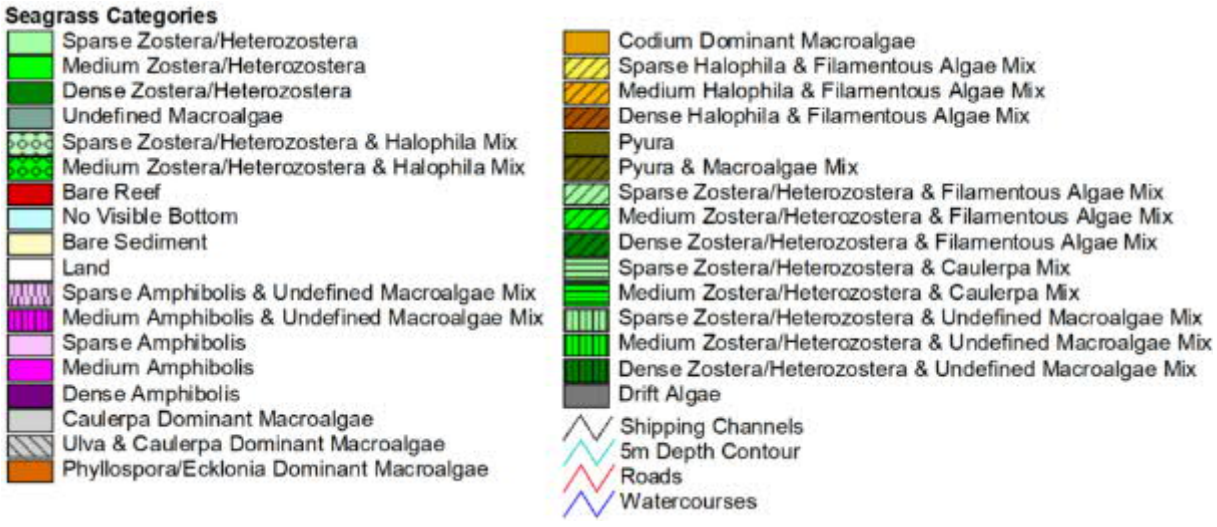


Figure 5-62 shows the seagrass polygons mapped by Blake and Ball in 2001 at the northern end of Corio Bay and into Limeburners Bay. The map shows that the northern shore of Corio Bay is dominated by medium density *Zostera* with some dense patches. Sparse *Zostera* is more evident further up into Limeburners Bay as well as along the shoreline of the northern coastline and at the Avalon Coastal Reserve further around to the east.

In front of the refinery, there is a mixture of sparse to medium *Zostera* and *Halophila* which extends offshore around 280 m at its thickest point.

Blake and Ball recorded only a very small amount of sparse *Zostera* and *Halophila* around the Refinery Pier, to the south of the pier along the shoreline. There is no seagrass recorded beyond the 5 m depth contour.

There is far less *Halophila* recorded in the bay compared to *Zostera*. Blake and Ball recorded some sparse *Halophila* along the western edge of the Limeburners Bay channel with a few patches of medium density further into the Bay.

Halophila seagrass is typically found in deeper water compared to *Zostera* and is normally patchy with sparse sediments between plants, whereas *Zostera* is typically found in shallower water with dense seagrass meadows on the seabed.

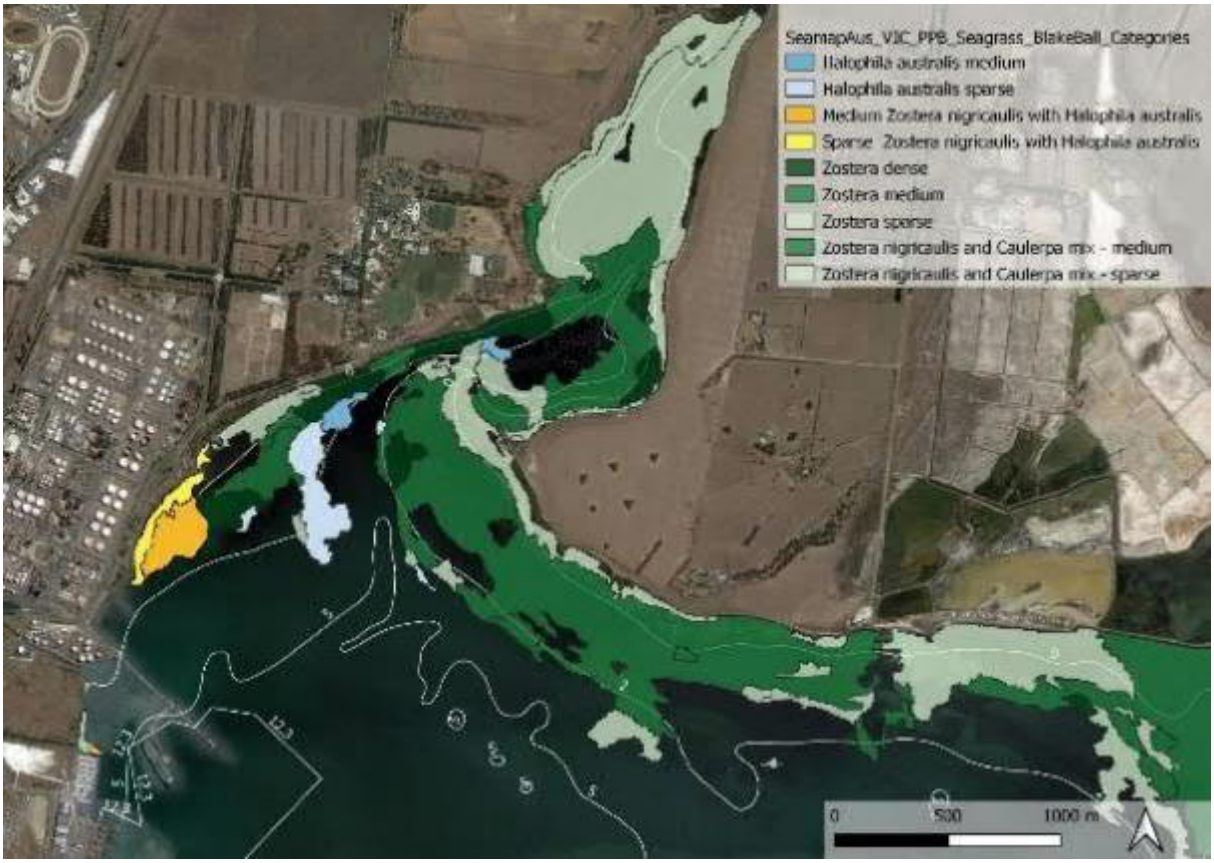


Figure 5-62. Seagrass Mapping by Blake and Ball (2001)

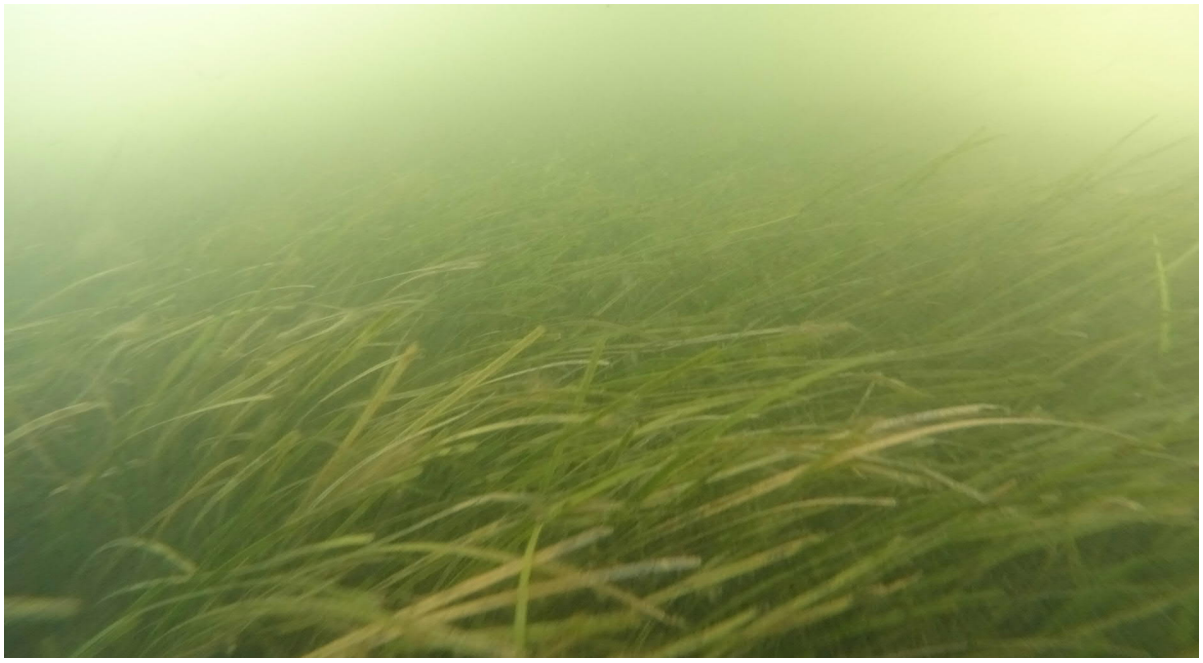


Figure 5-63. Example of Thick Zostera near Refinery Shoreline

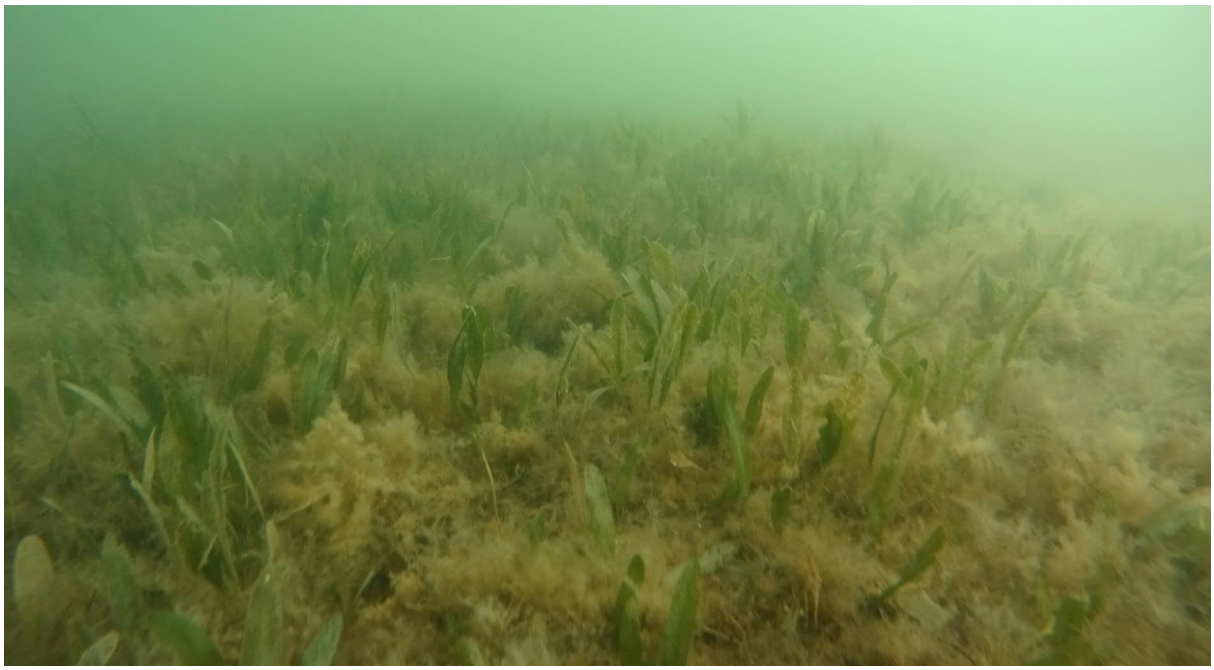


Figure 5-64. Example of Halophila Offshore from Refinery Shoreline

5.17.3 Variability of Seagrass Extent over Time

The location, depth and density of seagrass is subject to change over time due to variations in weather, floods, droughts, turbidity, nutrient inputs, diseases, grazing and other factors. Thus, seagrass can have large natural variations from year to year but also from month to month. Additional factors influencing seagrass growth and development are sea urchin grazing and sediment movement.

Aerial images from NearMap show the seagrass beds in the north of Corio Bay and in Limeburners Bay in detail. Images have been provided by AECOM from 2009 to 2021, and significant changes to the seagrass beds are evident from the photos.

Figure 5-65 shows the seagrass beds at the channel into Limeburners Bay in November 2009 and April 2011. In 2009 the seagrass around the entrance to Limeburners Bay was patchy and sparse with clumps of denser seagrass inshore of the 2 m depth contour. By 2011, the *Zostera* beds were denser. Seagrass along the eastern side of the Limeburners Bay channel is thicker and the patches of bare sediment have been covered by medium to dense *Zostera*. On the western side of the channel, the seagrass is less patchy but the edge of the beds has receded closer to the shoreline.



Figure 5-65. Limeburners Bay (November 2009 – April 2011)

The seagrass beds in this area remain relatively consistent over the next two years with only minor variations. The extent of *Zostera* differs from season to season and year to year as it recedes and regrows. The next major difference in seagrass habitat around Limeburners Bay occurs between June 2013 and September 2013, as shown in Figure 5-66. Over the 3-month period there is a major decrease in seagrass coverage on both sides of the channel. To the west there is a significant reduction as the seagrass beds receded towards the shoreline. A band of thick *Zostera* close to the coast is evident in both figures, but the sparse *Zostera* further offshore has been replaced by bare sediment. On the eastern side of the channel, the dense seagrass has become very sparse, and the patches of bare sediment have increased in size.



Figure 5-66. Limeburners Bay (June 2013 – September 2013)

Figure 5-67 shows the seagrass cover at the entrance to Limeburners Bay in October 2016 and January 2017. The images show a major reduction in seagrass over the three-month period. In October 2016 that there are large patches of sediments (particularly on the western side of the channel) that have no seagrass cover. By April 2016 these areas had been covered with sparse seagrass. In 2017 these is a large reduction in seagrass cover with almost all of the seagrass on the eastern side of the channel disappearing except for a strip along the shoreline. On the western side of the channel the patches of dense seagrass reduced in size leaving large areas of bare sediment.

There is a seasonal aspect to the lifecycle and growth of seagrasses, however, the aerial images show that there is a longer cycle in seagrass extent from year to year.



Figure 5-67. Limeburners Bay (April 2016 – January 2017)

Figure 5-68 shows the extent of seagrass in March 2020 and March 2021. The seagrass cover was slightly denser in 2020 compared to 2021. On the western side of the channel there is a reduction in seagrass to the north by 2021 where the spit of land extends off the shoreline. There is also a reduction in seagrass in the deeper section beyond the 2 m depth contour. While the area of seagrass cover on the eastern side of the channel is much the same, there is an increase in patchiness and more bare sediment in 2021 compared to 2020.



Figure 5-68. Limeburners Bay (March 2020 – March 2021)

Other researchers have recorded significant changes in the extent of seagrass in Port Phillip Bay. Ball et al, 2014 mapped seagrass cover at three sites in the Bay from 1939 to 2011 and noted expansion of seagrass cover between the 1960s to 1990s, with large declines at all three sites after 1998, which they attributed to reduced nutrient input during the drought. Lee et al 2015 mapped seagrass cover in the Bellarine Bank in 2003, 2010 and 2013, and noted significant changes in seagrass cover there, which they attributed to movement of coastal sediments.

5.17.4 Conclusion on Variation in Seagrass Extent

The comparison of sequences of images shows that seagrass cover can change significantly over time. While there is some seasonal variability, there are larger changes from year to year. It is clear that seagrass cover in Corio Bay is not constant and is subject to a large degree of natural change. The current extent of seagrass has increased significantly compared to recent years as shown by the images of 2016 – 2017.

5.17.5 Extent of Seagrass near the Refinery

A video tow analysis of the seabed in Corio Bay was carried out to assess the distribution of seagrass and other benthic habitats near the refinery, in the vicinity of the existing discharges from the refinery. Figure 5-69 below shows the NearMap areal image from the Refinery Pier to Limeburners Bay in March of 2021. Overlaid onto the image are the results of the video tows for the location and density of *Zostera* seagrass.

The video tows are shown as a line of dots. The white circles indicate no seagrass is evident. Categories 1 – 3 increase from light green to dark green and represent very sparse to very dense seagrass cover. The figure shows that there is good correlation between the visible seagrass in the image and the results of the video tows. The visible patches of bare sediment and very sparse seagrass match up well with the white and light green circles and the dense seagrass matches well with the dark green circles.



Figure 5-69. Result from CEE Seagrass Transects (Zostera)

In the north section of Corio Bay (Area A), *Zostera* was found in 13 transects. Sites that are closest to Refinery Pier, and perhaps are the most likely to be affected by the dredging, VIV 01 and VIV 16 had low density patches of *Zostera*. High *Zostera* densities were recorded mostly at > 500 m north and > 2 km east of Refinery Pier.

Areas of seabed with high densities of the bare stems of *Zostera nigricaulis* were observed on some towed video transects. Although algal epiphytes were present on the bare stems, the density of the epiphytes over the stems is not considered sufficient to have prevented light from reaching the seagrass. In addition, healthy seagrass was observed at the same depth on other parts of a transect or nearby.

The presence of bare stems together with abundant sea urchins at these sites indicates that grazing of seagrass leaves by sea urchins may be a cause of the loss of leaves from *Zostera nigricaulis*.

Halophila species are comparatively small with short stems and leaves, that might grow under highly dense *Zostera* meadows. The *Halophila* can be difficult to see in images that are dominated by *Zostera*.

Figure 5-70 shows the results for halophila overlaid onto the areal image for March 2021. As expected, there is H*alophila* cover at depths greater than where the *Zostera* is found such as in the channel into Limeburners Bay, although there are several locations where there is a mixture of the two seagrass types, particularly on the eastern side of the channel, closer to a depth of 3 to 5 m.



Figure 5-70. Result from CEE Seagrass Transects (Halophila)

Sparse to dense patches of *Halophila* were recorded at seven transects in the north of Corio Bay (Area A Sites VIV 01, VIV 02 and VIV 07 have varying levels of *Halophila* density. *Halophila* is not recorded at any of these sites in the Seamap Australia dataset

Table 5-19 shows a summary of the depth profiles of the seagrass detected during the 2021 CEE seabed mapping. Dense *Zostera* extends from low water to 3.7 m depth.

Sparse *Zostera* extends down to 5.5. m depth. Dense *Halophila* extends from 1 m to 4.3 m depth. Spare *Halophila* extends down to 5.9 m. There were only a few areas where sparse plants were observed at greater depths.

Table 5-19. Summary of Observed Depths of Seagrass

	Zostera sp.			*Halophila* sp.		
	Dense	Medium	Sparse	Dense	Medium	Sparse
5th percentile	Low water			~1 m		
Median	2.2	2.9	3.7	3.6	3.8	4.1
95th percentile	3.7	4.5	5.5	4.3	5.0	5.9

Figure 5-71 shows an image of sparse *Halpohila* seagrass which was observed during the video transects in north Corio Bay. The image shows very sparse and patchy *Halpohila* leaves as well as a layer of filamentous algae which becoms thicker as the seagrass becomes more dense.



Figure 5-71. Sparse Halophila Seagrass in North Corio Bay

Seagrass near Main Discharge Channel (W1)

Seagrass around the main outlet channel for the refinery discharge has been observed through towed underwater camera images and through field observations. These investigations show that seagrass is prevalent in the plume from discharge point W1 with medium to dense *Zostera* being observed directly at the mouth of the channel.

Figure 5-72 is a plot of the area of seagrass observed in video tows in 2021. The image clearly shows that there is dominant seagrass habitat at the mouth of the discharge point W1 channel which is licensed to discharge residual chlorine at a level of up to 228 ML/d.

The EPA licence discharge limit for W1 is 100 µg/L total residual chlorine although the actual residual chlorine in the discharge is around 6 µg/L (see Figure 5-78). The observed distribution of seagrass suggests that seagrass is not negatively impacted by the residual chlorine or the temperature of the refinery discharge as there is healthy and dense seagrass prevalent along the shoreline within close proximity to all of the licensed discharges. In ecological terms, the limiting factor for seagrass growth does not appear to be temperature or chlorine, but is most likely to be one or more of available light, sediment characteristics and predation.



Figure 5-72. Seagrass Extent Around Discharge Point W1

5.17.6 Macroalgae

The term “filamentous algae” is a general term to refer to macroalgae with a filamentous plant body. Filamentous algae were observed growing epiphytic on *Zostera*, on organisms such as sponges and ascidians, and on the seabed. Its distribution within the bay follows a similar pattern to that of seagrass.

Figure 5-73 shows the extent of filamentous algae on transects in northern Corio Bay. Although present in all sections of the Bay, higher densities of filamentous algae were associated with shallower depths and seagrass. Within the bay the highest abundances of filamentous algae were observed from 1 km to 2 km north of Refinery Pier.

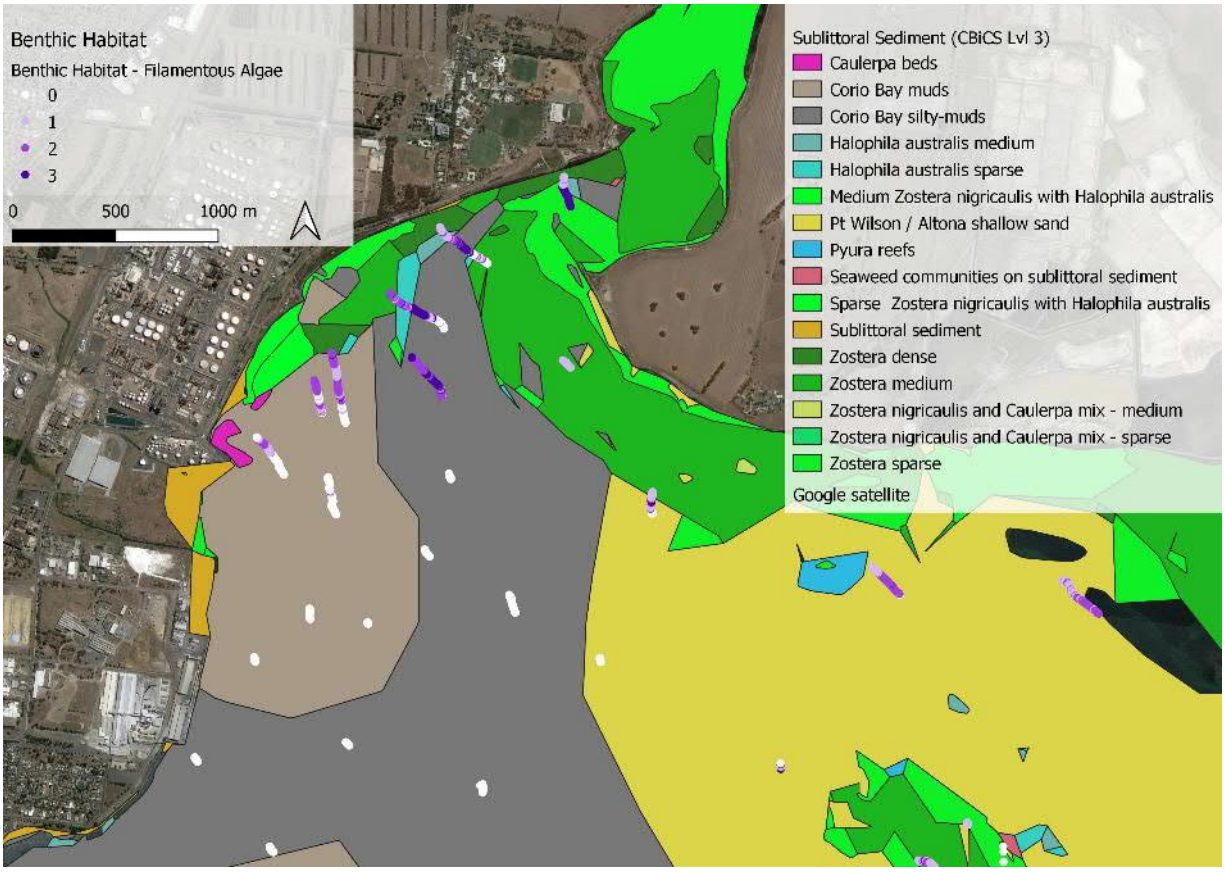


Figure 5-73. Filamentous Algae in North Corio Bay 2021

The Port Phillip Bay Environmental Study (CSIRO, 1996) listed 64 species of *Chlorophytes* (green algae) in the Bay, 109 species of *Phaeophyta* (brown algae) and 276 species of *Rhodophyta* (red algae). The distribution of macroalgae is influenced by sediment type, wave action, light availability, nutrient availability, salinity, currents and temperature. Some taxa are found only or mainly in the calmer waters of Corio Bay and on the north-west coast of Port Phillip Bay while other taxa are ubiquitous.

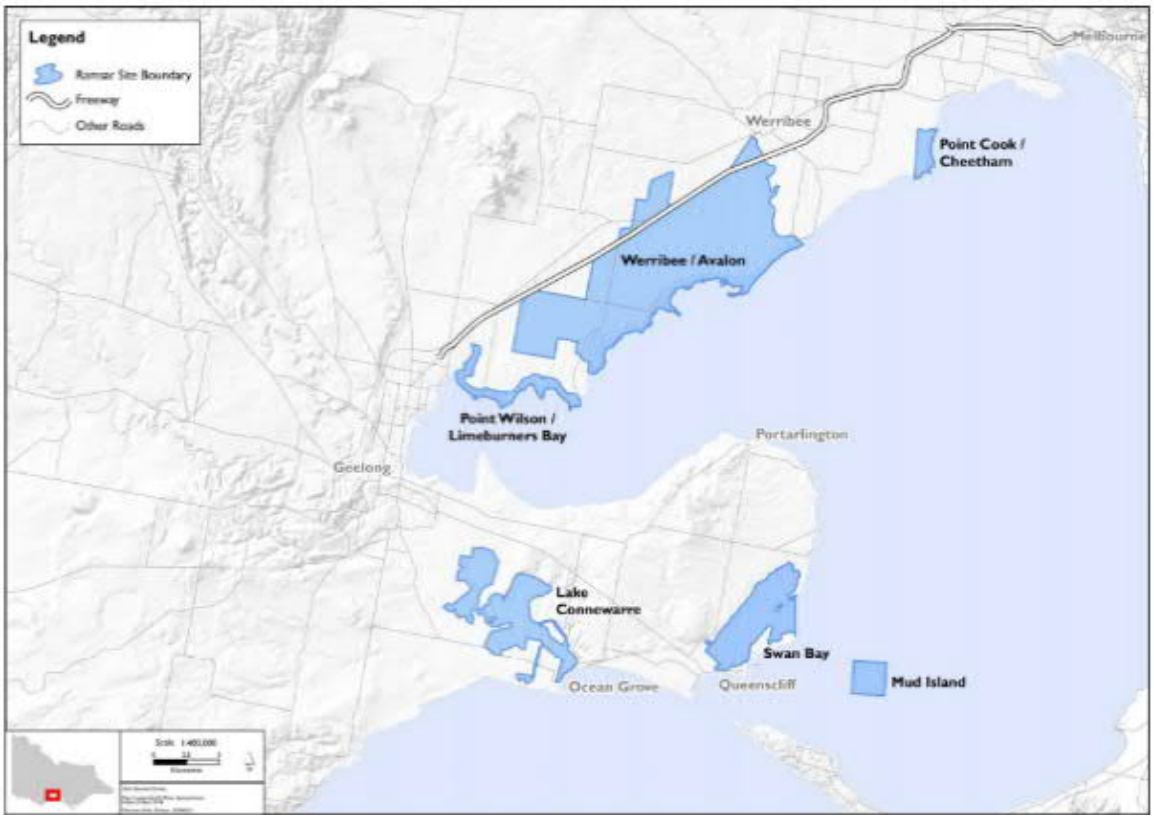
In Corio Bay, brown algae coexist with seagrass to a depth of about 5 m. Beyond that depth, there is very sparse growth of *Caulerpa sedoides* over much of the muddy seabed and patches of filamentous unattached algae. Algae is also observed on Zostera and Halophila seagrass around the discharge channel as explained in Section 11.4.

5.18 Ramsar Site

Port Phillip Bay is home to the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site which is located along the western side of the Bay and covers six separate areas including the former Cheetham salt works near Point Wilson, and another salt works near Point Cook, the sewage treatment ponds at Werribee, Lake Connewarre, Avalon, Swan Bay, Mud Islands and the coastal strip and seagrass beds along Point Wilson to Limeburners Bay. Figure 5-74 shows the location of the six separate components of this Ramsar site highlighted in light blue.

The six sites have a total area of 22,650 hectares and include a combination of freshwater wetlands, estuaries, intertidal shorelines, sub-tidal beds, inland saline

wetlands and the Western Treatment Plant wastewater treatment facility (DEWLP, 2021).



Source: (DELWP, 2021) Figure 3.

Figure 5-74. Port Phillip Bay and Bellarine Peninsula Ramsar Site

The area of interest in regard to the project is the shoreline and nearshore area of Point Wilson / Limeburners Bay which are located approximately 1 km directly north of Refinery Pier where the FSRU would be moored. This section covers approximately 942 ha and excludes the Avalon saltworks (DELWP, 2021).

A description of the site including the *Ecological Character Description (ECD)* of the critical components, processes and services (CPS) of the sites and limits of acceptable change (LAC) is provided in Section 12.

5.19 Dolphins and other Marine Mammals

Port Phillip Bay and Corio Bay are home to several dolphin species such as the common dolphin (*Delphinus delphis)* and the common bottlenose dolphin (*Tursiops Truncatus*). The Burrunan dolphin (*Tursiops australis)* is endemic to southern Australia and a new species first described as a separate species in 2011 by Dr Kate Robb, (MMF.org, accessed 2021). The existence of *Tursiops australis* as a separate species is still under contention as it is not currently recognized by the International Committee for Taxonomy.

Dolphins are a common sight in Corio Bay particularly the Burrunan dolphin. Other species, such as the common bottlenose dolphin, are typically found in deeper water, although they swim into the Bay at times.

Seals are another marine mammal that live in Port Phillip Bay. The seals do not breed in the Bay but are often found on many of the navigation beacons (e.g., Popes Eye, South Channel Fort and South Channel Marker) and smaller structures and buoys (*Commissioner for Environmental Sustainability Victoria*, accessed 2021). They seem to prefer sites around Port Phillip Heads. Seals may occasionally venture up to Corio Bay.

Given the shallow bathymetry of Corio Bay, the Bay is not visited by larger whales such as killer whales, blue whales or southern right whales. Corio Bay is not known as an important area for large marine mammals as it is not an established breeding or feeding ground for whales.

5.20 Penguins

The nearest penguin breeding colony to Corio Bay is the breakwater at St Kilda. Penguins are habituated to a wide range of human-related activities including boating, shipping, dredging and industrial activities. The penguins from St Kilda feed in shipping channels between St Kilda harbour and Williamstown, and also disperse widely in Port Phillip Bay following schools of anchovies and pilchards. While there is not an established colony of penguins in Corio Bay, individuals or small groups of penguins may enter the Bay from time to time to feed on anchovies.

5.21 Introduced Marine Species

A comprehensive survey of introduced species in the Port of Geelong took place on 28 August to October 1997 and the results are detailed in the *Marine Biological Invasions of Port Phillip Bay Victoria*, CRIMP Technical Report #20 (1999).

Sampling in 1997 of Introduced Species

A range of sampling methods were used in the 1997 survey to capture a wide array of invasive species in the Port of Geelong. Seven sites in Corio Bay sampled including Point Henry Pier, Rippleside Pier, Bulk Grain Pier, Corio Quay, Lascelles Wharf, Refinery Pier and Point Wilson Jetty (Currie et al, 1998).

Phytoplankton was sampled in sediments and through the water column. Sediment samples were taken using cores near the pylons at each location (CRIMP, 1999). The water column samples were taken using vertical tows with a small phytoplankton net with one sample from each location (CRIMP, 1999).

Zooplankton was collected using a 3 m long net with a 60 cm diameter inlet and

300 µm mesh. The net was towed for 10 minutes at each location during daylight hours.

Trapping was used to collect crabs, shrimp and other scavenging organisms (CRIMP 1999). Three different sizes of net were used with 10 cm or 2 cm mesh. Each trap was deployed overnight at five sites at each location (CRIMP, 1999).

Epibenthos was sampled with an Ockelmann sled at 19 sites near commercial and recreational wharfs and piers. Other samples were taken by Point Henry Pier and Point Wilson Jetty. The sled was towed for 5 minutes at each site.

Benthic Infauna was sampled using 0.1 m^2 grabs and diver cores at 40 sites.

Seine netting was used to sample inshore fish with a 10 mm mesh net 60 m long and 1.25 m high. The net was used at each location once during the day and once at night.

Results of 1997 Survey of Introduced Species

There was a total of 19 different exotic species found in the sampling program and the results are presented in Table 5-20 from *Marine Biological Invasions of Port Phillip Bay Victoria*, CRIMP Technical Report #20 (1999).

Table 5-20. Introduced Species in the Port of Geelong (1997)

Taxa/species	Locations						
	1	2	3	4	5	6	7
Algae							
Ulva lactuca			+	+		+	+
*Undaria pinnatifida**				+			
Polychaeta							
Euchone limnicola		+				+	
Myxicola infundibulum	+						+
*Sabella spallanzanii**	+	+	+	+	+	+	+
Mollusca							
Corbula gibba	+			+		+	+
Musculista senhousia	+	+	+	+	+	+	+
Theora lubrica	+		+	+	+	+	+
Arthropoda							
*Carcinus maenas**			+	+			
Cirolana harfordi			+				
Jassa marmorata		+	+	+	+		+
Bryozoa							
Bugula dentata	+			+	+	+	+
Bugula neritina		+	+	+		+	+
Watersipora subtorquata	+	+			+	+	+
Ascidia							
Ascidiella aspersa	+	+	+	+	+	+	+
Ciona intestinalis		+		+		+	
Styela clava	+	+	+	+	+	+	+
Styela plicata		+			+	+	+
Pisces							
Amoya pflaumi	+			+		+	+

**Note: Identification changes include - (Musculista = Arcuatuala) and (Corbula = Varicorbula)*

The 19 identified invasive species are widely spread over Corio Bay, and 14 of them were detected at Refinery Pier. Examples of the invasive species are described below.

Ulva lactuca is a green alga that is widely distributed across the world's oceans and was detected at Refinery Pier on one of the piles (CRIMP, 1999).

Euchone limnicola is a small sabellid polychate that burrows in soft sediments. The numbers in Corio Bay were low compared to other areas of Port Phillip Bay.

Sabella spallanzanii is a large worm found on piers at all the sampling sites. The worm was found on piers and in some of the sediment samples. It originated on the Mediterranean and Atlantic coasts of Europe (CRIMP, 1999).

Varicorbula gibba is a suspension-feeding mollusc that grows to 15 mm in length. They live at the surface of soft sediments. These north Atlantic molluscs had low densities in Corio Bay in 1997.

Arcuatuala senhousia is a mussel which grows up to a length of around 30 mm and grows on hard and soft substrates. This species is abundant in Corio Bay. It originated on the Chinese and Japanese coasts and was most likely introduced on ship hulls or in ballast water. *Arcuatuala senhousia* is increasing in abundance over time. It grows in mats on the soft sediments of Corio Bay and is entering seagrass beds (CRIMP, 1999).

Theora lubrica are deposit feeding bivalves which can grow to 14 mm in length. Theora lubrica originates from the western Pacific and is found in high densities around the coast of Japan. This species is a dominant organism in Corio Bay (CRIMP, 1999).

Bagula dentata is a bryozoan that grows to 5 cm high and is small, bushy and green. This species was mostly collected by scraping piles. Colonies are on many piers including Refinery Pier.

Bulga neritina is a purple-brown bryozoan which forms colonies up to 8 cm in height. Similar to Bagula dentata, this species was found on most pier piles in Corio Bay, but at low abundance.

Waterslpora subtorquata in an encrusting bryozoan that is found as a band on jetty piles around the low water mark. This species was found on jetty piles on several piers including Refinery Pier. The species is currently distributed worldwide, and its origin is not known (CRIMP, 1999).

Ascidella aspersa is an ascidian that can grow to 60 mm in length. It attaches to solid substrates and this often results in dense colonies. It is found in the northern hemisphere in the Mediterranean, English Channel and Irish Sea.

Ciona Intestinalis is an ascidian which grows to around 15 mm under artificial substrates. Only a few individuals were found in 1997.

Styela Clava is a cylindrical ascidian which grows to 60 mm on hard substrates. The greatest abundance was found at depths of around 3 m on wooden piles. This species is a native of the northern Pacific and has been found in the English Channel and the Irish Sea as well as the coast of North America (CRIMP, 1999).

Styela Plicata is an ascidian which grows to 90 mm on solid substrates. Only five individuals were collected during the survey: all from pile scrapings. This species occurs in the Atlantic and Pacific oceans as well as along the Australian Coast.

Acentrogobius pflaumi is an introduced goby which grows to 80 mm in length. This species is found in Chinese, Korean and Philippine waters (CRIMP, 1999).

Port Phillip Bay is known to have a large number of introduced species. These species cause additional stress and impact on the existing environment including competition with native species, elimination of native species, alteration of habitats, hybridisation and trophic alterations (CRIMP, 1999). High abundance of non-native species detected during the 1997 surveys indicate that they are already having an impact on the ecosystem of Port Phillip Bay and Corio Bay.

The data collected in the 1997 survey was checked with the National Marine Pest Information System (NIMPIS) developed by the Australian Government, which is a more up to date register of introduced marine pests. Figure 5-75 provides a list of introduced species found in Corio Bay. All of the species included as marine pests in the map from NIMPIS (2022) are included in the 1997 introduced species assessment.

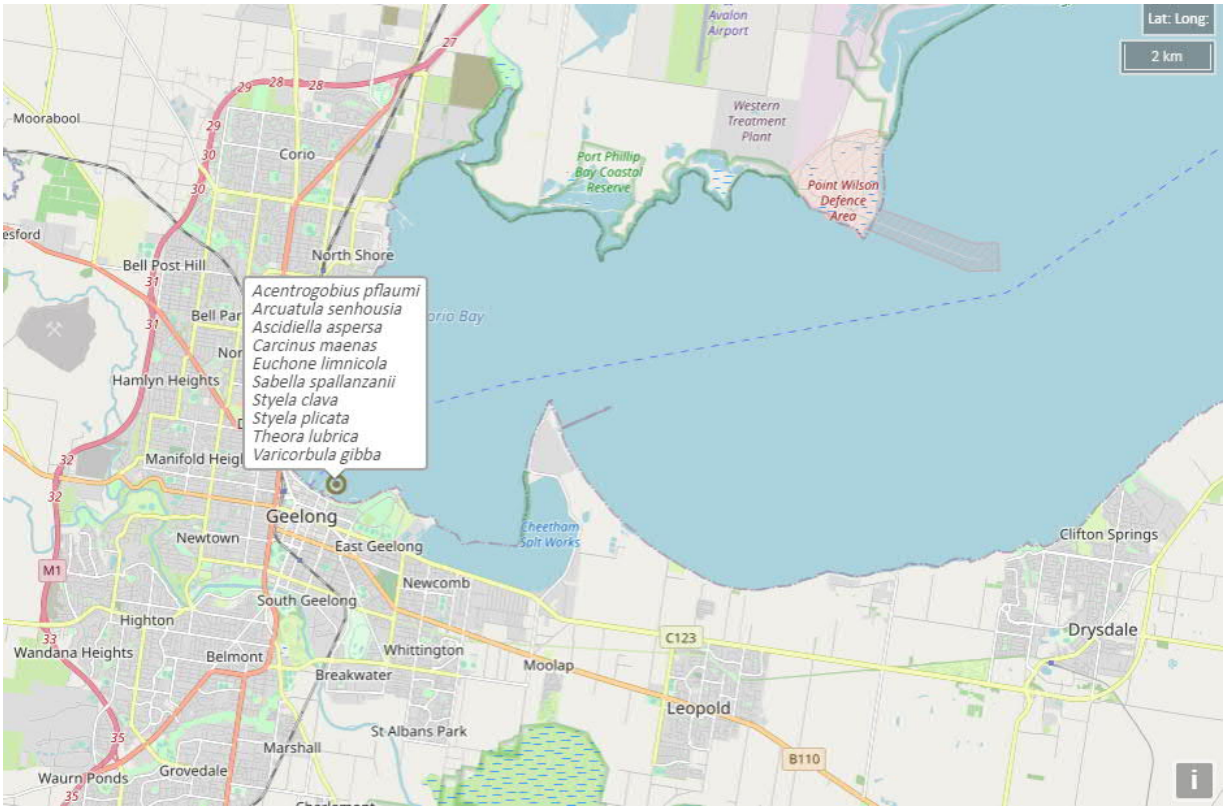


Figure 5-75. Corio Bay Introduced Pests (NIMPIS, 2022)

In late 1990's or early 2000's the Northern Pacific Seastar (*Asterias amurensis)* was also introduced and has been evident in Port Phillip Bay. This species is not listed in NIMPIS as an introduced species in Corio Bay, however, the species has been seen by CEE staff during video tows while conducting field work in Corio Bay.

5.22 Protected Matters

There are 25 marine threatened or migratory species listed under the EPBC Act and FFG Act that may occur in Corio Bay, as shown in Table 5-21. The table excludes bird species as they are addressed in another Technical Report D: *Terrestrial ecology impact assessment*.

These species are listed in Table 5-21 and the following subsections address their likelihood of occurring within Corio Bay.

Table 5-21. Listed Threatened Species Potentially Occurring in Study Area

Common name	Scientific name	EPBC	FFG
Mammals			
Blue Whale	*Balaenoptera musculus*	Endangered, Migratory	Listed
Southern Right Whale	*Eubalaena australis*	Endangered, Migratory	Listed
Humpback Whale	*Megaptera novaeangliae*	Vulnerable, Migratory	Listed
Burrunan Dolphin	*Tursiops australis*	Listed marine (NA)	Listed
Sharks			
White shark	*Carcharodon carcharias*	Vulnerable, Migratory	Listed
Grey nurse shark	*Carcharius taurus*		Listed
Freshwater/Marine Migratory Fish			
Australian mudfish	*Neochanna cleaveri*		Listed
Australian grayling	*Prototroctes maraena*	Vulnerable	Listed
Marine Fish*			
Southern Bluefin Tuna	*Thunnus maccoyii*		Listed
Australian Whitebait	*Lovettia sealii*		Listed
Turtles			
Leatherback Turtle	*Dermochelys coriacea*	Endangered, Migratory	Listed
Loggerhead Turtle	*Caretta*	Endangered, Migratory	
Green Turtle	*Chelonia mydas*	Vulnerable, Migratory	
Marine Invertebrates			
Southern hooded shrimp	*Athanopsis australis*		Listed
Brittle star	*Amphiura triscacantha*		Listed
Sea-cucumber	*Apsolidium densum*		Listed
Sea-cucumber	*Apsolidium handrecki*		Listed
Brittle star	*Ophiocomina australis*		Listed
Sea-cucumber	*Pentocnus bursatus*		Listed
Sea-cucumber	*Thyone nigra*		Listed
Sea-cucumber	*Trochodota shepherdi*		Listed
Chiton	*Bassethullia glypta*		Listed
Opisthobranch	*Platydoris galbana*		Listed
Opisthobranch	*Rhodope genus*		Listed
Stalked Hydroid	*Ralpharia coccinea*		Listed

5.22.1 Marine Mammals

Blue Whale

Corio Bay is remote from Blue Whale aggregation areas in Bass Strait and further south and plausible migration pathways. It is very unlikely that Blue Whales would be found in Corio Bay.

Southern Right Whales

Southern Right Whales intermittently pass along the central Bass Strait coast and a few may enter Port Phillip Bay for short periods. Corio Bay is not an aggregation or breeding area for Southern Right Whales. Southern Right Whales were sighted between Barwon Heads and Inverloch in 2020, most of which were in Bass Strait. There were 10 whales sighted in Western Port Bay, 4 in Port Phillip Bay and zero in Corio Bay (see Figure 5-76).



Figure 5-76. Southern Right Whales in Port Phillip Bay

Source: Geelong Advertiser

Humpback Whales

Corio Bay is not an aggregation point or breeding area for Humpback Whales. In the three previous years (2017 to 2019) an average of 15 whales were sighted in Port Phillip Bay each year, most near the entrance of along the eastern shore. No whales were sighted in Corio Bay at any time in 2017 to 2020.

Brydes Whales

In Australia, Brydes Whales are mostly recorded in northern Western Australian waters and off Queensland. It is unlikely these occur frequently along the southern Australian coastline or in Bass Strait. There are no records of Brydes Whales in Victorian waters.

Pygmy Right Whale

Pygmy Right Whale are widely distributed in the southern hemisphere. In Victoria there have been a small number of observations recorded near Warrnambool, but none in Port Phillip Bay or elsewhere in Victoria.

Killer Whale

Small pods of Killer Whales are observed in Bass Strait from time to time including the area offshore from Western Port, particularly around Seal Rocks. There is one recorded sighting inside Port Phillip Bay between 2015 and 2020. No killer whales have been recorded in Corio Bay.

Dusky dolphin

There are no records of Dusky Dolphins in Victorian waters and there does not appear to be any breeding or feeding grounds for Dusky Dolphins in Corio Bay.

Burrunan Dolphin

The bottlenose dolphin is resident in Port Phillip and the Gippsland Lakes, and the dolphins recently listed under the FFG Act as a new species, the Burrunan Dolphin. The original range has since been extended to include populations in South Australia, Victoria and Tasmania (Charlton-Robb et al 2015). As discussed earlier in this section, these dolphins may swim and feed in Corio Bay at times.

5.22.2 Fishes

White Shark

White Sharks occur in all oceans of the world, including Bass Strait and Port Phillip Bay. The seal breeding colony at Seal Rock at the Western Entrance to Western Port is a known feeding area for White Sharks and these sharks have been observed and caught in Port Phillip Bay. They are highly mobile, and it is likely that individual great white sharks will pass through Corio Bay from time to time.

Grey Nurse Shark

The distribution of Grey Nurse Sharks (western and eastern populations) in Australia is considered to be confined to Western Australia, southern Queensland and the New South Wales coast (DoEE, 2014). There are no recent records of Grey Nurse Sharks in Victoria south of Mallacoota. Grey Nurse Sharks are unlikely to be found in the central Bass Strait region or in Corio Bay.

Mackerel Shark (Porbeagle)

In Australia, the Porbeagle occurs from southern Queensland to southwest Australia, primarily in waters near the continental shelf. It may occasionally and temporarily enter coastal waters, however there are no records from Victorian Coastal Waters or Bass Strait.

Australian mudfish

The Australian Mudfish is a small, 80 mm long fish associated with coastal wetlands and streams. Larvae and juveniles of the mudfish are thought to spend some time in marine waters before migrating back into streams and wetlands. Only 29 adult specimens have been identified from seven sites in Victoria, from the east side of Wilsons Promontory to rivers west of Cape Otway. No specimens were identified in the ichthyoplankton sampling program carried out in Corio Bay as part of the marine assessment.

Australian Grayling

The Australian Grayling (Prototroctes maraena) is a small (300 mm long) freshwater fish that has larval and juvenile stages in the marine environment. They are found in

coastal streams of southern New South Wales, coastal rivers and streams from East Gippsland (Genoa River) to the Hopkins River near Warrnambool in western Victoria and most rivers and streams around Tasmania. Large populations may occur in rivers in eastern Victoria such as the Tambo River (Backhouse et al 2008).

In Victoria, grayling occur in the Yarra, Barwon, Bunyip and Lang Lang Rivers Adult graylings migrate downstream from their freshwater habitat to spawn just upstream of the brackish waters from March to July. Fertilised eggs do not appear to survive in marine waters. The larvae then disperse into the marine environment where they remain for four to five months before returning to freshwater streams in spring to become resident freshwater adults (Crook et al 2006, Jones et al 2016).

There is a known population of Australian Grayling in the Yarra River and individuals have been recorded in the Werribee River (O'Connor 2015; Amtstaetter et al. 2021).

The freshwater creek flowing to Corio Bay, Hovells Creek, is much smaller than the Yarra or Werribee Rivers, and grayling is not listed as an ecological value for the Point Wilson area of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan* (DELWP, 2020). None of the monthly ichthyoplankton surveys in Corio Bay identified a grayling.

Southern Bluefin Tuna

Southern Bluefin Tuna are an oceanic species, widely distributed in southern oceans from New Zealand to southern Africa and into the South Atlantic Ocean. They prefer deep ocean waters or the productive waters of the continental slope. Hence, in Victoria, they are only found in western and eastern Victoria where the continental shelf is narrow. They are unlikely to be found in Corio Bay.

Australian Whitebait

The Australian Whitebait is a small (77 mm maximum length) fish which lacks scales and has translucent or silvery colouring, though adults may turn completely black in estuaries following spawning. Occurring primarily in Tasmania, in Victoria it is only known from the Tarwin River and Anderson Inlet on the east coast of Victoria.

5.22.3 Turtles

Leatherback Turtles (Dermochelys coriacea) are occasionally seen in Victoria between April and May, when the waters of Bass Strait are warmest. Sightings and stranding's have been recorded all along the Victorian Bass open coast, Port Philip Bay and the Gippsland Lakes. These turtles could visit Corio Bay

The Loggerhead Turtle (Caretta caretta) inhabits tropical and subtropical seas, though it is thought likely they occasionally occur in south-east Australia in the warmer months. There are 13 records of Loggerhead Turtles in Victoria (Atlas of Living Australia, 2017), the majority of which were recorded on the Victorian coastline west of Melbourne. Seven were of dead specimens and most others were live beach stranding's. There are no records from Corio Bay.

The Green Turtle (Chelonia mydas) is a tropical species, and generally only occurs in waters where temperatures average 20°C or more. It may occasionally occur in temperate waters, however there are only seven records of Green Turtles in Victorian waters, most of them for dead specimens found on beaches.

5.22.4 Marine Invertebrates

Thirteen marine invertebrates are listed under the FFG Act, including three species of crustacean, seven species of echinoderm, three species of mollusc and one cnidarian (hydroid). These marine invertebrates are only known from between one and seven individual specimens which have been collected at between one and four different localities in Victorian waters.

5.22.5 Migratory Birds

The assessment of potential impact on migratory birds is contained in Technical Report D: *Terrestrial ecology impact assessment* (AECOM, 2021).

5.23 Discharges from the Geelong Refinery

The refinery uses 350 ML/d of seawater for cooling purposes as part of normal refinery operations. This arrangement has continued for over 40 years. The seawater intake channel extends 120 m into Corio Bay just to the north of Refinery Pier. Chlorine is added to the seawater at around 0.3 to 0.4 mg/L to control biofouling in the pipes and heat exchangers. The chlorine concentration decreases substantially during the time of passage through the pipe network. The discharged seawater is warmer than the ambient seawater due to the transfer of heat in the refinery processes.

After use, the seawater is returned to Corio Bay at four discharge points along the coast in front of the refinery. The conditions of discharge and the corresponding mixing zones are listed in EPA Licence No. 46555 dated 3/6/2016. The largest of the discharges is W1 which is the main outlet channel located south of Refinery Pier. W1 has a flow limit of 228 ML/d which is the largest of the four discharges. A summary of the discharge limits is listed in Table 5-22 below.

Table 5-22. Summary of EPA Licence Discharge Limits for Viva Energy

Discharge point	Type	Limit	Unit
W1	Flow	228	ML/d
	Chlorine	0.1	mg/L
	Temperature	35	°C
W3	Flow	2	ML/d
	Chlorine	0.2	mg/L
	Temperature	35	°C
W4	Flow	35	ML/d
	Chlorine	0.2	mg/L
	Temperature	35	°C
W5	Flow	85	ML/d
	Chlorine	0.1	mg/L
	Temperature	35	°C
Total of all four discharges	Flow per day	350	ML/d
	Residual chlorine	35	kg/d

The refinery EPA Licence permits the four discharges to release up to 35 kg/d of chlorine in 350 ML/d of seawater.

Figure 5-77 shows the location of the four discharges, the discharge rate and the extent of the mixing zones as defined in the EPA Licence. The largest of the discharges (W1) has a mixing zone radius of 500 m. W5 has the second largest discharge rate of 85 ML/d and a mixing zone radius of 120 m. W4 is the second smallest discharge of 35 ML/d with the smallest mixing zone radius of 80 m. W3 is the smallest discharge of 2 ML/d (discharging seaweed caught on the screens) and has a mixing zone radius of 100 m.

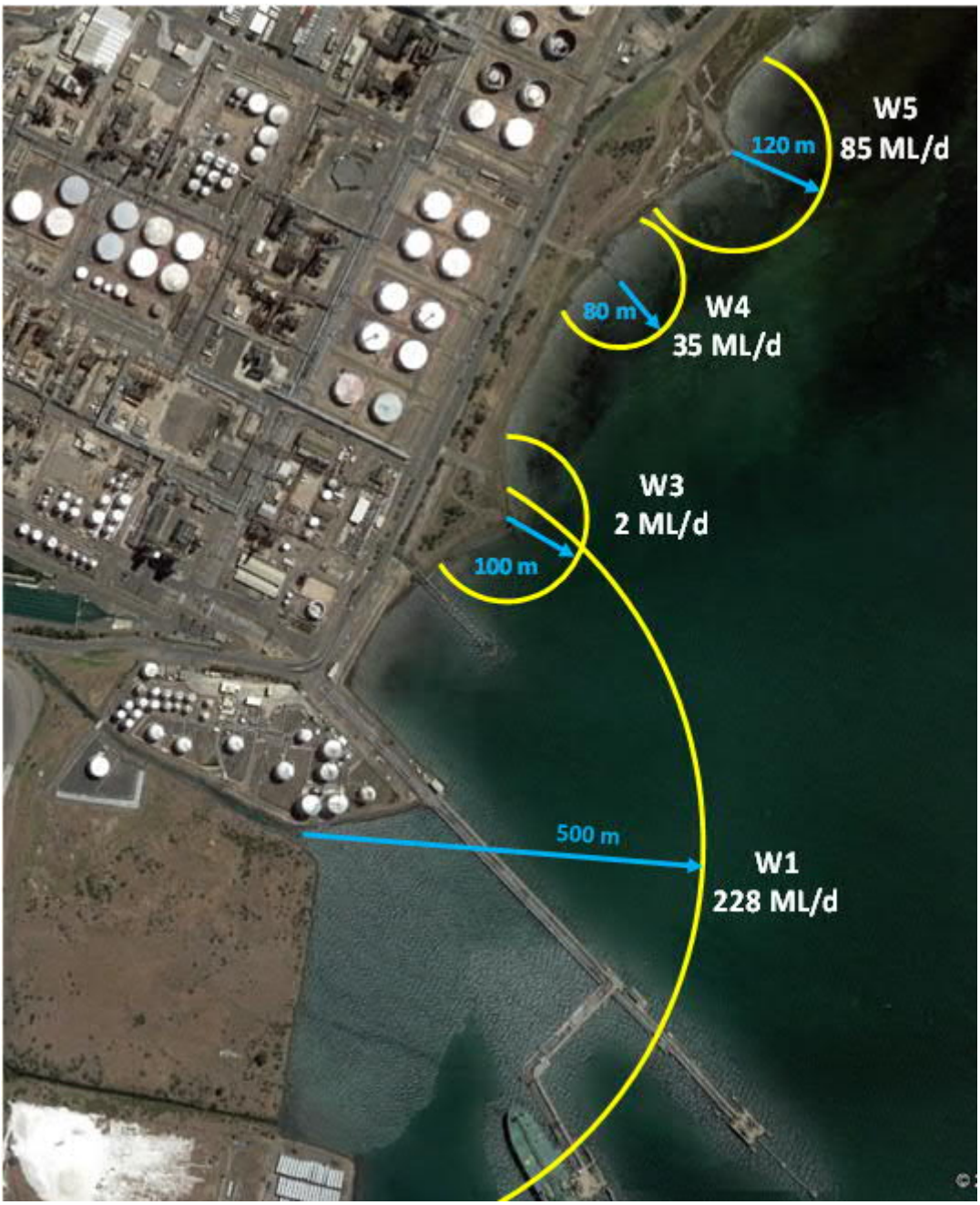


Figure 5-77. Map of Viva Refinery Discharge Points

As mentioned, W1 has a discharge limit of 228 ML/d with a temperature increase up to 10°C above ambient. The warmer water which is discharged through the channel creates a buoyant plume about 1 m deep that disperses into the Bay.

Figure 5-78 below shows a contour map of the warm plume from field measurements in May 2021. The plume from the outlet channel disperses between the shoreline and the pier and is pushed northward by the current. When the measurements were being taken the discharge temperature was 23°C and the ambient water temperature over the top metre was 13°C. Thus, there is some dilution of the plume as the plume temperature decreases to 19°C at around 50 m from the exit of the channel and then continues to decrease towards ambient as the plume spreads and disperses into the Bay.

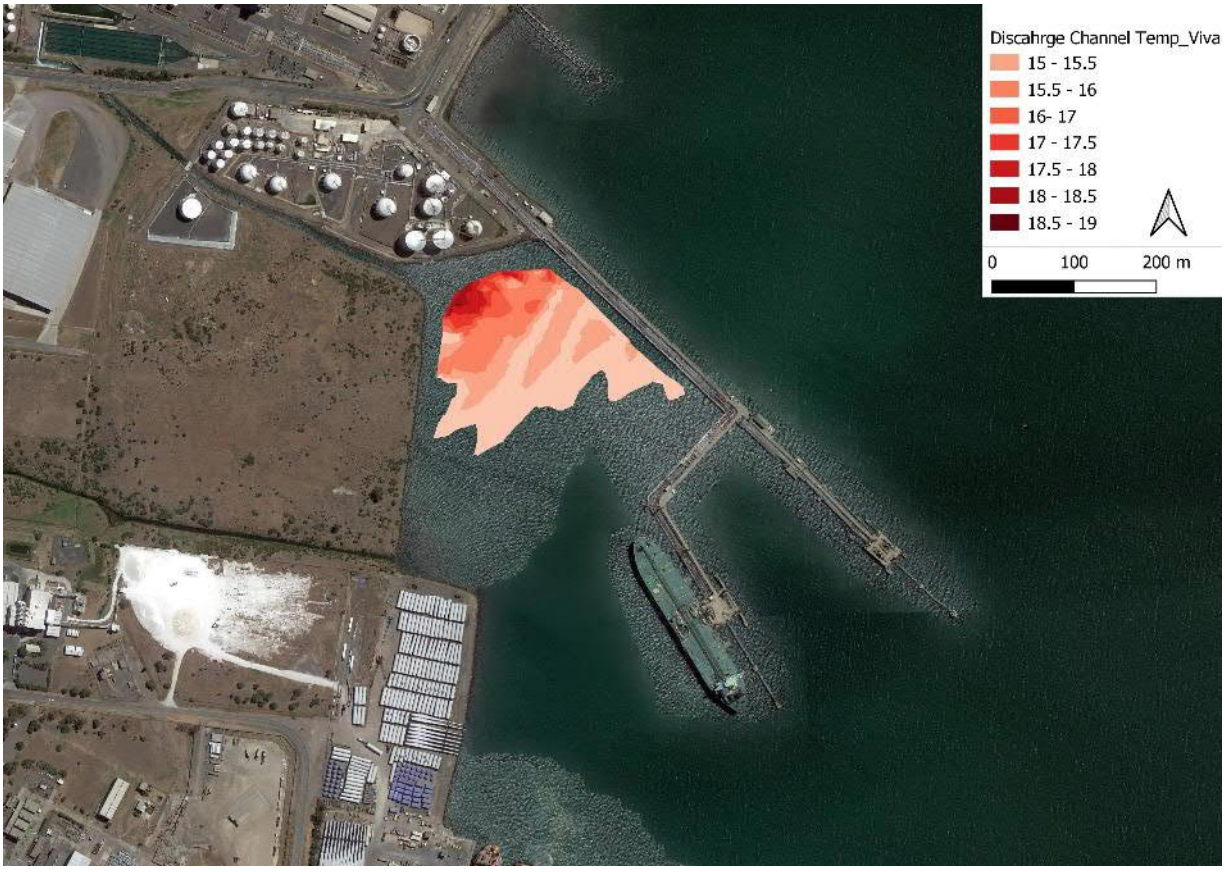


Figure 5-78. Warm Water Temperature Plume from W1 Discharge

Figure 5-79 shows the temperature profiles at several sites in the Bay near the W1 outlet channel. The profile shows the elevated temperature of the surface plume which extends over the top metre of water. At lower depths, the seawater temperature decreases back to the ambient temperature recorded elsewhere in the Bay.

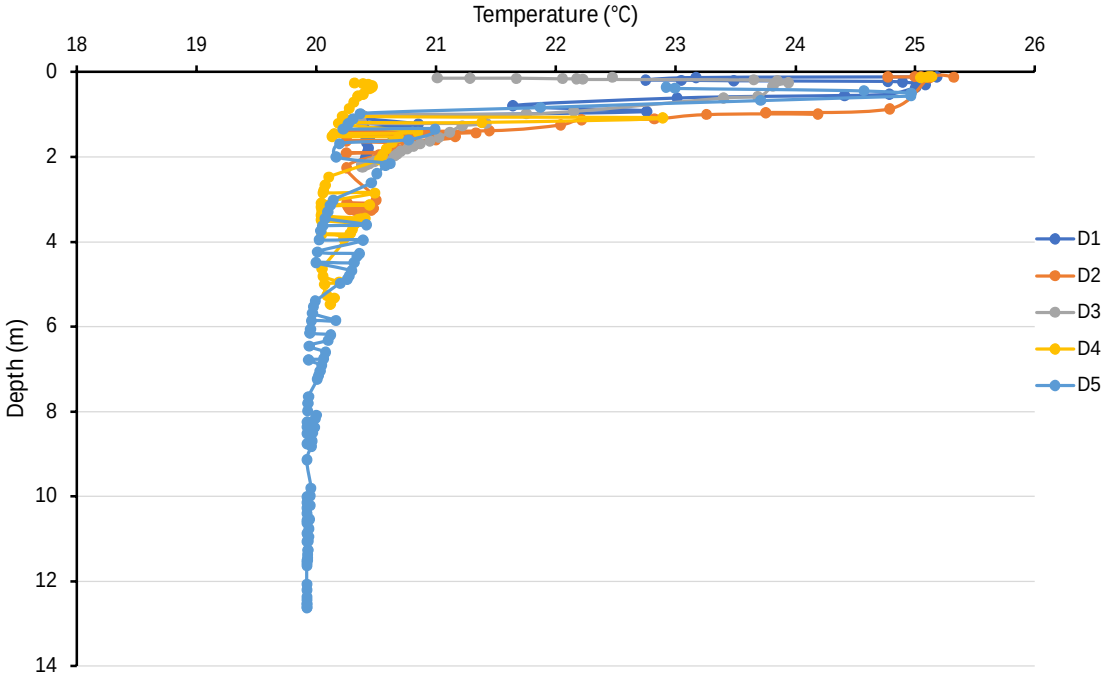


Figure 5-79. Warm Water Temperature Profile Near W1

Further temperature profiles were taken in the Bay in a line extending north from Refinery Pier and between the 2 m contour and the shoreline. Given the seawater circulation patterns of Corio Bay, it is expected that the warm water plumes will travel northward.

Figure 5-80 shows the locations and average temperature at each profile site averaged over the top 1 m of depth. A reference site is located in the Bay further to the east. The map shows that the ambient seawater temperature was 12.9°C. The profiles along the shoreline show elevated water temperature up to 1°C above the ambient temperature. This confirms that the warmwater plume is dispersing northward with the natural currents of Corio Bay. The discharge temperature measured coming out of the outlet channel was 23°C.



Figure 5-80. Average Seawater Temperature Near Discharges

Figure 5-81 shows the eastern shore of Corio Bay adjacent to Viva Refinery. The image shows two of the discharges from the refinery (W4 and W5) and two public drains from the land. It can be seen from the image that the refinery discharges have little impact on the seagrass with only a small area of bare sediment around W5 where the main plume disperses.

However, the two public drains have a larger impact on the seagrass as the runoff carries mud into the bay. These sediments created bare patches where seagrass cannot grow and are visible along the shore to the north and south of discharge W5.

The measured temperature increase of the warm water plume in Corio Bay as shown in Figure 5-80 is consistent with the modelled computer predictions which are shows and described in Section 8 – Impact Assessment for Temperature Discharge.



Figure 5-81. Discharges into Corio Bay

Inflow and Discharge Rates

The seawater inflow into the refinery is controlled by pumps. Viva Energy calibrated the pumps and confirmed that the total seawater inflow rate was usually 350 ML/d, unless parts of the refinery were shut for maintenance, when a lower inflow would be used. Based on an inspection of flow records for 2017-2020, the average seawater inflow rate was 330 ML/d.

The distribution of seawater in the refinery is controlled by valves. Viva Energy confirmed that the flow distribution is controlled to ensure that the discharge flow limits in the EPA Licence are not exceeded.

Temperature and Chlorine in Discharges

Viva Energy records the temperature and residual chlorine level in the four discharges. The results below are for W1, which is the largest discharge. Similar analyses were carried out for all the discharges ("*Analysis of Existing Discharges from the Refinery*", CEE 2021).

Figure 5-82 shows the temperature rise (above the ambient seawater temperature) in the discharge from W1 for 2015 to 2020. The temperature increase ranges from 1 °C to 10 °C. A typical value adopted for modelling the temperature effects of the existing W1 discharge is 8 °C. Note the X-axis lists sample number (after sorting from highest concentration to lowest concentration).

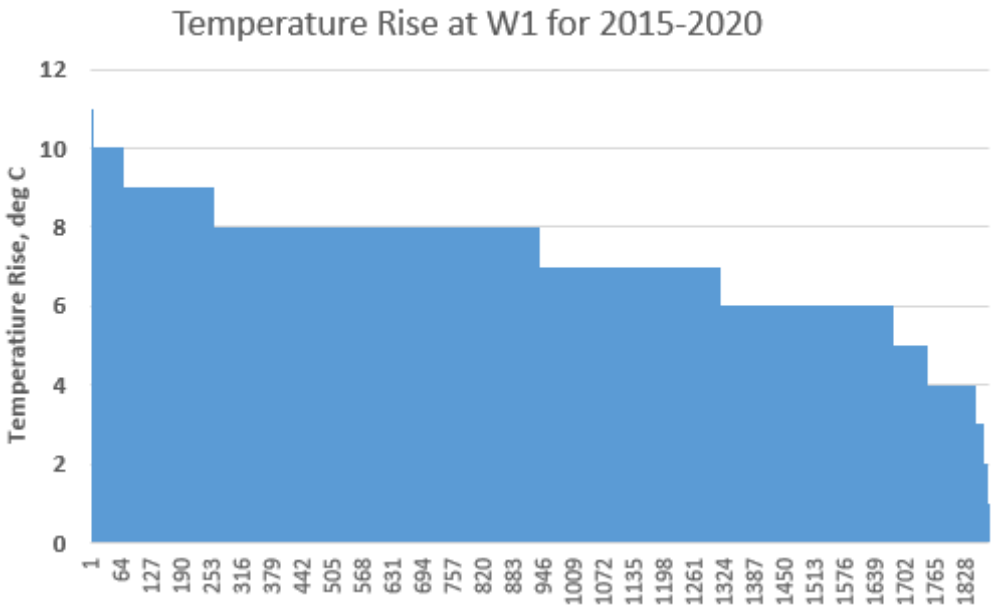


Figure 5-82. Temperature Increment at W1 for 2015 to 2020

Figure 5-83 shows the residual chlorine concentration (in mg/L) from W1 for February 2018 to December 2020. The chlorine in the outlet is consistently below the EPA Licence limit of 0.1 mg/L with concentrations that range from zero up to 0.08 mg/L. For modelling purposes, the adopted chlorine concentration is 0.06 mg/L.

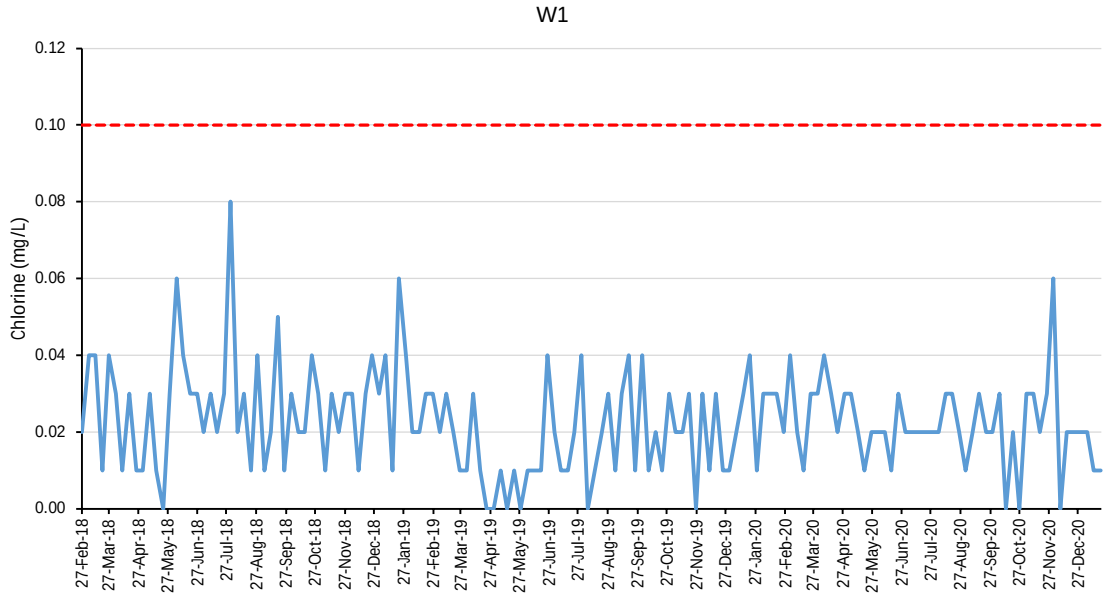


Figure 5-83. Chlorine Discharge from W1 for 2018 to 2020

The analysis of monitoring data showed that the residual chlorine level and temperature rise in the four discharges was within the EPA Licence limits. Table 5-23 summarises the resulting discharge parameters developed from the analysis and used as inputs in the regional modelling (CEE, 2021).

Table 5-23. Summary of Existing Refinery Discharges to Corio Bay

Discharge point	Type	Limit	Unit
W1	Flow	228	ML/d
	Chlorine	0.06	mg/L
	Temperature	+ 8	°C
W3	Flow	2	ML/d
	Chlorine	0.18	mg/L
	Temperature	ambient	°C
W4	Flow	35	ML/d
	Chlorine	0.06	mg/L
	Temperature	+ 9	°C
W5	Flow	85	ML/d
	Chlorine	0.05	mg/L
	Temperature	+ 10	°C
Total of all four discharges	Flow per day	350	ML/d
	Residual chlorine	20	kg/d

It is noted that the existing chlorine discharge to Corio Bay is approximately 20 kg/d which is well below the maximum of 35 kg/d permitted in the EPA Licence.

5.24 Port of Geelong and Shipping

5.24.1 Development of Corio Bay

The township and port of Geelong are located on the coastline of western Corio Bay. Geelong and the port have grown greatly over many years. The town of Geelong was established in the 1830's. The long sandbar between Point Henry and Point Lillias meant that vessels with a draft of over 3 m could not enter or leave Corio Bay. The first dredging program for the North Channel occurred in the 1850's. In the early 1860's, the South Channel was formed to allow better access to the Bay (GeelongPort, 2018)

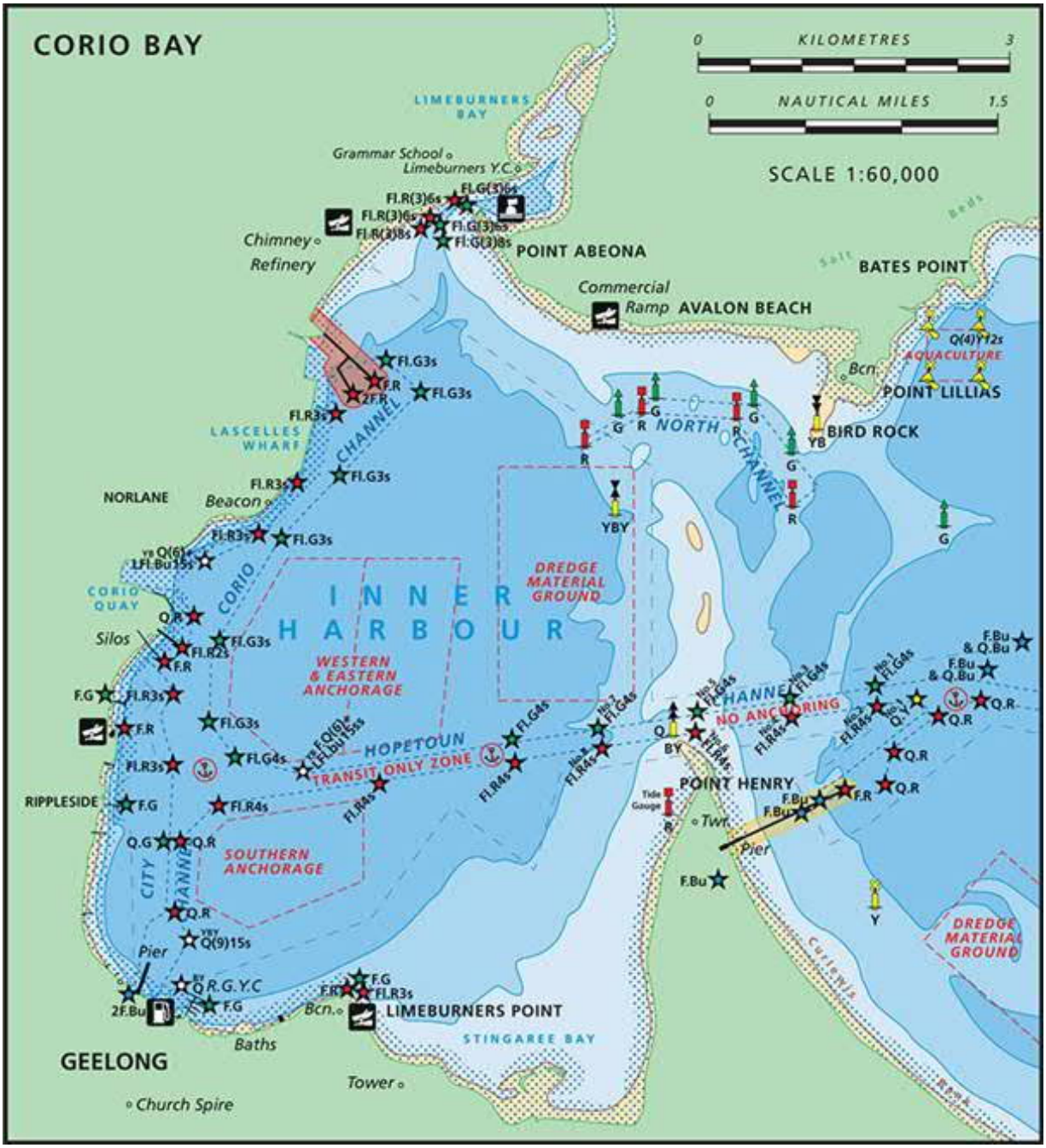


Figure 5-84. Map of Corio Bay and Shipping Channels

The 1890's saw a third dredging program as the Hopetoun Channel was cut into Corio Bay with a minimum depth of 7.1 m and a navigable width of 39.6 m (GeelongPort, 2018). In the early 1900's the Hopetoun Channel was widened and deepened as the port of Geelong continued to develop.

The surrounding land at this time was used for a variety of industries. In the early 1900's the Ford automotive company and Shell Company terminal were initiated (GeelongPort, 2018). Later in the 1900's, Corio Bay became known for its extensive exports of woollen products and developed more industries such as meat works. Shell purchased an additional 100 ha for further development (GeelongPort, 2018).

In 1954, the Shell Refinery officially opened and processed 3 million tonnes of crude oil per year. Further deepening of the existing channels was required. In 1958 a

widening program commenced and the channel from Refinery Pier to Point. Richards was increased to 91.4 m wide and 10.9 m deep. By the 1960's, the port was the fourth busiest shipping outlet in the country (GeelongPort, 2018).

In 2004, the Victorian Regional Channels Authority (now Ports Victoria) commenced further deepening works which brought the channel to a depth of 12.3 m (GeelongPort, 2018). Today, the port of Geelong has approximately 600 ship visits per year and has millions of tonnes of imports and exports (GeelongPort, 2018).

In summary, shipping channels for the port of Geelong have been progressively enlarged and modified over a period of approximately 150 years to allow for safe ship access to the port (Worley Parsons 2011) with approximately 20 million m^3 of material dredged to create and maintain the shipping channels between 1854 and 1997. . Recent dredging works have included (Maunsell 1993):

- Capital and maintenance dredging in Lascelles Wharf, Corio Quay and Bulk Grain Pier (1980)
- Capital dredging at Port Henry Channel (1984)
- Maintenance and capital dredging in Corio Quay and Corio Channel (1988)
- Maintenance dredging in Wilson Spit Channel (1991)
- Capital dredging (Channel Improvement Program) in Point Henry, Bulk Grain Pier, Lascelles Wharf and Refinery Pier (1996-1997) – 4.5 million m^3 of dredged material.

More recently the Corio Bay Safety Adjustment Program (CBSAP) has been implemented to make changes in channel alignment and water depths in the City Bend and at the junction of the Hopetoun and Corio Channels. These dredging works included:

- Geelong Dredging Program 2014 (City Bend / Corio Quay) - 200,000 m^3 of dredged material
- Geelong Dredging Program 2015 (Refinery Pier No. 4 / trial dredge east of Point Wilson) - 240,000 m^3 of dredged material
- Geelong Dredging Program 2017 (eastern side of Corio Channel) - 160,000 m^3 of dredged material

5.24.2 Shipping in Geelong

The Port of Geelong is a large port in Australia, so large vessels are a common sight in Corio Bay. In the 2016/17 period (the most recent maritime Sea Freight Statistical Report), Geelong was the eighth highest value port in Australia in terms of imports with a total of $2.9 billion. The highest value port was the Port of Melbourne at $58.8 billion.

In that same period, Geelong was the seventh largest port in terms of total throughput with a total of 8 million tonnes. The largest port was Sydney with a total of 21 million tonnes. The port of Geelong has approximately 700 vessel visits per year, which is approximately 20 % of the 3,330 vessels entering the Port of Melbourne.

Figure 5-85 shows the top ten ports in Australia during the 2016/17 period. Geelong has been added to the graph with an estimated 700 vessels for comparison. While

Melbourne and Port Hedland are the largest ports, Geelong is an established and important port, particularly for bulk liquid cargo.

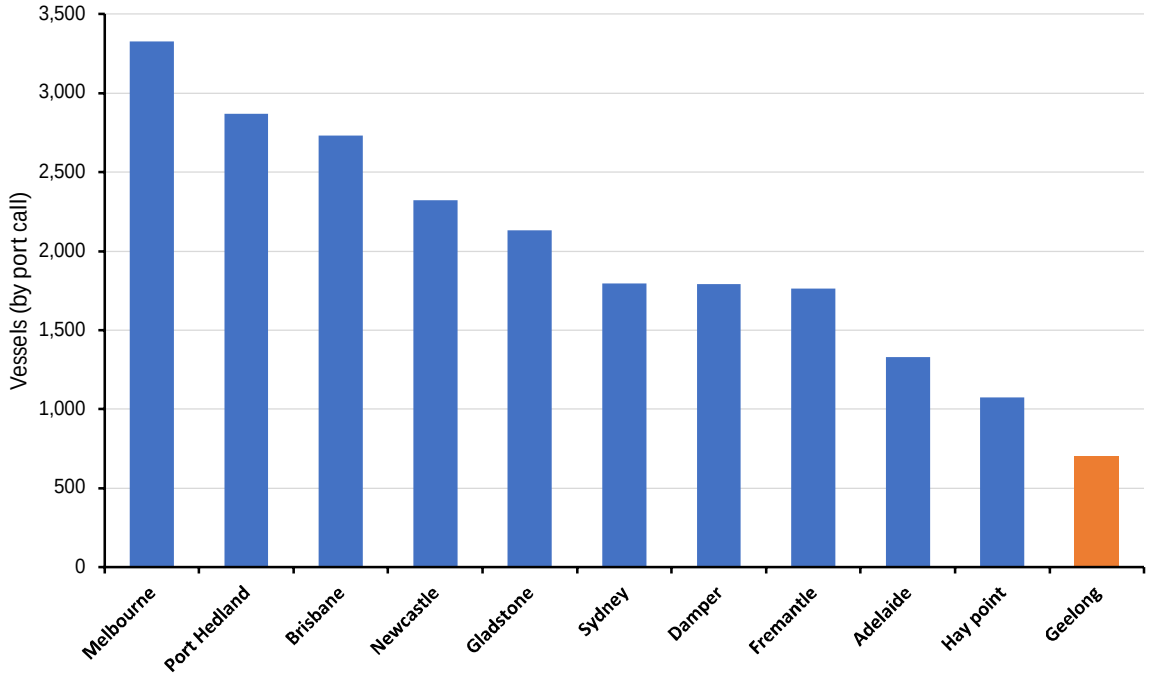


Figure 5-85. Top 10 Ports in Australia (By Port Call)

Figure 5-85 shows the type of cargo by weight handled at the port of Geelong in 2020. The dominant type of cargo is bulk liquids at around 6.8 million tonnes per year. Other cargos (between 0.6 million tonnes and 1.6 million tonnes per year) are fertilisers, general cargo, dry bulk cargo and woodchips. The large volume of liquid cargo is to supply the Viva Energy Refinery.

5.25 Conclusion on Marine Environmental Context

Corio Bay is a marine aquatic environment as the salinity is always within the normal range for ocean waters, apart from the entrance of Hovells Creek. The range of aquatic biota in Corio Bay is very similar to the range in Port Phillip Bay.

The seabed and shores of Corio Bay have been substantially modified over the last 170 years, with shipping channels being dredged and the Port of Geelong established, the western shoreline being heavily developed for industrial uses, and seawalls, marinas and jetties constructed as part of urban Geelong.

Extensive salt evaporation ponds were constructed on the north and south shores around 1900 and continued in production for many years. Now the abandoned Avalon and Moolap salt pans have become important wetlands for migratory birds.

Despite these changes, Corio Bay has good water quality and a diverse range of marine life that is habituated to existing conditions in the Bay. The Bay has a dynamic and self-sustaining ecosystem which includes about a thousand species of plants and animals. Unfortunately, these numbers include at least 19 introduced marine pest species.

Corio Bay has satisfactory levels of dissolved oxygen and nutrients, and studies of Port Phillip Bay as a whole suggest that toxicant levels are not a threat.

Seagrass beds are an important habitat in Corio Bay with a diverse range of invertebrates and small fish. There are extensive seagrass beds around the perimeter of Corio Bay, including along the northern shore next to the refinery. The spatial extent of seagrass varies from year to year in response to seasonal weather and other factors.

6 Hydrodynamic Modelling of Corio Bay

6.1 Purpose of Hydrodynamic Modelling

To contribute to the assessment of potential marine diversity impacts from the Viva Gas Terminal Project, hydrodynamic and water quality models were developed to:

- Simulate the existing currents, temperatures and salinities in Corio Bay, which includes the response to tides, meteorological conditions, Hovells Creek inflow and existing refinery intake and discharges;
- Simulate the dilution in the plumes created by the various discharges;
- Simulate the fate and transport of the proposed refinery and FSRU discharges (open loop, closed loop and ballast water) including heated, cooled and chlorinated discharges;
- Simulate the fate and transport of fine sediments (clay and slit) that are likely to be mobilised during dredging operations and dredge material deposition; and
- Simulate the potential transport, dispersion and entrainment of plankton from different regions in the bay.

The plume dispersion was modelled by several approaches – CFD modelling for the shoreline discharges and INITDIL for the diffuser discharges. The near-field model predictions were checked using the Cederwall and VPLUMES models.

The regional hydrodynamics and water quality was modelled using the Aquatic Ecosystem Model 3D (AEM3D). It is a three-dimensional hydrodynamic and water quality model that has previously been used for assessments in Port Phillip Bay, including the following projects:

- Tools for the Management of Nutrient and Sediment interactions with seagrass ecosystems in Port Phillip Bay: *Sediment processes and light modelling for Seagrass Sediment transport for assessing impacts on seagrass health*, EPA, 2015;
- Integrated catchment and bay modelling for the development of the new *Port Phillip Bay Environmental Management Plan*, Melbourne Water, 2015-17; and
- Discharge from Western Treatment Plant, Melbourne Water.

The AEM3D model was adapted to focus on Corio Bay by incorporating a finer grid (cells of 20 m by 20 m in plan and 1 m deep) to represent the fine scale hydrodynamics of the bay. The near-field plume predictions were coupled to the fine scale grid in the regional model, ensuring conservation of mass of water, heat, chlorine and other materials.

6.2 Near-field Modelling of Refinery Plumes

The purpose of near-field hydrodynamic modelling was to establish the initial dilution and plume geometry close to the point of discharge, until the plume enters the 20 m by 20 m by 1 m grid of the regional model.

The initial dilution is due to the initial momentum and buoyancy of the discharge plumes. Higher dilution is achieved when the plumes discharge at a high velocity, as

this creates high shear and rapid mixing between the plumes and the adjacent seawater.

The density difference between the discharges and ambient seawater is also a factor influencing plume behaviour. The current refinery discharges are 8°C to 10°C warmer than ambient seawater, and therefore spread out in the surface waters. The future refinery discharges are 7°C cooler than before, but still would be mildly (1°C to 3°C) above ambient seawater temperature. Ballast water would be discharged at ambient seawater temperature.

The backup alternative discharges from the FSRU would be via the diffuser at 7°C below ambient temperature. As this discharge is cooler than the adjacent seawater, the plumes would be more dense than ambient seawater (lower density of 0.8 kg/m^3) and descend towards the seabed. Shear between the descending plumes and the adjacent seawater would cause mixing and dilution. The high discharge velocity from the diffuser ports (of 5 m/s) would add to the initial mixing and dilution near the diffuser.

6.2.1 Near-field CFD Model

A CFD model was used to simulate the path and dilution of the four existing refinery discharges, as well as the refinery seawater intake (Worley, 2021). The mixing and dispersion simulations were performed using the computational fluid dynamics (CFD) software, *Ansys/CFX*, which is licensed to Advisian (Worley Group). It computes the Navier-Stoke equations for flow behaviour and uses a thermal model for heat transfer calculations.

The Worley report describes the methodology as follows:

- Define the extent of the model as a 100 m by 100 m square.
- Within the defined extent, set out the 3-D geometry of the seabed, shoreline and structures such as the sides of the inlet and discharge channels.
- Discretise the flow with a 3-D mesh in regions of interest with layers of cells through the flow depth.
- Assign initial conditions inside the domain for temperature, salinity and seawater level at the different tide levels.
- Assign the appropriate fluid properties as a function of temperature and salinity.
- Assign roughness to the seabed, concrete and steel structures.
- Use a k-ε turbulence model to simulate turbulence.
- Assign inflow and outflow boundary conditions corresponding to the discharge conditions. e.g., water temperature, flow rate and chlorine concentration, and the sea state at the domain boundaries.
- Carry out a steady-state analysis to compute the distribution of flow, velocity, temperature, and chlorine concentration in the flow domain.

6.2.2 Near Field Modelling of Refinery Discharge W1

W1 is the largest refinery discharge with a maximum flow of 228 ML/d. Figures 6-1 and 6-2 show the predicted surface layer temperature for discharge in winter and summer, respectively. Each change in colour corresponds to a temperature change of

1ºC. In the winter model, the discharged seawater has a temperature of 19 °C while the ambient seawater temperature is 10.8°C. In the summer model, the discharged seawater has a temperature of 28.8°C while the ambient seawater temperature is 22.3°C.

In both models, the plumes extend into the bay, flow along the northern shore and past Refinery Pier. For the winter case, with the seawater discharged at 19°C, most of the plume is at 17ºC after 100 m of travel apart from a strip along the shore which is at 18ºC. The offshore edge of the plume experiences faster dilution and reduces to 12ºC, which is 1.2ºC above the ambient temperature.

Winter

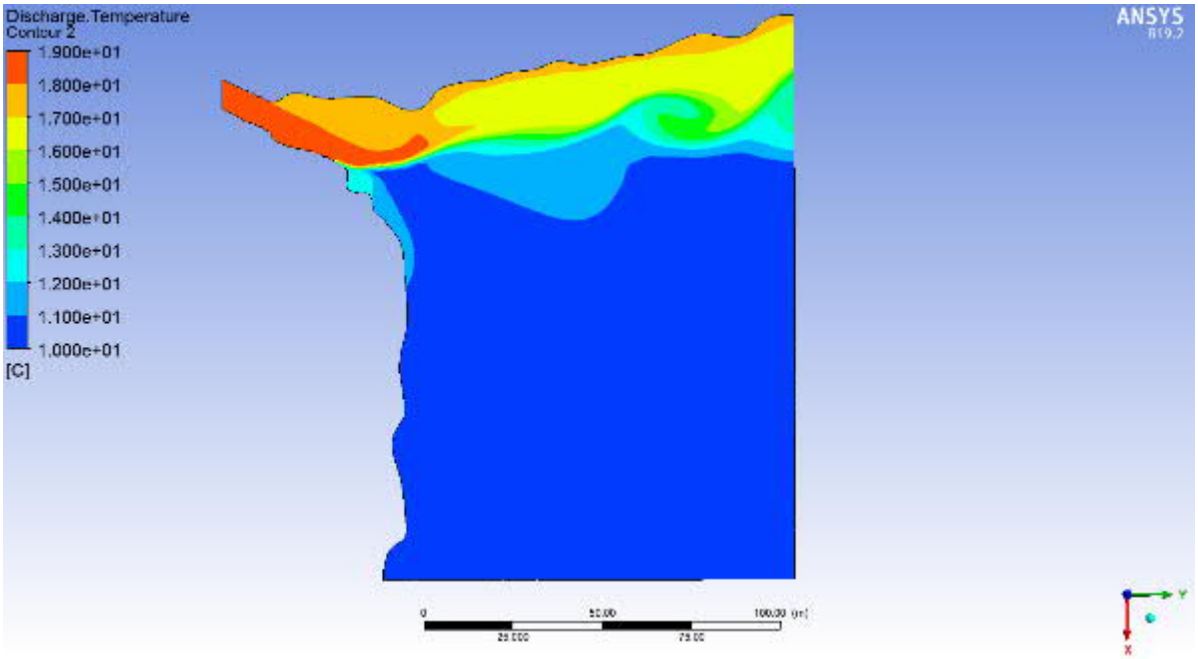


Figure 6-1. CFD Prediction of Plume from W1 Discharge in Winter

The summer model shows a similar pattern to the winter model, but with slightly less lateral mixing and slightly more dilution with distance offshore. The discharged seawater is at 29°C and initial dilution reduces this to 27 to 28°C shortly after discharge. The 27ºC contour extends 100 m from the outlet although there is a band of seawater at 26°C which extends along the middle and the southern edge of the plume.

In both models, the decrease in temperature is 2 to 3 degrees within 100 m of the discharge. The connection from the CFD model to the regional hydrodynamic model was made at 20 m along the path of the W1 plume.

Summer

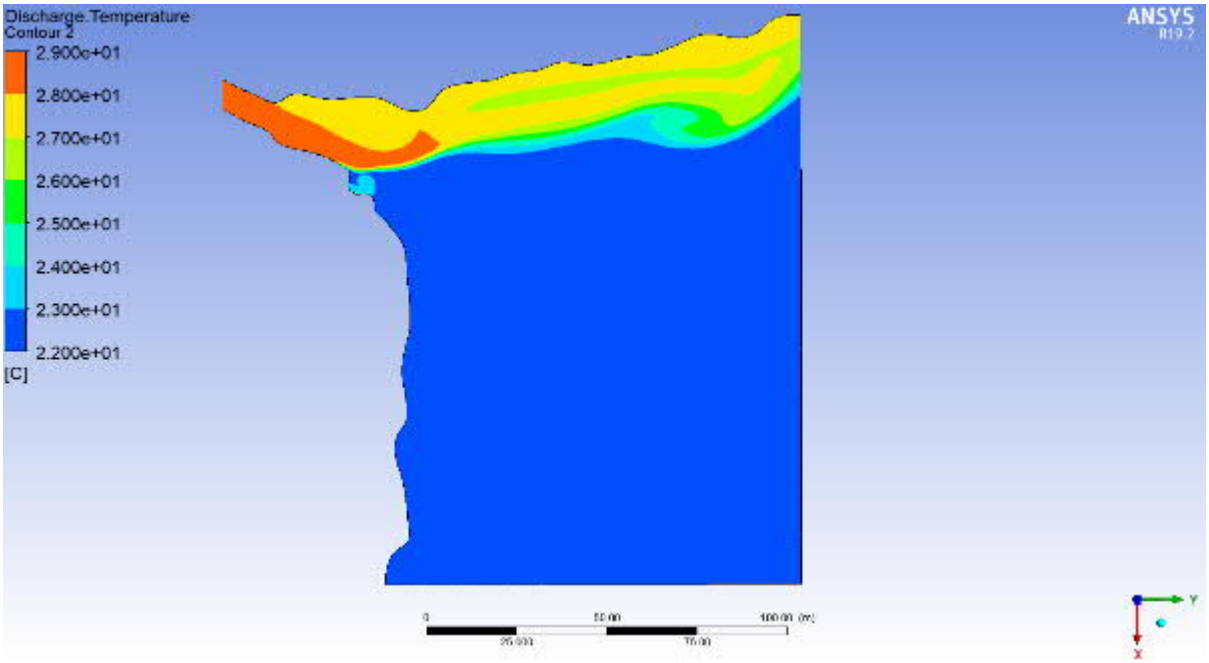


Figure 6-2. CFD Prediction of Plume from W1 Discharge in Summer

6.2.3 Near Field Modelling of W5 Discharge

Figure 6-3 and Figure 6-4 show the predicted surface layer temperature for the 85 ML/d discharge from W5 in winter and summer, respectively. Each change in colour corresponds to a temperature change of 1^{o}C. In the winter model, the discharged seawater has a temperature of 20.7°C while the ambient seawater temperature is 10.8°C. In the summer model, the discharged seawater has a temperature of 30.8°C while the ambient seawater temperature is 22.3°C.

In both models, the plume extends south-west from the discharge channel into the Bay. For the winter case, the central core of the plume is at 17^{o}C after 100 m of travel with temperatures down to 12^{o}C at the edges of the plume. This is 1.2^{o}C above ambient.

For the summer case, the central core of the plume is at 26^{o}C after 100 m of travel with temperatures down to 23^{o}C at the edges of the plume. There is more lateral mixing in the summer case which gives the plume a width of around 50 m at a distance of 100 m offshore.

The connection from the CFD model to the regional hydrodynamic model was made at 20 m along the path of the W5 plume.

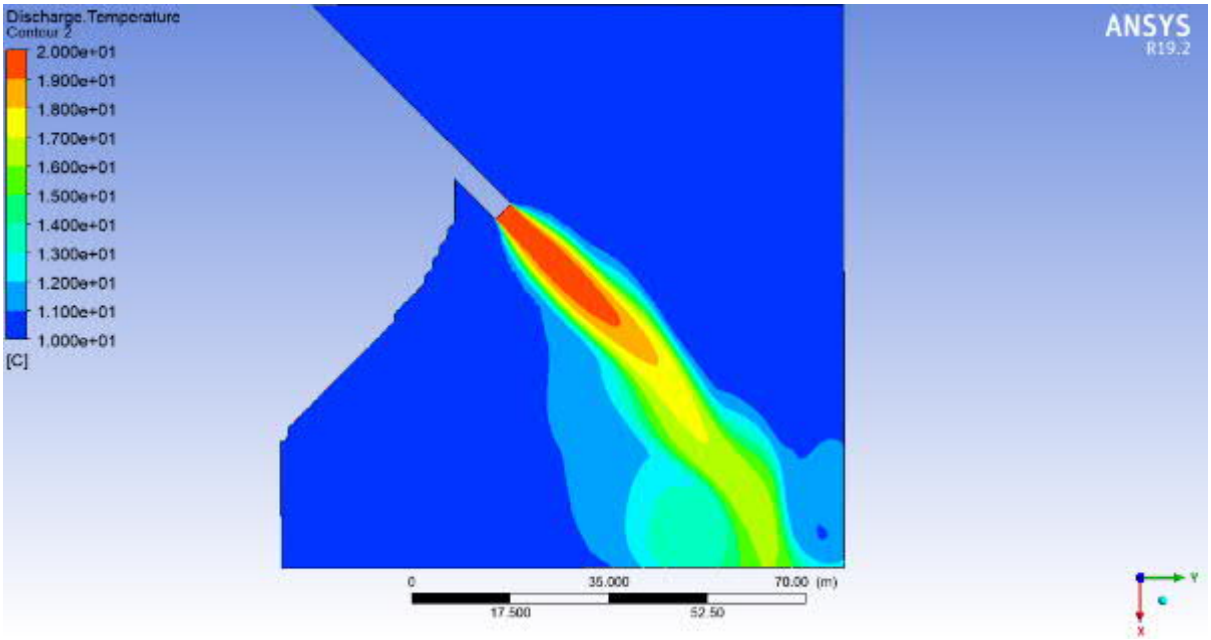


Figure 6-3. CFD Prediction of Plume from W5 Discharge in Winter

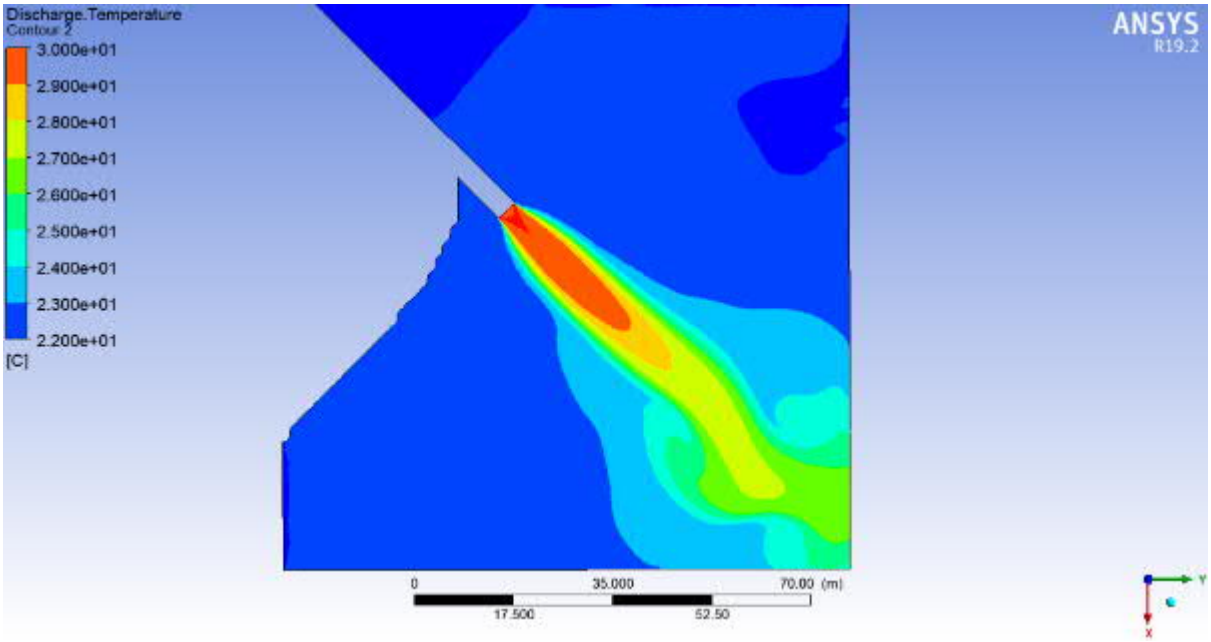


Figure 6-4. CFD Prediction of Plume from W5 Discharge in Summer

6.2.4 Near Field Modelling at the Inlet

Figure 6-5 shows the CFD near-field model predictions of the temperature pattern at the refinery seawater intake when the cool water from the FSRU is directed into the intake during winter. The ambient seawater is at 10°C and there is a plume of cooler water around the entrance of the inlet of cooler water which moves into the channel at around 3°C. The decrease from the ambient temperature of 7ºC is due to the FSRU discharge being 7°C below the temperature of the ambient seawater.

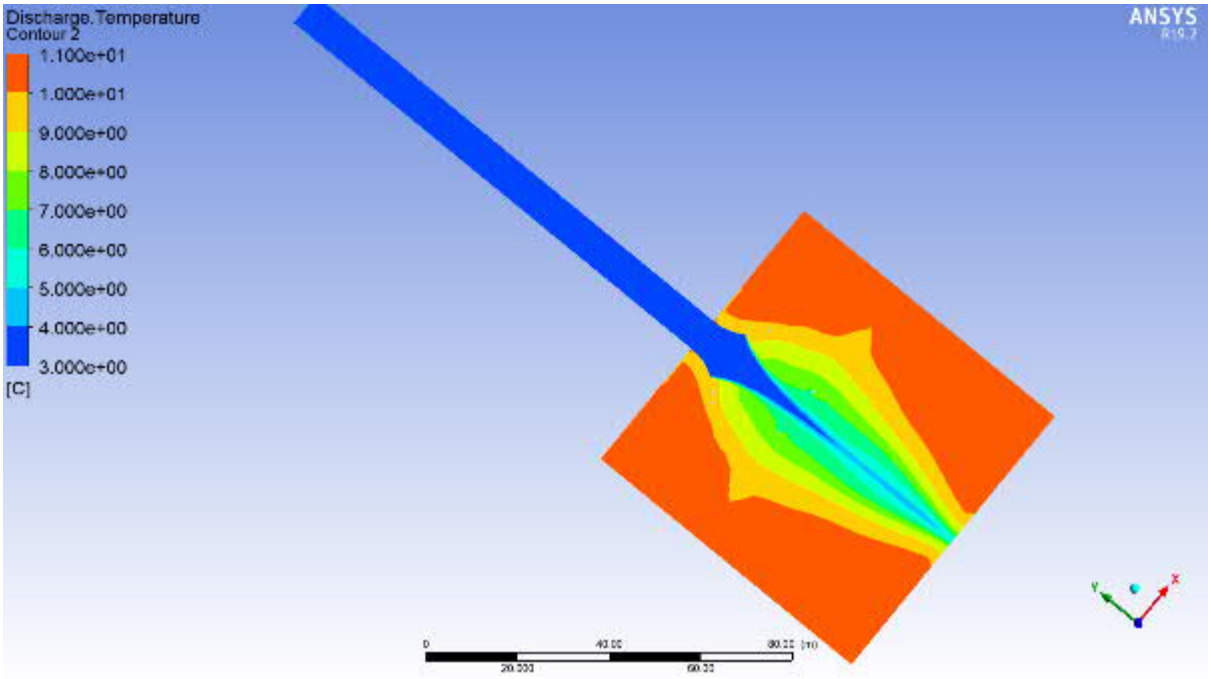


Figure 6-5. CFD Prediction of Temperature Pattern at Intake in Winter

The situation shown in Figure 6-5 represents the lowest winter temperature in Corio Bay and may be considered an extreme case as the temperature in the FSRU falls below the density maximum of 4oC during passage through the FSRU. In practice, the FSRU would be operated so the discharge temperature is not below 4oC, and this would be achieved either by increasing the seawater flow rate relative to the gas production, or by operating the FSRU in closed loop mode, where some heating of the seawater is achieved by combusting some of the LNG on board the FSRU.

The transfer of seawater from the FSRU would be designed so there is no leakage into Corio Bay from the refinery inlet. The flow rates from the FSRU and into the refinery would be managed so there is always a zero or net inflow from Corio Bay into the inlet, to add to the FSRU discharge and achieve the normal refinery intake of 350 ML/d. Note that for most of the year the FSRU discharge is well under 350 ML/d (see Section 1).

As a result, the temperature pattern at the inlet would be much the same as shown in Figure 6-5 throughout the year, with small variations due to the discharge rate from the FSRU. After the modelling was completed, a design decision was taken to discharge the FSRU flow well up the intake channel, to minimise leakage in all circumstances.

6.2.5 Near Field Modelling at the Diffuser

If the refinery is not operating, cooler seawater from the FSRU would be discharged through a diffuser located under the new pier. The diffuser is shown schematically in Figure 6-6. It would be 0.5 m below LAT and have approximately 100 small diameter high-velocity ports.

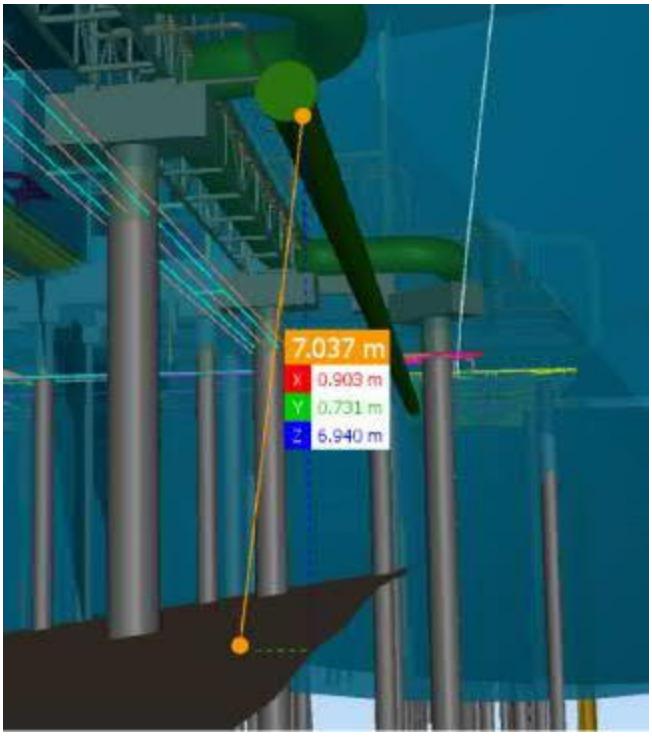


Figure 6-6. Diffuser Located under New Pier

Figure 6-7 shows a schematic diagram of the discharge plumes formed from the ports on the diffuser underneath the new pier. The diffuser would be attached to the northern piles supporting the pier, at 1 m below mean sea level with approximately 100 ports spread along the 300 m length of the diffuser. The ports would be angled at 30 degrees below horizontal to avoid impingement with the water surface, and discharge at 5 m/s at peak flow. Figure 6-7 is a cross-section showing the diffuser located under the pier and the plumes formed from the discharge from each of the ports.

The individual discharge plumes would spread with distance from the diffuser and merge at about a 9 m depth into a single long plume. The combined plume would continue to travel downward to the seabed, and then under the FSRU. At the base of the slope leading into the berth channel, the initial dilution at slack water predicted by INITDIL is 20:1

The connection from the CFD model to the regional hydrodynamic model was made at 20 m along the plume. The extended plume transfers into the lower two layers of the regional model with conservation of mass.

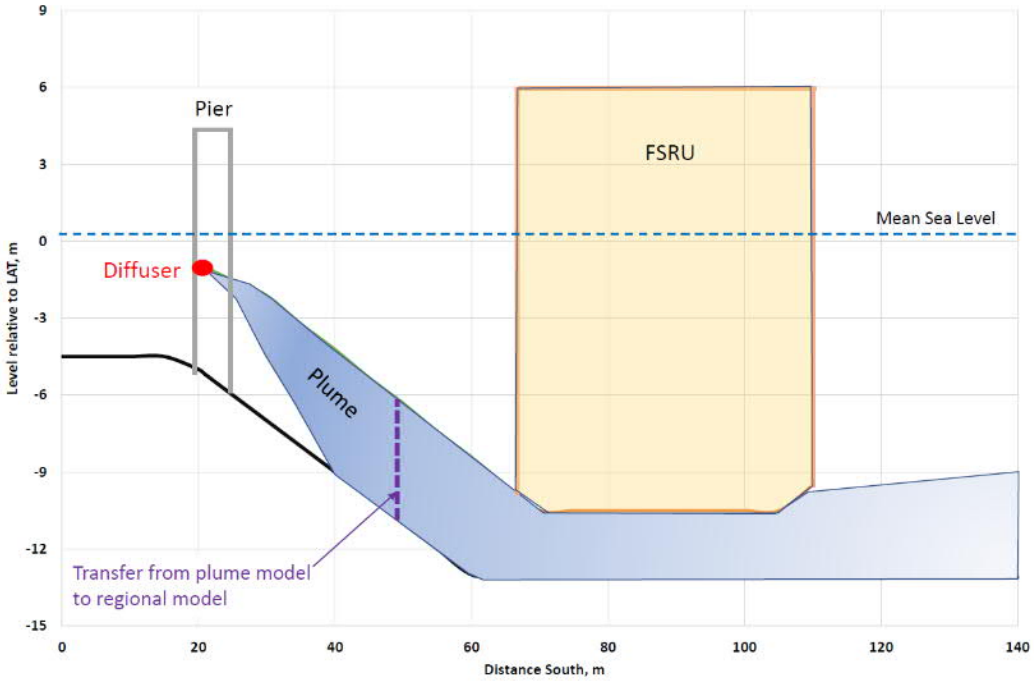


Figure 6-7. Schematic Diagram of Plumes from Diffuser under New Pier

The INITDIL model used to predict dilution was developed by CEE and integrates the equations for conservation of momentum (in the horizontal and vertical directions) and continuity of mass. The equations and the model have been published in peer reviewed journals (Wallis, 1985). The program follows the path of each jet from discharge through each port until it reaches neutral equilibrium (submerged field) or reaches the surface (surface field), calculating the plume width, velocity, horizontal and vertical position, entrainment and dilution at each increment of distance.

The model has been verified by confirming that measured dilutions match predicted dilutions (see Figure 6-8). The comparisons show the measured dilutions are the same or slightly higher than the predicted dilutions for many outfalls including Altona, Wonthaggi, Black Rock, Devonport, Wellington, Perth, Barry Beach, Black Rock and Blackmans Bay (Wallis, 2016; CEE, 2020).

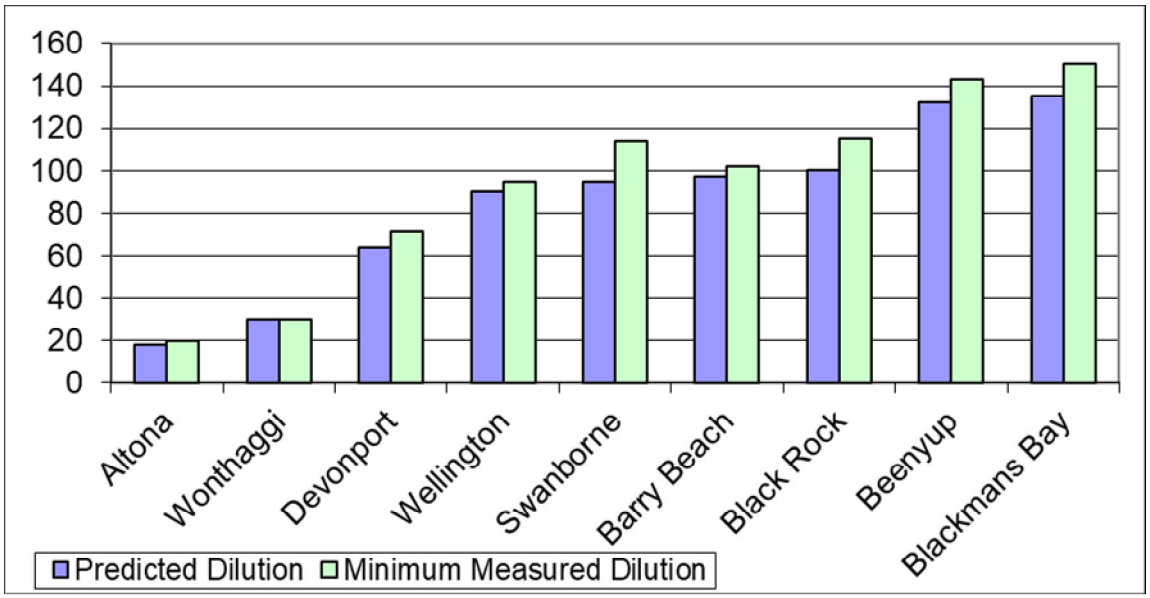


Figure 6-8. Comparison of Predicted Dilution with Measured Dilution

The dilution predicted by the published and verified plume model INITDIL was checked using the Cederwall plume model and the US EPA dilution model VPLUMES.

The Cederwall model encapsulates the results of a large number of laboratory tests and has been verified by full-scale tests. The model was developed for simulating the discharge of a buoyant effluent discharged from an open-ended pipe but can also be applied to a dense discharge from a diffuser, although the inclined port of the Viva diffuser does not exactly match the Cederwall horizontal port arrangement. The dilution calculated using the Cederwall model was 25:1.

The Cederwall model provides a single dilution value when the plume reached the seabed while the INITDIL model predicts the plume dilution, plume width and plume velocity as a function of distance along the plume. The predictions of these parameters from the INITDIL model are plotted in Figure 6-9. The dilution increases with distance, although at a slightly decreasing rate with longer travel. The width of the individual plumes increase linearly with distance to 6 m, which equals the port spacing, so the individual plumes merge into a line just before the transfer to the regional model. The plume velocity decreases in inverse proportion to the distance travelled.

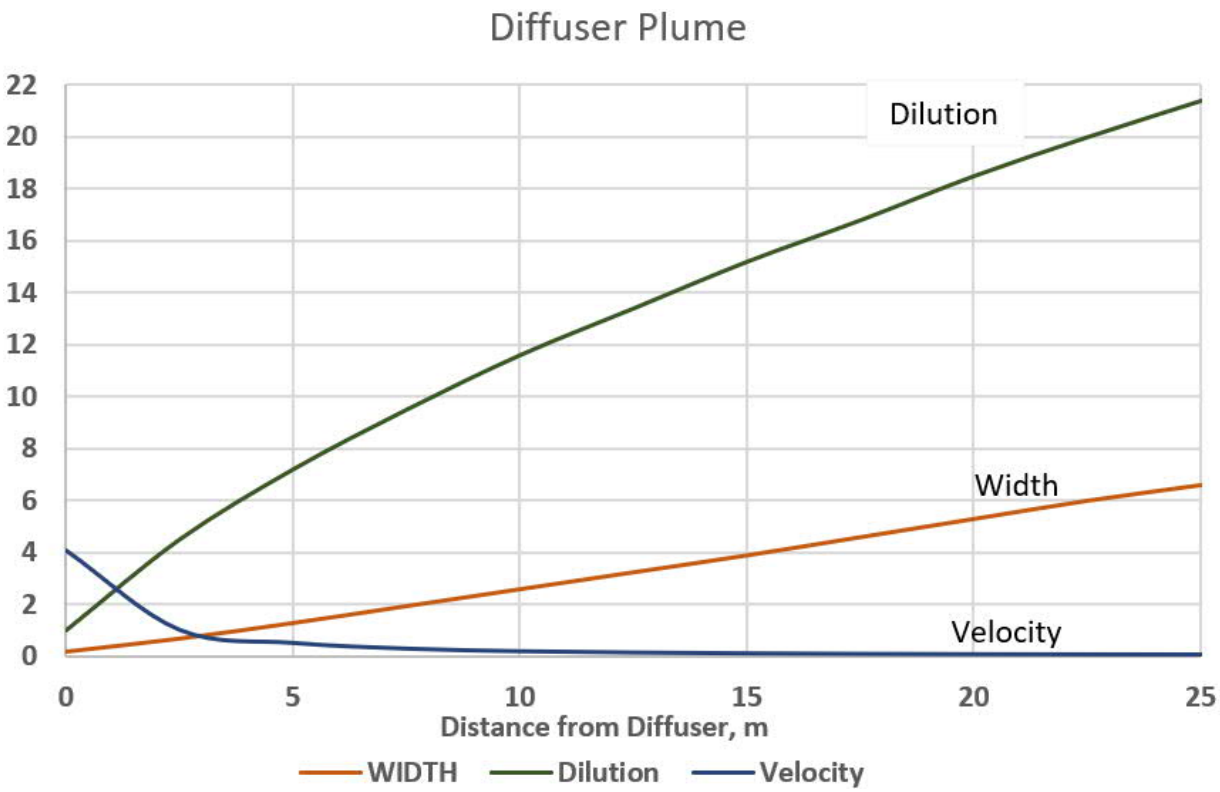


Figure 6-9. Diffuser Plume Width, Dilution, Velocity and Distance – INITDIL

The predicted dilution of 20:1 is for the “worst case” situation of slack water. The dilution is predicted to increase to 24:1 at the median current speed of 0.045 m/s and to 28:1 at the highest current speed of 0.08 m/s. There would be no increase in dilution as the plume passes underneath the FSRU but then dilution would increase on the far side of the FSRU, as predicted in the regional model.

As a second check, the initial dilution was calculated using the UM3 model in the Visual Plumes package released by the USEPA (Frick et al, 2005). Visual Plumes (VPLUMES) is a windows-based mixing zone model that predicted initial dilution for single and merging submerged plumes in arbitrarily stratified ambient currents. The predictions include the plume dilution, translation, plume rise or descent and other plume variables.

The predictions of these parameters from VPLUMES are plotted in Figure 6-10. The dilution increases with distance, and the predicted dilution at a distance of 20 m, where the transfer from the plume model to the regional model occurs, is predicted to be 22:1.

The width of the individual plumes increases linearly with distance to 6 m, which equals the port spacing, so the individual plumes merge into a line at 19 m, shortly before the transfer to the regional model.

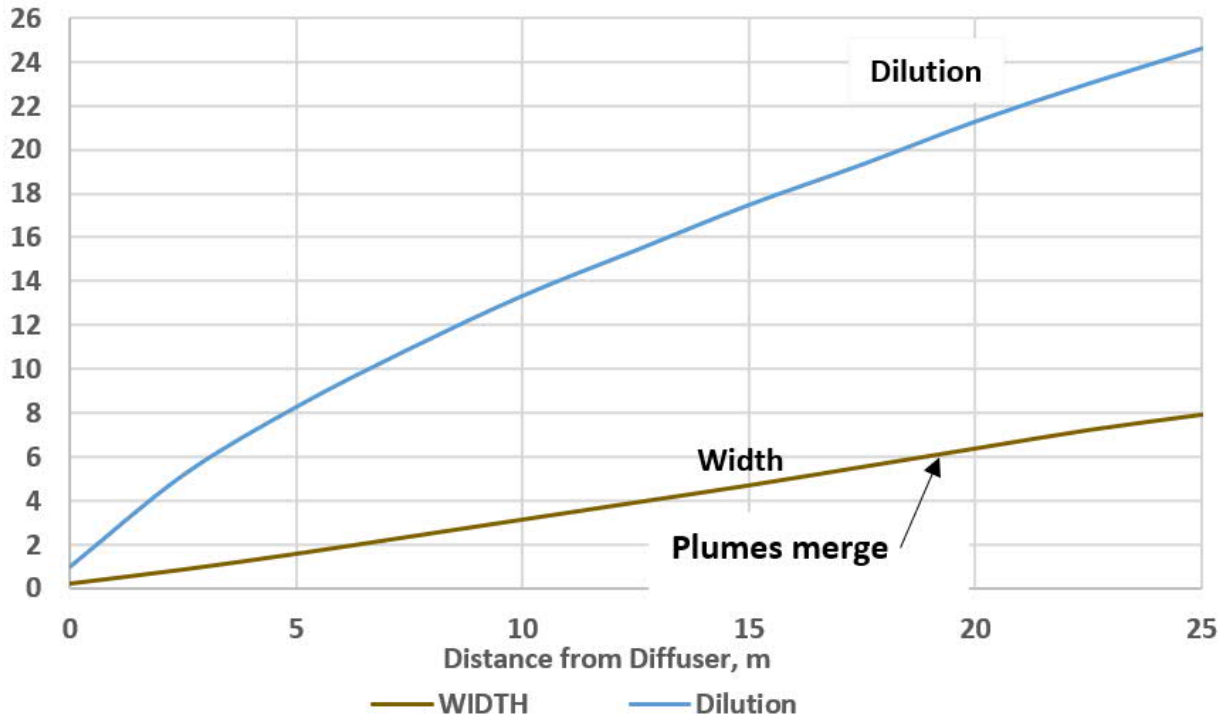


Figure 6-10. Diffuser Plume Width and Dilution with Distance - VPLUMES

Summary on Nearfield Modelling

Initial dilution modelling has been carried out using three standard and well-tested near-field models. The models predict a descending plume that reaches the seabed and flows under the FSRU. The predicted initial dilution ranges from 20:1 to 23:1 to 25:1 depending on the model used and ambient currents. The conservative or 'worst case' dilution of 20:1 is carried forward to the regional hydrodynamic modelling.

Diffuser Plume Predictions

The connection from the plume model to the regional hydrodynamic model was made at 19 m along the path of the plume, where it is on the seabed at a dilution of 20:1. Figure 6-11 shows the predicted temperature change in the plume on the seabed in the port area, with a discharge of 350 ML/d. Figure 6-12 shows the predicted chlorine concentration in the plume on the seabed in the port area.

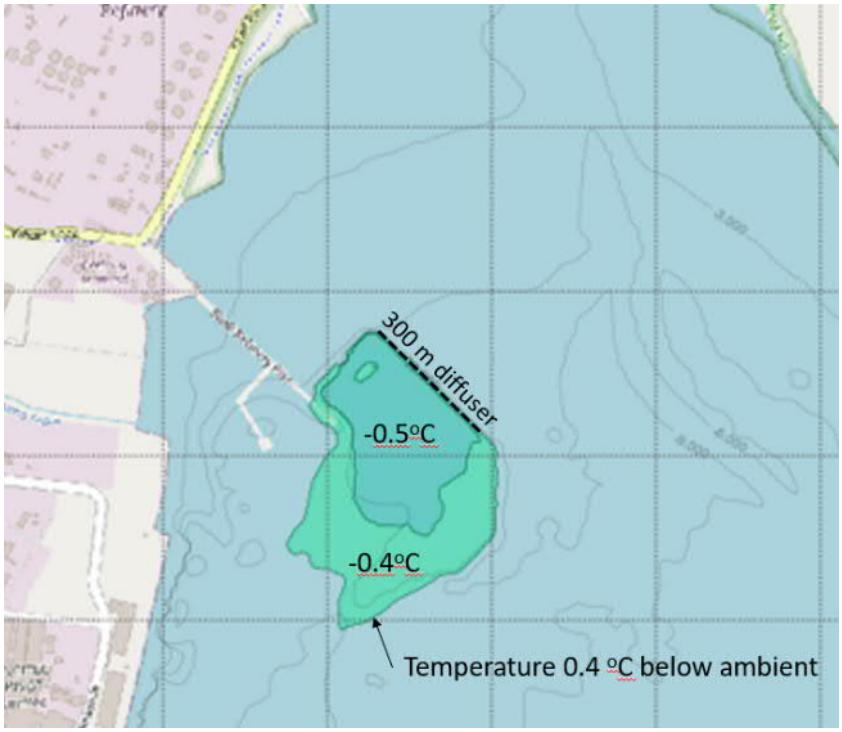


Figure 6-11. Regional Model Prediction of Temperature from Diffuser Discharge

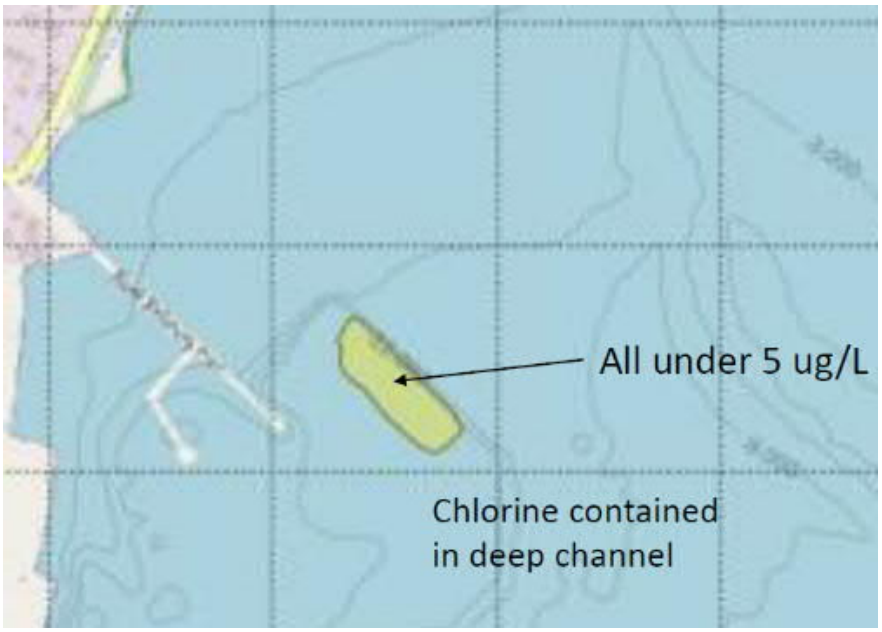


Figure 6-12. Regional Model Prediction of Chlorine from Diffuser Discharge

Closed Loop Plume Predictions

In the backup *closed loop* operation, the LNG would be heated using gas-fired boilers and there would be a discharge of warm seawater at high velocity (4 m/s to 6 m/s) through two pipes at the rear of the FSRU. The discharge rate would be 77 ML/d at 5.4ºC above ambient in normal operations and 155 ML/d at 4.1ºC above ambient when the condenser was discharged. INITDIL predicts the plume dilution at the

seabed would range from 10:1 to 15:1, depending on the discharge rate and current speed.

6.3 Field Studies of Bay Temperature Profiles

CEE conducted temperature transects around the area of the discharge plumes to measure vertical temperature profiles. Figure 6-13 shows how the temperature from the W1 discharge spreads through the Bay. The field measurements are discussed in more detail in Section 5 and the temperature modelling in Section 8.

Figure 6-13 (also in Section 5) shows a contour map of temperature taken between the shore and Refinery Pier over the top meter of water depth. The plot confirms that the W1 plume flows to the north, following the currents of the bay. The measured temperature pattern shows more lateral mixing than the near field modelling suggests. However, the measured decline in plume temperature averages 3ºC at 100 m which corresponds to the dilution predicted by the near-field model.

The extra spread of the plume at the surface is due to the buoyant warm water from the discharge spreading laterally over the cooler surface waters of the Bay.

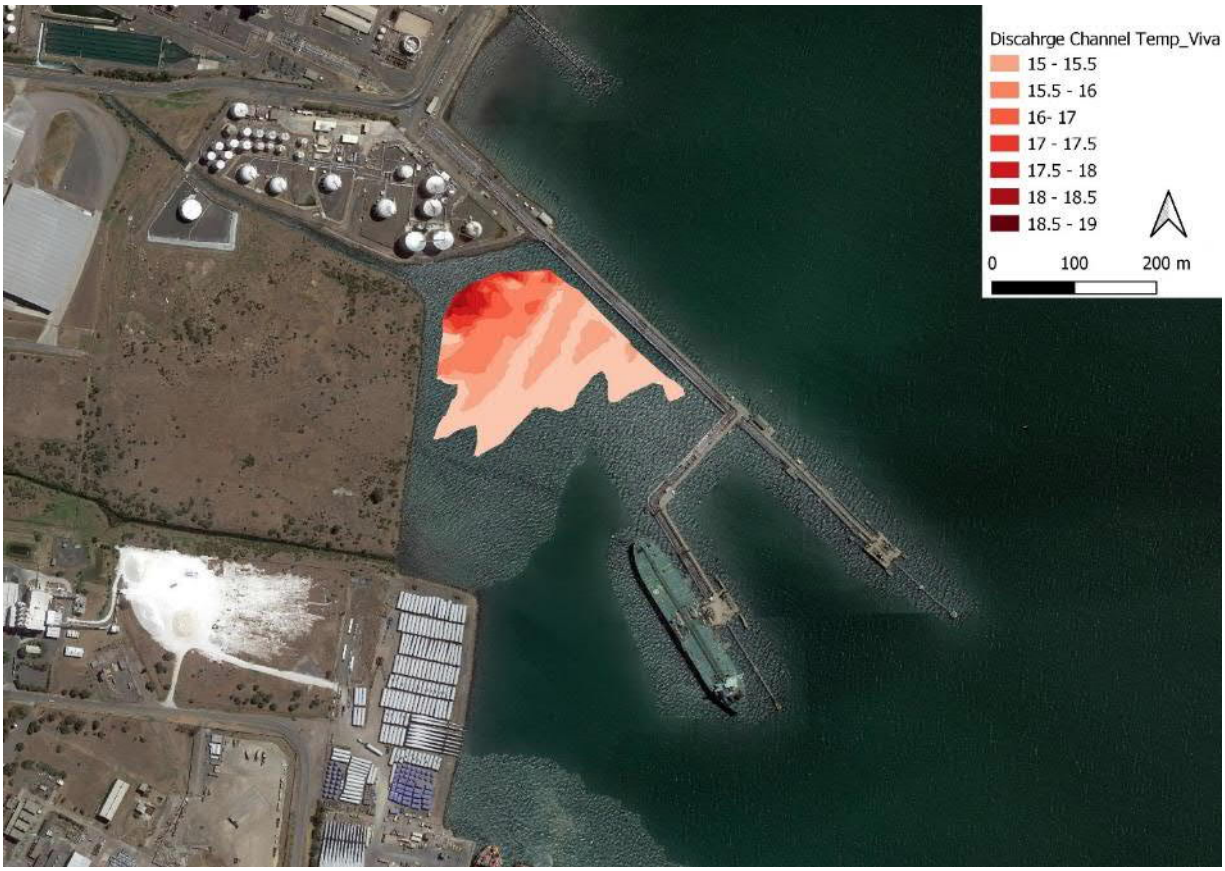


Figure 6-13. Field Measurements from W1 in Winter

6.4 Regional Modelling

6.4.1 Description of AEM3D Model

The Aquatic Ecosystem Model 3D (AEM3D) for Corio Bay was developed by HydroNumerics. AEM3D originates from the ELCOM-CAEDYM model devised by the Centre for Water Research, University of Western Australia (Hodges et al. 2000,

Dallimore et al. 2003, Romero et al. 2004, and Bothelo and Imberger 2007), which has been applied to numerous estuarine and oceanographic systems (e.g. Chan et al. 2002, Spillman et. al. 2007, Hillmer and Imberger 2007 and Silva et al. 2014). The AEM3D model includes comprehensive water quality modelling, with the hydrodynamics, heat transfer, sediment transport and particle tracking algorithms used for this project.

6.4.2 Model Configuration

AEM3D predicts velocity, temperature, and salinity distribution in water bodies subjected to forcing from the ocean (salinity, temperature, low-frequency oscillations, tides and waves), the atmosphere, surface flows, groundwater flows and flows from built structures (such as discharge channels and diffusers). The model solves the unsteady, viscous Navier-Stokes equations for incompressible flow using the hydrostatic assumption for pressure (Hodges et al. 2000). Simulated processes include baroclinic and barotropic responses, rotational effects, tidal forcing, wind stresses, thermal forcing, inflows, outflows, and transport of salt, heat and passive scalars.

The regional model was used to:

- Simulate the existing currents, temperatures and salinities in Corio Bay, which includes the response to tides, meteorological conditions, Hovells Creek inflow and refinery seawater intake and discharges;
- Simulate the transport and dispersion of the proposed FSRU and refinery discharges (open loop, closed loop and ballast water) including heated, cooled and chlorinated discharges both through the refinery and the diffuser;
- Simulate the fate and transport of fine sediments (clay and slit) that are mobilised during dredging and deposition of dredge material; and
- Simulate the potential entrainment of plankton from different regions of the bay.

Heat exchange through the water surface is modelled as non-penetrative components of long-wave radiation, sensible heat transfer, and evaporative heat loss, complemented by penetrative shortwave radiation. Non-penetrative effects are introduced as sources of temperature in the surface-mixed layer, whereas penetrative effects are introduced as source terms in one or more grid layers based on an exponential decay and a light extinction coefficient in accordance with Beer's Law.

Salt is conserved based on source terms (inflows), advection, diffusion and evaporation. The salinity of the simulated water is used in the derivation of the density.

Sediment transport is modelled as concentrations of inert particles with prescribed diameter, density and settling velocities, including allowance for cohesive interaction. Resuspension rates are determined for each particle size based on the particle density, bottom shear stress (above a critical shear stress) and defined erosion rates.

6.4.3 Regional Model Inputs

The model is based on the oceanographic and meteorological data for the 2019-2020 period.

The bathymetry data were obtained from the Victorian Coastline DEM (VCDEM) at 10 m resolution from Spatial Systems CRC for all of Port Phillip Bay. It was

supplemented by recent surveys by VCDEM data to update the depth contours in the project area.

The model resolution in the project area was 20 x 20 m in plan by 1 m vertical extending to a lateral grid of 400 x 400 m by 1 m vertically in the outer regions of the domain (see Figure 6-14). The 1 m vertical resolution of the model allows the natural thermal stratification observed in Corio Bay and the stratification introduced by the cool and warm discharges to be simulated.

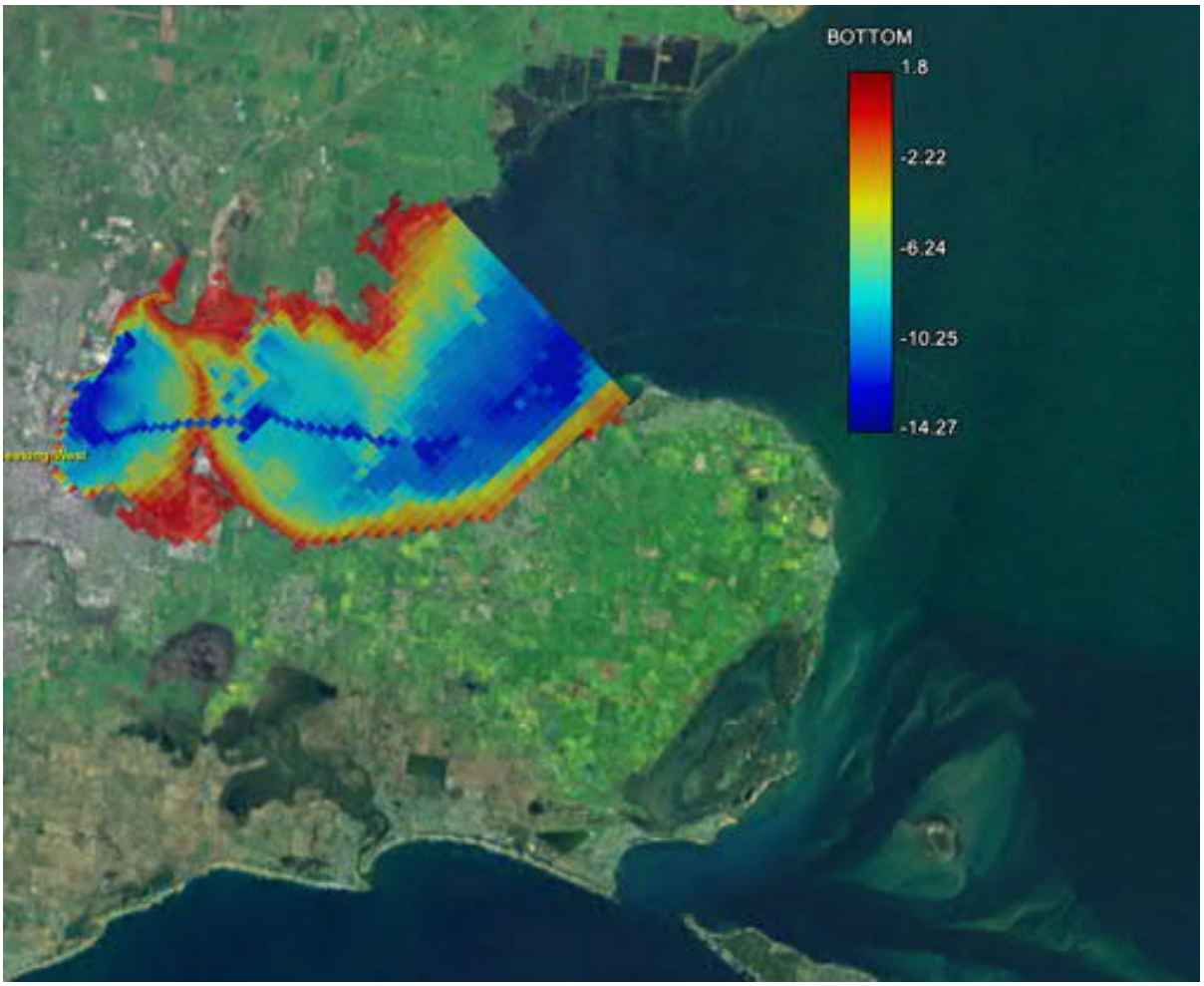


Figure 6-14. Bathymetry and Model Grid in Inner Harbour and Corio Bay

Meteorological data were obtained from the Australian Bureau of Meteorology (BoM) including meteorological conditions at Avalon in the north of Corio Bay and Geelong Racecourse (Geelong) in the west. Regional solar radiation conditions were obtained for Melbourne Airport.

Wind Speed and Direction

Wind speed records from Geelong and Avalon were used in the model. At both meteorological stations the most frequent strong wind patterns were westerlies and southerlies, with strongest winds typically from the west. It was noted that the temperature contours were higher using the Geelong winds than the Avalon winds (see HydroNumerics report sensitivity study) because winds are weaker at Geelong compared to Avalon. The more conservative Geelong winds were used for the report.

Air Temperature

Air temperatures recorded at Geelong and Avalon were used in the model, applied at 30-minute intervals. The air temperatures recorded at Avalon and Geelong are typically within 1-2^{o}C of each other. During the peak of summer, the temperatures reach up to mid-40s during the day and down to 12 to 13^{o}C in the evenings. During winter, daytime temperatures are typically less than 15^{o}C and the night-time low temperatures approach 0^{o}C in mid-winter.

Relative Humidity

Relative Humidity recorded at Geelong was used in the model. The range in the warmer summer months is from 10% to over 95%. In the cooler winter months, the range reduces to approximately 40 to 60% up to more than 95%.

Shortwave Solar Radiation and Longwave Radiation

Incoming shortwave solar radiation from the sun that reaches the Earth's surface is measured at Melbourne Airport Values are similar over a large area. During clear summer days the solar radiation reaches above 1100 W/m^2 and on clear winter days the solar radiation levels reach only 500-600 W/m^2. During each night the incoming solar radiation levels reduce to zero and during cloudy days the radiation is significantly reduced by 50 per cent or more. Radiation values are applied at 30-minute intervals.

Incoming longwave radiation is also recorded at Melbourne Airport and is within the infrared portion of the radiation spectrum. Incoming longwave radiation at Melbourne Airport typically ranges between 250 and 400 W/m^2, occasionally peaking at 480 W/m^2 in the warmest months of summer.

Tide Heights

Tidal data from Point Richards obtained through the BoM was available at 6-minute intervals from 1999 up to February 2020 and used in the model. The tidal oscillations are semi-diurnal (two high waters and two low waters per day) and over the 2019-20 period the records show sea level ranged from -0.6 m to +1 m AHD during spring tides and approximately -0.3 m to +0.6 m AHD during neap tides.

Seawater Temperature

Long term records of sea surface temperature in Port Phillip Bay are recorded by BoM and published by the University of Melbourne School of Earth Sciences (see http://www.baywx.com.au/temps.html). The records illustrate that mean temperatures range from 22^{o}C in summer to 11^{o}C in winter; with summer maximums of 25^{o}C and winter minimum temperatures of approximately 10^{o}C.

Salinity

Salinity data for Port Phillip Bay were provided via the Australia Ocean Data Network (https://portal.aodn.org.au/). Data was sourced from Australia's Integrated Marine Observing System (IMOS). The salinities vary over long time periods from drought year conditions of 37 psu in 2008 to less than 34 psu during higher rainfall years (e.g. 2011). For the modelling in this project, a constant salinity of 36.5 psu was applied at the model boundary.

Hovells Creek Inflow

The main streamflow into Corio Bay is from Hovells Creek via Limeburners Bay in the north of Corio Bay (see Figure 6-15). Flows in Hovells Creek are small compared to the larger rivers that enter Port Phillip Bay (e.g.. the Yarra, Maribyrnong and Werribee).

The typical monthly discharge rates in Hovells Creek were calculated and applied in the model at the northern end of Limeburner's Bay. The salinity of the creek water was assumed to be zero and the temperature was estimated using a 3-day moving average of the air temperature recorded at Geelong.



Figure 6-15. Hovells Creek and Limeburners Bay

6.5 Verification of Hydrodynamic Predictions

Simulated sea levels in Corio Bay were in good agreement with the records at Geelong over the July 2019 to February 2020 period, as shown in Figure 6-16, with an R^2 correlation of 0.93. During low tides the sea-level dropped to -0.6 m and at high tide the sea level rose to 0.8 m. The tidal phase and high tide levels were accurately reproduced by the model.

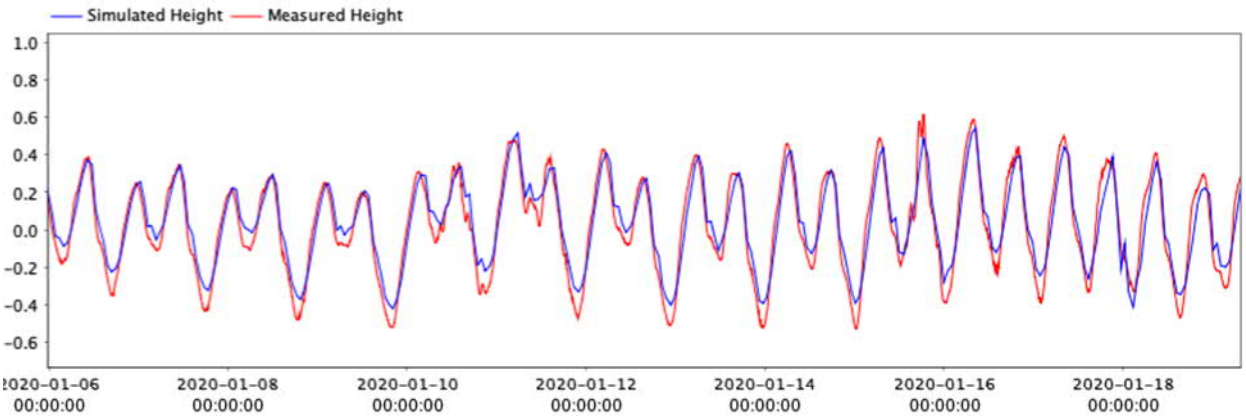


Figure 6-16. Predicted and Observed Water Levels in Corio Bay

Currents were measured in Corio Bay in summer 2020 and autumn 2021, as described in Section 5. At all depths the measured currents are typically weak, and the same weak current speeds were predicted by the regional model. Wind shear causes strong currents near the surface and the model reproduces these currents.

The comparisons between measured and predicted currents for both current meter deployments show good agreement (HydroNumerics, 2021). Current roses were generated from the measured data and the model predictions to compare the observed currents to the modelled currents during the deployments. In Figure 6-17 the predicted (left) and measured (right) current roses for the autumn deployment are comparable. The model slightly over-predicts the northerly water movement, which exaggerates the likelihood of discharges reaching the Ramsar Site north of the project. This is a conservative outcome..

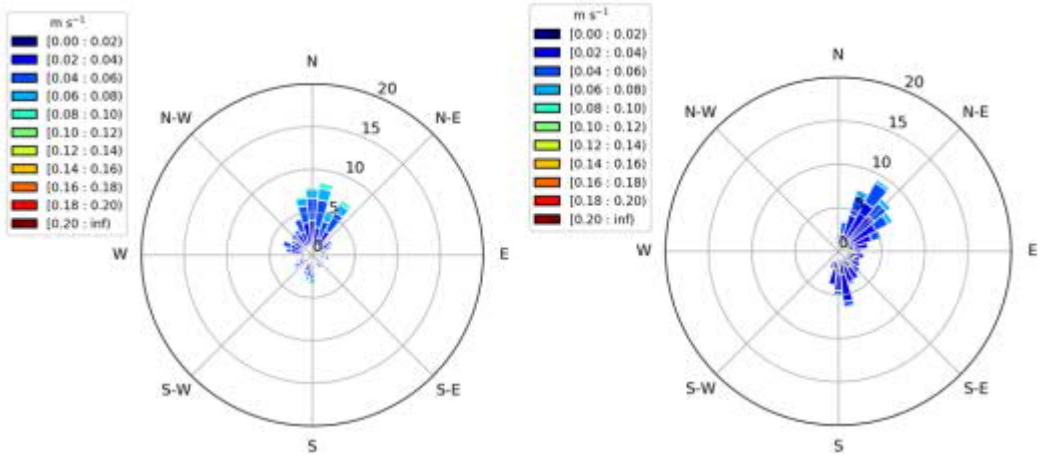


Figure 6-17. Predicted and Observed Currents in Corio Bay

6.6 Description of Modelling Scenarios

This section summarises the discharge scenarios that were simulated using the combination of near field and regional hydrodynamic models.

6.6.1 Case 1 – Existing Discharge Conditions

The base case is the existing operation of the refinery with the four existing discharges. Both temperature and residual chlorine plumes were modelled, taking account of temperature loss to the atmosphere and chlorine decay due to various processes.

Viva Refinery has four existing seawater discharges into Corio Bay designated W1, W3, W4 and W5, as they extend from south to north along the shore of Corio Bay in front of the refinery. The largest of the discharges is W1 which is the main discharge channel located south of the Refinery Pier. W1 has a maximum licenced discharge of 228 ML/d and is the largest of the four discharges.

Table 6-1 shows the estimated current discharge rates from the four discharge points. The total discharge rate is 350 ML/d which meets the Licence limit.

Table 6-1. Parameters for Existing Refinery Discharges

Designation	Discharge Rate	Temperature	Chlorine
W1	228 ML/d	+ 8 deg C	0.06 mg/L
W3	2 ML/d	ambient	0.18 mg/L
W4	35 ML/d	+ 9 deg C	0.06 mg/L
W5	85 ML/d	+ 10 deg C	0.05 mg/L
Total	**350 ML/d**	**8.5 deg C**	**20 kg/d**

6.6.2 Case 2 – Peak 350 ML/d Flow to Refinery Inlet

The FSRU would use up to 350 ML/d of seawater (at peak operation) and transfer it to the refinery inlet. As a consequence, the temperature of all refinery discharges would decrease by 7^{o}C as the FSRU cools the seawater by 7^{o}C in the process of reheating the LNG (Table 6-2). The refinery would add extra chlorine to match the existing inlet conditions and the chlorine in the refinery discharges would be the same as in Case 1.

The revised temperature pattern was modelled and as the reduced temperature marginally affects plume dispersion and thus slightly alters the chlorine distribution in the future compared to the existing case.

Table 6-2. Parameters for Future Peak Refinery Discharges

Designation	Discharge Rate	Temperature	Chlorine
W1	228 ML/d	+ 1 deg C	0.06 mg/L
W3	2 ML/d	- 7 deg C	0.18 mg/L
W4	35 ML/d	+ 2 deg C	0.06 mg/L
W5	85 ML/d	+ 3 deg C	0.05 mg/L
Total	**350 ML/d**	**1.5 deg C**	**20 kg/d**

6.6.3 Case 3 – Peak 350 ML/d Flow to Diffuser

The FSRU would use 350 ML/d of seawater (at peak operation) and all the flow from the FSRU would be discharged to the diffuser under the pier. There would be no

discharge from the refinery. In this case, the discharge from the diffuser would have a temperature 7ºC below ambient and a chlorine concentration of 100 µg/L (Table 6-3).

The initial dilution produced by the diffuser is 20:1, so the starting conditions in the regional model are a temperature of 0.35ºC below ambient and a chlorine concentration of 5 µg/L. Both temperature and chlorine were modelled simultaneously.

Table 6-3. Parameters for Diffuser Discharges

Designation	Temp. Difference	Chlorine
Diffuser	- 7 deg C	100 mg/L
End of plume	- 0.35 deg C	5 µg/L

6.6.4 Case 4 - Closed Loop with Peak Discharge of 350 ML/d

The FSRU would use 350 ML/d of seawater (at peak operation) and operate in closed loop mode, where heat is added to the seawater in the FSRU. In the Case 4 scenario, the FSRU would warm seawater from two pipes at the rear of the FSRU at 3 to 5 m/s and 9 m below the water surface. The pipes would point downward at angles of 30 to 45 degrees below the horizontal.

The discharge jets would travel quickly down to the seabed and CEE plume modelling using INITDIL showed that the discharges would have a minimum initial dilution of 10:1.

6.6.5 Case 5 – Average Flow of 250 ML/d to Refinery Inlet

The FSRU would use 250 ML/d of seawater (average operation) and transfer it to the refinery inlet. The refinery would extract an extra 100 ML/d via the inlet and add extra chlorine to match the existing inlet conditions. The chlorine in the refinery discharges would be the same as in Case 1. The revised temperature pattern was modelled.

6.6.6 Case 6 – Average Flow of 250 ML/d to Diffuser

The FSRU would use 250 ML/d of seawater (average operation) and all the flow from the FSRU would be discharged to the diffuser under the pier. There would be no discharge from the refinery. The discharge from the diffuser would have a temperature 7ºC below ambient and a chlorine concentration of 100 µg/L. The initial dilution produced by the diffuser is 20:1, so the starting conditions in the regional model are a flow of 7,000 ML/d at a temperature of 0.35ºC below ambient and a chlorine concentration of 5 µg/L. Both temperature and chlorine were modelled.

6.6.7 Case 7 – Reduced Chlorine Option

The chlorine concentration of 100 µg/L in the FSRU discharge is a maximum value. Some FSRU suppliers indicated that the concentration was often 60 µg/L and on occasions even lower. This case explores a discharge chlorine level of 60 µg/L.

6.7 Particle Tracking

The movement and dispersion of plankton and larvae in Corio Bay, and out into Port Phillip Bay, was assessed by tracking neutrally-buoyant particles using the hydrodynamic model of Corio Bay.

The modelling examined the dispersion of larvae from various sites in Corio Bay, including the Ramsar site in northern Corio Bay, and the potential for entrainment of biological constituents into the existing refinery intake and the proposed FSRU intake.

The three starting sites for the particle dispersion simulations are as follows:

1. Ramsar site along north coast of Corio Bay;
2. Fish breeding area in north Corio Bay; and
3. Fish breeding area in south Corio Bay.

For this report, the eastern boundary of Corio Bay is the line connecting Point Lillias to Point Henry – this assumes that the Outer Harbour is in Port Phillip Bay. While 94 % of this section of the Point Wilson-Limeburners Bay site is in Corio Bay, 8 % of the Ramsar site is counted as being in Port Phillip Bay. For counting particles, the area of Corio Bay was also split in half across a central east-west line, creating north Corio Bay and south Corio Bay segments.

Methodology in Dispersion Simulations

The model is initiated with 10844 neutrally buoyant and equally spaced particles within the boundaries of the site being investigated (eg, the Ramsar site). The particles start at 10 cm above the seabed and move vertically and laterally in the water column depending on the currents predicted by the hydrodynamic model in response to the tide, wind and other processes. The position of each particle is calculated every 20 seconds (the model time step) based on the current patterns at the location of each particle. Each particle position is recorded to file every 2 hours. Note that in 2 hours at the median current speed of 0.045 m/s, the particles would move 320 m, so the trajectories of the particles between the 2-hour output intervals are estimated by linear interpolation between sequential locations.

The recorded locations are analysed to determine how many of the released particles reach selected areas within the model grid. The counts were made for 7, 14, and 28 days after release of the particles and repeated for release at high tide and low tide. The model shows how many particles make their way from the release site to Port Phillip Bay, south Corio Bay, the intake of the refinery or the intake of the FSRU.

Assessment of Entrainment

To assess entrainment of plankton, an entrainment zone for the refinery intake was defined, comprising a 50 m x 50 m area extending from the water surface to 2 m below the surface. Particles that are released from the sites and subsequently enter the entrainment zone are counted and assumed to be entrained. For the FSRU, a similar intake entrainment zone was defined, comprising a 50 m x 50 m area extending from 9 to 11 m below the water surface, corresponding to the depth of the seawater intake on the FSRU. The implications for entrainment are described in Section 10.

6.8 Modelling Movement of Silt and Clay from Dredging

Localised dredging is proposed adjacent to the existing shipping channel at Refinery Pier to provide sufficient water depth for the new FSRU and LNG carriers to berth and a turning basin for the LNG carriers. Figure 6-18 shows the 12 ha area to be dredged.



Figure 6-18. Proposed 12 ha Area to be Dredged in Corio Bay

It is planned to deposit the dredged material within the existing spoil disposal site in Port Phillip Bay to the east of Point Wilson. The location of the spoil disposal site is shown in Figure 6-19. The material to be dredged is mostly clay and silt and would be removed by conventional backhoe dredging equipment and transported by barges to the disposal site.

The AEM3D model was also used to simulate the dispersion and settling of fine sediments released by dredging, or from disposal of dredge spoil from a barge at the spoil disposal site.

The particles are introduced via source terms that specify the load (in kg/s) released at various levels in the water column, particle size and settling velocity. The silt particles settle at a velocity based on a Stokes settling relationship. Clay particles settle at a slow rate, based on the measured rate of settling of agglomerated clay particles in seawater.



Figure 6-19. Proposed Spoil Disposal Site in Port Phillip Bay

Resuspension rates are calculated for each particle size, based on the particle density, bottom shear stress (above a critical shear stress) and erosion rates. Once the critical shear stress for resuspension is reached and the material lifts from the bed, the erosion rate is applied. The resuspension of sediment from the bed in the AEM3D model uses the expression of Bengtsson et al. (1990).

The resuspension and deposition of the sediments changes the bottom morphology (with the inclusion of packing in the sediments after settling).

Dredged Material Composition

Particle size distributions from depth layers within the dredge footprint area show the composition of the sediments to be dredged is mostly clay, silt and fine sand. Based on particle size distributions from the initial survey by Coffey, an average of 63 % of the material consists of fine material with a diameter of less than 63 microns, of which 46 % is clay (< 2 micron in diameter) with the remainder being silt with a particle size in the range of 2 to 60 microns.

Based on the sediment data, the regional model was configured to simulate four different sediment sizes, each with a density of 2,600 kg/m^3, which are:

- Clay with a particle size of 2 micron that makes up 46% of the dredged material;
- Silt with a particle size of 30 microns that makes up 17% of the dredged material;
- Fine sand with a particle size of 125 microns that makes up 12% of the dredged material; and

- The remaining 25% of material with a diameter of 250 microns (sand).

A later survey by AECOM reported a similar particle size distribution (62 % less than 63 microns) as described in Section 7. The size distribution was similar in each vertical layer but there was a large variability horizontally from borehole to borehole (AECOM, 2021).

Source Terms

The rate of loss of material during dredging operations was provided by Worley. During dredging, an estimated 9.2 kg/s of material would be spilled into the surrounding waters adjacent to the dredge, including the spill from the barges while being loaded. The sediment source terms in the model added within the dredge footprint over a 20 x 20 m model cell add 6.7 kg/s of clay and 2.5 kg/s of silt. The rest of the spill is considered to be sand that settles to the seabed close to the dredging site.

The vertical distribution of the material added in model simulations is as follows: 40 % is introduced in the 2 m surface layer, 30 % is added at mid-depth and 30 % in the layers within 2 m of the seabed.

The dredged material will be transported and deposited by split hopper barges at the disposal site. The majority of the sediment falls rapidly to the seabed when the split hopper opens, with a small fraction entrained into the water column.

The barge speed and discharge rate depends on the weather, which influences the safe speed of the barge. At a slow speed, an estimated 55 kg/s of material is entrained into the water column over the 15 minute duration of each barge release. At a fast speed, an estimated 110 kg/s of material is entrained into the water column over the 10 minute duration of each barge release.

Settling Rates

Settling rates for silt, fine sand and sand were calculated using Stoke's settling velocity.

Published measurements show that the setting velocity of clay in seawater reflects some coagulation and is 0.063 mm/s.

Periods for Simulation of Turbidity and Sedimentation

The dredging is proposed to be carried out in a period of approximately 8 weeks. To assess the effects of weather on the outcomes, the turbidity and sedimentation resulting from the dredging were simulated for a winter period (August-September) and a summer period (November-December). Modelling across two seasonal patterns with differing wind patterns (southerly wind patterns in summer and northerly wind patterns in winter) is sufficient to determine patterns in turbidity and sedimentation during dredging.

6.9 Results of Modelling

The subsequent Sections of this assessment report include the results from the near-field and regional hydrodynamic models, generally as plots of temperature or chlorine concentration contours, but also as particle distributions and suspended solids concentration contours.

The results are presented in the following Sections.

- Section 7 presents the results of the simulations of dredging and spoil disposal operations, including simulations from medium-size and large-size backhoes used for dredging;
- Section 8 presents the results of the simulations of temperature levels in the existing and future discharge plumes (warmer and cooler than ambient seawater).
- Section 9 presents the results of the simulations of chlorine concentrations in existing and future discharge plumes (taking into account the thermal conditions in the various plumes).
- Section 10 presents the results of the simulation of the movement and dispersion of particles representing plankton travel and entrainment in Corio Bay.

An analysis of the sensitivity of model predictions to input parameters is provided in Section 8 (for temperature) and Section 9 (for chlorine). A separate report by Hydronumerics provides greater detail on the regional hydrodynamic model, including plots showing the results of all simulations.

7 Dredging Assessment

This section provides an assessment of the potential marine impacts associated with dredging at Refinery Pier immediately adjacent to the existing shipping channel in Corio Bay. The dredging would create a new berth for a FSRU at a proposed extension to the existing pier and provide a turning basin for the LNG carriers that would supply the FSRU.

7.1 History of Dredging in Corio Bay

The town of Geelong was established in the 1830's. Geelong has been an important port in Victoria since the 1850's. The existing channels and anchorages in Corio Bay are shown in Figure 7-1 with Refinery Pier highlighted in red.

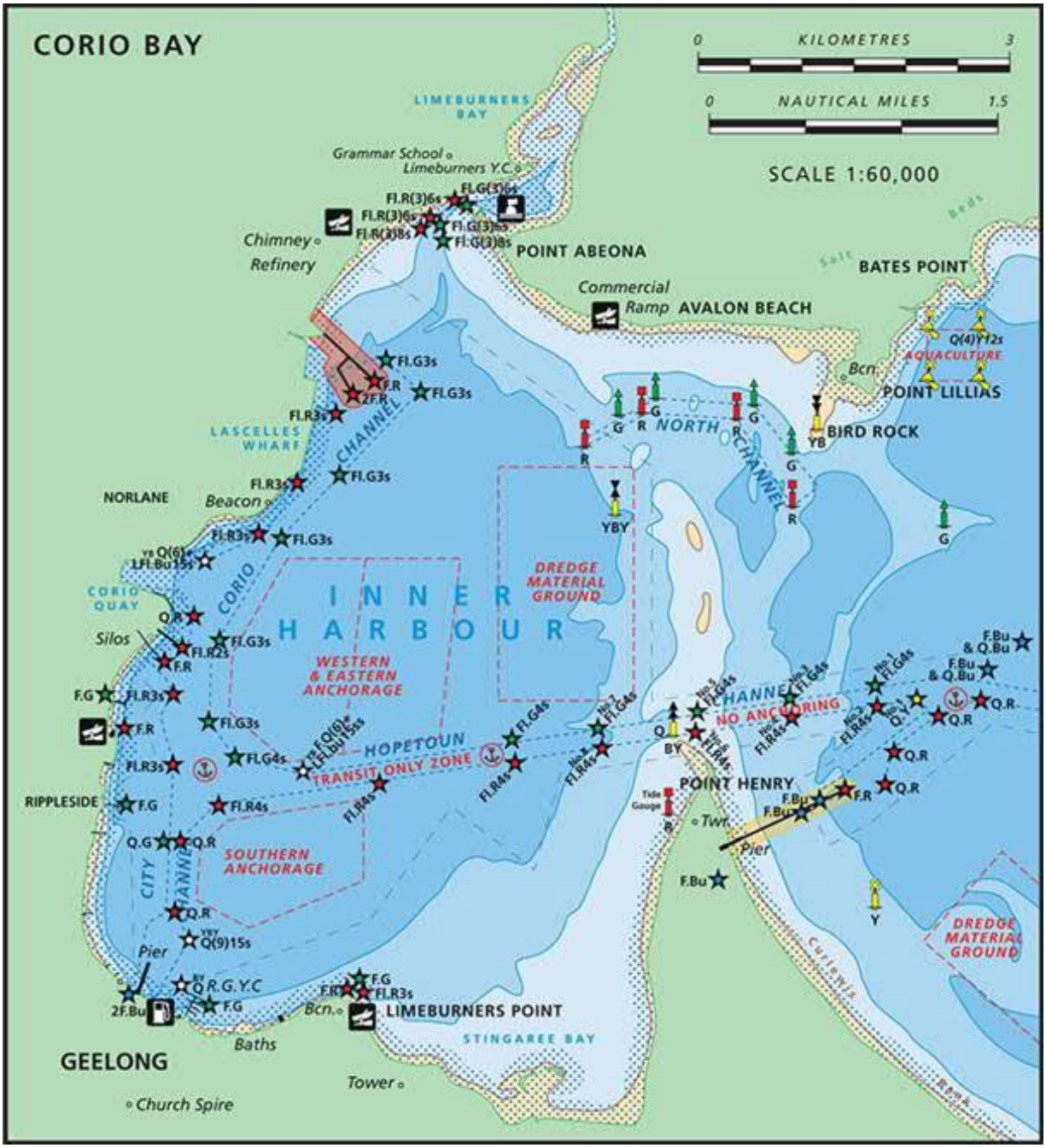


Figure 7-1. Shipping Channels in Corio Bay

The first dredging program for the North Channel into Corio Bay occurred in the 1850's. In the early 1860's, the South Channel was formed to allow better access to the Bay (Geelong Port, 2018). The 1890's saw a third dredging program as the Hopetoun Channel was cut into Corio Bay with a minimum depth of 7.1 m and a navigable width of 39.6 m (Geelong Port, 2018). In the early 1900's the Hopetoun Channel was widened and deepened as the port of Geelong continued to develop.

In 1954, the Shell Refinery (now operated by Viva Energy) opened to process crude oil into a range of fuels. Further deepening of the existing channels was required to provide access for oil tankers. In 1958, a channel widening program commenced and the channel from Refinery Pier to Point Richards was increased to 91.4 m wide and 10.9 m deep. By the 1960's, Geelong was the fourth busiest port in the country (Geelong Port, 2018).

In 2004, the Victorian Regional Channels Authority (now Ports Victoria) commenced further dredging to increase channel depths to 12.3 m (Geelong Port, 2018). Today, the Port of Geelong has approximately 700 ship visits per year and handles millions of tonnes of imports and exports (Geelong Port, 2018).

In summary, shipping channels for the Port of Geelong have been progressively enlarged and modified over a period of approximately 150 years to allow for safe ship access to the port (Worley Parsons 2011) with approximately 20 million m^3 of material dredged to create and maintain the shipping channels between 1854 and 1997.

Apart from the main channels, further dredging works have included:

- Capital and maintenance dredging of shipping berths and basins in Lascelles Wharf, Corio Quay and Bulk Grain Pier (1980)
- Capital dredging at Port Henry Channel (1984)
- Maintenance and capital dredging in Corio Quay and Corio Channel (1988)
- Maintenance dredging in Wilson Spit Channel (1991)
- Capital dredging (Channel Improvement Program) in Point Henry, Bulk Grain Pier, Lascelles Wharf and Refinery Pier (1996-1997) – 4.5 million m^3 of dredged material.

More recently there has been dredging to make changes in channel alignment and water depths in the City Bend and at the junction of the Hopetoun and Corio Channels. These dredging works included:

- Geelong Dredging Program 2014 (City Bend / Corio Quay) - 200,000 m^3 of dredged material
- Geelong Dredging Program 2015 (Refinery Pier No. 4 / trial dredge east of Point Wilson) - 240,000 m^3 of dredged material
- Geelong Dredging Program 2017 (eastern side of Corio Channel) - 160,000 m^3 of dredged material

To date, a total of about 30 million m^3 of material has been dredged from Corio Bay.

7.2 Extra Berth for Viva Project

The project would involve an extension of the existing Refinery Pier with an angled pier arm and a new berth for mooring the FSRU to hold and convert liquefied natural gas (LNG) into natural gas. LNG carriers would moor alongside the FSRU and transfer the LNG to it. Figure 7-2 shows the proposed location of the new pier, and the FSRU and LNG carrier.

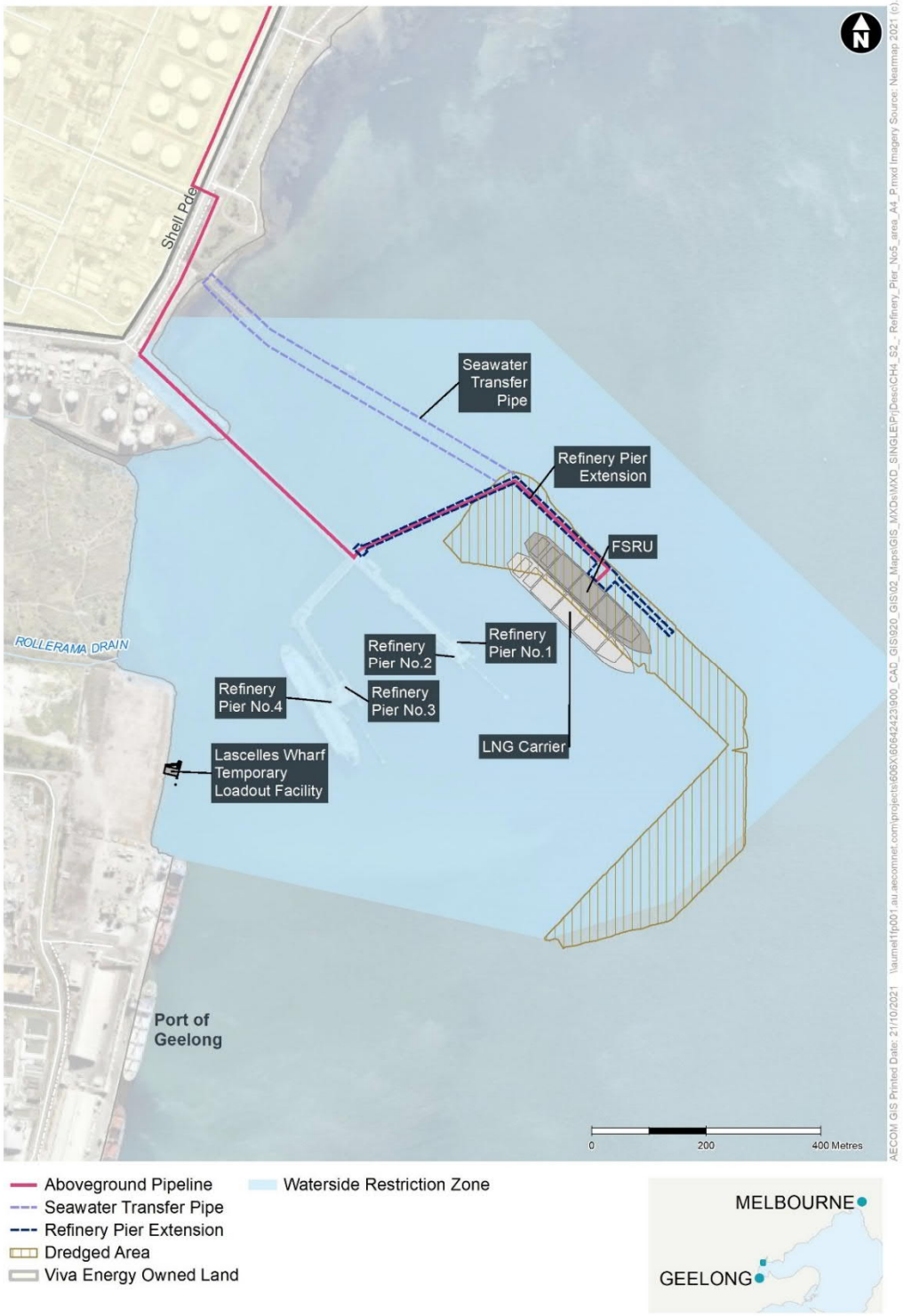


Figure 7-2. Proposed Dredging Footprint

Seawater used by the FSRU for heating LNG would be piped to the refinery via a seawater transfer pipe (see Figure 7-2) which would require a trench to be excavated (involving approximately 8,000 m^3 of sediment). The dredging footprint is 12 ha and is shown (hatched brown) in Figure 7-2.

The main dredging program would involve the removal of 490,000 m^3 of sediment to provide the new berth pocket and swing basin. This corresponds to 1.6 per cent of the 30 million m^3 of sediment dredged from Corio Bay in the past.

7.3 Methodology for Predicting Dredging Impacts.

The main issues that were identified and investigated to assess potential dredging impacts were:

1. **Modification of Seabed** – including changes in distribution of habitat, potential for significant adverse effect on infauna, epibiota and plankton, effects on productivity of Corio Bay, and effects on threatened and listed species.
2. **Turbidity and Reduced Light** – including potential for adverse effect on seagrass communities, plankton communities, fish and food supply for seabirds feeding in Ramsar wetlands to the north.
3. **Mobilisation of Contaminants** – including potential for significant adverse toxic effect or bioaccumulation for benthic communities, plankton communities, fish larvae, larger pelagic communities, marine mammals and seabirds feeding in Ramsar wetlands to the north.
4. **Settlement of suspended material on seabed (sedimentation)** – including potential for significant adverse effect due to clogging or burial of benthic invertebrates, benthic algae, seagrass communities and threatened or listed species.
5. **Mobilisation of Nitrogen** – including potential for changes in phytoplankton abundance or species richness.

The methodology for assessing the impacts of the dredging component of the proposal was as follows.

1. Establish dredging footprint;
2. Establish quantity of material to be dredged;
3. Establish characteristics of material to be dredged;
4. Establish dredging equipment and duration of program;
5. Establish spill and loss rates for dredging program;
6. Establish settling rates of materials;
7. Model the release, transport and settling of spilled material;
8. Establish existing conditions for suspended solids, turbidity and light;
9. Calculate change in suspended solids and turbidity;
10. Compare to natural variations in turbidity;
11. Assess implications of sedimentation in dredge spoil disposal site;
12. Assess implications of reduction in light near dredging area;
13. Assess implications of sedimentation in north Corio Bay;
14. Assess implications of reduction in light near dredge spoil disposal site;
15. Assess implications of mobilisation of contaminants and nitrogen;
16. Review implications of previous dredging programs; and
17. Finalise effects and impact assessment for dredging.

7.4 Dredging Footprint

It is proposed to dredge an area of 12 ha at Refinery Pier adjacent to the existing shipping channel to create a new berth for the FSRU and create a basin to allow the LNG carriers to turn before proceeding to berth or leave via the existing channel.

The additional 12 ha would increase the area dredged in the Port of Geelong, including the main channels in Corio Bay and the entrance channels in the Geelong Arm from 310 ha to 322 ha. In the context of Corio Bay, this constitutes less than 0.3 per cent of the 4,300 ha of Corio Bay.

Figure 7-3 shows the depth of dredging in various parts of the footprint. The FSRU berth would be dredged to a depth of 13.1 m below chart datum of lowest astronomical tide (LAT) and is shown in purple. This section would involve excavation of 6 m to 9 m below the existing seabed. The turning basin would be dredged to a depth of 12.7 m (below LAT) and is shown in brown. This section would involve excavation of 3 m to 6 m below the existing seabed. . The edges (batter from surface to base of dredging) is shown in pink and would involve excavation of 0 m to 3 m below the existing seabed.

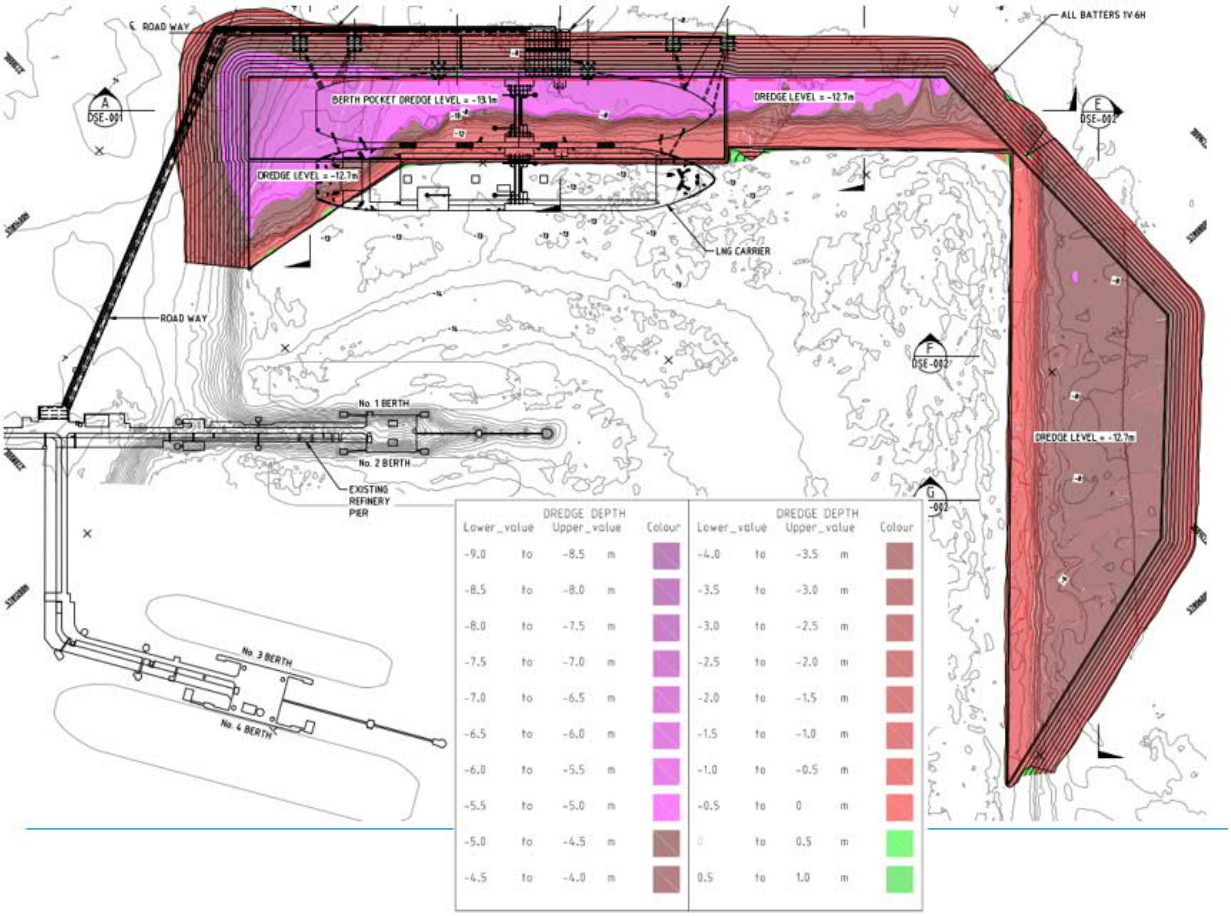


Figure 7-3. Extent of Proposed Dredging

The berth section of dredging is approximately 600 m long and an average of 130 m wide. The turning basin is approximately 500 m long and an average of 160 m wide.

7.5 Quantity of Material to be Dredged

All the material to be excavated is sediment – there is no rock or reef. Table 7-1 lists the types of sediments to be dredged, and the quality of material, from the surface layer (Unit A1 – sand and silty clay) to the lowest layer (Unit B1 – stiff clay). There is a thin layer of sand at an intermediate depth. The total quantity of material to be excavated, allowing for over-dredge and contingency, is 490,000 m^3.

Table 7-1. Material to be Dredged

Layer	Sediment description	Volume (m^3)
Unit A1	Clay and sandy clay – very soft to soft	260,000
Unit A2	Clay and sandy clay – firm	49,000
Unit B0	Sand	9,000
Unit B1	Clay – stiff to hard	77,000
Over-dredge	Clay – stiff to hard	60,000
Contingency	Various	35,000
Total volume		**490,000**

It is expected that the dredging would be carried out by a backhoe dredge operating from a barge with three jack-up piles or spuds (Figure 7-4). The backhoe has a large bucket (approximately 16 m^3) and excavates in a semi-circle in front of the barge. When this is completed, the spuds are lifted, the barge moves forward, the spuds are re-set in the seabed and dredging re-commences. The dredge operates 24 hours per day, 7 days a week, and at normal production rates, should be able to remove the planned 490,000 m^3 of sediment in approximately 8 weeks.



Figure 7-4. Example of Dredging by Backhoe Dredge

7.6 Dredging Proposal

Sediment excavated by the backhoe would be loaded into three split hopper barges of 1,600 m^3 capacity. Full barges would transport the material to the existing dredge spoil disposal site 8 km east of Point Wilson and discharge into the south-western portion of this site (see Figure 7-5). Each barge would make three round trips per day.

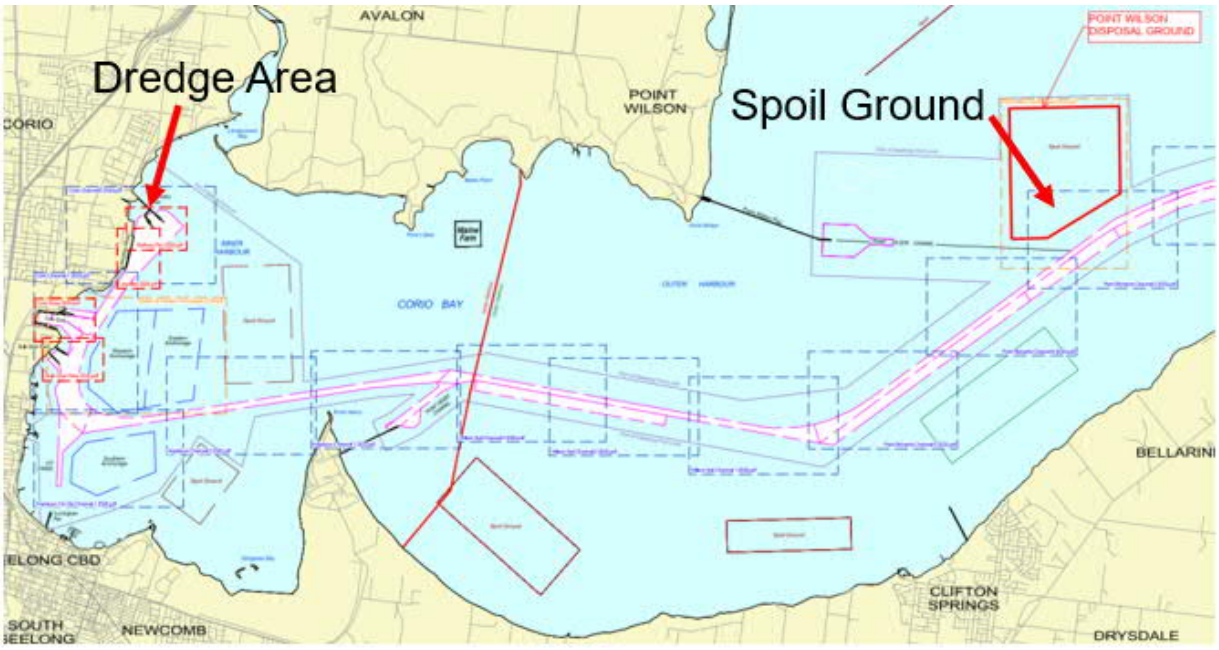


Figure 7-5. Location of Dredge Area and Spoil Ground

Table 7-2 lists the particle size distribution of the material to be dredged based on borehole sampling in 2020 (Coffey, 2020). An average of 46 % of the material is clay, with silt being the next largest fraction at 17 %. There is also a small proportion of fine, medium and coarse sand.

Table 7-2. Particle Size Distribution for Sediments – Coffey

Material	Size range	Unit 1a	Unit 1b	Unit 2	Average
Clay	< 2 micron	47 %	44 %	47 %	**46 %**
Silt	2 – 63 micron	16 %	18 %	17 %	**17 %**
Fine sand	63-125 micron	15 %	12 %	9 %	**12 %**
Med sand	125-250 micron	11 %	13 %	8 %	**11 %**
Coarse	> 250 micron	12 %	13 %	19 %	**15 %**

Dredging would commence at the north-west corner, proceed for 600 m to the south-east along the alignment of the new pier arm, turn to the south-west and then proceed for a further 500 m along the turning basin. The area that would be dredged each day is approximately 9,000 m^2, depending on the depth of excavation.

Further testing of the particle size distribution and other properties of the sediment was carried out in 2021 (AECOM, 2021). The sites sampled by AECOM in the proposed dredging area are shown shaded brown in Figure 7-6 (excluding the blue shaded area).

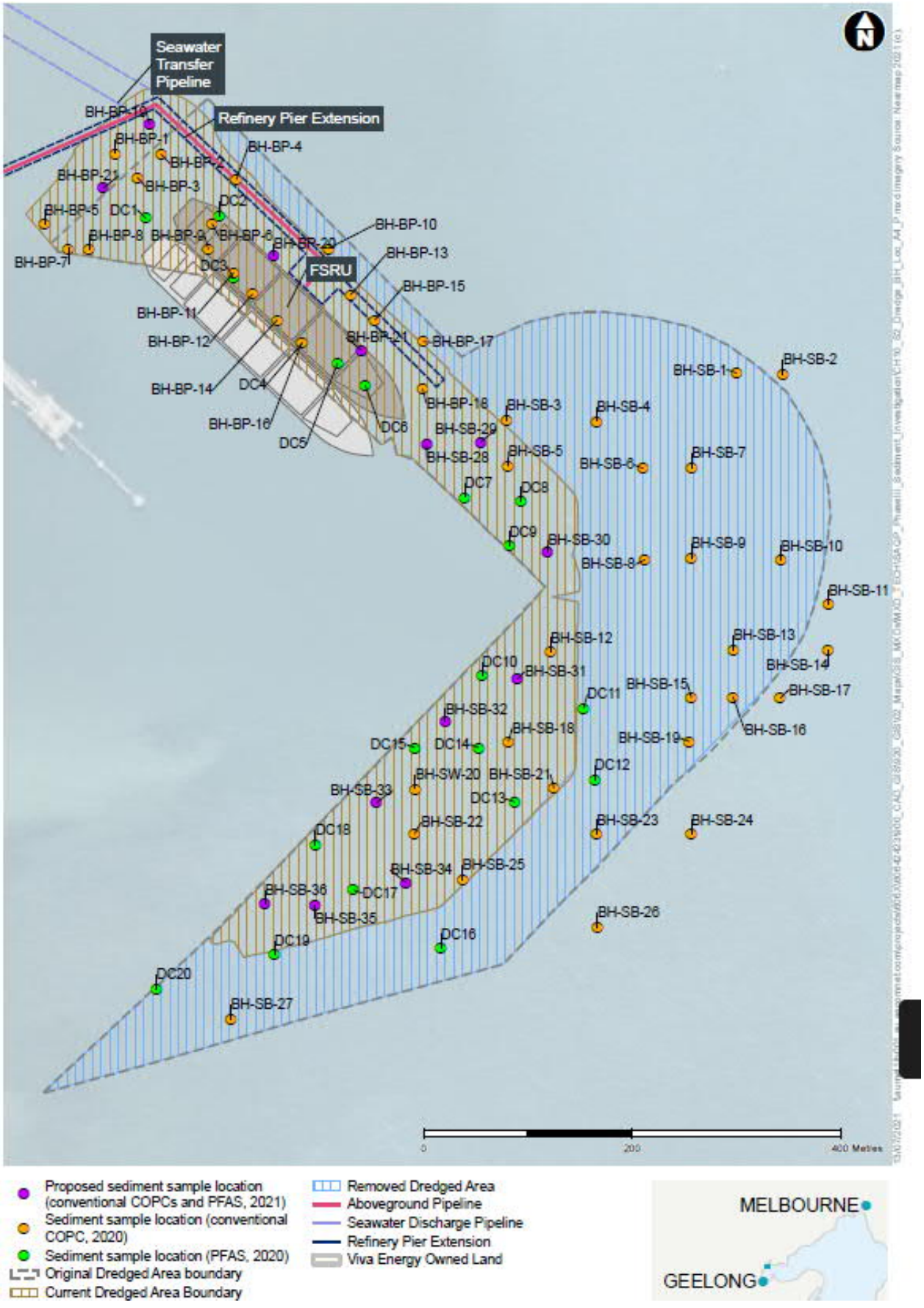


Figure 7-6. Sediment Sampling Sites in Proposed Dredging Area

The AECOM results used different size ranges in their classification and therefore came up with different proportions of clay, silt and sand. However, there is a similar proportion of fine sediment (**63 % < 63 microns**) in the Coffey distribution as the proportion of fine sediment (**64 % < 63 microns**) in the AECOM distribution (Table 7-3).

Table 7-3. Particle Size Distribution for Sediments – AECOM

Material	Size range	Unit 1a	Unit 1b	Unit 2	Average
Clay	< 2 micron	32 %	38 %	40 %	**37 %**
Silt	2 – 75 micron	40 %	31 %	27 %	**33 %**
Fine sand	75-125 micron	18 %	18 %	22%	**19 %**
Med sand	125-250 micron	7 %	8 %	9 %	**8 %**
Coarse	> 250 micron	3 %	5%	2 %	**3 %**

Note that size distribution boundaries on this table are different from previous table

The particle size distribution varied from borehole to borehole, as illustrated in **Figure 7-7**. The fine sediments in these 10 boreholes (shown as the blue proportion at the base of each column) ranged from a minimum of 33 % (BP-15) to a maximum of 80 % (BP-12). For these 10 boreholes, the proportion fine sediments was 58 % +/- 14 %.

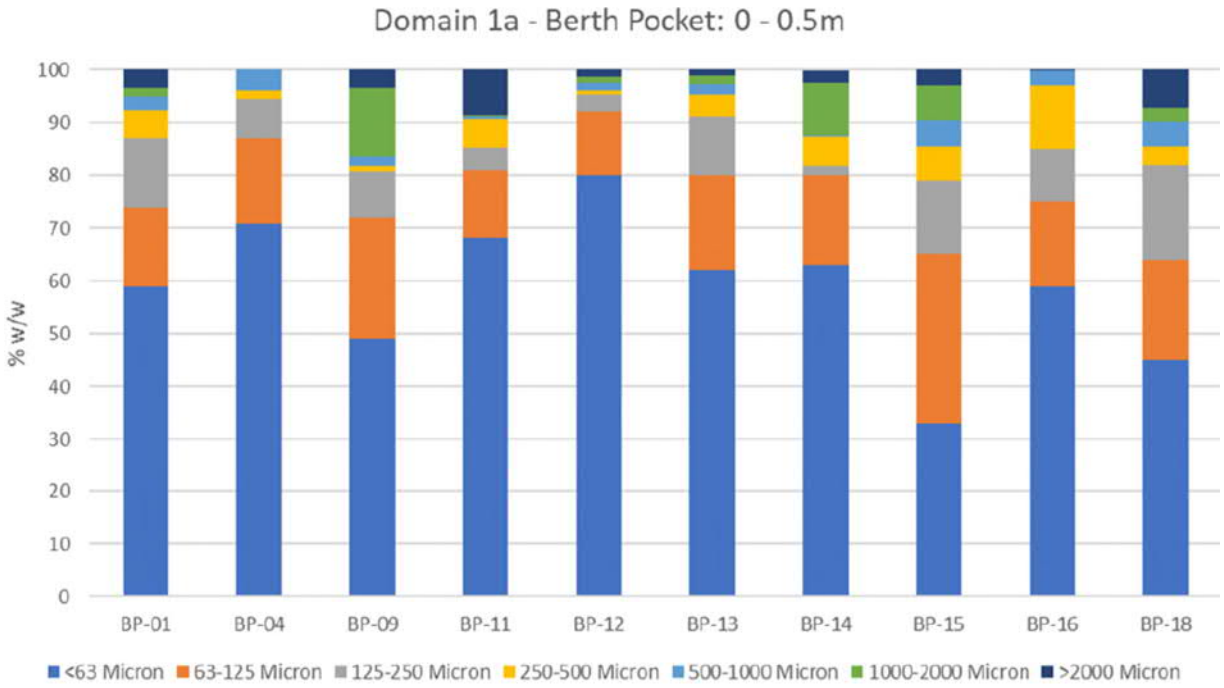


Figure 7-7. Sediment Size Distribution in Surface Layer of Dredging Area

Basis of Modelling Fine Sediments

Recognizing the variability of the proportion of fine materials (< 63 microns), the modelling of suspended solids is based on a **percentage fines of 70 %**. This is a conservative assumption made to ensure that the predicted distribution of turbidity encapsulated during periods when dredging may be removing a patch of particularly

fine material. Noting that the **average** percentage of fine sediments in the dredging area is 63 % (from Coffey, 2020) or 64 % (from AECOM, 2021) the suspended solids distributions from the regional model are about 10 % over-estimated (on average).

Comparison of Dredging Area and Spoil Disposal Site

AECOM measured sediment particle size distributions on 55 cores from the dredging area, 6 cores from the spoil disposal area and 18 cores from the seabed outside the spoil disposal area (in the vicinity of Point Wilson). **Figure 7-8** compares the average components of the cores (using the AECOM definitions of particle size distribution).

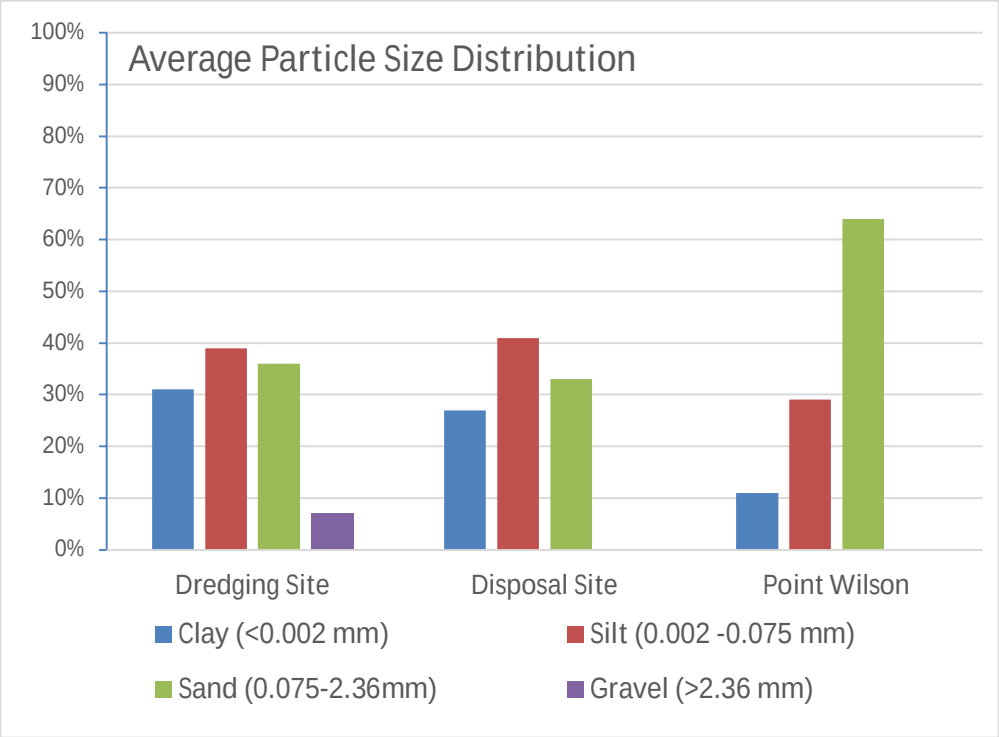


Figure 7-8. Sediment Size Distribution in Dredging and Disposal Site

The particle size distribution at the dredging site and the spoil disposal area are very similar, being approximately equal proportions of clay, silt and sand. This would be expected as the sediment layer in the dredge spoil disposal site constitutes sediment that has previously been dredged from Corio Bay and deposited at that site. The particle size distribution of the Point Wilson area has less clay and more sand, which matches the seabed classification shown in the existing seabed characteristics in Section 5.

The infauna studies (see Section 5.16), showed the abundance and types of infauna are the same in the area to be dredged and the dredge spoil disposal site (both around 80 to 88 organisms/grab). As such, the proposed disposal of the extra sediment from north Corio Bay in the dredge spoil disposal site would not alter the sediment characteristics and the same infauna community would develop in the new sediment as occurs now in the existing sediment.

7.7 Spill and Loss Rates

Spill and loss rates for the various stages in dredging were supplied by Worley/Boskalis (a dredging operator) and are based on experience gained by

Boskalis in previous dredging projects in Corio Bay and for the Port of Geelong. To ensure that conservative predictions were made for suspended solids and turbidity, spill rates were derived on the assumption that clay and silt **comprised 70 % of the sediment** being dredged. The fine sediments contribute to dispersed suspended solids and turbidity during dredging as the sand settles out rapidly onto the seabed near the dredge.

Worley/Boskalis supplied three scenarios for dredging (Table 7-4). The large backhoe dredger operating over an 8-week period (highlighted in yellow) had the highest spill rates and was therefore chosen for modelling as the worst case for the environment. The duration, assuming no downtime is listed in the table as 5.7 weeks for the large backhoe – the 8-week duration is another conservative assumption. The spill rate used in the modelling was 610 t/d of fines (clay and silts) from the backhoe and 270 t/d from the barge overflow totalling 800 t/d (equivalent to 9.2 kg/s).

Estimated total loss and spills during dredging are 34,000 to 39,000 m^3 at the dredge site, depending on the assumptions about dredge size, duration and spill rates. The EES modelling is based on a total spill at the dredge site of 44,000 m^3 (to allow the largest equipment to be used if it is available) and therefore is conservative (and provides some flexibility for subsequent refinement of dredging equipment and timing).

Table 7-4. Parameters for Dredging Options

Parameter	Unit	Small Backhoe	Medium Backhoe	Large Backhoe
Dredging	**m^3**	**490,000**	**490,000**	**490,000**
BH production	m^3/week	43,970	50,205	86,545
Duration	weeks	11.1	9.8	5.7
Total spill, wet	%	8.5%	8.1%	7.1%
Total spill, wet	kg/s	6.2	6.7	10.1
Total spill, wet	t/d	536	579	873
Fines (< 63 um)	%	70%	70%	70%
Fines spill, wet	kg/s	4.3	4.7	7.1
Fines spill, wet	t/d	375	405	610
Total BH spill	**Total**	**29,250**	**27,680**	**24,210**
Proportion	%	**6.0%**	**5.6%**	**4.9%**
Barge loads/week	number	38	43	58
Overflow period	minutes	20	20	14
Spill rate, wet	kg/s	19.6	22.4	38.6
Fines Spill, wet	**t/d**	89	116	190

Parameter	Unit	Small Backhoe	Medium Backhoe	Large Backhoe
Total spill at site	t/d	460	520	800
Top 2 m	kg/s	2.1	2.4	**3.7**
Middle 3 m	kg/s	1.6	1.8	**2.8**
Bottom 2 m	kg/s	1.6	1.8	**2.8**
Total spill, wet wt	kg/s	5.4	6.0	**9.2**

The total spill rates of 6.0 kg/s and 9.2 kg/s were used in the regional model.

The spillage at the dredge site was distributed over the water column as follows:

- 40 % released in the top 2 m = 3.7 kg/s;
- 30 % released at mid-depth = 2.8 kg/s; and
- 30 % released in bottom 2 m = 2.8 kg/s.

Settling Rate for Fine Particles

Sediments were simulated by AEM3D as concentrations of inert particles with a prescribed size and settling rate. The particles were added into the appropriate grid cells in the dredging zone with the load and particle size distribution. The particles settle at a velocity from Stoke's settling equations or at a user-prescribed settling velocity. The settling rates used were:

- Clay with a particle diameter of <2 µm and settling velocity of 0.063 mm/s (from Sutherland et al, 2014); and
- Silt with a particle diameter of 30 µm settling velocity of 0.8 mm/s.

Losses at Dredge Spoil Disposal Site

At the dredging site, the sediment would be loaded into three split hopper barges and taken to the dredge spoil disposal site to the east of Point Wilson (round trip travel time of approximately 4 hours)

Depending on weather conditions, the barges travel at 2 knots or 5 knots during the discharge period. A **slow barge** travels at 2 knots and discharges the spoil over 15 min. The corresponding loss rate for sediment in the water column was provided by Worley/Boskalis as 55 kg/s. Thus, the amount suspended in the water column would be 50 t, with the major proportion of the sediment falling to the seabed. The spill in the water column at the discharge site from the slow barge was distributed as follows:

- 30 % released at 2 m depth = 16.5 kg/s;
- 30 % released at 5 m depth = 16.5 kg/s; and
- 40 % released at the seabed = 22 kg/s.

A **fast barge** would travel at 5 knots and discharge the spoil over 10 min. The corresponding loss rate for sediment in the water column was provided by Worley/Boskalis as 110 kg/s. Thus, the amount suspended in the water column would be 66 t, with the major proportion of the sediment falling to the seabed. The

spill in the water column at the spoil discharge site for the fast barge was distributed as follows:

- 60 % released at 2 m depth = 66 kg/s;
- 20 % released at 5 m depth = 22 kg/s; and
- 20 % released at the seabed = 22 kg/s.

7.8 Model of Transport, Dispersion and Settling

The AEM3D model was used to simulate the transport, dispersion and mixing of the spilled material. In north Corio Bay, the model has a 20 m by 20 m by 1 m deep grid, and a time step of 1 minute. The spilled material at the dredge site was added to four grid squares (40 m by 40 m in area). The spilled material at the dredge spoil disposal site was added to a line of grid squares for the time and distance of the barge travel while discharging sediment.

Simulations were made using tides, seasonal winds and seawater temperature and salinity conditions for two periods of 8 weeks (in winter and summer, respectively):

- August - September 2020; and
- November – December 2020.

7.9 Baseline Conditions for Suspended Solids, Turbidity and Light

Existing conditions in Corio Bay in terms of suspended solids, turbidity and light attenuation are described in Section 5-5.

The EPA monitoring data in Section 5.5 showed suspended solids average 2 mg/L in the central waters of Corio Bay. In the northern waters near the Ramsar site the average suspended solids is 5 mg/L. Turbidity is a measure of water clarity and averages 1 NTU in the central waters of Corio Bay, with high turbidity in the northern waters, and much higher turbidity near the seabed in the north of the Bay. Records of inlet conditions kept by Viva Energy show that turbidity peaks can result from resuspension of seabed sediments during storms or from phytoplankton blooms.

Light attenuation was measured by CEE in Corio Bay over May-June 2021 using two Odyssey PAR sensors recording light simultaneously at two depths. The PAR sensors were deployed in Corio Bay near the Ramsar site in water that was 7 m deep. Over the period, the light attenuation coefficient ranged from 0.6 to 0.8 m^{-1} with an average of 0.75 m^{-1}. This result shows there is medium to high natural turbidity in Corio Bay.

Lee (2015) measured light attenuation in Port Phillip Bay from 2008 to 2011. Over the period October 2008 to September 2009 at Long Reef (near Werribee), the light attenuation coefficient ranged from 0.2 to 1.2 m^{-1} with an average of 0.6 m^{-1}. The program developed a relationship between light and suspended solids, with the relationship of best fit being:

$K_d = 0.124 \times TSS + 0.12$ (total suspended solids in mg/L). $R^2 = 0.72$

The average k_d value of 0.75 m^{-1} in Corio Bay corresponds to a TSS of 5 mg/L.

In the Corio Bay Channel Improvement Program, which involved dredging approximately 510,000 m^3 of sediment from Refinery Pier, the Corio Bay channel bend and the Point Henry swing basin, a relationship was developed from monitoring data between turbidity (T) and suspended solids (TSS) which was:

T = 0.33 x TSS (where T is in NTU and TSS in mg/L). No R^2 in source reference.

Cardno (2011) reported on monitoring of sediment discharged from a hopper barge at the dredge spoil disposal site. Highest recorded turbidity was 6 NTU at the surface and 15 NTU near the seabed. This suggests a peak TSS of 18 mg/L at the surface.

Monitoring by Lawson and Treloar (1998) for the Corio Bay Channel Improvement Program showed the following results for average turbidity in Corio Bay:

- Pre-dredging turbidity = 0.4 to 1.2 NTU (23 surveys)
- During dredging turbidity = 0.5 to 2.5 NTU (19 surveys); and
- Post-dredging turbidity = 0.4 to 1.0 NTU (7 surveys).

Monitoring reported by the Port of Melbourne during the Williamstown Channel dredging in 2008 showed an increase from background of 2 NTU to a peak of 22 NTU for a day during dredging, and then an exponential decline back to 2 NTU over the following four days.

In summary, Corio Bay has higher turbidity and light attenuation than Port Phillip Bay, possibly due to phytoplankton (as there is a high phytoplankton content in the waters of north Corio Bay) and waves resuspending sediment. In addition, plankton-induced turbidity was observed by CEE's divers and is visible in photographs taken during the 12-month marine monitoring program. Short periods of elevated turbidity and suspended solids levels occur in Corio Bay during periods of strong winds when wave action mobilises shallow and shoreline sediments, as occurs on other muddy shores (Fettweiss et al, *Storm influence on SPM concentrations*, 2010).

7.10 Change in Suspended Solids and Turbidity

The regional model predicted the increase in suspended solids (SS) concentrations above ambient conditions over an eight-week period of dredging under two seasonal scenarios: August September, and November-December. Figure 7-9 shows the **predicted increase** in median SS concentration due to dredging over an 8 week dredging period of August-September 2020. At the surface, there is a small patch (7 ha) of 5 mg/L SS above ambient and a large patch (210 ha) of 2 mg/L SS. At the seabed, there are higher concentrations with a 35 ha patch at 20 mg/L SS and a larger area of 290 ha of 2 mg/L SS above ambient.

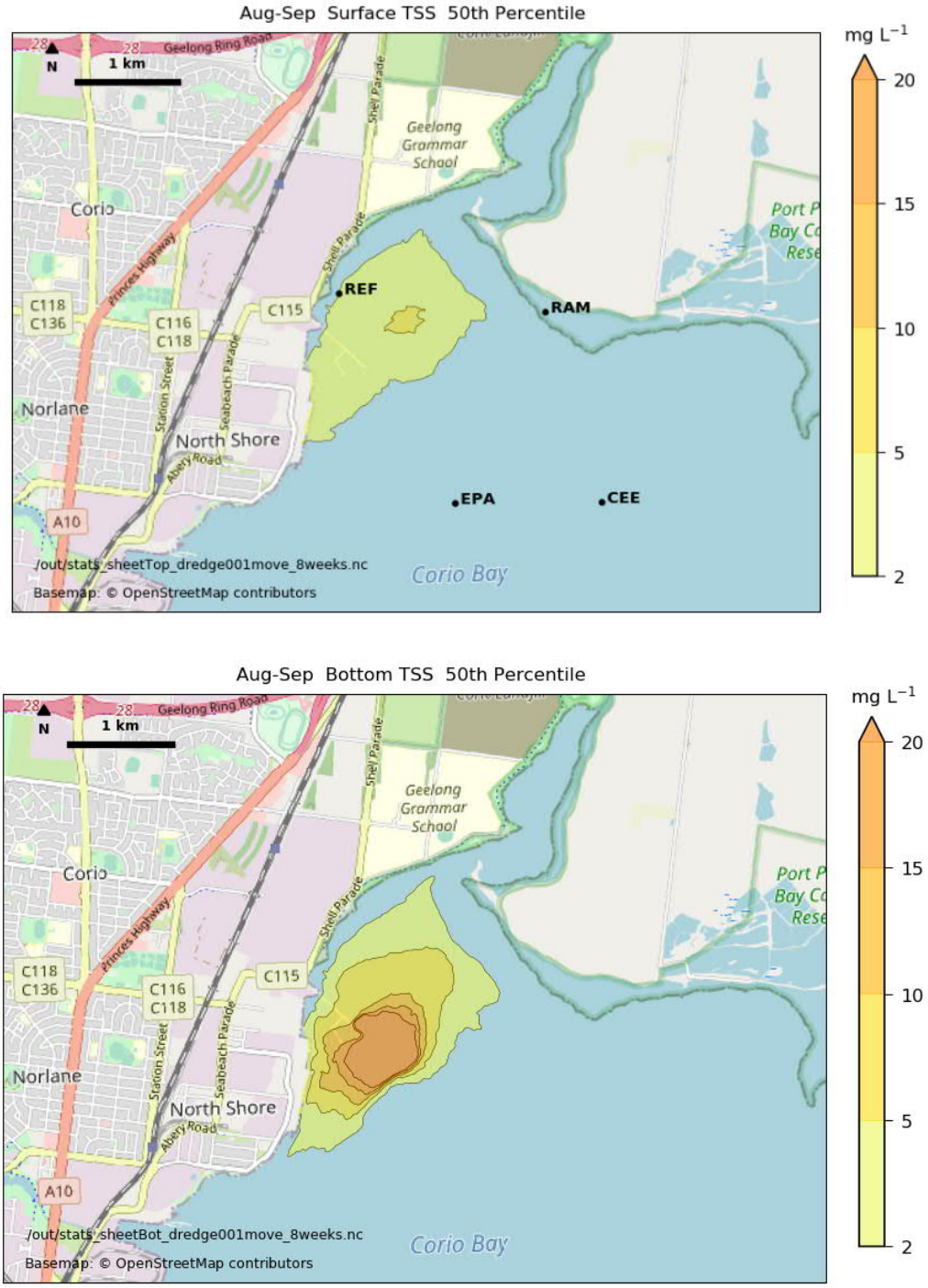


Figure 7-9. Median TSS Concentration at the Surface and Seabed-Aug-Sept

The time series of suspended solids concentration above background was modelled at four sites in Corio Bay (REF, RAM, EPA and CEE in the upper panel of Figure 7-9). The results for the Aug-Sept 2020 modelling period are shown in Figure 7-10. The refinery cooling water inlet site (REF) is close to the dredging area and would experience the highest SS concentrations. The blue line shows the predicted instantaneous SS concentration. About every 2 weeks, there is a pulse where the SS exceeds 10 mg/L and can be up to 20 mg/L. To attenuate these peaks entering the refinery cooling system, and to protect the adjacent seagrass, it is proposed to install a silt curtain between the dredging zone and the refinery seawater intake and

adjacent seagrass. The pink line shows that the 5-day moving average SS concentration is between 2 and 5 mg/L, with one event of up to 9 mg/L. The green line shows the 8-week average SS is 3.5 mg/L, corresponding to a turbidity increase of about 1.2 NTU.

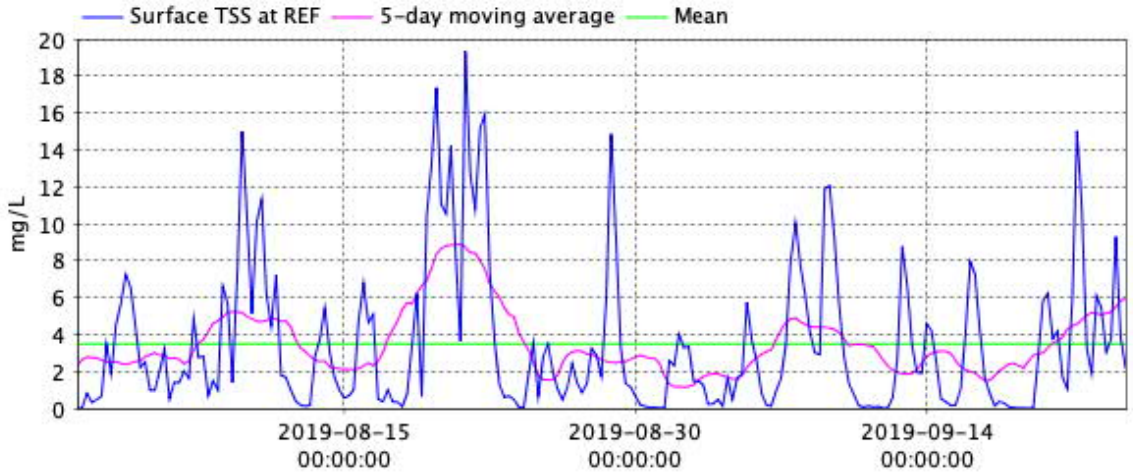


Figure 7-10. Time Series of TSS Concentration at Refinery Inlet – Aug-Sept

Figure 7-11 is the predicted time series of surface SS above background SS over the 8 weeks of dredging (if in Aug-Sept 2020) at the Ramsar site (RAM). The blue line shows the instantaneous SS concentration. Peak SS concentration is 12 mg/L for only a few hours. The pink line shows the 5-day moving average SS concentration, which ranges from 0 to 3 mg/L (peak of 1 NTU). The green line shows the 8-week average, which is less than 1 mg/L or less than 0.3 NTU. Turbidity increases at the Ramsar site are quite minor. The light attenuation coefficient will increase from 0.75 m-1 to 0.85 m-1 based on the 8-week average and up to 1.1 m-1 for the peak 5-days.

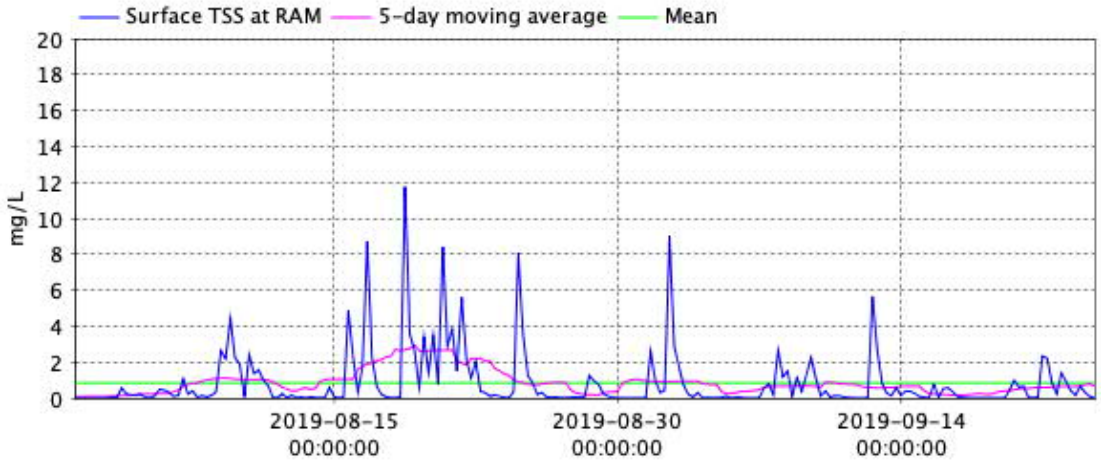


Figure 7-11. Time Series of TSS at Ramsar Site – Aug – Sept

Figure 7-12 is the predicted surface SS above background over the 8 weeks of dredging (if conducted in Aug-Sept 2020) at the EPA site (middle of north Corio Bay). The blue line shows the instantaneous SS concentration. Peak SS concentration is 4 mg/L for a few hours, with most concentrations below 2 mg/L. The pink line shows the 5-day moving average SS concentration ranges from 0 to 1 mg/L (peak of 0.3

NTU). The green line shows the 8-week average, which is under 1 mg/L or less than 0.3 NTU. Turbidity increases in the central part of north Corio Bay during the dredging period are quite minor. The increase in the light attenuation coefficient will be from 0.75 to 0.80 m-1 over the 8-week period and up to 0.87 m-1 for the peak 5-days.

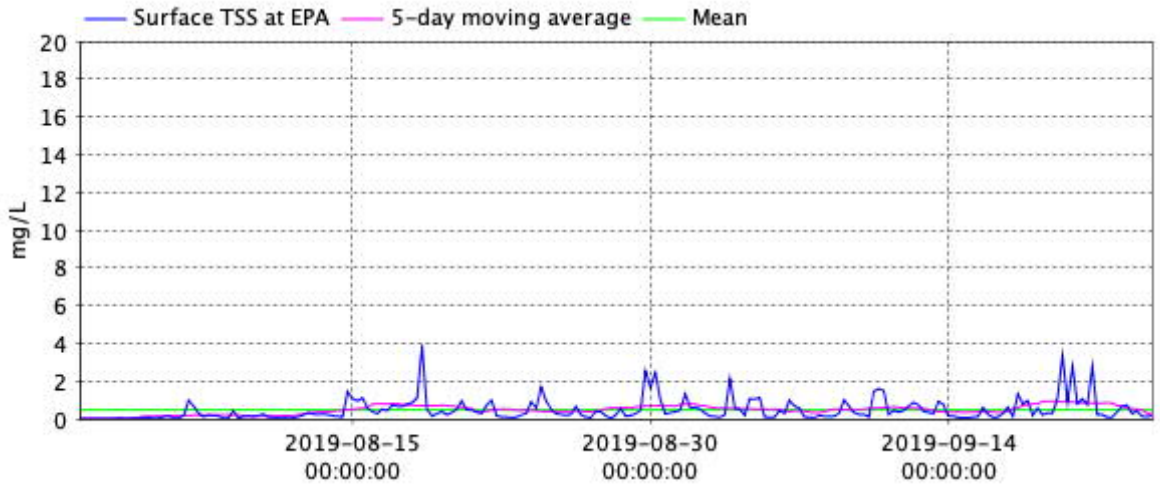


Figure 7-12. Time Series of TSS at North Corio Bay (EPA Site) – Aug – Sept

Figure 7-13 is the predicted time series of surface SS over the 8 weeks of dredging (if conducted in Aug-Sept 2020) at the CEE site (east of north Corio Bay). The blue line shows the instantaneous SS concentration. Peak SS concentration is 3 mg/L for a few hours. The pink line shows the 5-day moving average SS concentration, which is always less than 1 mg/L (peak of 0.3 NTU). The green line shows the 8-week average is 0.3 mg/L or around 0.1 NTU. Turbidity increases in the east Corio Bay are negligible.

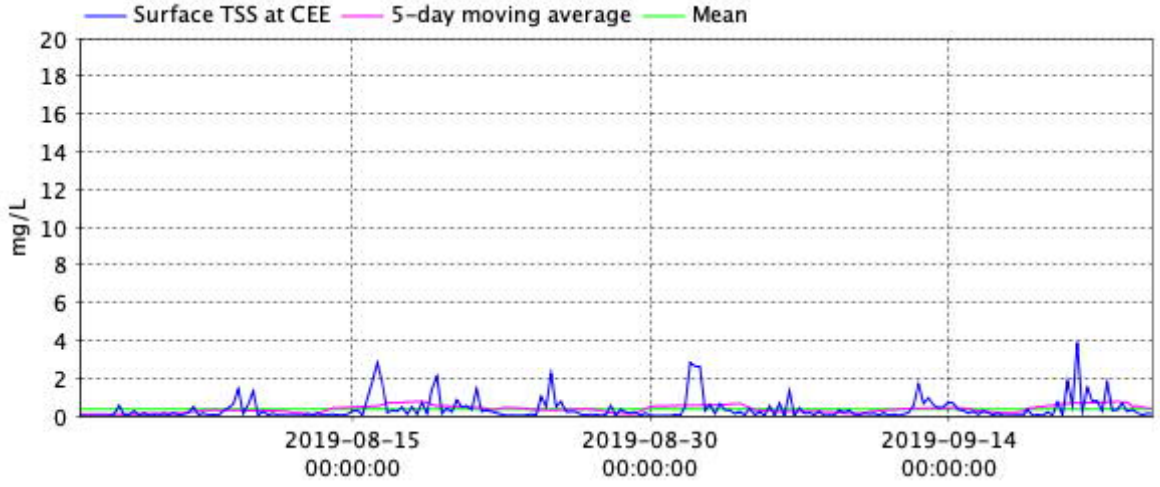


Figure 7-13. Time series of TSS at East Corio Bay (CEE Site) - Aug–Sept

In summary, the area of elevated suspended solids and turbidity is limited to the dredging zone and the surrounding area. The Ramsar site and central Corio Bay will have only a minor increase in turbidity. The increase in turbidity would be similar to that recorded in the 1996-1997 Corio Bay Channel Improvement Program.

November-December Simulation

To check the sensitivity of the results to seasonal conditions, a second 8-week simulation of dredging was run for **November-December 2020**. Figure 7-14 shows the median suspended solids (SS) concentration in north Corio Bay over this simulated 8 week dredging period. The median suspended solids concentration at the surface was always below 5 mg/L SS with a 135-ha patch of 2 mg/L SS above ambient. At the seabed, there are higher concentrations with a 25 ha patch of 20 mg/L SS and 240 ha of 2 mg/L SS above ambient.

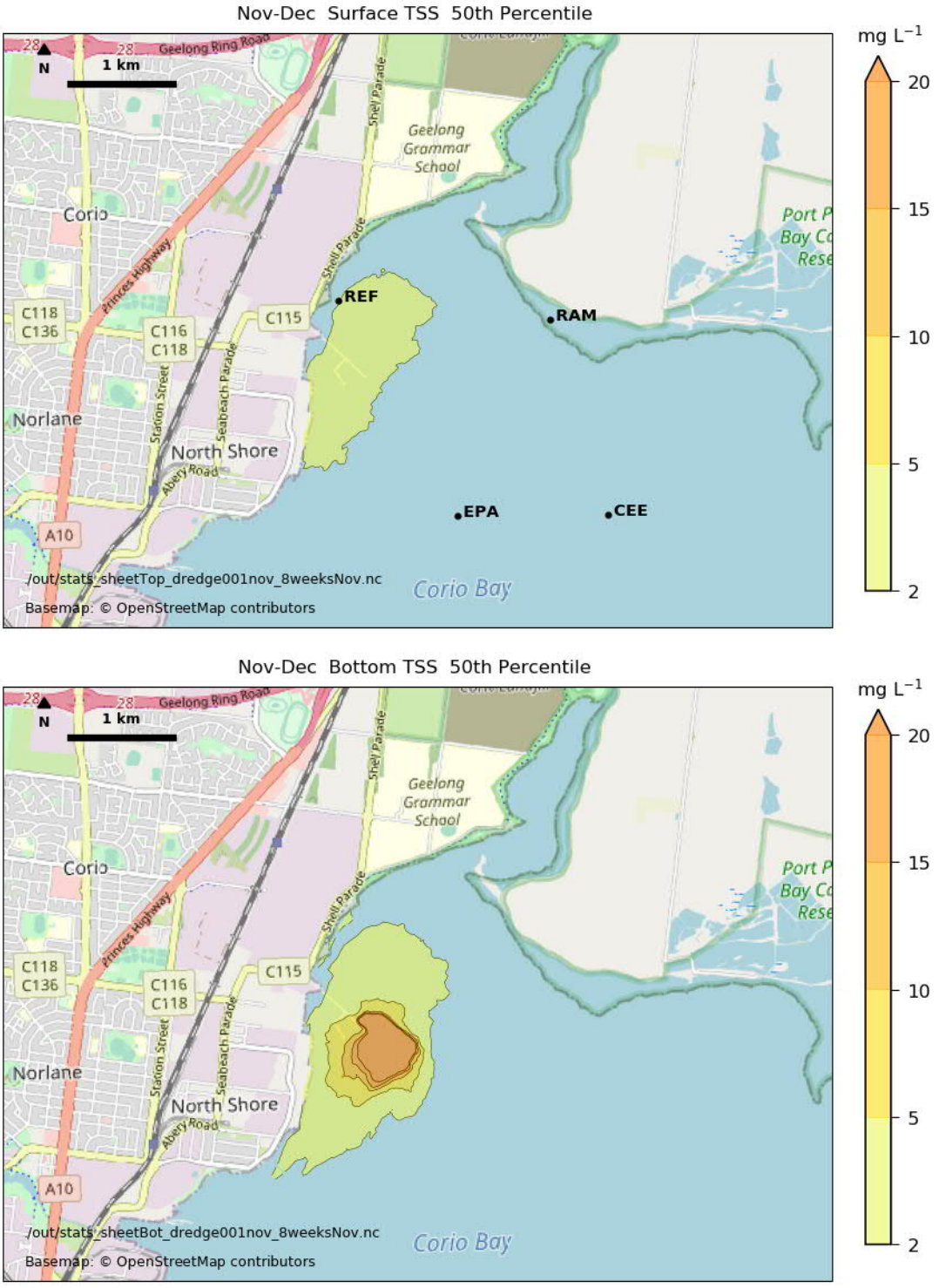


Figure 7-14. Median TSS Concentration at the Surface and Seabed – Nov-Dec

The time series of SS at the REF site at the refinery inlet over the 8 weeks of dredging (if conducted in Nov-Dec 2020) is shown in Figure 7-15. The refinery inlet is close to the dredging area and would experience elevated SS concentrations. The blue line shows the predicted instantaneous SS concentration. There are several events with SS concentration increasing above 15 mg/L. To attenuate these peaks extending into the refinery cooling system and the adjacent seagrass bed, it is proposed to install a silt curtain between the intake and the dredge area.

The pink line shows the 5-day moving average SS concentration which ranges between 1 and 8 mg/L. The green line shows the 8-week average which is 3.5 mg/L (the same as for the Aug-Sept period), corresponding to an increase in turbidity of about 1.2 NTU.

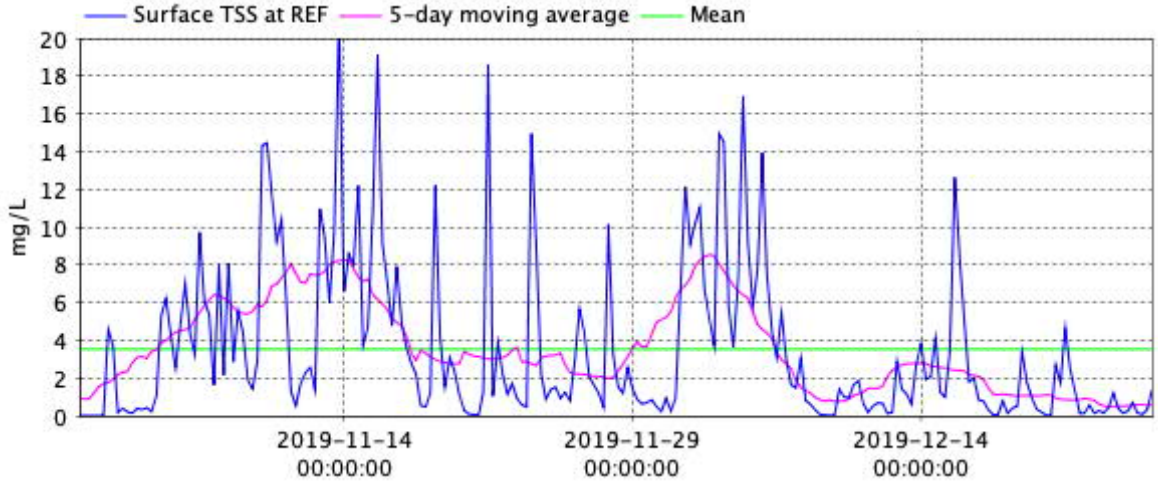


Figure 7-15. Time Series of TSS Concentration at Refinery Inlet – Nov-Dec

Figure 7-16 is the predicted time series of SS over the 8 weeks of dredging (if conducted in Nov-Dec 2020) at the Ramsar Site (RAM). The blue line shows the instantaneous SS concentration. Peak SS concentration is 9 mg/L for a few hours. The pink line shows the 5-day moving average SS concentration, which ranges from 0 to 2 mg/L (peak of 0.7 NTU). The green line shows the 8-week average, which is under 1 mg/L, or less than 0.3 NTU. SS and turbidity increases in the Ramsar site are minor, in relation to the background SS of 5 mg/L. The light attenuation coefficient would increase from 0.75 m-1 to 0.85 m-1 based on the 8-week average and up to 1.8 m-1 for the peak 5-days.

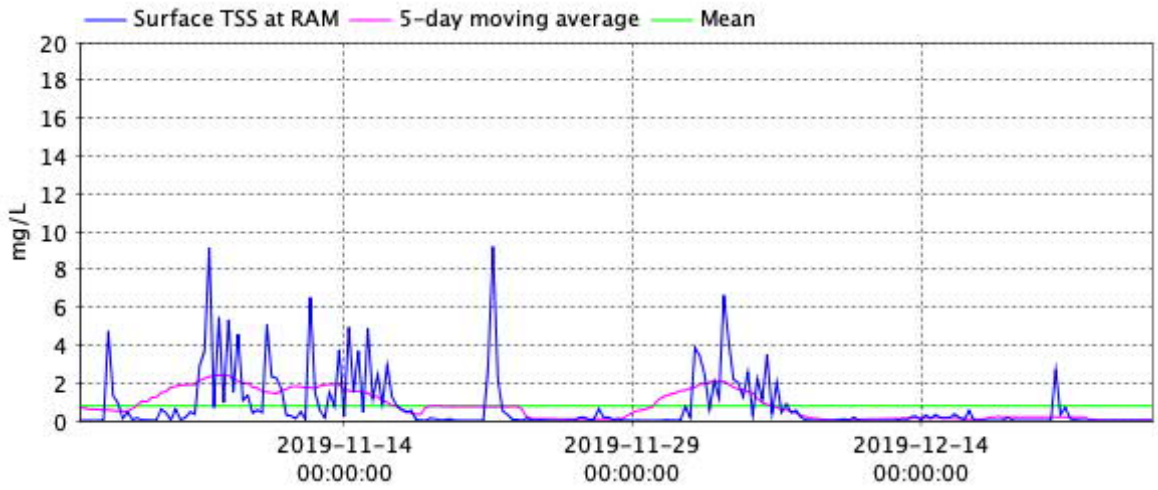


Figure 7-16. Time Series of TSS at Ramsar Site – Nov-Dec

Figure 7-17 is the predicted time series of surface SS over the 8 weeks of dredging (if conducted in Nov-Dec 2020) at the middle of north Corio Bay. The blue line shows the instantaneous SS concentration. Peak SS concentration is 6 mg/L for a few hours, with most concentrations below 2 mg/L. The pink line shows the 5-day moving average SS concentration, which ranges from 0 to 2 mg/L (peak of 0.6 NTU). The green line shows the 8-week average, which is under 1 mg/L or less than 0.3 NTU. Turbidity increases in the central part of north Corio Bay during the dredging period are minor. The increase in the light attenuation coefficient would be from 0.75 m-1 to 0.80 m-1 based on the 8-week average and up to 0.94 m-1 for the peak 5-days.

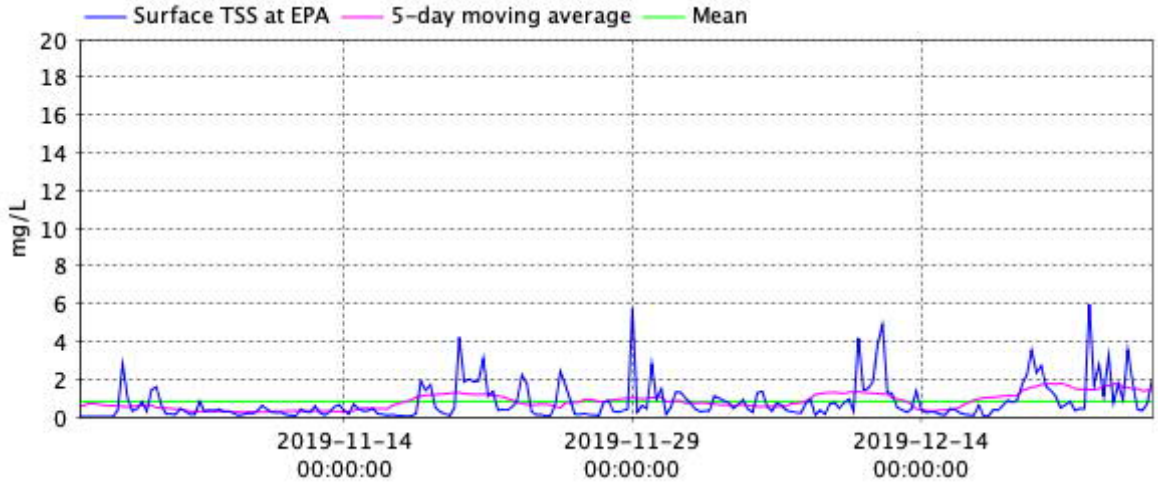


Figure 7-17. Time Series of TSS at North Corio Bay (EPA Site) – Nov-Dec

Figure 7-18 is the predicted time series of surface SS over the 8 weeks of dredging (if conducted in Nov-Dec 2020) at the CEE site (east of north Corio Bay). The blue line shows the instantaneous SS concentration. Peak SS concentration is 2.5 mg/L for a few hours. The pink line shows the 5-day moving average SS concentration, which is always less than 1 mg/L (peak of 0.3 NTU). The green line shows the 8-week average, which is 0.3 mg/L or around 0.1 NTU. Turbidity increases in east Corio Bay are

negligible.

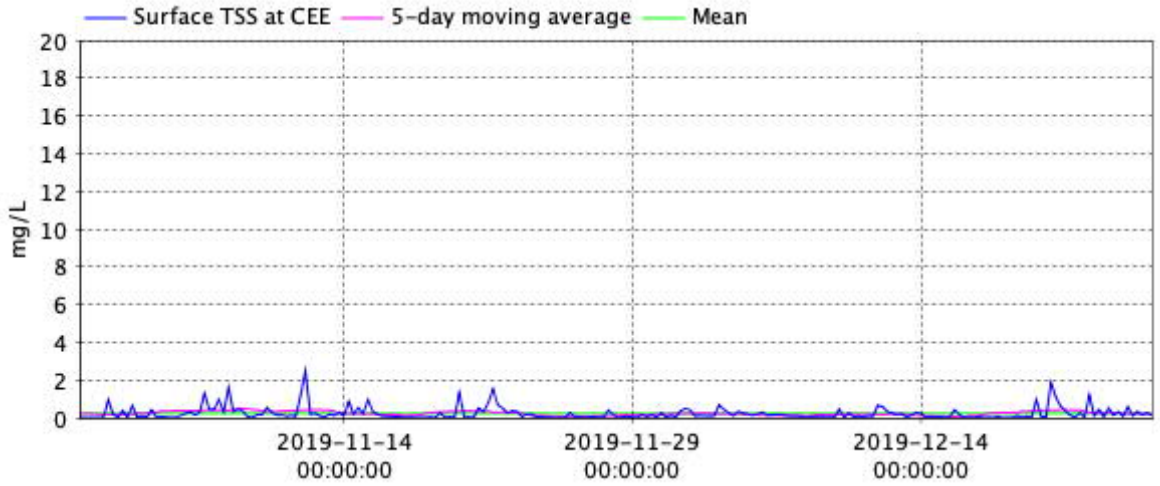


Figure 7-18. Time series of TSS at East Corio Bay (CEE Site) - Nov-Dec

Elevated suspended solids and turbidity are limited to the dredging area and nearby. The Ramsar site and central Corio Bay would have only a minor increase in turbidity.

7.11 Assessment of Change in Light Availability

The increment in SS in the surface waters near the proposed dredging is 5 mg/L over 5 ha. Using the relationship between SS and turbidity outlined in Section 5-5, this increase in SS corresponds to an increase in light attenuation of 0.75 m^{-1} which is twice the existing light attenuation rate in the Bay.

Figure 7-19 plots the percentage of surface light at depth for a range of light attenuation rates (k_d), from 0.3 m^{-1} to 1.5 m^{-1}.

For seagrass species such as *Zostera*, 5% of surface irradiance is required for survival though summer months (Bulthuis 1983). With a k_d value of around 0.75 m^{-1} the depth at which 5% of light will be reached is around 4 m (Figure 7-19). This matches with observed seagrass in Corio Bay which is dense at around the 2 m bathymetry contour and grows sparsely down to around 4 m depth.

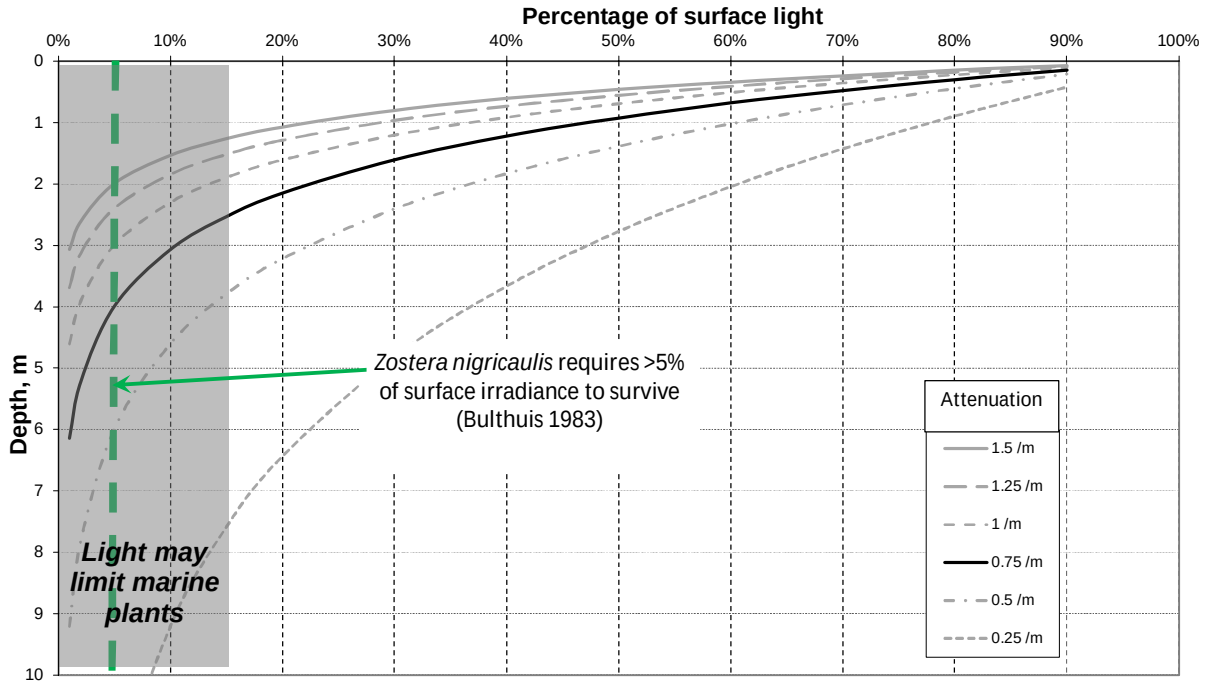


Figure 7-19. Available Light at Function of Depth and k_d Value

During the proposed 8-week dredging program, the light attenuation is predicted to increase in the 5 mg/L SS zones near the dredging site from 0.75 m^{-1} to 1.5 m^{-1} (as 0.75 x 2 = 1.5). During the period with dredging and higher light attenuation, the depth at which light reaches 5 % of incident light would be reduced to 2 m. The increase in turbidity and light attenuation would occur in an area of 160 ha and a loss in productivity of seagrass is expected in the shallow waters within this zone. If dredging occurs in summer or autumn, seagrass growth would slow considerably. There would be little effect in winter when seagrass is mostly dormant.

The settling rates used for silt and clay in the regional model (0.063 mm/s for clay and 0.8 mm/s for silt) would allow fine sediments remaining in the water column to settle out in 1 to 2 days, after dredging stops. Hence the light transmission will recover quickly to the original conditions after dredging ceases. Thus, seagrass recovery will begin shortly after completion of dredging.

As shown in the time-series SS plots, the suspended solids concentration from dredging at the seagrass beds is 2 to 3 mg/L, with occasional peaks up to 15 mg/L. The ambient SS in north Corio Bay averages 5 mg/L with peaks of 15 mg/L (see EPA Monitoring data for 2019). Thus, the dredging could double SS levels in a zone of about 160 ha over a period of 8 weeks. There would be a decrease in primary productivity, as assessed in Section 10. The predicted increase in suspended solids levels, and associated turbidity levels, are within the tolerance range of seagrass (Ref. Victorian Guidelines for Dredging). If the dredging occurs in winter, there will be minor effects on seagrass and algae, as this is the dormant period.

The settling rates used for silt and clay in the regional model (0.063 mm/s for clay and 0.8 mm/s for silt) would allow fine sediments remaining in the water column to settle out in 1 to 2 days for clays (0.063 mm/s = 5.4 m/day) and 3 hours for silt (0.8 mm/s = 2.9 m/hr), after dredging stops. Hence the light transmission will recover quickly to the original conditions after dredging ceases. Thus, seagrass recovery will begin

shortly after completion of dredging. There is more rapid clearing of surface water turbidity at the spoil disposal site because the discharge is at 4 m depth from the barge (refer to Section 7-16).

7.12 Impact Assessment of Change in Turbidity

Figure 7-20 shows the 50th percentile surface TSS concentrations in the August – September model. The light brown area on the 5 m depth contour represents TSS of 5 mg/L while the larger grey area represents TSS of 2 mg/L. The green zones on the map indicate areas that have dense seagrass – all of these zones are inshore of the 2 m depth contour. These zones have been confirmed through a combination of towed camera images, aerial imagery and field observations.

It can be seen that the area of predicted 5 mg/L SS does not extend over any seagrass. The area of predicted 2 mg/L SS extends over a 6 ha patch of seagrass. Note that the use of a silt curtain, a recommended mitigation measure, would reduce the SS concentration at this patch of seagrass, and adjacent seagrass along the shoreline.



Figure 7-20. Comparison of Suspended Solids Contour and Seagrass Beds

The Corio Bay Channel Improvement Program involved dredging approximately 510,000 m^3 of sediment from Refinery Pier, the Corio Bay channel bend and the Point Henry swing basin. A relationship between turbidity (T) and suspended solids (SS) was developed in the monitoring which was:

T = 0.33 x TSS (where T is in NTU and TSS in mg/L)

Using that relationship, the predicted SS concentrations listed above and established in monitoring programs can be converted to predicted turbidity. The background SS

used for the impact assessment is an average TSS of 5 mg/L and a peak of around 15 mg/L. This matches EPA SS data for Corio Bay in 2019 of an average SS of 5 mg/L and a peak of 14 mg/L in August 2019 and 19 mg/L in December 2019.

The corresponding background or ambient turbidity is an average of 1.7 NTU and a peak of 5 to 6 NTU.

The August - September predictions of surface SS show a 5ha area exceeding 5 mg/L, corresponding to a local turbidity increase of 1.7 to 2 NTU (in the zone near the port area, as depicted in Figure 7-29).

The November - December predictions of surface SS show no zone exceeding 5 mg/L but a 210ha area exceeding 2 mg/L, corresponding to a turbidity increase of 0.7 NTU (in a large part of north Corio Bay for a period of 8 weeks).

The predictions for the Ramsar site show 5-day average concentrations corresponding to a turbidity increase of 1 to 2.7 NTU, and peak turbidity values of 4 to 5 NTU.

Thus, the dredging could double surface turbidity is a small zone (about 5 ha) with a 30% increase in turbidity for 8-weeks over 210 ha and double SS levels in a zone of about 160 ha over a period of 8 weeks. There would be a decrease in primary productivity, as assessed in Section 10. The predicted increase in suspended solids levels, and associated turbidity levels, are within the tolerance range of seagrass (Ref. Victorian Guidelines for Dredging). If the dredging occurs in winter, there will be minor effects on seagrass and algae, as this is the dormant period.

Compare Turbidity Predictions with Previous Measurements

Monitoring by Lawson and Treloar (1998) for the Corio Bay Channel Improvement Program showed the following results for average turbidity in Corio Bay:

- Pre-dredging turbidity = 0.4 to 1.2 NTU (23 surveys)
- During dredging turbidity = 0.5 to 2.5 NTU (19 surveys); and
- Post-dredging turbidity = 0.4 to 1.0 NTU (7 surveys).

These results show an average turbidity increase of 0.1 to 1.3 NTU, which is similar to (but slightly smaller than) the predicted turbidity increase in north Corio Bay of a local turbidity increase of 1.7 to 2 NTU.

Monitoring reported by the Port of Melbourne during the Williamstown Channel dredging in 2008 showed an increase from background of 2 NTU to a peak of 22 NTU for a day during dredging, and then an exponential decline back to 2 NTU over the following four days. The Williamstown Channel is more confined than Corio Bay and the measured peak is higher than for Corio Bay; the average increment is the same.

Cardno (2011) reported on monitoring discharge of sediment from a hopper barge at the dredge spoil disposal site. Highest recorded turbidity was 6 NTU at the surface. This value is similar to the peak of 7 NTU predicted for this project (see Section 7-13).

Monitoring of Corio Bay by NSR in 1997 showed that, prior to dredging, the turbidity was 0.7 NTU (in calm conditions) to 2 NTU (after a storm). During dredging, the turbidity averaged 1 NTU, which was only slightly elevated above the background.

Conclusion

The monitoring results from previous dredging programs show similar turbidity values to the values predicted by the modelling described above. It is concluded that the model predictions provide a valid basis for assessing the impacts of dredging.

7.13 Accretion of Solids on the Seabed

The suspended solids resulting from the proposed dredging would settle and accrete on the seabed. Settling of sediments is simulated by the AEM3D model using inert particles with a defined size range, density and settling velocity.

Resuspension of settled particles is calculated from bottom shear stress (above a critical shear stress) and the particle density. Once the critical shear stress for resuspension has been reached and the material lifts from the bed, the erosion rate is calculated using the Bengtsson et al. (1990) erosion equation in $g/m^2/day$. Because of the weak currents in Corio Bay, and the cohesion and flocculation of the predominant clay material, it was found that the rate of resuspension in Corio Bay was very small.

Figure 7-21 shows the increment in seabed elevation due to sedimentation in the August – September period. Highest accretion (of 20 mm in 8 weeks) occurs on the seabed in the area dredged but this is of no significance, as the bed would be dredged down to the defined depth.

Lower accretion rates of 2 to 10 mm in 8 weeks would occur in north Corio Bay over a large area surrounding the dredging zone. This rate of accretion (0.04 mm/day to 0.2 mm/day) would have negligible impact on the muddy seabed and the infauna or mobile marine communities that inhabit the muddy seabed. This seabed is generally bare of surface-dwelling biota except for microscopic algae (microphytobenthos or ‘MPB’), patches of ephemeral unattached filamentous macroalgae and sparsely distributed fan worms *Sabella Spallanzani* (an introduced species).

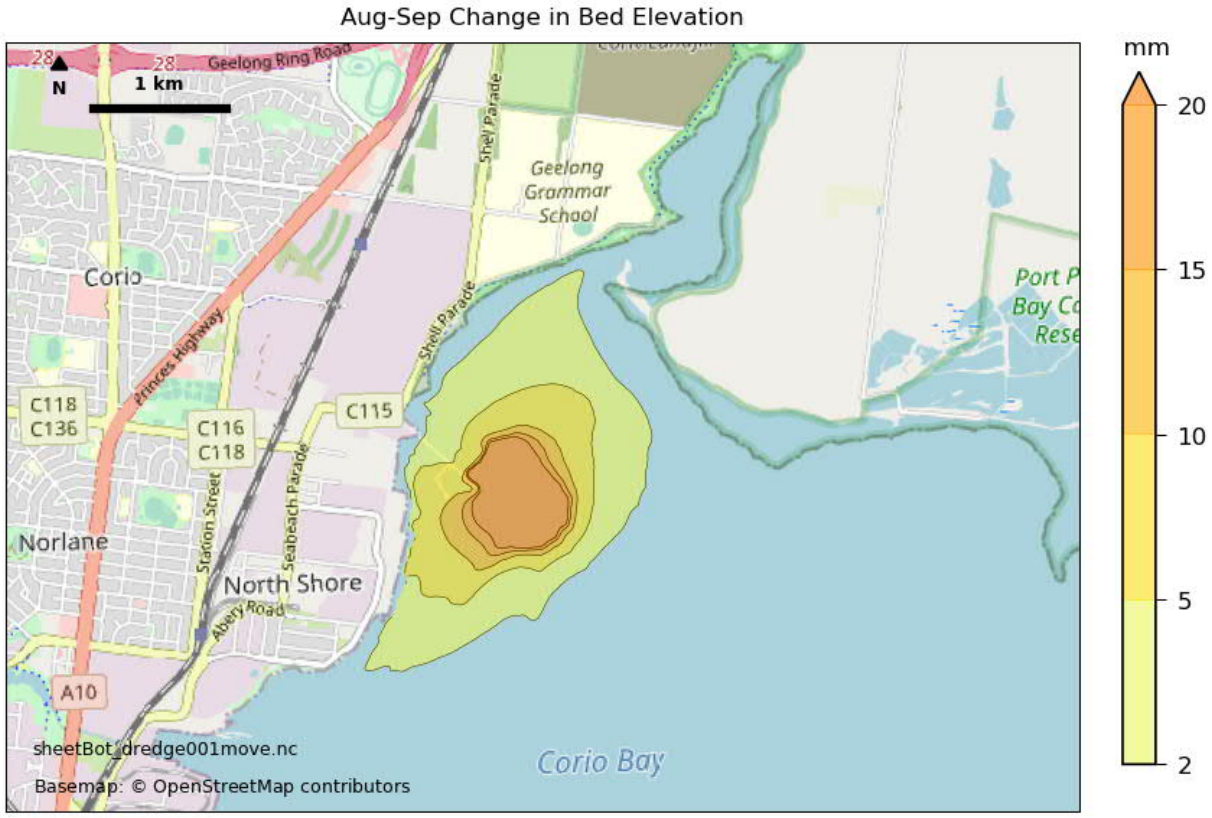


Figure 7-21. Increment in Seabed Elevation in 8 weeks of dredging in Aug-Sep

Infauna monitoring for the project demonstrated that the sediments of Corio Bay contain large numbers of bioturbating polychaetes, crustaceans, echinoderms and bivalves. Approximately 90 % of the infauna in samples from the dredging area are deposit feeders, that sift through the surface layer of sediment to find organic materials that suit their tastes. Deposit feeding infauna are capable of burrowing through 0.1 to 10 cm^3 of sediment per hour (Gingras et al,) to a depth of 10 to 50 mm per day.

The additional deposition of suspended material from dredging (0.04 mm/day to 0.2 mm/day) represents a very small proportion of the daily volume of sediments disturbed (bioturbed) by the deposit feeders through the sediments over a day.

Figure 7-22 shows the increment in seabed elevation due to sedimentation in the Nov-Dec modelled simulation period. The rate and extent of accretion is similar to that in the Aug-Sept simulation. Highest accretion (of 10 to 20 mm in 8 weeks) occurs in the area dredged. Lower accretion rates of 0.04 mm/day to 0.2 mm/day would occur in north Corio Bay over a large area surrounding the dredging zone. This rate of accretion would have negligible impact on the muddy seabed and the infauna or mobile marine communities that inhabit muddy seabed, as outlined above.

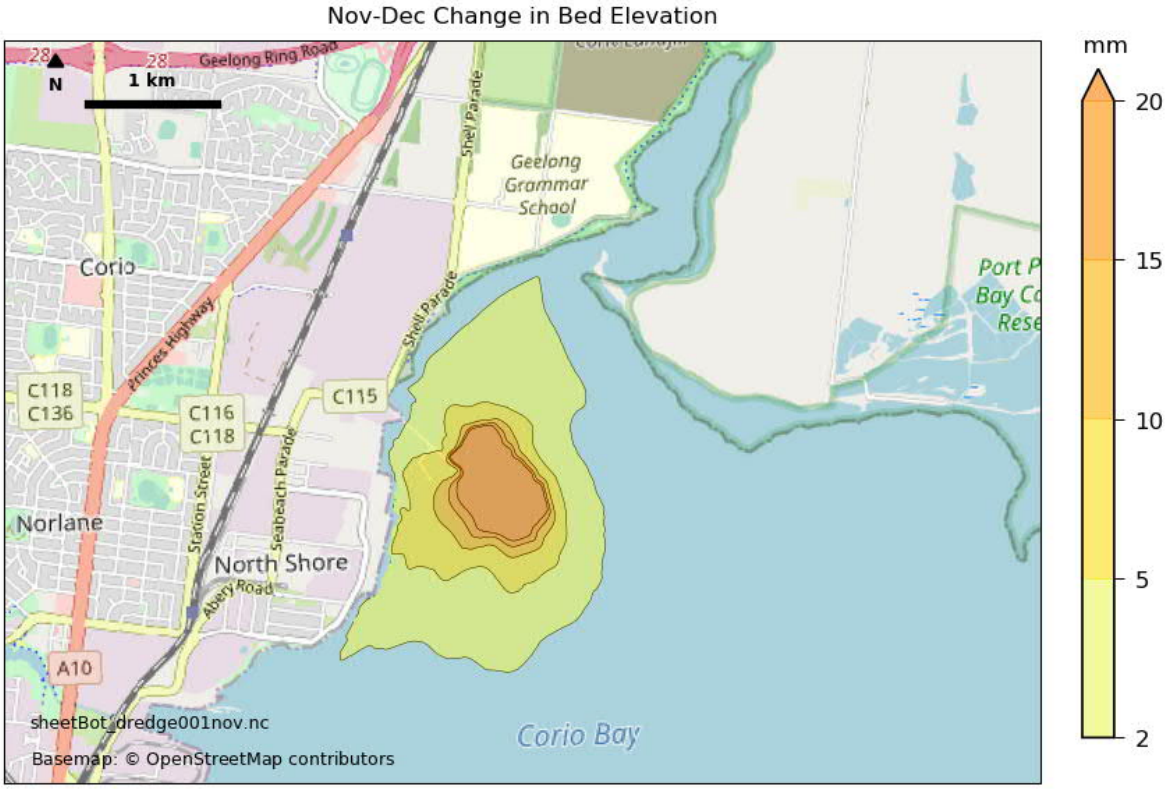


Figure 7-22. Increment in Seabed Elevation in 8 weeks of dredging in Nov-Dec

The accretion rate on seagrass beds is from zero to 3 mm, which is expected to have negligible to very minor impact as seagrass naturally traps and accumulates sediment with sedimentation rates up to 20 mm/yr (Cabaco et al., 2008) and 31 mm/yr (Potouroglou et al., 2017). With the low range of sedimentation expected from the proposed dredging (generally under 10 mm/yr outside the dredging activity zone), the accumulation of sediment containing nitrogen and accompanied by dissolved oxygen, is positive for the growth of seagrass (NIWA, 2004). Thus, the sedimentation rates shown in Figure 7-18 are expected to have negligible impact on seagrass beds as they are located beyond the 5 mm accretion zone.

7.14 Suspended Solids at Dredge Spoil Disposal Site

The dredged sediment from the project would be discharged from split hopper barges at the dredge spoil disposal site 8 km east of Point Wilson on six occasions per day (average discharge rate of 1,500 m^3/barge). The regional model was used to simulate the dispersion and settlement of the spilled material at the dredge spoil disposal site.

If the barge is travelling slowly, the amount lost in the water column would be 50 t, with the majority of the sediment falling to the seabed. If the barge is travelling faster, the amount lost in the water column would be 66 t.

Figure 7-23 shows the 90-percentile suspended solids (SS) concentration just above the seabed at the dredge spoil disposal site for the slow barge option. At the seabed, there would be a plume along the barge track with elevated SS concentrations (up to 20 mg/L) and a larger patch with low SS concentrations. At the surface, there would be very little SS and it would return to ambient conditions in approximately one hour after release as most of the discharge is at 4 m depth, under the barge.



Figure 7-23. 90-Percentile TSS Concentration at the Seabed - Slow Barge

Figure 7-24 shows the median suspended solids (SS) concentration on the seabed at the dredge spoil disposal site for the fast barge option, which involves a larger release of sediment over a longer track. The outcome is similar to the slow barge situation. At the seabed, there would be a long plume along the barge track with elevated SS concentrations and a larger patch with low SS concentrations. At the surface, there would be very little SS and it would return to ambient conditions approximately an hour after release. Two turbidity monitoring sites will measure the extent of turbidity.

Overall, the plumes of elevated SS concentration extend from the base of the barge (about 4 m below sea level) to a muddy seabed. The localised plumes in the water column constitute a local impact on phytoplankton, but are small in the context of the area of the Geelong Arm, and would have periods of clear water as well as turbid water each day. Thus, the environmental effects would be minor and localised.

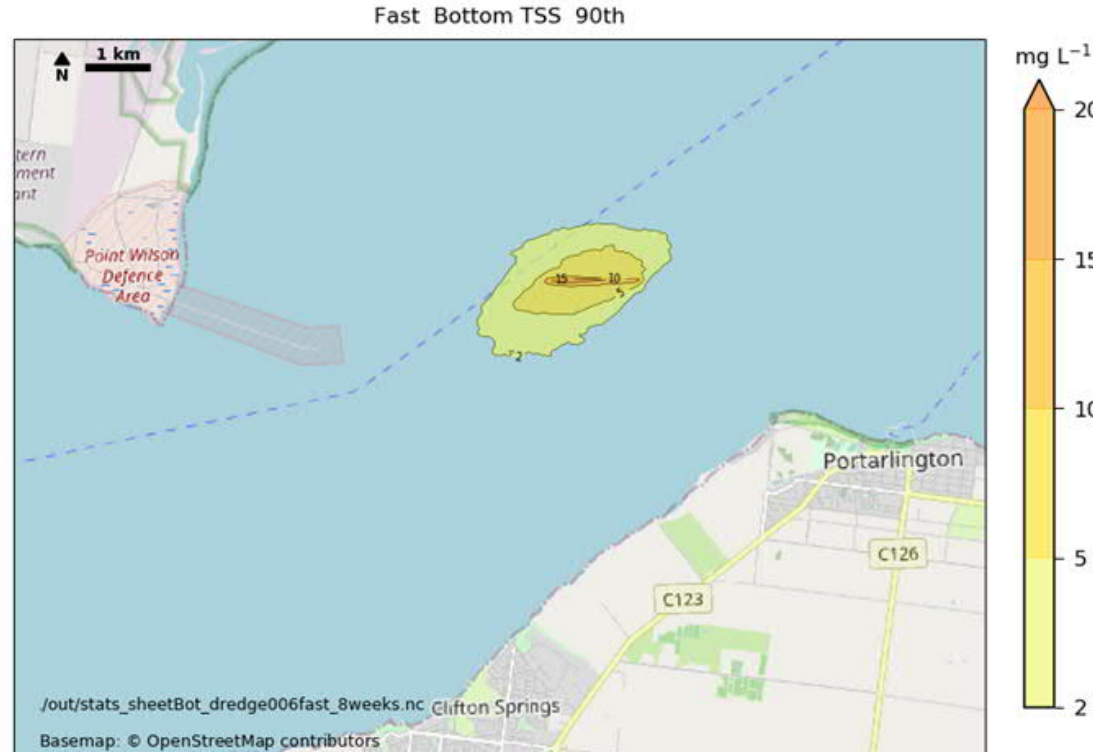


Figure 7-24. 90-percentile Concentration at the Seabed – Fast Barge

Figure 7-25 shows the change in seabed elevation due to the settling of spilled material at the dredge spoil disposal site for the fast barge option. The maximum accumulation is 20 mm which is small in relation to the 400 to 500 mm added from the proposed spoil disposal from the project. The seabed communities would recover within 6 months.

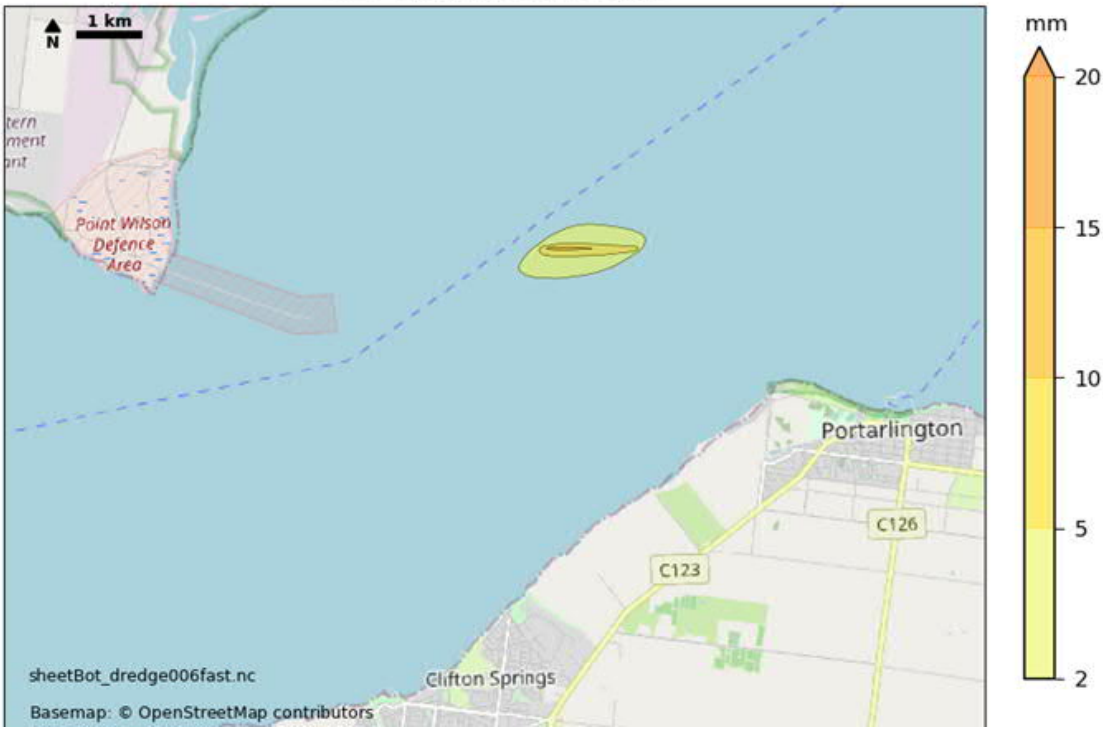


Figure 7-25. Change in Seabed Elevation after 8 Weeks with Fast Barge

7.15 Assessment of Mobilisation of Contaminants

Sediments, particularly when surrounded by urban and industrial areas, can contain elevated levels of contaminants. A detailed assessment was made of a wide range of contaminants in sediments (including metals, polycyclic aromatic hydrocarbons, organochlorine pesticides, polychlorinated biphenyls and petroleum hydrocarbons) in the Corio Bay sediments was made by Coffey (2020) and AECOM (2021) as part of the assessment of appropriate dredge spoil disposal sites. This section summarises the levels of metals in dredged sediments and assesses the environmental implications.

Metals in sediments are derived from normal geological weathering processes on land and in the sea, runoff from urban and rural zones and discharges or spills from industries and vessels.

The *National Assessment Guidelines for Dredging* (NAGD - Commonwealth of Australia, 2009) provides guidance on the assessment and management of dredged material to protect the marine environment from pollution caused by dumping dredge spoil at sea. This is to meet the requirements of the following Commonwealth Acts:

- Environment Protection (Sea Dumping) Act 1981.
- Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

The NAGD sets out five phases in the assessment of potential contaminants:

- Phase I – Evaluation of existing information;
- Phase II – Sampling and analysis of sediments;
- Phase III – Elutriate and bioavailability testing;
- Phase VI – Toxicity and bioaccumulation testing; and
- Phase V – Weight of evidence assessment.

Early work undertaken for the project by Coffey in 2020 (Coffey, 2020) reviewed existing information (Phase I) and described the sampling and analysis of sediments in the area where dredging is proposed (Phase II) as well as results from elutriate testing (Phase III). Further sediment samples were collected in 2021 and a contaminant risk analysis undertaken by AECOM (AECOM, 2021). Both sets of analyses of contamination are summarised in this Section.

Historical Extent of Contamination of Seabed in Corio Bay

Between 1983 and 1986, Fabris and colleagues at the Marine Science Laboratory conducted comprehensive studies of the contamination of Port Phillip and Corio Bay sediments and marine life, and assessed the toxicity risk. The findings were presented in a series of laboratory reports.

A subsequent publication by Phillips, Richardson, Murray and Fabris (1992) provided contour plots of metal concentrations in Corio Bay sediments. These plots are reproduced in Figure 7-26.

Metal contamination is widespread in Corio Bay. Higher concentrations for some metals occur close to historical inputs along the urban western shore (eg, cadmium, chromium, copper, zinc), while inputs from the broader catchment via Hovells Creek also are apparent (eg, cadmium, cobalt and vanadium).

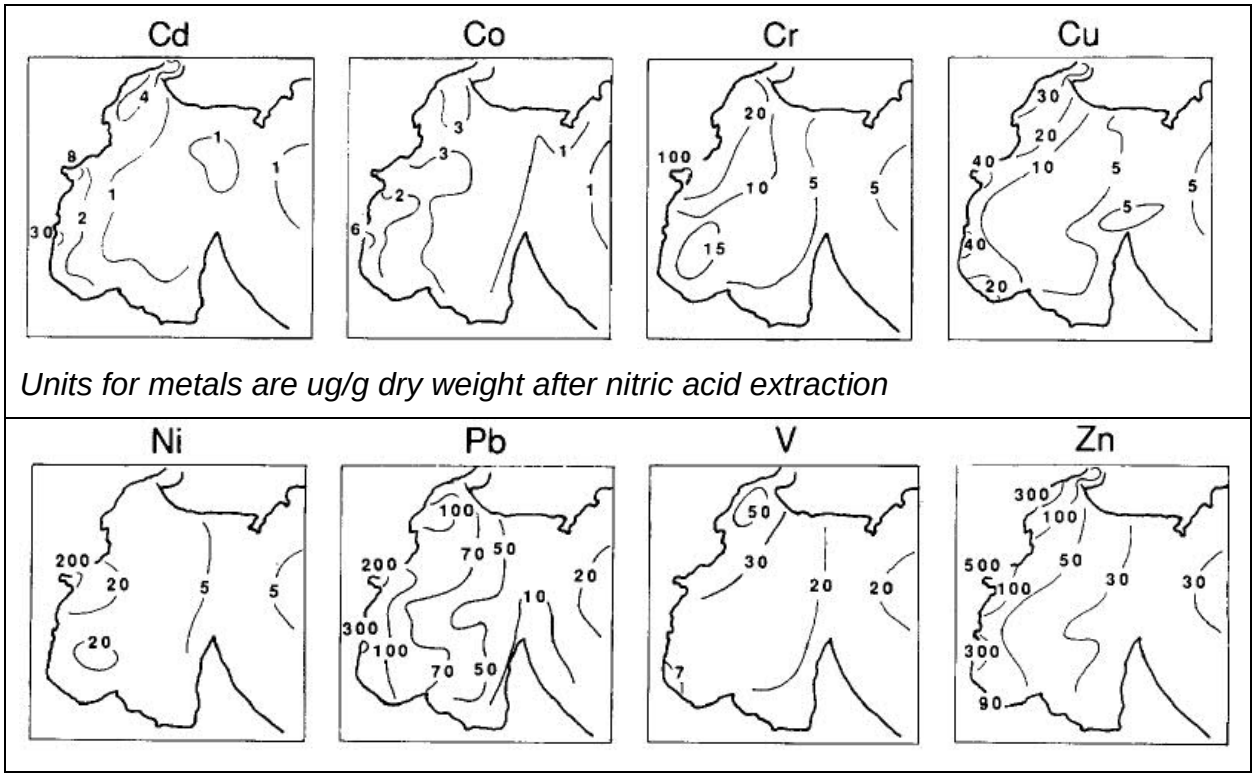


Figure 7-26. Metal Concentration in Corio Bay Sediments

Limits for Sediment Contamination by Metals

Limits for sediment contamination by metals are listed in the NAGD including the conservative screening guideline values (GV) and upper guideline values (high GV) as indicators of potential toxicity problems.

The screening sampling involved collection of 20 sediment samples in the top 1 m ofg the seabed in the proposed dredging area. This was undertaken to assess the contamination status of the top sediment layer which was considered likely to have higher levels of contamination than deeper sediment layers.

The sediment samples were analysed by Coffey for metals, organotins, TPH, BTEX, PAHs, organophosphorous and organochlorine pesticides, TOC, PSD and acid sulfate soil parameters. Table 7-5 compares the measured 95-percentile sediment concentrations of metals in the top 1 m of sediment to the NAGD screening GV.

The screening comparison identified that lead, mercury and nickel exceeded the NADG screening GV. Concentrations of TBT, TPH and PAHs detected in sediment samples were below the sediment GV.

Further sampling and analysis over the full depth of dredging was undertaken by Coffey to assess the bioavailability (potential for uptake of contaminants by marine life) of lead, mercury and nickel in dredged sediment. The results were the same as for the top layer.

Table 7-5. Screening Assessment of Metals in Sediment - Coffey

COPC	NAGD sediment guideline value (screening level)	Sediment concentration (mg/kg)	
		95% UCL (0 – 0.5 m)	95% UCL (0.5 – 1.0m)
Arsenic	20	16.2	18.3
Cadmium	1.5	0.6	1.0
Chromium	80	41.3	43.8
Copper	65	17	14
Lead	50	75	95
Mercury	0.15	0.22	0.21
Nickel	21	22.9	25.5
Silver	1	0.8	<0.1
Zinc	200	80.5	65.0
TBT (µg/kg)	9	0.5	0.5
TPH	550	175	267
PAHs (total)	10	0.40	0.33

Source: Coffey, 2000, Table 5-1

Arsenic and Nickel

Concentrations of arsenic and nickel were similar in all sediment layers indicating that the concentrations represent naturally occurring background levels and are not indicative of contamination.

Cadmium and Antimony

Concentrations of antimony and cadmium were generally below the GV, with only occasional results in the shallow marine sediments (Layer 1a) above the GV. The 95% upper confidence limit (UCL) concentrations determined for antimony and cadmium did not exceed the GV.

Lead and Mercury

Lead and mercury were detected at concentrations above the GV in most of the shallow samples (Layer 1a). The 95 % concentrations for both of these analytes also exceeded the GV in this layer. A single sample from the deeper, stiff clay marine sediments had concentrations of lead and mercury above the trigger values, but the 95 % concentration met the GV.

Other metals

Chromium, copper, selenium, silver and zinc were detected in sediment samples but the maximum concentrations were below the GV in all three sediment layers.

Comparison with 1992 Sediment Analysis

The 95 % UCL contaminant concentrations in the surface layer in Table 7-5 were compared to the earlier contaminant concentrations shown in Figure 7-26. There was little change in concentrations in the area of Refinery Pier, although it was

expected that lead concentrations near stormwater outlets would have decreased due to the introduction of unleaded petrol.

Comparison of Dredging Area and Dredge Spoil Disposal Ground

As noted earlier, the particle size distribution at the proposed dredging site and the dredge spoil disposal site are very similar, being approximately equal proportions of clay, silt and sand. This reflects the fact that the sediment layer in the dredge spoil disposal site constitutes sediment that has previously been dredged from Corio Bay and deposited at that site.

AECOM collected 6 sediment samples at the dredge spoil disposal site and compared the contaminant levels to 55 sediment samples from the dredging site. The median contaminant levels were very similar, which demonstrates that disposal of the dredged material will not increase contamination at the dredge spoil disposal site.

Elutriation Tests - Coffey

Elutriate tests (Phase 3) were undertaken by Coffey to assess the quantity of metals that could be dissolved in seawater. They were carried out on 15 sediment samples (14 from layer 1a and one from layer 1b) using seawater collected at the sampling site. The elutriate testing results for lead, mercury and nickel were compared to the trigger values for marine ecosystems (95% protection level) from ANZG 2018. The results from the elutriate testing are summarised in **Table 7-6**.

Table 7-6. Elutriate Test Results for Lead, Mercury and Nickel

COPC	Trigger value for 95% species protection – marine (ANZG, 2018) (µg/L)	Elutriate range (µg/L) *(number of results exceeding trigger value)*	Elutriate 95% UCL (µg/L)	Site seawater range (µg/L)
		18 samples	18 samples	2 samples
Lead (Pb)	4.4	1 - 7 *(1)*	2.2	<1
Mercury (Hg)	0.4	0.1	NC	0.1
Nickel (Ni)	70	1 - 22	NC	1 - 2

Lead was detected above the trigger value in one elutriate sample, however the 95 % concentration was below the trigger value. The concentrations of mercury and nickel were below the trigger value in all elutriate and seawater samples.

Based on the sequence of contamination testing, it was considered by Coffey that the dredged sediment is suitable for disposal at the proposed dredge spoil disposal site 8 km east of Point Wilson.

Assessment by AECOM

Technical Report B: *Dredged sediment disposal options assessment* made a more detailed evaluation of whether sediment from the dredging area is suitable for disposal at the existing Point Wilson Disposal Ground in accordance with NAGD (2009) assessment guidelines.

Fieldwork was conducted by AECOM in August-September 2021 to collect sediment, pore water and seawater samples from the Loading Site, Disposal Ground and ambient baseline in accordance with a *Sampling, Analysis and Quality Plan* (AECOM, 2021). Data generated from this 2021 fieldwork was combined with data reported by

Coffey (2020) and AMA (2020) as all three data sets were required to satisfy the NAGD (2009) assessment and reporting requirements.

The NAGD (2009) sets out a staged method for assessing potential contaminant impacts during dredging and disposal activities that may pose risks to ecological receptors. While initial results from the sediment sampling identified some chemical concentrations that exceeded the assessment criteria, further tests were carried out in accordance with the NAGD (2009) staged approach to examine the potential toxicity to ecological receptors. These further test results identified no potential adverse impacts to ecological receptors at both the dredging site or the spoil disposal site.

AECOM drew the following conclusions regarding the existing sediment conditions at the Loading Site (dredging site), Disposal Ground and ambient baseline locations in Corio Bay:

1. The physical characteristics of the dredging site and the spoil disposal site are generally very similar. The seabed around the perimeter of the spoil disposal site also has clay and silt, but a higher percentage of fine sands.
2. Sediments at the dredging site have 95% concentrations (UCL) and/or mean concentrations that exceed the default guideline value (DGV) for antimony, arsenic, lead, mercury and nickel. The 95-percentile results for the surface layer at the dredging site are listed in Table 7-7.

Table 7-7. Sediment Contamination at Dredging Site - Domain 1a

COPC	95 % UCL AECOM, mg/kg	95 % UCL< Coffey and AMA, mg/kg	DGV, mg/kg
Antimony	1.89	1.56	2
Arsenic	13.9	15.9	20
Cadmium	0.87	0.86	1.5
Chromium	37	46	80
Copper	25	20	65
Lead	**74**	**72**	50
Mercury	**0.32**	**0.27**	0.15
Monobutyltin as Sn	--	1.31	-
Nickel	21	**25**	21
Silver	--	0.11	1
Tributyltin as Sn	--	0.0006	0.009
Zinc	73	77	200
PFOS (1%TO)	0.00023	0.00042	0.06
PAHs (1% TOC)	0.163	0.249	10

Table Notes Bold and green highlight = exceeds DGV

3. Sediment elutriate analyses were then carried out for the metals exceeding the DGV in the AECOM tests. The mean elutriate concentrations were below the

DGV indicating a low potential for bioavailability (and hence ecotoxicity) to marine biota. The results for the elutriation tests are listed in Table 7-8.

Table 7-8. Sediment Elutriation Test Results

COPC	Maximum Conc. (mg/L) AECOM (2021)	Maximum Conc. (mg/L) Coffey (2020)	Mean[3] Conc. (mg/L) Combined Data	Mean Seawater Conc. (mg/L)	DGV (mg/L, unless otherwise specified)
Arsenic	**0.019**	0.01	0.0044	0.003	0.0125
Lead	0.001	0.007	0.0006	<0.001	0.0044
Mercury	<0.00005	<0.0001	-	<0.00005	0.0004
Nickel	0.005	0.022	0.002	0.07	0.07
PFOS µg/L	0.0099	0.006	0.004	0.002	0.00023

Table Notes Bold and green highlight = exceeds DGV

4. The maximum arsenic concentration marginally exceeds the DGV in the AECOM dataset from sediment samples collected at four seabed locations. However, the mean arsenic concentration over both elutriate data sets does not exceed the DGV.
5. Silver and zinc elutriate concentrations were above the DGV in the Coffey (2020) data set. These elutriate tests were isolated occurrences and are likely to be significantly diluted by the dredging process. Thus, the results were not considered by AECOM to be significant exceedances that would contribute to adverse impacts to aquatic biota.
6. Low levels of perfluorooctane sulfonate (PFOS) were detected in sediments at the ambient baseline locations, dredging site and spoil disposal site; and in seawater collected within the outer harbour of Port Phillip Bay (but all below the adopted DGV).
7. In addition, per- and polyfluoroalkyl substances (PFAS) were detected in seawater above the laboratory limit of reporting (LOR) at concentrations ranging between 0.0004 and 0.0009 µg/L.
8. With the exception of PFOS, the PFAS detected in seawater were not recorded in the sediment samples collected from any location (including the Loading Site) indicating widespread concentrations of PFAS in seawater across Corio Bay.

Conclusion of AECOM Sediment Contamination Assessment

The results identified no potential adverse impacts to ecological receptors at either the dredging site or the spoil disposal site (AECOM, 2021)

On the basis of the Sediment Quality Assessment undertaken by AECOM in accordance with the NAGD (2009), it was concluded that the sediments proposed to be dredged are suitable for offshore disposal at the Point Wilson Disposal Ground.

7.16 Assessment of Mobilisation of Nitrogen

Dredging releases some of the water held within the sediment, and this pore water typically contains higher levels of nutrients than in the water column above. The ecological influence of these additional nutrients depends on the amount of nutrient released during dredging and background concentrations in the water column.

The EPA *Guidelines for Dredging* (EPA, 2001) include a model to estimate nutrient release by dredging, based on previous dredging to deepen the Geelong Channel in 1997. The model is:

Mass of nutrient released/day = pore water concentration (µmol.L-1) x volume dredged/day (L) x porosity x proportion of pore water released x formula weight.

Applying the parameters for this project (with 9,000 m^3/d dredged), the release of ammonia is calculated as 1.2 kg/d and the release of nitrate is calculated as 0.1 kg/d. Over an 8-week dredging period, the release of total nitrogen (TN) is estimated to be 70 kg. This is approximately 0.03 % of the total nitrogen in Corio Bay of 21,100 kg (300 million m^3 of seawater at an average of 225 mg/L of TN).

A similar calculation can be made for nutrient release at the dredge spoil disposal site. The release adds 0.8 µg/L of TN per day of disposal. As most of the released nitrogen is ammonia, it will be assimilated within a day or so of release.

The EPA dredging guidelines note that *"As phytoplankton populations require less light than seagrass, and are more ephemeral than macroalgae, impacts of turbidity on phytoplankton would not normally be measurable. Given the usual scale of dredging and the rapid dilution and mixing in the water column, impacts on phytoplankton would usually be expected to be smaller than the effects of natural phenomena, such as storms, which impact far larger areas"*.

"There is no unequivocal evidence that dredging increases the risk or duration of algal blooms. Nutrient release or disturbance of Alexandrium cysts by dredging could increase the risk of algal blooms, but turbidity caused by dredging reduces light so may lessen the risk of blooms".

North Corio Bay has a productive phytoplankton population as described in Section 5. During the proposed dredging program, there is likely to be a localised reduction in plankton populations near the dredging zone due to higher turbidity. The turbidity would decline quickly after dredging ceases, and it is possible that there could then be a small, localised phytoplankton bloom.

There is a small possibility that weather conditions at the end of dredging could favour a natural bloom of more toxic algae. Regular monitoring of plankton during and after dredging is proposed to monitor for toxic algal blooms and enable appropriate notifications to be made if required.

7.17 Impact Assessment for Dredging

This section provides an assessment of the effects of the proposed dredging and spoil disposal on environmental conditions in Corio Bay and Port Phillip Bay.

Context of Dredging Proposal

As context, the project would result in dredging 490,000 m^3 of sediment to provide a new berth and turning basin. An additional 8,000 m^3 of sediment would be trenched to install a seawater transfer pipe from the FSRU to the existing refinery seawater

intake. To date, dredging in Corio Bay and for the approach channels has moved approximately 30 million m^3 of material.

The proposed dredging program corresponds to only 1.6 per cent of the amount of sediment dredged from Corio Bay historically. Several similar dredging programs have been carried out in Corio Bay in the last 20 years without long-term adverse impacts. The size of the proposed dredging program is similar to the annual maintenance dredging program by the Port of Melbourne.

The 8,000 m^3 of sediment excavated for trenching of the seawater transfer pipe would be placed to one side and then returned over the installed pipe.

No Change in Dredge Spoil Disposal Site

The 490,000 m^3 of dredged sediment would be transported to the existing dredge spoil disposal site east of Point Wilson. The particle size distribution of the dredging site and the dredge spoil disposal site are very similar, being approximately equal proportions of clay, silt and sand. This would be expected as the sediment layer in the dredge spoil disposal site constitutes sediment that has previously been dredged from Corio Bay and deposited at that site.

The infauna studies (see Section 5) showed the abundance and types of infauna are the same in the area to be dredged and the dredge spoil disposal site (both around 80 to 88 organisms/grab). As such, it is considered that the proposed disposal of the dredged sediment from north Corio Bay in the spoil disposal site would not alter the sediment characteristics and the same infauna community would develop in the new sediment surface as occurs now in the existing sediment surface.

Increased Turbidity near Dredging Site

There would be an area of elevated suspended solids and turbidity at the dredging site and the nearby surrounding area. The increase in turbidity would be much the same as recorded in the Corio Bay Channel Improvement Program and may cause a local reduction in plankton and seagrass productivity over the 8-week period of dredging.

The Ramsar site and central Corio Bay would have only a minor increase in turbidity and the change is insufficient to cause any adverse impacts on productivity in the Ramsar site or in central and south Corio Bay. The effects of increased turbidity at the spoil disposal site will be localised and last only an hour or two after the release of each load of sediment. The number of turbidity peaks depends on the frequency of storms, and thus will be determined by weather patterns during the actual period of dredging.

Reduced Light Transmission near Dredging Site

During the 8-week dredging program, the light attenuation is predicted to increase over the defined zones predicted by the modelling from 0.75 m^{-1} to 1.5 m^{-1}. This increase in turbidity and light attenuation would occur in about 160 ha, and a loss in productivity of phytoplankton and MPB (microphytobenthos) is expected within this zone.

The light transmission would recover quickly to the original conditions after dredging ceases – within one or two days – based on the particle settling rates and experience in previous Corio Bay dredging programs. Thus, any seagrass growth slowed by turbidity would recover shortly after completion of dredging.

Release of Contaminants

Based on the contaminant testing undertaken for the project, small quantities of lead, mercury and nickel would be released during dredging. The sediments have slightly elevated levels of these contaminants, as well as naturally-occurring arsenic and zinc. Infauna have long been habituated to these metal levels.

As large areas of the seabed in Corio Bay have elevated metal concentrations, the seawater in Corio Bay has a long residence time, and there is widespread bioturbation which would move metals into suspension, it is considered that plankton also are habituated to the sediment contaminant conditions.

There may be some minor short-term localised increase in metals in a few species, but this would cease after the 8-week dredging program is completed.

No Impacts on Ramsar Site

As shown in Figure 7-16, the 5-day average SS at the Ramsar site boundary ranges from 0 to 2 mg/L and the average SS over the 8 weeks of dredging is under 1 mg/L (less than 0.3 NTU). SS and turbidity increases in the Ramsar site are minor, in relation to the background SS of 5 mg/L. The Ramsar site along the north coast would have only a minor increase in turbidity and the change is insufficient to cause any adverse impacts on productivity in the Ramsar site or in central and south Corio Bay. No significant amount of suspended solids or turbidity would enter Limeburners Bay. Thus, dredging would not affect Critical Processes and Services at the Ramsar site.

Cumulative Impacts Considered

The effects of dredging would be localised to the dredging area and the dredge spoil disposal site but extend over a small zone of seagrass. To limit the impact ion seagrass near the dredging site, and also limit the effect of turbid water on the refinery cooling system, a silt curtain is recommended for installation between the dredging area and the intake to mitigate the effects of dredging.

There is very little overlap between the existing temperature and chlorine plumes and the turbid dredging plumes, except on the margins of each of the plumes, where the combined effects would be minor.

Overall, the principal effect of the dredging program is a localised reduction in primary productivity, as detailed in Section 10, and the loss of the infauna in the 12-ha dredged area, until they re-develop. Infauna sampling in nearby channels which were dredged a few years ago, show a viable infauna community exists in these areas.

EPA Environment Reference Standard Risk Assessment

The *Environment Reference Standard* provides a risk assessment framework for assessment of the impacts of dredging as summarised below in Table 7-9.

Table 7-9. Risk Ranking in EPA Environment Reference Standard

Line of Evidence	Risk Ranking		
	High	**Medium**	**Low**
Marine ecology	Significant and high effects on abundance and	Significant and moderate effects on abundance and	No significant effects on abundance and diversity

	diversity	diversity	
Other lines of evidence	Significantly different from control and high effect size	Significantly different from control and moderate effect size	Not significantly different from control
Weight of evidence assessment	High risk of significant adverse effects	Medium risk of significant adverse effects	Low risk of adverse effects – meets objectives for protection of environmental values

Measurements and analyses that are presented in this marine assessment and used in the risk ranking are as follows:

- Monthly surveys of the abundance and species distribution of phytoplankton, zooplankton and ichthyoplankton in Corio Bay, including a site at the refinery intake, sites throughout Corio Bay and sites in Port Phillip Bay;
- Mapping and assessment of seabed habitat and ecological condition on transects throughout Corio Bay;
- Surveys of infauna abundance and species distribution at sites in Corio Bay and Port Phillip Bay;
- Analysis of extensive monitoring data from various Port Phillip Bay studies;
- Targeted survey of seagrass under refinery plumes and in Ramsar site;
- Experimental studies of chlorine decay rate in Corio Bay;
- Model predictions of the extent of SS and, by calculation, the extent of changes in turbidity and light attenuation;
- Assessment of sediment contamination; and
- Prediction of quantity of nitrogen released, mostly as ammonia from pore water.

In summary, the proposal would involve a localised effect on marine ecology, generally limited to the 8-week dredging program.

The evidence for infauna and seagrass indicates no significant adverse long-term effects on abundance and diversity of seagrass or algae. Conditions in the dredged areas after dredging would be the same as in the other areas of dredged channels in Corio Bay and Port Phillip Bay.

Referring to the risk ranking in Table 7-9, it is concluded that dredging poses a **medium short-term risk but a low long-term risk** based on the following evidence:

- Reduced light transmission and hence reduced productivity in the dredging area of 12 ha (out of about 3,500 ha of muddy substrate in Corio Bay);
- Loss of infauna in dredging area (until they re-develop after dredging completed); and
- No long-term change in seagrass beds along the shore of the refinery or in the Ramsar zone.

Biotope Complexes Potentially Affected by Plumes

The dredging area would occupy the sublittoral zones near Refinery Pier. Biotope complexes (based on the DELWP classification system) that would be potentially affected are:

- ba5 Sublittoral sediment;
- ba5.b Non-reef sediment epibenthos;
- ba5.3 Sublittoral mud;
- Plankton communities;
- Pelagic communities.

As described in Section 4, the assessment of environmental risk follows the sequence of steps defined in the FeAST documentation provided by DELWP in July 2021. The pressure assessed in this Section is the change in turbidity and light attenuation in seawater in north Corio Bay, and at the dredge spoil disposal site. Scales for the frequency and intensity of this pressure have been defined by DELWP and are summarised in Table 7-10.

Table 7-10. Defined Scales for Parameters in Environmental Risk Assessment

Parameter	Classification			
	Very poor	**Poor**	**Affected**	**Good**
Frequency	**Permanent**	**Frequent =** *3 times per year*	**Regular =** *1 per year*	**Occasional =** *1 per 5 years*
Intensity	**High (*3*) =** *ecosystem functional change*	***Medium (2)* =** *communities shift a distinct level*	***Low (1)* =** *noticeable change but not significant*	***Very Low (0)* =** *no significant effect*
Tolerance/ resistance	**Very Low (2)** (>75 %)	**Low (3)** (25- 75 %)	**Medium (4)** (25 %)	**High (5)** No significant effect
Recovery	**Very Low (2)** (>25 years)	**Low (3)** (7- 25 years)	**Medium (4)** (2-10 years)	**High (5)** (<2 years)

For each biotope complex, the parameter values have been assessed and are listed, with reasoning, in Table 7-11.

Table 7-11. Environmental Risk Assessment for Dredging Plume

Biotope Complex	Marine Ecology Assessment				Evidence Assessment	Risk Ranking
	Frequency	Intensity	Tolerance	Recovery		
Existing Plume along shoreline in front of refinery						
ba5 Sublittoral sediment	Occasional	Low = noticeable but not significant	High tolerance to turbidity and sedimentation	High – in < 2 years	Infauna have life cycles of months and are tolerant of turbidity and sedimentation	Low Risk
ba5.b Non-reef sediment epibenthos	Occasional	Low = noticeable but not significant	High tolerance to turbidity and sedimentation	High – in < 2 years	Sediment epibenthos are tolerant of turbidity and sedimentation	Low Risk
ba5.3 Sublittoral mud	Occasional	Medium = infauna removed with sediment	Medium tolerance as need to re-develop	High – in < 2 years	Infauna have life cycles of months and will redevelop. Already seen in previously dredged channel sites	Medium Risk
Plankton communities	Occasional	Low = noticeable but not significant	High tolerance to several hours of lower light	High – in < 2 years	Plankton will tolerate several hours with low light, as they pass through dredging area	Low Risk
Pelagic communities.	Occasional	Low = noticeable but not significant	High tolerance as can move out of plume	High – in < 2 years	Mobile community and can easily avoid plume if desired. Very small zone of effect on seabed and in water column	Low Risk
The turbid plume would occupy the whole water column in the dredging area, but with higher effects near the seabed. Actual recovery period would be much less than the minimum listed in the method of 2 years. Plankton periodically experience high turbidity and low light from storm-induced turbidity. Pelagic communities are mobile and can avoid plume if desired.						

7.18 Conclusions

The project would involve the dredging of 490,000 m^3 of sediment to provide a new berth and turning basin. An additional 8,000 m^3 of sediment would be removed and replaced to install a seawater transfer pipe between the FSRU and the existing refinery seawater intake to enable reuse of the FSRU discharge in the refinery.

To date, dredging for the Port of Geelong has removed about 30 million m^3 of material. Several similar dredging programs have been carried out in Corio Bay in the last 20 years without long-term adverse impacts. The size of the proposed dredging program is similar to the annual maintenance dredging program by the Port of Melbourne.

The 490,000 m^3 of sediment would be transported to the existing spoil disposal site 8 km east of Point Wilson. The particle size distribution of the dredging site and the dredge spoil disposal site are very similar, being approximately equal proportions of clay, silt and sand. This is expected, as the sediment layer in the spoil disposal site constitutes sediment previously dredged from Corio Bay and deposited at that site.

The infauna studies (see Section 5) showed the abundance and types of infauna are the same in the area to be dredged and at the dredge spoil disposal site (both around 80 to 88 organisms/grab). As such, it is considered that the proposed disposal of the extra sediment from north Corio Bay in the dredge spoil disposal site would not alter the sediment characteristics and the same infauna community would develop in the new sediment layer as occurs now in the existing sediment.

There would be an area of elevated suspended solids and turbidity at the dredging site and the nearby surrounding area. The increase in turbidity would be much the same as recorded in the Corio Bay Channel Improvement Program and cause a local but not permanent, reduction in plankton, MPB and seagrass productivity.

The Ramsar site along the north coast and central Corio Bay would experience only a minor increase in turbidity and the change is insufficient to cause any adverse impacts on productivity in the Ramsar site or in central and south Corio Bay. The effects of increased turbidity at the dredge spoil disposal site would be localised to the disposal site and last only an hour or two after the release of each load of dredged sediment. No significant amount of suspended solids or turbidity would enter Limeburners Bay. Thus, dredging would not affect Critical Processes and Services of the Ramsar site.

During the 8-week dredging program, the light attenuation is predicted to increase over the defined zones predicted by the modelling from 0.75 m-1 to 1.5 m-1. This increase in turbidity and light attenuation would occur in an area of approximately 80 ha, and a short-term loss in productivity of seagrass would be expected within this zone.

The light transmission would recover quickly to the original conditions after dredging ceases – within one or two days. Thus, productivity would recover shortly after completion of dredging.

Based on the contaminant testing, small quantities of lead, mercury and nickel would be released during dredging. The sediments have slightly elevated levels of these contaminants, as well as naturally-occurring arsenic and zinc. Infauna have long been habituated to these metal levels and no change in the infauna community would occur.

As large areas of the seabed in Corio Bay have elevated metal concentrations, the seawater in Corio Bay has a long residence time, and there is widespread bioturbation which would move metals into suspension, it is considered that plankton also are habituated to the sediment contaminant conditions.

There may be some minor short-term localised increase in metals in the water column, but this would cease after the 8-week dredging program is completed.

Over an 8-week dredging period, the release of total nitrogen is estimated to be 70 kg. This is around 0.03 % of the total nitrogen in Corio Bay of 21,100 kg. During the dredging program, there is likely to be a localised reduction in plankton populations due to higher turbidity, and the release of almost 70 kg of ammonia. The turbidity would decline quickly after dredging ceases. It is possible that there could be a small localised phytoplankton bloom as a response to the nitrogen released, if weather conditions are favourable.

The effects of dredging would be localised to the dredging area and the dredge spoil disposal site, but extend over a small zone of seagrass. To limit the impact ion seagrass near the dredging site, and also limit the effect of turbid water on the refinery cooling system, a silt curtain is recommended for installation between the dredging area and the intake to mitigate the effects of dredging.

There is very little overlap between the existing temperature and chlorine plumes and the turbid dredging plumes, except on the margins of each of the plumes, where the combined effects would be minor.

Overall, the principal effect of the dredging program would be a localised reduction in primary productivity, as detailed in Section 10, and the loss of the infauna in the 12 ha dredged area, until they re-develop. Infauna sampling in nearby existing channels which were dredged a few years ago, showed a viable infauna community has returned to the area.

The risk assessment ranked the risk to infauna in the sublittoral mud of the dredging area as a **medium short-term risk but a low long-term risk**. It is noted that the area impacted is 12 ha out of a total area of 3,500 ha of sublittoral mud in Corio Bay.

Potentially, the only risk is if the dredging occurs in early spring and causes seagrass and algae to miss the spring growth season. To mitigate this risk, and also to avoid a similar loss of spring growth in plankton and fish larvae, it is recommended that the dredging should not be carried out in the spring season.

In summary, the evidence for infauna and seagrass indicates no significant adverse long-term effects on abundance and diversity of infauna, seagrass or plankton. A few months after dredging has been completed, conditions in the dredged areas would be the same as in the other areas of dredged channels in Corio Bay and Port Phillip Bay.

8 Temperature Assessment

This section provides an assessment of the potential marine impacts associated with the discharge of warm water from the Geelong Refinery, and cooled water from the FSRU, to Corio Bay from the operation of the proposed project.

As outlined earlier in this report, the project involves transferring the seawater used in the regasification process in the FSRU to the refinery for reuse as cooling water. The refinery would discharge the seawater at the same discharge points as currently in use, at the same rates, but with a temperature much closer to ambient temperature than currently. Alternatively, when the refinery is offline for maintenance activities, cold water from the FSRU would be discharged through a diffuser into Corio Bay.

8.1 Definitions of Heat, Temperature and Power

The thermal energy of the waters of Corio Bay is the sum of the mechanical energies of its water molecules, dissolved constituents and suspended material. The total thermal energy in Corio Bay is proportional to its temperature

The meaning of heat in everyday language differs from the meaning in hydrodynamics or physics. In everyday language, **heat** means the condition of being hot or having a high temperature. In physics, **heat** refers to the kinetic energy resulting from the random motion of atoms or molecules in an object. For example, in conversation, we may say "*the heat was unbearable*" but in physics, we would say that "*the temperature was high*". Heat is a form of energy flow, whereas temperature is not.

Temperature is a measure of the tendency of an object to transfer energy to its surroundings. When two parcels of water at different temperatures come into contact, energy is transferred from the hotter parcel to the colder parcel until they reach thermal equilibrium (that is, energy is transferred until both parcels are at the same temperature, when they are in thermal equilibrium. The SI unit of heat is joule (J) defined as the energy required by a force of one newton to travel a distance of one metre. Heat is also measured in calories (1J = 4.2 calories).

Power is the rate of transferring energy. One joule is the equivalent of one watt of power radiated or dissipated for one second. The simple conversion between heat and power is that 1 watt = 1 joule/second.

A calorie (cal) is the energy needed to change the temperature of 1 g of water by 1 ^{o}C. The kilocalorie (kcal) is commonly used and is the energy needed to change the temperature of 1 kg of water by 1 ^{o}C.

In this section, the water temperature is described using the everyday meaning (although, as described above, we actually mean the heat of the water). However, the energy involved in heating and cooling water, whether due to a heat exchanger for liquefied natural gas (LNG) or a refinery, or the solar radiation received from the sun, is described in terms of power (in watts).

8.2 Heat Exchange in the FSRU and the Refinery

For 65 years, the refinery at Geelong has been using seawater from Corio Bay as cooling water. Refinery processes generate heat and the excess heat is transferred to the seawater by a series of heat exchangers in the refinery.

Existing Seawater Flow Arrangement

Figure 8-1 is a schematic diagram of the existing flow arrangement (upper diagram) and the proposed flow arrangement if the FSRU discharge is used for refinery cooling water (lower diagram). Currently, seawater is drawn into the refinery via an intake channel that extends 120 m out from the shore into Corio Bay to the north of the Refinery Pier. Approximately 350 ML/d of seawater is pumped from the intake channel to a series of pipes and heat exchangers where the excess heat is transferred to the seawater.

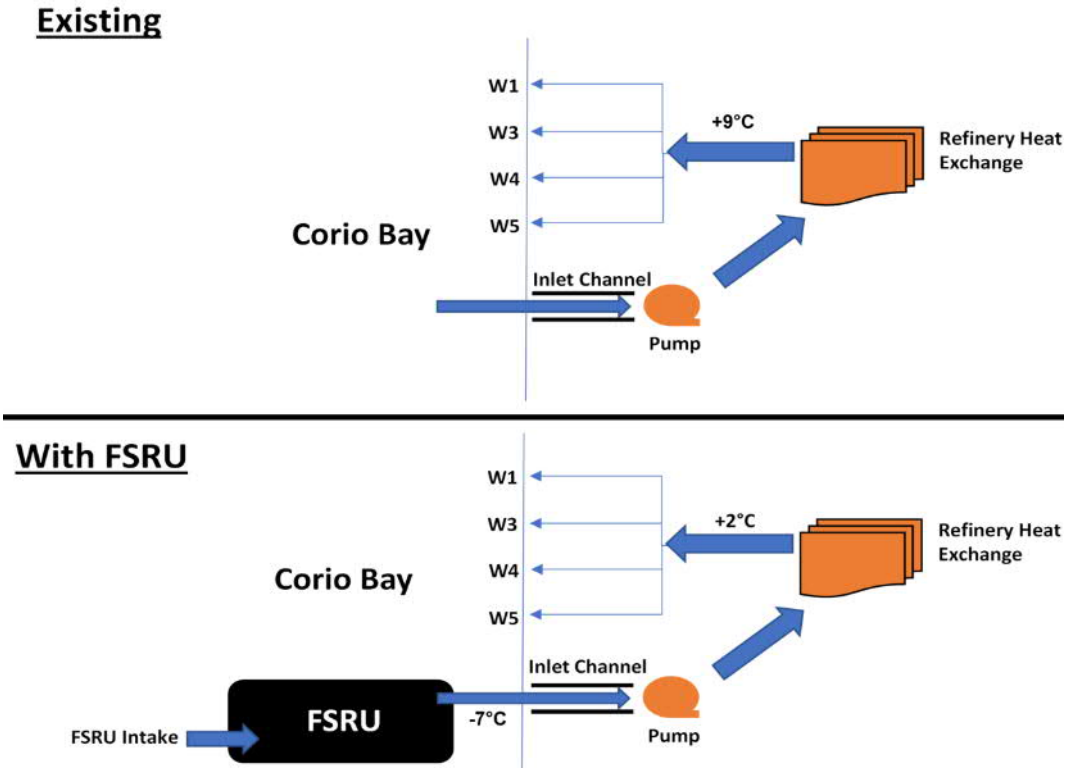


Figure 8-1. Schematic Diagram of Water Flow

The warmer seawater is returned to Corio Bay via four licenced discharge points, known as W1, W3, W4 and W5. Figure 8-2 shows the location of the intake channel and the four discharge channels. The flow rate from each discharge channel is shown in the figure, as well as the circular mixing zone defined for each discharge point in the EPA operating licence. Water quality parameters in the plumes meet EPA limits at the edge of the mixing zone.

Future Seawater Flow Arrangement

The proposed gas terminal involves a FSRU which is continuously moored at Refinery Pier. The FSRU would convert LNG back to a gaseous state (a process known as regasification) using seawater as the heat source. The cooled seawater (7 °C below ambient temperature) from the FSRU would be piped to the refinery seawater inlet for reuse within the refinery and would replace the seawater currently pumped in by the refinery. As the seawater temperature entering the refinery would be 7 ^{o}C lower than ambient, the temperature of each of the discharges also would decrease by 7 ^{o}C.

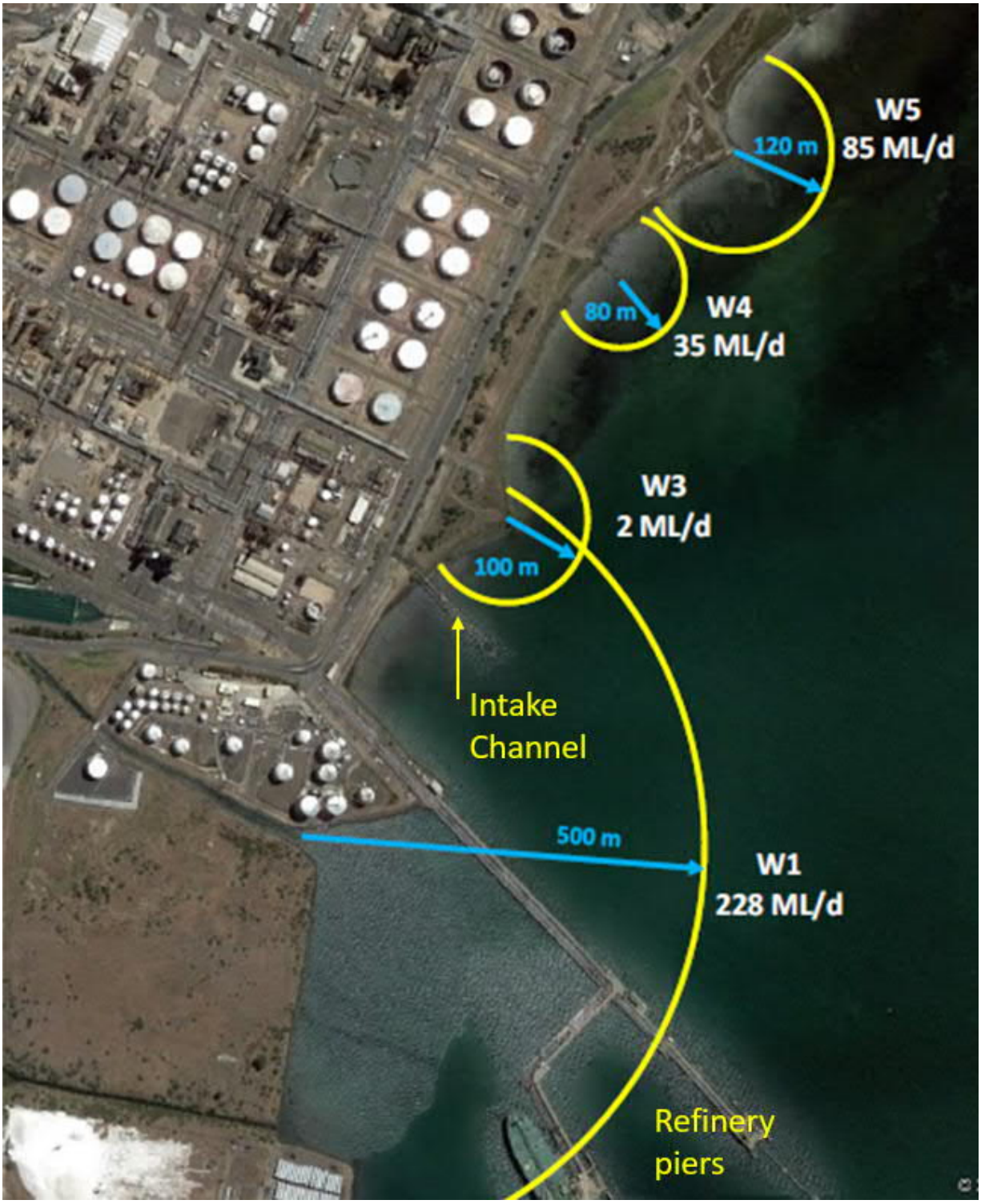


Figure 8-2. Seawater Intake and Discharge Points for VIVA Refinery

Table 8-1 lists the flow rate and temperature rise from each discharge point for the existing arrangements, and for the proposed future flow rates and temperature changes with the FSRU in operation (1) at full capacity and (2) at average capacity.

Under the present arrangement, the temperature of the four discharges range from ambient (W3) to 10 ^{o}C above ambient (W5), with an overall average temperature rise of 8.5 ^{o}C.

Under the future arrangement, the temperature of the four discharges range from 7 ^{o}C below ambient (W3) to 3 ^{o}C above ambient (W5), with an overall average temperature rise of 1.5 ^{o}C. There would be no change in the total intake or total discharge rate of seawater (remaining at 350 ML/d). With the FSRU operating at average flow, there is less heat loss in seawater used on the FSRU for regasification, and thus a smaller reduction in the temperature of the discharges.

Table 8-1. Schedule of Discharge Points with Flow and Temperature Rise

Discharge Point	Type	Unit	Existing Situation	Future Peak	Future Average
W1	Flow	ML/d	228	228	228
	Temperature	deg C	+ 8	+ 1	+ 3
W3	Flow	ML/d	2	2	2
	Temperature	deg C	ambient	-7	-5
W4	Flow	ML/d	35	35	35
	Temperature	deg C	+ 9	+ 2	+ 4
W5	Flow	ML/d	85	85	85
	Temperature	deg C	+ 10	+ 3	+ 5
All four discharges	**Flow**	**ML/d**	**350**	**350**	**350**
	Temperature	**deg C**	**+ 8.5**	**+ 1.5**	**+ 3.5**

The seawater would be drawn from Corio Bay into the FSRU through the sea chests in the FSRU hull and circulated through heat exchangers where the LNG would vaporise to a gas.

The amount of seawater used by the FSRU would vary each day depending on the demand for gas. The maximum rate of seawater extracted for peak gas production would be 350 ML/d, the average rate would be 250 ML/d and the minimum rate would be approximately 120 ML/d. The difference between the seawater volume piped from the FSRU to the refinery inlet and the refinery seawater requirement of 350 ML/d would continue to be drawn from the refinery intake channel.

8.3 Methodology for Predicting Temperature Plumes.

As described in Section 6, the plumes that are produced by the four refinery discharges were predicted using the following methodology:

- Near-field CFD hydrodynamic model of each plume to the point where the plume connects to the 20 m grid cells in the regional hydrodynamic model;
- Regional hydrodynamic model of Corio Bay with tides and currents simulated on a 20 m by 20 m by 1 m deep 3-D grid, with a time step of 5 minutes.
- Heat exchange through the water surface is simulated by bulk transfer models. The energy transfer is represented by surface long-wave radiation, sensible heat transfer and evaporative heat loss, complemented by penetrative shortwave radiation.

- Shortwave solar radiation from the sun that reaches the Earth's surface is measured (in watts/m^2) at Melbourne. The intensity of the solar radiation is a function of the time of day, time of year and the extent of cloud cover that blocks incoming radiation. During clear summer days the solar radiation is more than 1100 W/m^2 and on clear winter days the solar radiation is only 500-600 W/m^2. During each night the incoming solar radiation levels reduce to zero. During cloudy days the radiation is reduced by 50 per cent or more.
- Incoming longwave radiation refers to heat that is emitted from the warmed upper atmosphere (and is a function of the extent of cloud cover). Incoming longwave radiation at Melbourne Airport typically ranges between 250 and 400 W/m^2, occasionally peaking above 480 W/m^2 in the warmest months of summer.
- Long term records of sea surface temperature in Port Phillip Bay were used to define the temperature at the eastern boundary of the Corio Bay model grid. The BoM records show mean temperatures range from 23 ^oC in the summer to 11 ^oC in the winter; with summer average maximums warming to around 27 ^oC and winter average minimum temperatures dropping to approximately 10 ^oC (see Figure 8-3).

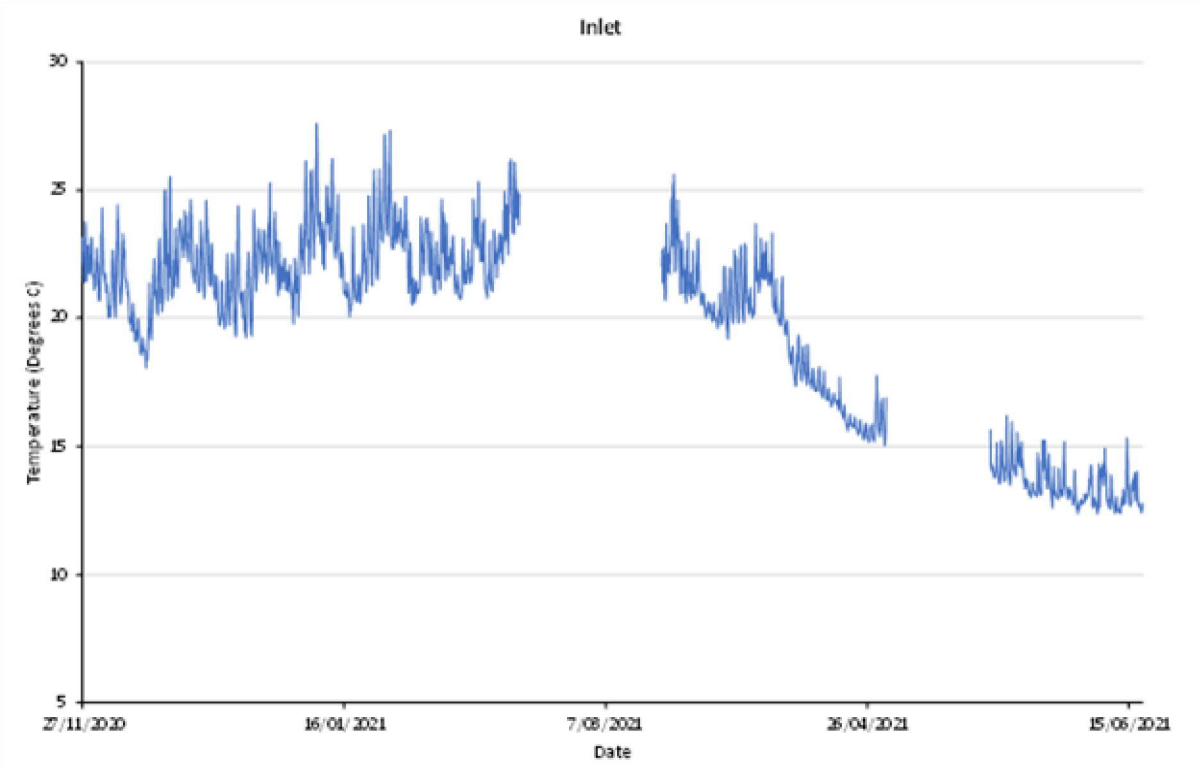


Figure 8-3. Corio Bay Sea Surface Temperature

Temperature Pattern in Discharge Plumes

Fluctuations in the surface water temperature near the refinery W1 outlet are influenced by the wind and the tide. A time series plot of predicted seawater temperature at the surface (red line) and the seabed (blue line) near W1 in Figure 8-4 shows that, in the initial 6 days of the simulation for October 2019, the thermal stratification is greatest when the wind is weak and the tide is ebbing, which draws the plume offshore as a thin surface lens. The thermal gradient ranged from 1 ^oC to 6 ^oC in the period plotted.

When the wind increases, the stratification of the plume erodes to the south of W1 but is maintained to the north of W1.

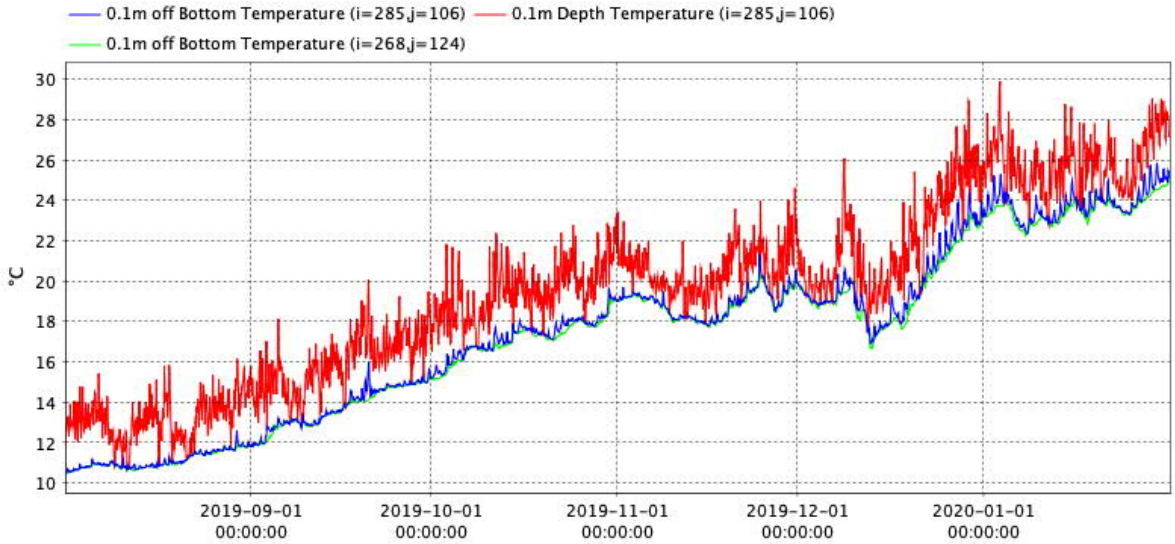


Figure 8-4. Vertical Stratification of Plume from W1 Discharge -2019

The time series in Figure 8-5 shows the thermal stratification of the discharge plume from W1 in January 2020. In this month, the water level was consistently lower and the winds weaker, which created stratification that extended out from the shore until the stronger winds returned. The thermal gradient ranged from 1 ^{o}C to 6 ^{o}C in the period.

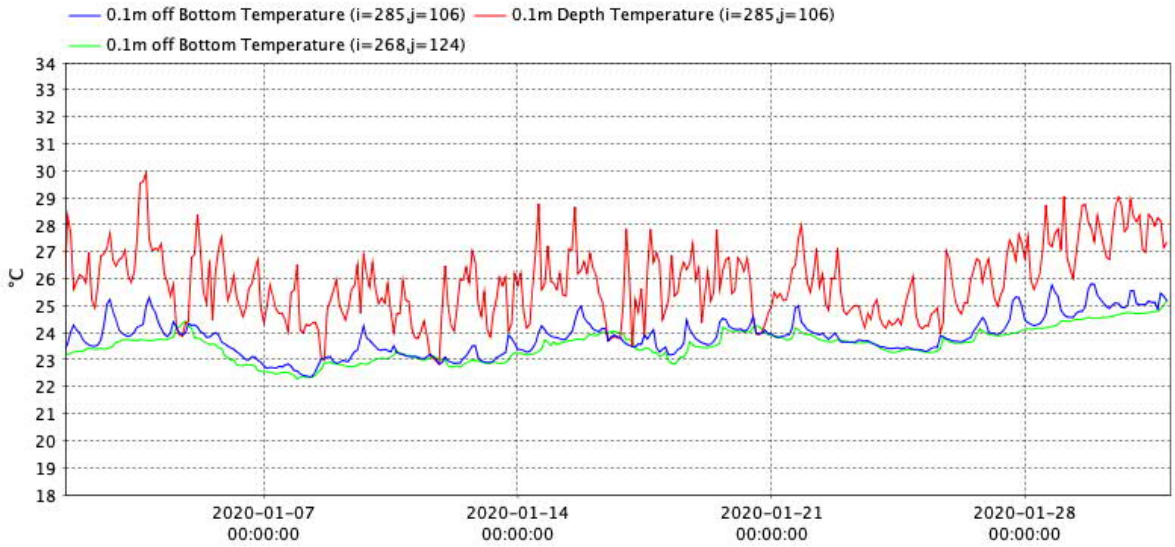


Figure 8-5. Vertical Stratification of Plume from W1 Discharge -2020

It can be seen in Figure 8-4 and Figure 8-5 that the thermal stratification varies from hour-to-hour, depending on the rate of mixing generated by the wind. Heat is lost to the atmosphere from the warmer surface plume until the seawater temperature in the plume returns to near-ambient levels.

Verification of Predicted Thermal Stratification

CEE made field measurements of the vertical stratification at nine sites in the vicinity of the W1 discharge. The measurement sites are shown in Figure 8-6. The measured vertical profiles of water temperature are shown in Figure 8-7.



Figure 8-6. Measurement Sites for Vertical Stratification Profiles

Source: (CEE, 2021)

Figure 8-7 shows that the surface layer of warmer water was generally only about 1 m thick – and a maximum of 1.5 m thick. The measured thermal gradient ranged from 3 ºC to 6 ºC in the period. The model accurately predicted the measured surface temperature and the vertical temperature profile, which confirms that the model predictions of the thermal plumes in Corio Bay have a good level of accuracy.

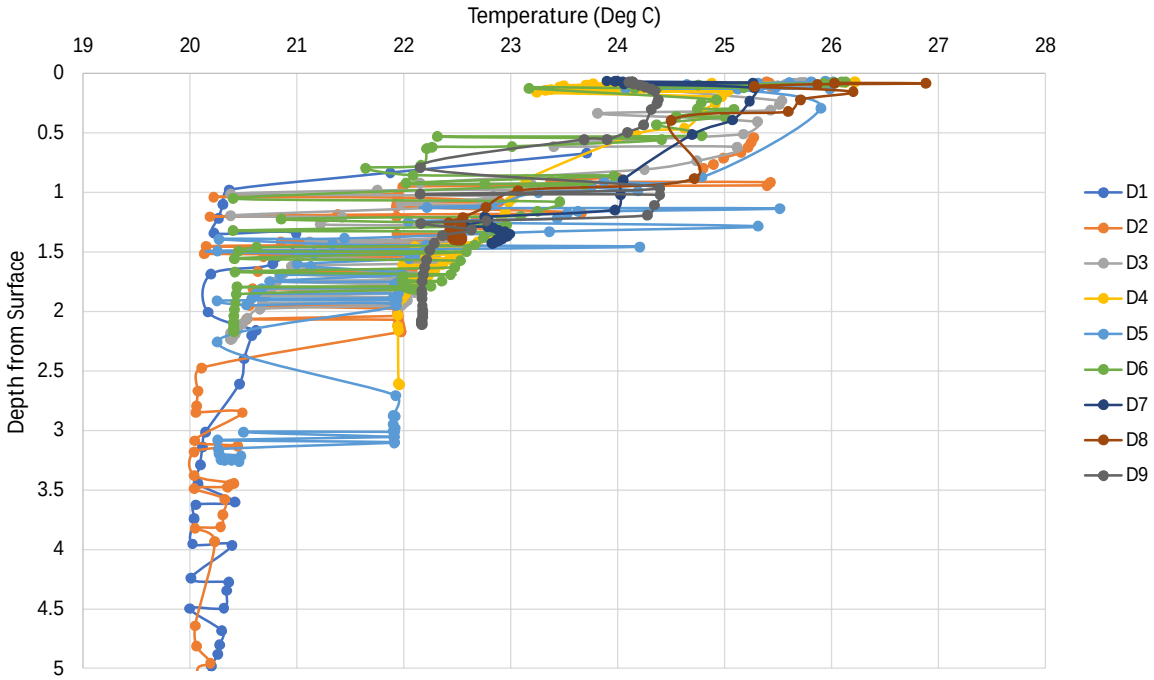


Figure 8-7. Measurement Sites for Vertical Stratification Profiles

Source: (CEE, 2021)

8.4 Temperature Plumes for Existing Situation

The **existing situation** is the continued operation of the refinery with the four existing seawater discharges. Geelong Refinery has four existing seawater discharge points into Corio Bay designated W1, W3, W4 and W5, from south to north, along the shore of Corio Bay in front of the refinery (refer to details in Table 8-1).

Figure 8-8 and Figure 8-9 show the predicted 50-percentile (median) and 90-percentile (peak) temperature difference (i.e., temperature difference from ambient) at the water surface for the existing discharges. The difference has been calculated by comparing the predicted water temperature over six-months from August 2019 to February 2020 to the scenario with no refinery discharges.

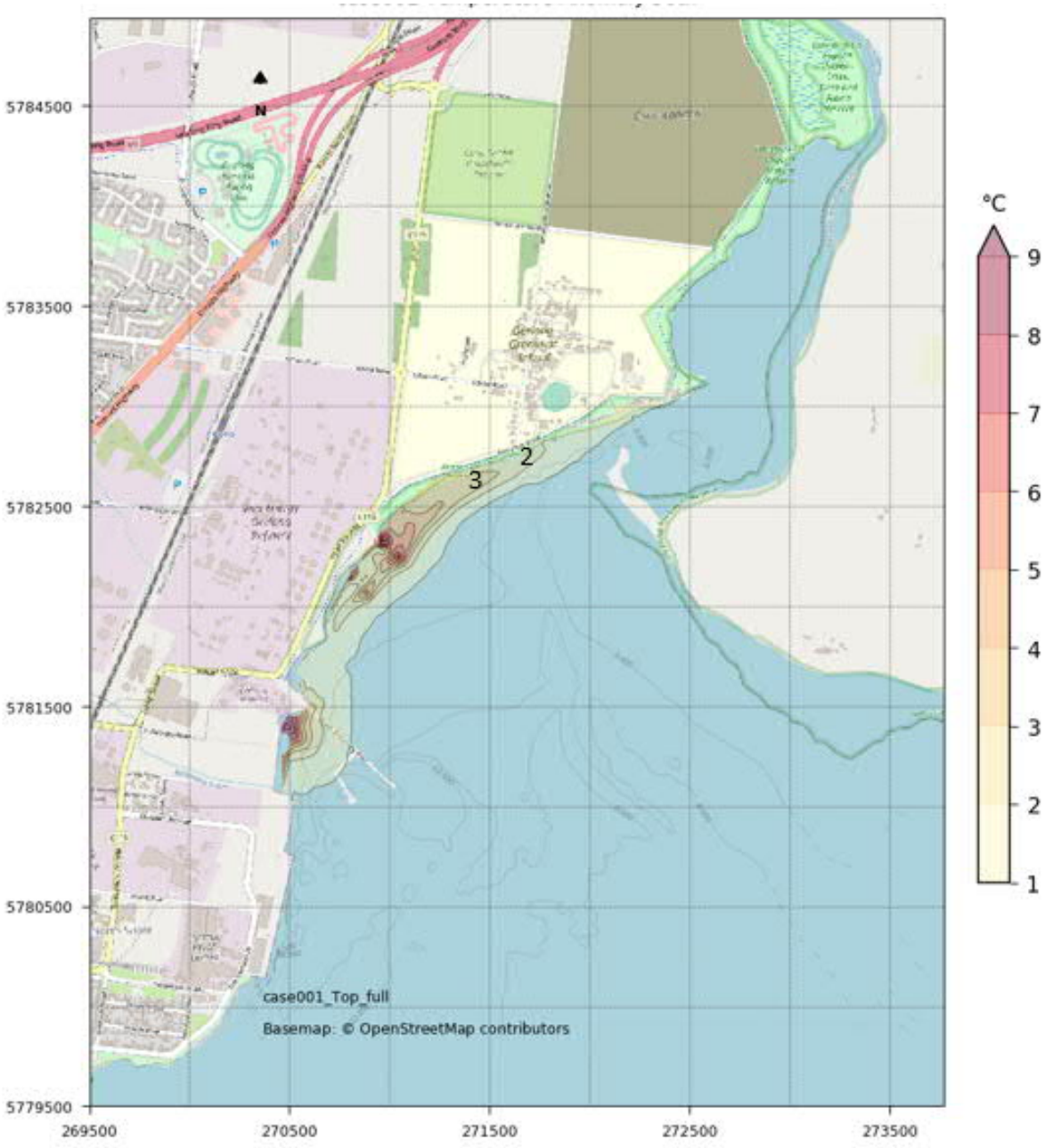


Figure 8-8. Predicted 50-percentile Temperature Change for Existing Situation

The plume of warmer water from the existing refinery discharges extends along the shoreline from the refinery discharge points to the entrance to Limeburners Bay.

The temperature increment is 3 ºC within 150 m of discharge W1. Near discharges W4 and W5, the 3 ºC contour extends about 200 m offshore and 700 m to the north along the shore. The plume of warmer water from the existing refinery discharges is around 1 ºC above ambient at the entrance to Limeburners Bay. As described in Section 9, the seagrass along the refinery shore under the plume is in healthy condition.

The contours for the 90-percentile temperature plot in Figure 8-9 are almost identical to the contours for the 50-percentile plot in Figure 8-8. This is because the discharge is continuous and a relatively stable temperature plume forms in shallow water along the shore. Water has a high heat storage capacity and therefore there is little change in the temperature contours from hour-to-hour or day-to-day.

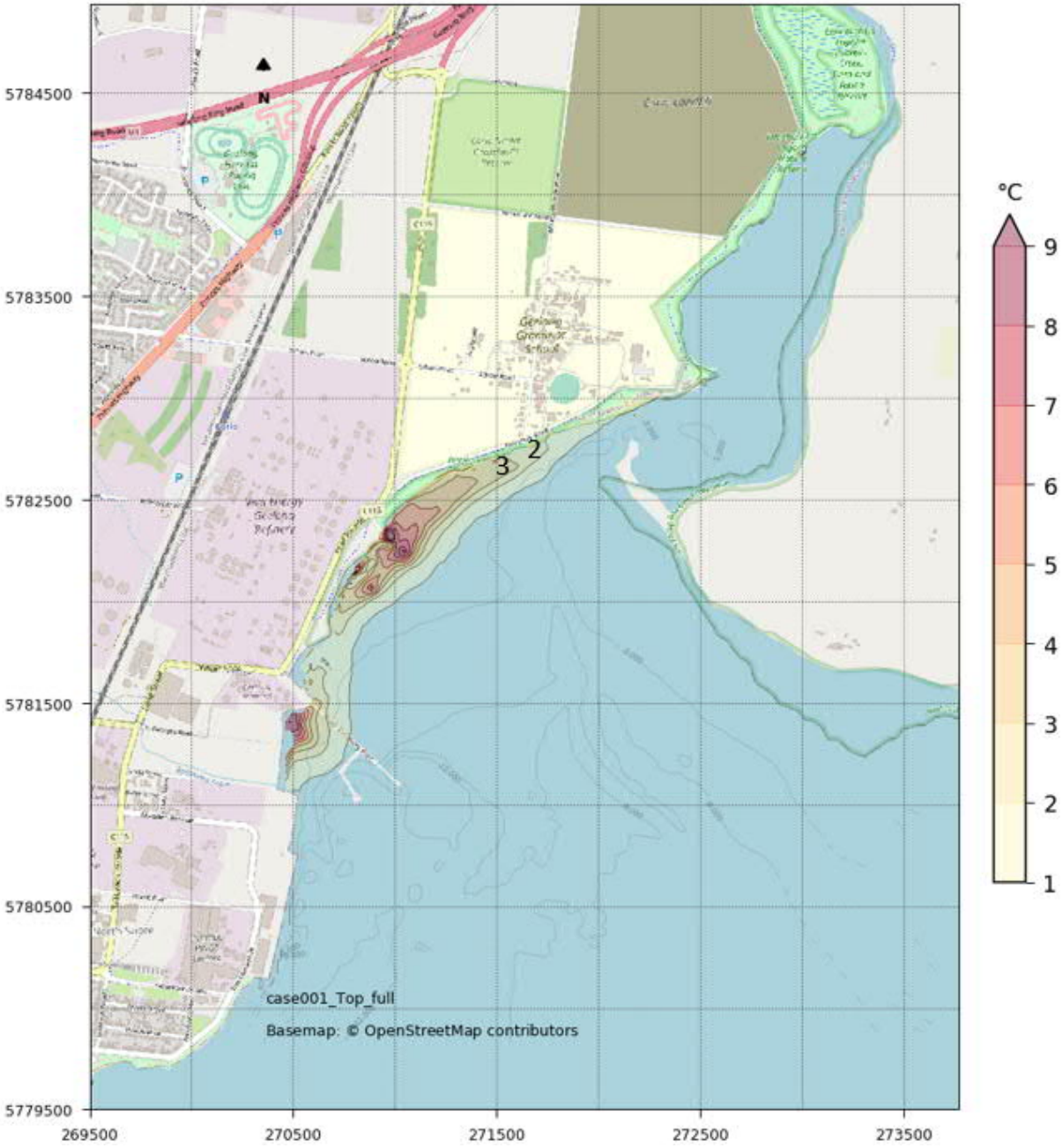


Figure 8-9. Predicted 90-percentile Temperature Change for Existing Situation

The temperature plume **for the existing situation** is located in shallow water and extends along the entire length of shoreline in front of the refinery to Limeburners Bay.

8.5 Temperature Plumes for Future Situation – Peak Flow

The future situation with peak flow involves the FSRU using 350 ML/d of seawater and transferring this flow of cooler water (at 7 ^{o}C below ambient temperature) to the refinery inlet for use as cooling water. The flow through the refinery would heat the water to the temperatures listed in Table 8-1 (“future peak” column) and the flow would be returned to Corio Bay through the four existing discharge points (W1, W3, W4 and W5) at 7 ^{o}C lower temperature than at present.

Figure 8-10 and Figure 8-11 show the predicted 50-percentile (median) and 90-percentile (peak) temperature difference at the surface for the future peak flow case.

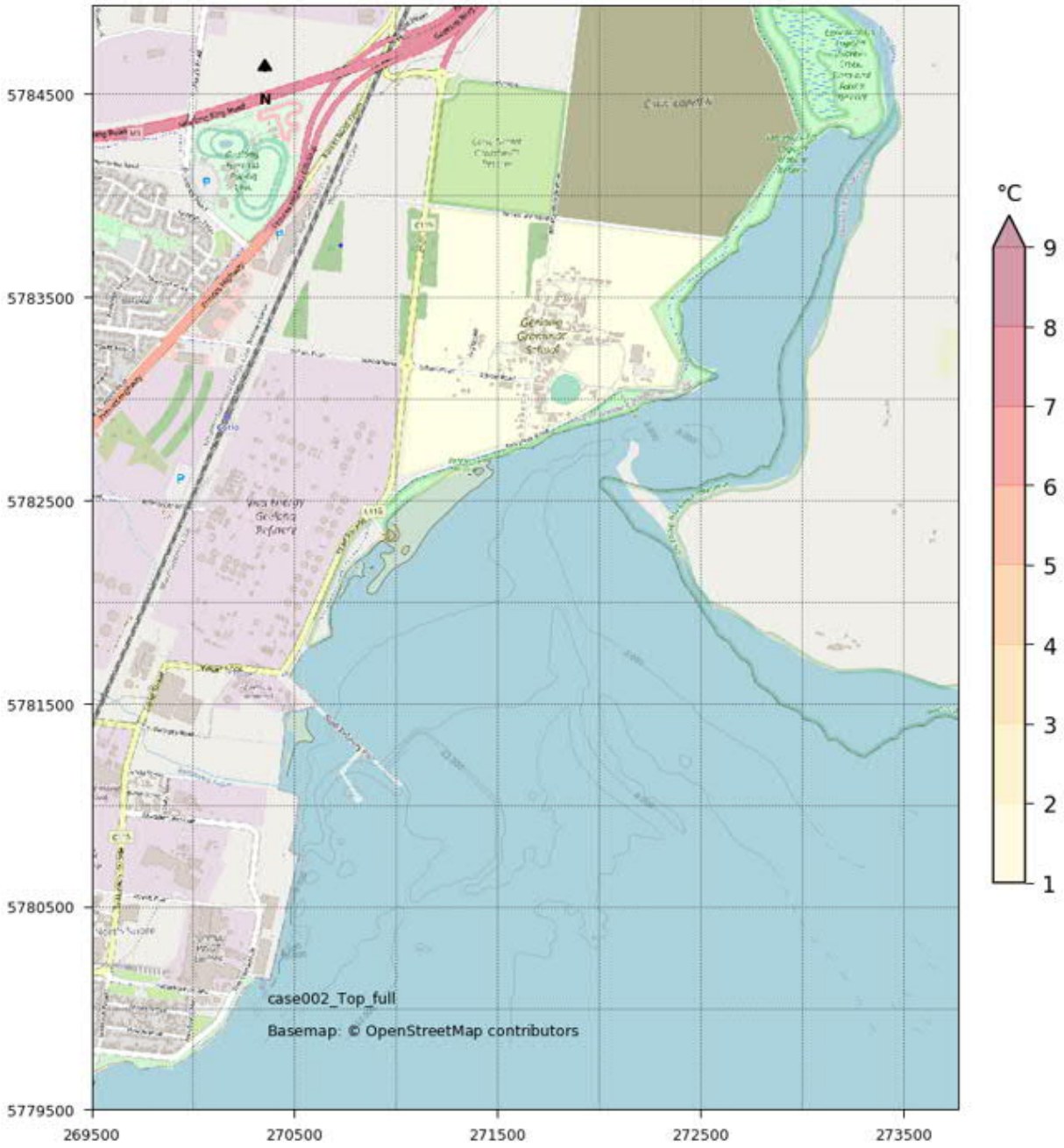


Figure 8-10. 50-percentile Temperature Change for Future Peak Flow

With the proposal in operation, there would be a much smaller temperature plume along the shoreline than for the existing situation, and most of the plume would only be 1 to 2 ^{o}C above ambient seawater temperature. The project would result in a smaller plume with lower temperatures in Corio Bay when compared to the current situation. This could be considered to be an environmental improvement (closer to natural conditions).

The predicted 90-percentile temperature difference for the future peak flow scenario in Figure 8-11 shows a similar but slightly smaller distribution to the 50-percentile difference. The warm plume decreases to less than 1 ^{o}C above ambient within 200 m

of the shore and extends for a shorter distance. The plume is 500 m away from the entrance to Limeburners Bay.

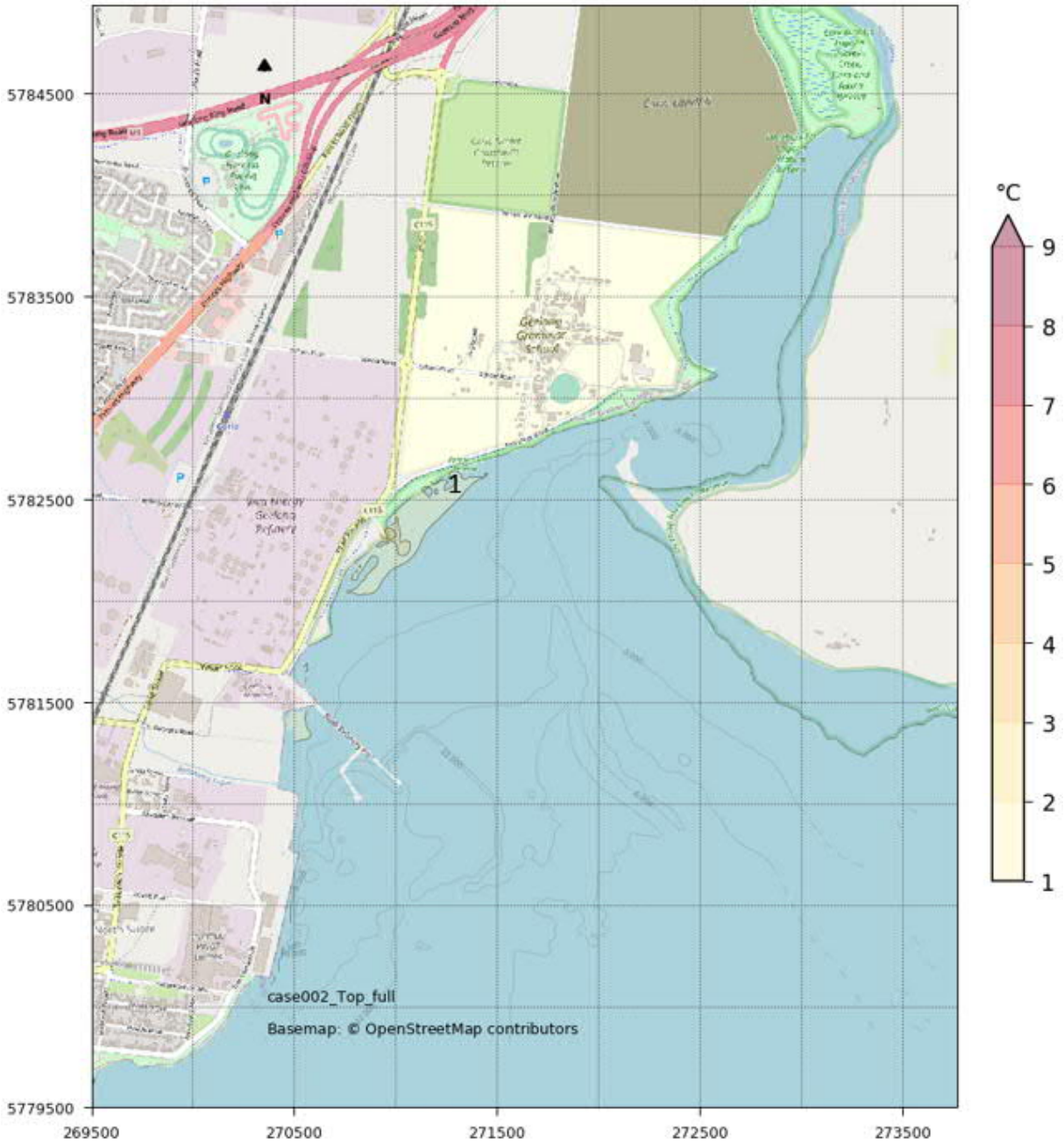


Figure 8-11. 90-percentile Temperature Change for Future Peak Flow

In summary, the temperature plume for the **future peak flow situation** would be smaller and less intense (i.e. smaller temperature rise) than the existing situation.

8.6 Temperature Plumes for Future Situation – Average Flow

The **future situation with average flow** involves the FSRU using 250 ML/d of seawater and transferring this flow of cooler water (at 7ºC below ambient temperature) to the refinery inlet. Refinery processes would heat the water to the lower temperatures listed in Table 8-1 (“future average” column) and the flow would be returned to Corio Bay through the four existing discharge points at the lower temperatures.

Figure 8-12 and Figure 8-13 show the predicted 50-percentile and 90-percentile temperature difference at the surface for the future peak flow case.

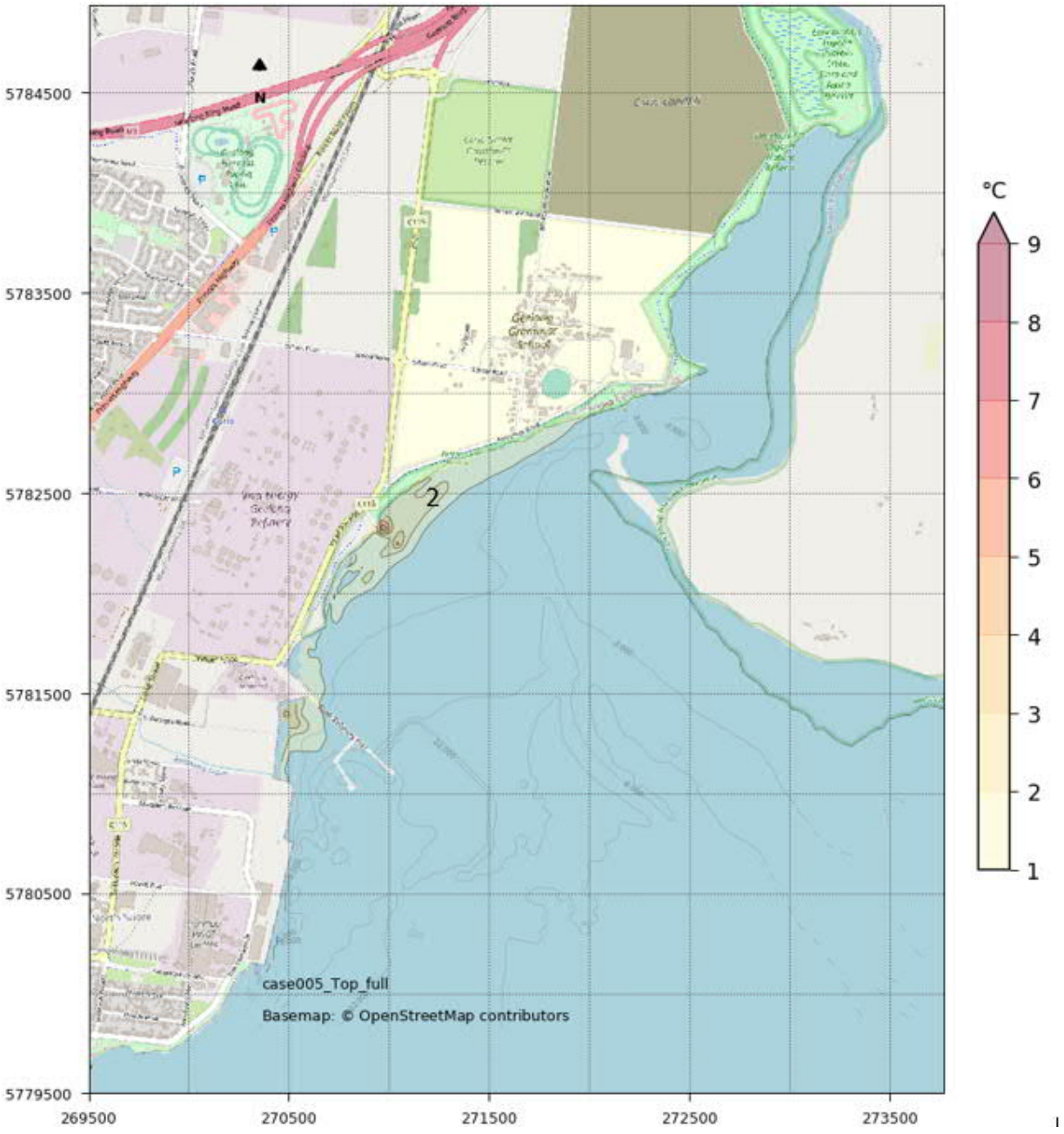


Figure 8-12. 50-percentile Temperature Change for Future Average Flow

The plume for the future **average production** extends a similar distance as the plume under existing conditions from the current refinery heated water discharge, but with a smaller temperature increase above ambient.

Figure 8-13 shows the predicted 90-percentile temperature difference for the future average flow scenario. The temperature distribution is similar to the 50-percentile difference but with slightly warmer temperatures (because this is a plot of the peak temperature change rather than the median or 50-percentile temperature change). The warm plume decreases to less than 1°C difference within 300 m of the shore and at the entrance to Limeburners Bay.

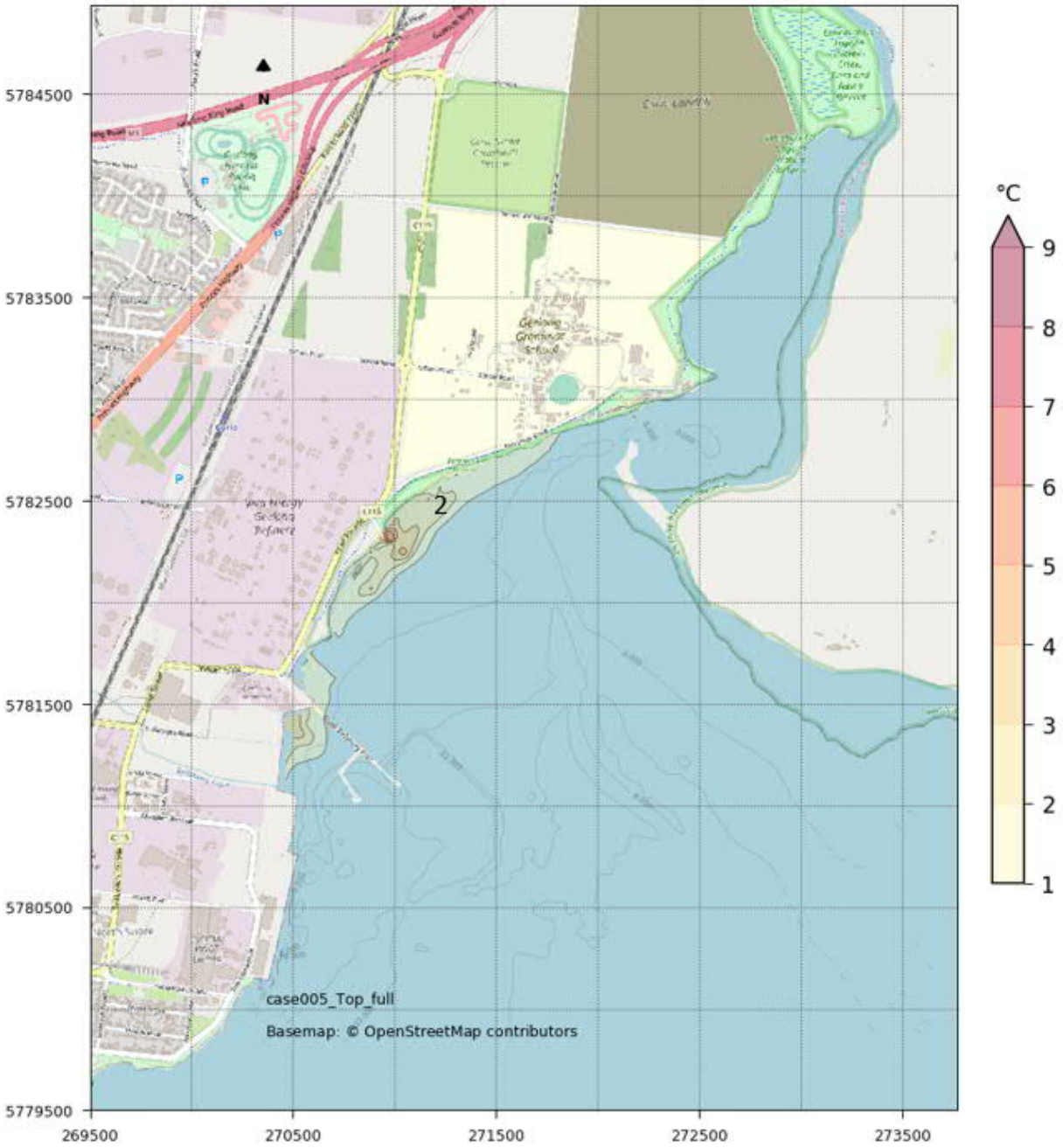


Figure 8-13. 90-percentile Temperature Change for Future Average Flow

In summary, the temperature plume for the **future average flow situation** would be smaller and less intense (i.e., smaller temperature rise) than the existing situation.

8.7 Temperature Plumes for Future Situation – Diffuser Discharge

A further scenario was modelled in the event that the refinery was closed for maintenance or other reasons and the FSRU discharge was not able to be used in the refinery. A full refinery shut down was assumed for this scenario, although current refinery maintenance seldom requires a full shutdown, as part of the refinery remains operational while other areas are offline.

In this scenario, the cooler water flow from the FSRU would be discharged through a 300 m long diffuser installed under the new pier extension. The discharge from the

diffuser would dilute by 20:1 as a result of the mixing caused by the high velocity discharge jets and the distribution of discharge ports along the diffuser (see discussion of near-field diffuser plume modelling in Section 6).

In the scenario, the FSRU would operate at 350 ML/d (peak operation) and all the cooler seawater from the FSRU would be discharged to Corio Bay via a diffuser. There would be no discharge from the refinery. Note the discharge from the FSRU would be 7 ^{o}C below ambient temperature.

The discharge from the diffuser would produce multiple small jets of cooler seawater that entrain ambient seawater as they descend from the ports on the diffuser to the seabed. At the dilution of 20:1, the temperature decrease would have reduced from 7 ^{o}C to 0.35 ^{o}C (and the chlorine concentration would have reduced from 100 µg/L to 5 µg/L.

A large field of diluted effluent, about 3 m thick, would form on the seabed in the dredged shipping channel. Temperature loss would be slow because the field is well away from the water surface. Therefore, the field grows until dispersion matches input.

Figure 8-14 shows the predicted 50-percentile temperature change at the seabed for the future peak flow case. The temperature of the field on the seabed is 0.5 ^{o}C below ambient close to the diffuser and 0.4 ^{o}C below ambient further away, over an area of seabed of about 65 ha.

Note that the field is at the seabed between about 10 m and 13 m water depth. There is negligible change in water temperature at mid-depth or on the surface.

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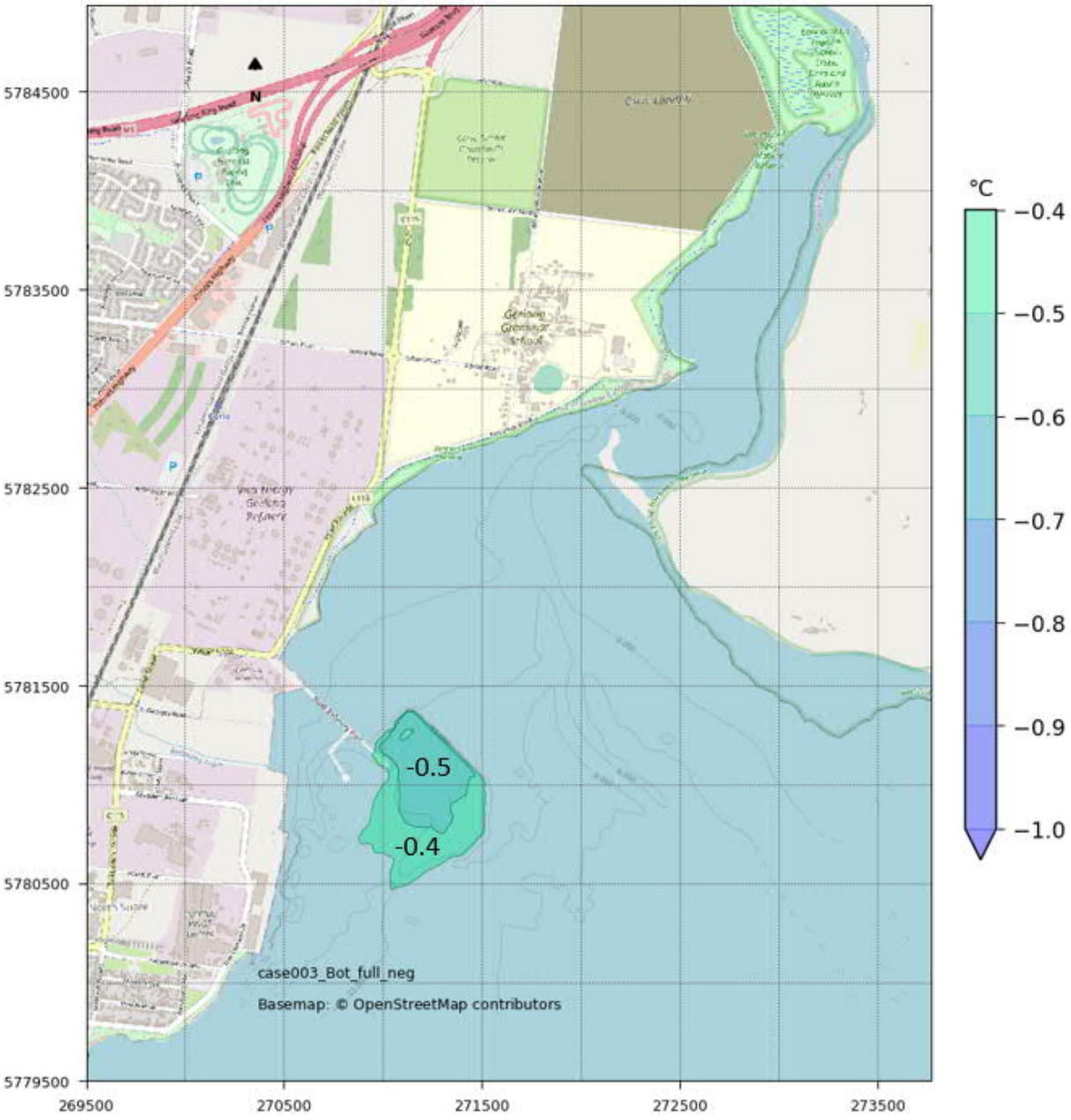
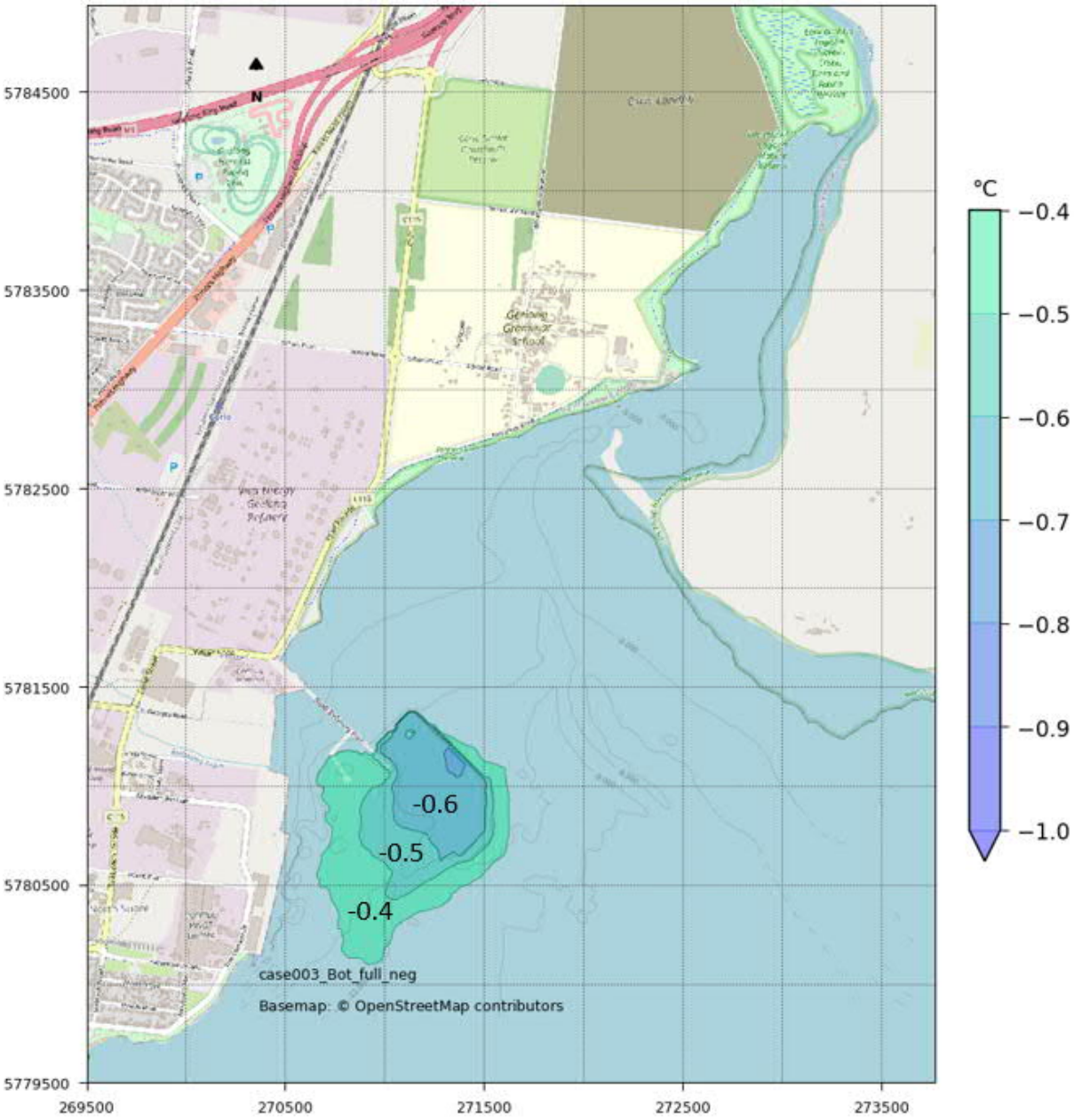


Figure 8-14. 50-percentile Temperature Change for Future Diffuser Discharge

Figure 8-15 shows the predicted 10-percentile (peak) temperature difference at the seabed for the future peak flow case. The temperature difference is negative as the discharge from the FSRU is at 7ºC below ambient temperature The 10-percentile concentration distribution is very similar to the 50-percentile distribution, with no temperature difference exceeding 0.6 ºC on the seabed and less than 0.1 ºC at 5 m above the seabed.

As the diluted field plume is cooler water, it is slightly more dense than ambient seawater and stays in the deeper water of the channel. The diluted field has a maximum temperature difference of approximately -0.7 ºC near the diffuser, and the contours reduce with distance as the field slowly spreads out in the channel and mixes upwards. Most of the diluted field is 0.4 ºC to 0.6 ºC below ambient temperature.

Figure 8-15. 10-percentile Temperature Change for Future Diffuser Discharge



For the scenario with discharge from the diffuser, there is no warm plume along the shoreline as there is no discharge from the refinery. The FSRU discharge occurs from the diffuser and a diluted field of slightly cooler water forms on the seabed, as described above.

8.8 Temperature Plumes for Future Closed Loop Discharge

The usual method of operation of the FSRU for the project is the open loop mode which involves transferring the cooler seawater from the FSRU regasification system into the refinery inlet as previously described in this report.

The FSRU can also operate in an alternative closed loop mode where LNG is used to fuel boilers that warm the LNG for conversion to a gaseous state. This would involve less seawater being discharged to Corio Bay as water is recycled within the vessel but creates additional greenhouse gases and air emissions from LNG combustion.

The potential impacts associated with closed loop mode have also been assessed. The excess heat generated by closed loop operation would be discharged as a warm water plume through two small pipes at the rear of the FSRU (see Section 6). Figure 8-16 shows the predicted 50-percentile (median) percentile temperature difference at the surface for a future peak flow operation. The maximum temperature rise is less than 1 ºC, apart from a small mixing zone between the discharge pipes and the seabed.

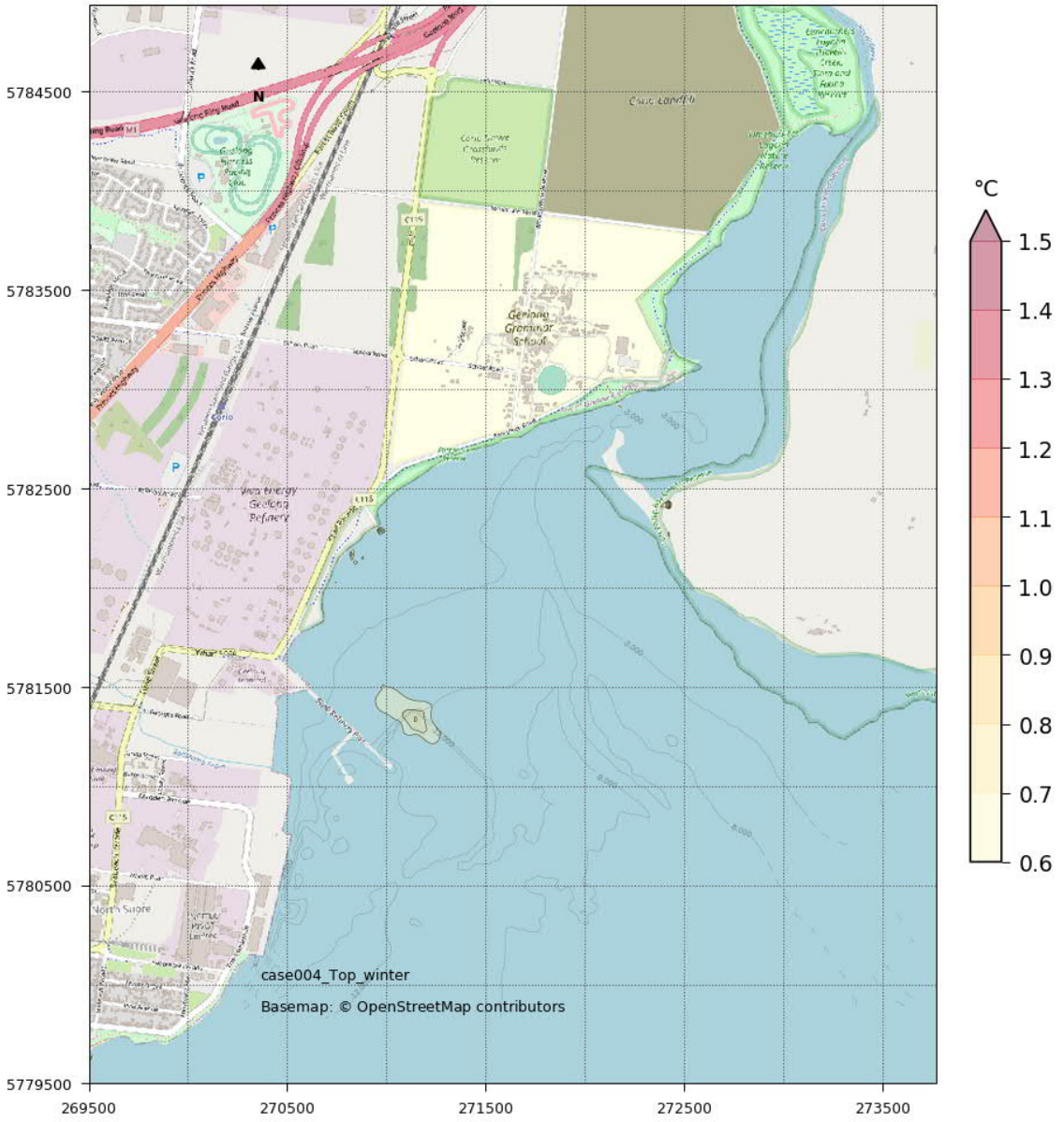


Figure 8-16. 50-percentile Temperature for Future Closed Loop Discharge

Figure 8-17 shows the predicted 90-percentile temperature difference at the surface for a future peak flow in closed loop mode. The temperature contours plotted are 0.6 ºC, 0.7 ºC, 0.8 ºC and 0.9 ºC. The maximum temperature rise is less than 1 ºC.

Note that in the event of closed loop operation being used, the existing refinery discharges would continue in the same manner as at present (these plumes are not shown in Figure 8-16 and Figure 8-17).

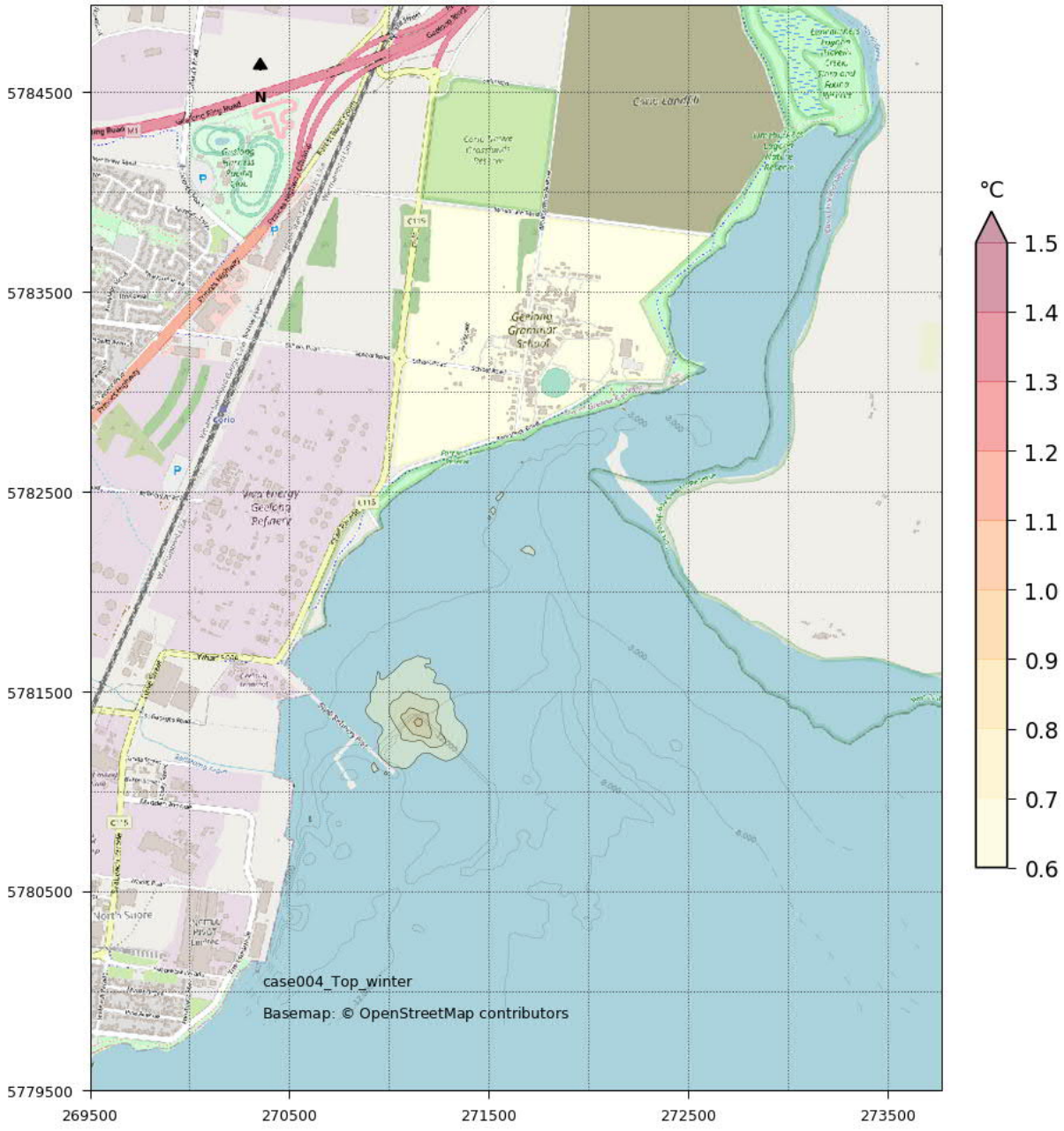


Figure 8-17. 90-percentile Temperature for Future Closed Loop Discharge

In summary, the temperature plume for the **closed loop peak flow situation** is much smaller than the existing plume from the refinery discharge and less intense, as the maximum temperature rise is less than 1 ^{o}C outside a small mixing zone.

8.9 Sensitivity Assessment

The computer modelling of temperature plumes was carried out with the standard parameter values in the dynamic regional model for a thermal plume in a wide estuary. As set out in Section 6, the sources of input data were as follows:

- Meteorological data from the BoM station at Geelong Racecourse;
- Regional solar radiation for Melbourne Airport;
- Air temperatures at Geelong Racecourse and Avalon;

- Relative Humidity recorded at Geelong Racecourse;
- Shortwave Solar Radiation and Longwave Radiation for Melbourne Airport;

Heat exchange through the water surface is modelled as the components of long-wave radiation, sensible heat transfer and evaporative heat loss, complemented by penetrative shortwave radiation.

In calibrating the model, it was noted that the predicted temperature contours were higher using the Geelong winds than the Avalon winds because winds are weaker at Geelong compared to Avalon. The more conservative Geelong winds were used for the main plots in this report. This sensitivity study examine the implications of (1) using the Avalon winds instead of the Geelong winds; and (2) adjusting the evaporative loss to account for the effects of small breaking waves on the shore.

The sensitivity studies adopted the 90-percentile existing temperature plume as the basis for assessment (as shown in Figure 8-9). Temperature contours are plotted as in earlier plots, except that the lowest temperature contour is 2 ^{o}C above ambient, as this is less than the proposed limit for the temperature increase in shallow water (+3 ^{o}C) and makes it easier to see the changes in the contours.

Figure 8-18 on the following page shows four plots of the 90-percentile plume temperature contour. The grid spacing in the plots is 500 m.

- Top LH – temperature contours for standard settings used in model (same as Figure 8-9) using winds from Geelong Racecourse;
- Top RH - temperature contours using winds from Avalon;
- Lower LH - temperature contours with extra evaporation from small waves;
- Lower RH - temperature contours with winds from Avalon and extra evaporation.

The winds from Avalon are stronger than for Geelong Racecourse because Avalon is in an open area with lower surface roughness that the urban surroundings at Geelong Racecourse. As a result, heat in the plume is lost to the atmosphere at a faster rate and the 2 ^{o}C contour is closer to the coast and does not extend as far to the north as in the standard run.

Increasing the evaporation has a similar effect to increasing the wind speed. The heat in the plume is lost to the atmosphere at a faster rate. As a result, the 2 ^{o}C contour is closer to the coast and does not extend as far to the north as in the standard run.

The combination of Avalon winds and increased evaporation leads to a reduction in the temperature contours. As a result, the 2 ^{o}C encompass a smaller area closer to the coast and, to the north, the 2 ^{o}C contour is shortened about 400 m away from the mouth of Limeburners Bay. Note that, in all cases, the 2 ^{o}C contour does not reach the Ramsar site.

Standard Model Settings – 90 %	**Use Wind Data from Avalon – 90 %**

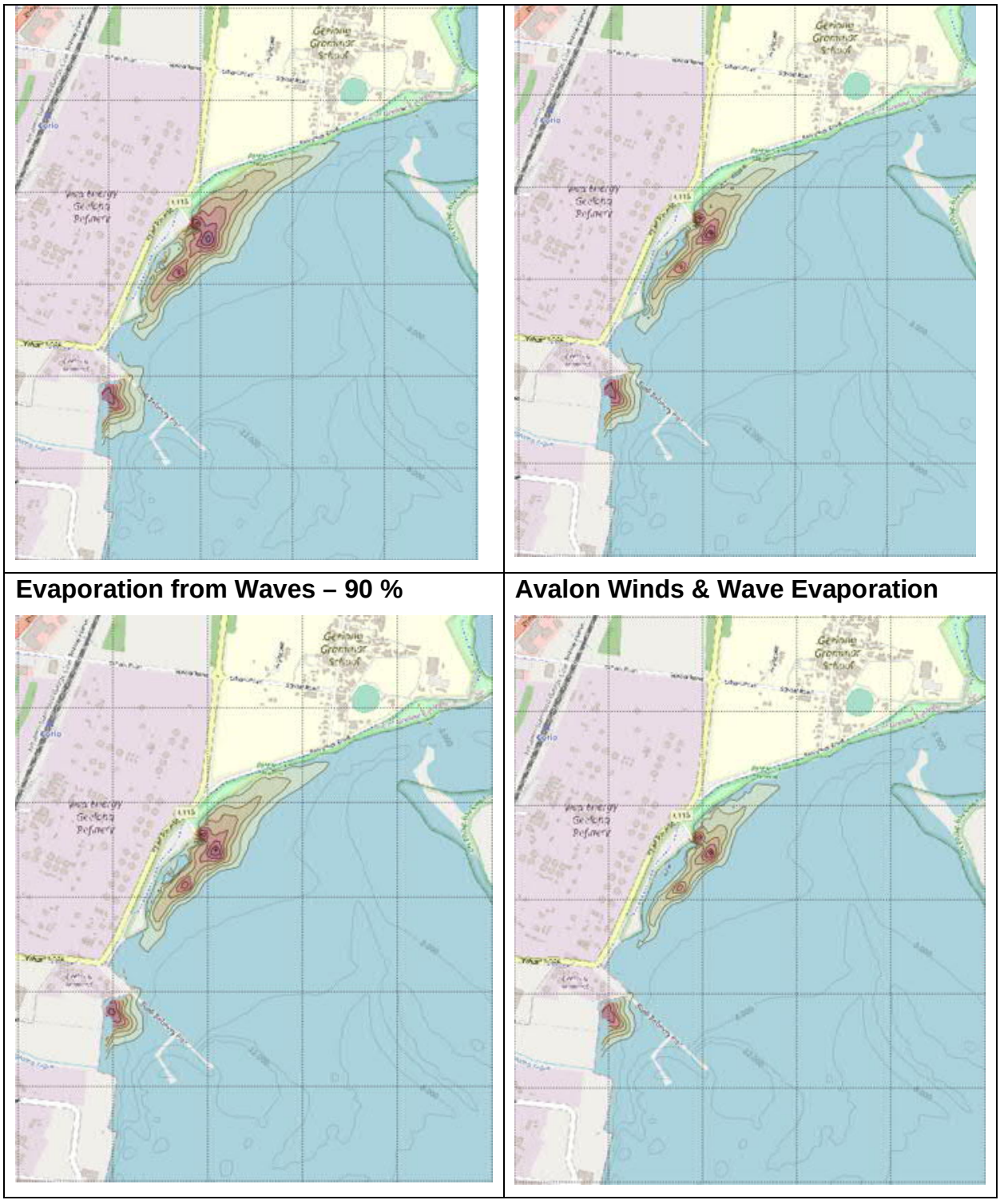


Figure 8-18. Existing Temperature Plume – Sensitivity Study
(same temperature scale as in Figures 8-9 to 8-13)

In summary, the sensitivity analysis of temperature plumes demonstrates that the model predictions provided in this report to assess temperature impacts are conservative, and probably over-state the extent of the plumes. Wind speeds and evaporation vary from day-today. In our view, the 2 ^{o}C temperature contour does not reach the boundary of the Ramsar site and does not enter Limeburners Bay.

8.10 Basis for Assessment of Changes in Water Temperature

This section provides an assessment of the effects of the existing and predicted temperature changes from the project on marine biotopes and ecological diversity. In making the assessment the following points were considered.

Existing Discharges have the Largest Temperature Changes

The largest temperature changes occur with the existing discharge arrangements from the refinery without the project and have been occurring in north Corio Bay for the last 65 years. This provides an empirical basis for assessing the effects of temperature changes in Corio Bay.

Proposal would Considerably Reduce Existing Temperature Plume

The proposal would involve reusing the FSRU discharge water in the refinery for cooling purposes and would result in a considerable reduction in the temperature and extent of the existing refinery discharge plumes.

The seagrass in north Corio Bay extends from the intertidal zone (supralittoral zone) to around the 4.5 m contour, although is sparse below 2 m depth. The warm chlorinated plume extends from the water line to about the 2 m depth and moves inward and outward from the shore with the tidal water variation. As a result of the tidal water movement, and the large diurnal variations in air and shallow seawater temperatures, the intertidal seagrass is subject to large variations in temperature each day.

The submerged shallow seagrass is subject to smaller temperature variations, but in absolute terms, a large temperature range. A survey was made of the extent and condition of seagrass from outlet W1 (where there is seagrass growing in the discharge channel) along the whole plume length and across the Ramsar site (where there is no plume). There were patches of dense and sparse seagrass in all regions, all in healthy condition, with the main risks to the seagrass beds being sediment movement, land drainage and sea urchins. The temperature plume appears to be a minor effect and was not apparent in the surveys.

In ecological terms, the limiting factor for seagrass growth does not appear to be temperature (or chlorine), but is due to variations in available light, sediment characteristics and predation. As described in Sections 5-15 and 5-16, there are variations in the extent of seagrass from year to year.

The seagrass growing along the shore of the refinery is currently exposed to a temperature increment above ambient seawater of 5 to 8 ^{o}C in small areas within the mixing zone. A longer section of seagrass (about 2 km long) is currently exposed to a temperature increment of 2 to 5 ^{o}C (see Figures 8-8 and 8-9).

With the project, the temperature increment would be 1 to 2 ^{o}C (see Figures 8-10 and 8-11). While plants may be expected to have higher productivity at warmer temperatures than lower temperatures, no significant change is expected because:

- The patchy composition of the seagrass in the plume area indicates that factors other than temperature are limiting growth:
- There is not a consistent change in seagrass density or condition with a reduction in temperature; and
- The density and condition of seagrass in the plume zone does not differ from that of seagrass elsewhere in Corio Bay, as recorded in extensive video transects made throughout the Bay (see Figure 5-59 in Section 5-17).

Cumulative Impacts Considered

The cumulative or combined effects of temperature change and chlorine concentration must be considered. Both are characteristics of the discharge from the refinery and would be a feature of any separate discharge from the FSRU. The combined effects are addressed in the next Section and in Section 13 of this report for the integrated risk assessments.

Different Biotopes Affected by Different Discharges

The temperature plume from the existing refinery discharges extends along the shore in front of the refinery to the entrance of Limeburners Bay. The proposal would considerably reduce the extent of the temperature plume, as explained above.

Two other discharge scenarios could occur in addition to the preferred operation - either FSRU discharge of cooler water from the diffuser or FSRU discharge of warmer water in closed loop mode of operation. These other scenarios discharge in the deeper port area and therefore affect different marine communities than the plume along the foreshore.

National Water Quality Management Strategy

The Australia and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) list **temperature** as a stressor of aquatic ecosystems and the potential effects as a "*Loss of native biota*".

Aquatic ecosystems are regulated by temperature. Biota, and physical and chemical processes, such as oxygen solubility and hydrophobic interactions, are sensitive to temperature changes. Large changes in temperature occur naturally as part of normal diurnal (daily) and seasonal cycles.

Growth, metabolism, reproduction, mobility and migration patterns can be altered by changes in water temperature. Animals try to remain near the centre of their tolerance range. High temperatures (usually over 40 ^{o}C) and low temperatures (usually under 5 ^{o}C) are considered deleterious. In the Corio Bay situation, the temperature changes do not enter the deleterious ranges for the current refinery discharges or for any of the FSRU operating modes which could occur for the project.

The ANZECC (1992) Guidelines recommend that the maximum permissible temperature increase in marine waters should be 2 ^{o}C, (this limit is based on the US EPA Guideline). Thus, the default limit on temperature changes is +/-2 ^{o}C.

An alternative suggested in the ANZECC 2000 Guidelines is to define the temperature limit based the natural 20, 50 and 80 percentile temperature. This will result is a larger acceptable temperature change in the intertidal zone and in shallow water, and a smaller acceptable temperature change in deep water, which is probably more appropriate from an ecological perspective. ANZECC 2000 advises that low risk trigger values for increases and decreases in temperature can be determined as follows:

- *Warm discharges should not increase the median temperature above the 80-percentile temperature, based on the seasonal distribution of seawater temperature data:*
- *Cool discharges should not decrease the median temperature below the 20-percentile temperature, based on the seasonal distribution of seawater temperature data.*

The annual variation in seawater temperature in Corio Bay is from 11 ºC to 22 ºC, as shown in Figure 8-3 and described in Section 5. On an annual basis, the 50 to 80 percentile temperature range is 3.3 ºC and to 20 to 50 percentile variation is the same. Thus a 2 ºC limit on temperature change would be smaller than the seasonal variation in seawater temperature.

In Corio Bay, the plume from the refinery extends along the shore in water depths to about 1 or 2 m. Seagrass and some seaweeds grow in the lower intertidal zone (see Figure 8-19) and are exposed to large daily variations in air temperature from high tide to low tide, and, during low tides, from day to night.



Figure 8-19. Patchy Seagrass in Intertidal Zone Adjacent to Outlet W4

Data from Avalon Airport show the annual air temperature variation is around 42 ºC (hottest hour to coldest hour), which is close to the annual variation in temperature experienced by intertidal marine biota. On a daily basis, the median range of air temperature is 10 ºC, the 80 percentile range is 14 ºC and the 20 percentile range is 7 ºC. Using these values, the 50 to 80 percentile temperature variation in the intertidal zone is 4 ºC. The 20 to 50 percentile variation is 3 ºC.

The temperature range in the waters of Corio Bay is smaller than in the atmosphere because of the heat capacity of water. Solar radiation is the principal natural process increasing water temperature while radiation and evaporation are the two principal processes decreasing water temperature. As these processes occur at or close to the sea surface, it is apparent that the diurnal change in water temperature is inversely proportional to depth.

Studies have shown that in water depths of about 0.5 m, the diurnal variation in temperature is approximately half the diurnal variation in air temperature. Adopting this range, the 50 to 80 percentile temperature range would be around 2 ºC and to 20 to 50 percentile variation would be the same.

Field Measurements from Temperature Loggers

Temperature loggers were installed in Corio Bay in water depths of 2 m, 5 m and 12 m. The 20 percentile to 80 percentile range was 1.0 ºC in the shallower depth and 0.8 ºC to 0.9 ºC in the deeper waters.

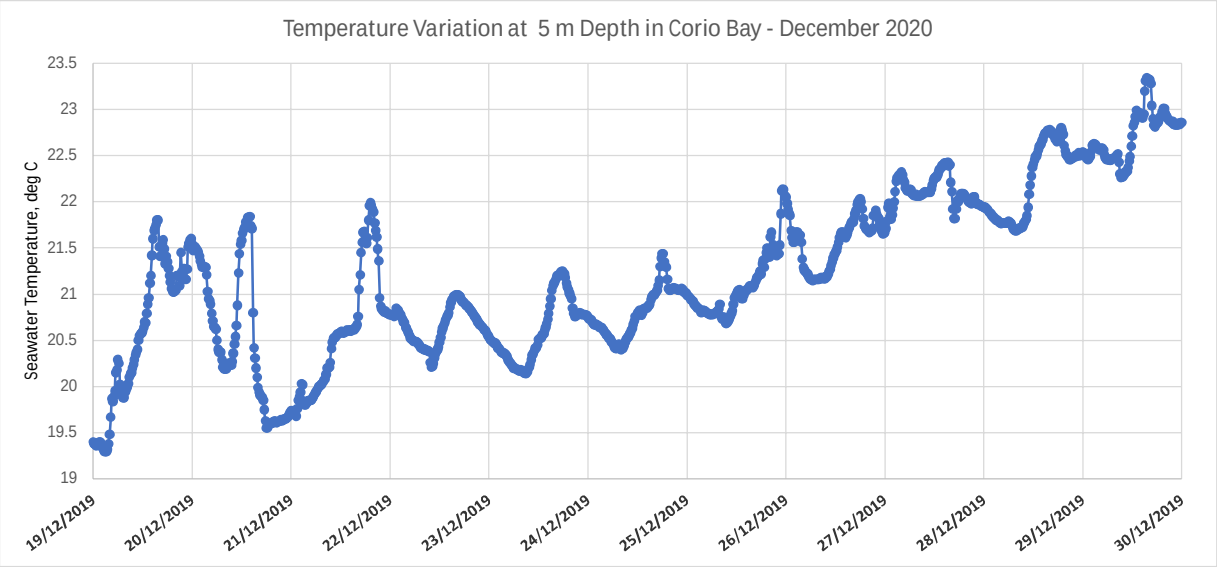
Figure 8-20 shows the measured temperature variation in December 2020 and February 2021 at 5 m depth. The measured seawater temperatures show that, on some days, the temperature variation over 24 hours was around 1 ºC whereas on other days it was up to 2.5 ºC. In a period of a week, a temperature variation more than 2 ºC was common. These measurements support the use of the permissible temperature increase of 2 ºC in marine waters, as the first option proposed in ANZECC 1992.

Applying the ANZECC 2000 second option, and the measured 20, 50 to 80 percentile temperatures, a limit for temperature change can be derived for warmer or cooler discharges in shallow water (depths of 0 to 2 m), slightly deeper water (2 to 5 m) and for deeper water (5 m to 15 m depth), based on the measured 50 to 80 percentile range, and the measured 20 to 50 percentile range, respectively.

The measurements show that, in a period of a week, a temperature variation over 2 ºC was common. These measurements support the use of the permissible temperature increase of 2 ºC in marine waters, as proposed in ANZECC 2000.

Based on the measured 20 to 50 percentile range (for the cooling limit) and the measured 50 to 80 percentile range (for the warming limit), the results of the logger measurements over a period of approximately two months were as follows:

- Logger at 1.5 m depth: percentile ranges were – 1.9 ºC and + 3.8 ºC;
- Logger at 2 m depth: percentile ranges were – 1.6 ºC and + 2.8 ºC;
- Logger at 4 m depth: percentile ranges were – 2.2 ºC and + 1.2 ºC; and
- Logger at 5 m depth: percentile ranges were – 1.1 ºC and + 0.8 ºC.



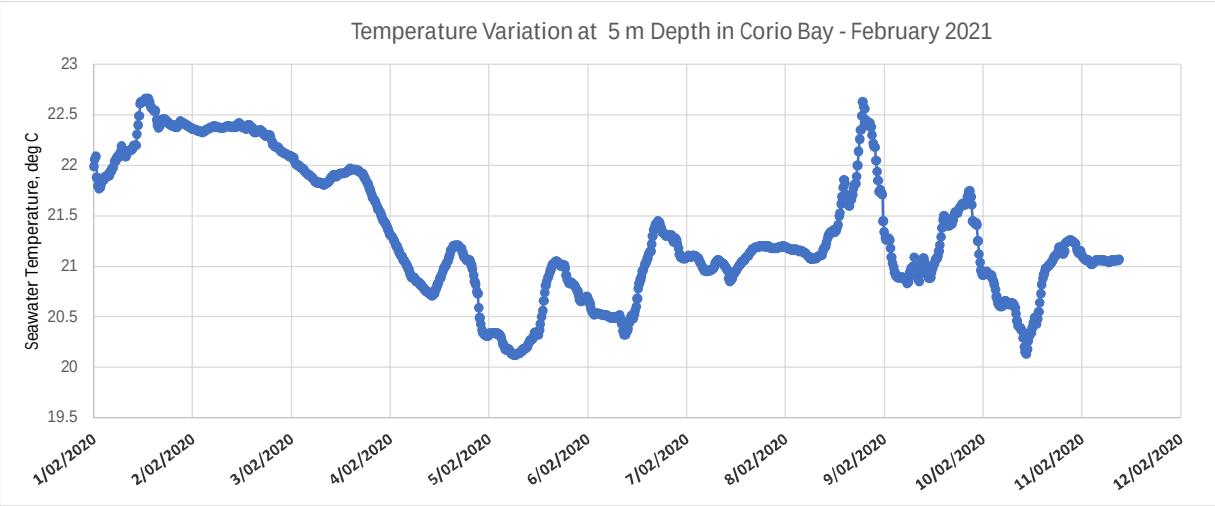


Figure 8-20. Measured Temperature Variation in Corio Bay

Table 8-2 summarises the adopted limits for seawater temperature change as a function of water depth. The limits are widest at the water surface (the intertidal zone) at +/- 3 ^{o}C, decrease to 2 or + 3 ^{o}C in shallow water (0 to 2 m depth), are more stringent in 5 m deep waters at 1 to 2 ^{o}C and most stringent in deeper waters at+/- 1 ^{o}C.

Table 8-2. Threshold Limits for Seawater Temperature Changes

Depth	Cooling Limit	Warming Limit
Intertidal	- 3 ^{o}C	+ 4 ^{o}C
0 to 2 m	- 2 ^{o}C	+ 3 ^{o}C
2 to >5 m	- 1 ^{o}C	+ 2 ^{o}C

The warm refinery plume is in shallow water, where the + 3 ^{o}C limit applies. The refinery plume with the project in operation would satisfy this requirement.

The diffuser plume is in deeper water where the - 1 ^{o}C limit applies. The predicted change in temperature with the diffuser plume is less than 1 ^{o}C and would meet this requirement.

8.11 Assessment with Reference to EPA ERS

The *Environment Reference Standard,* which is a fundamental component of the *Environment Protection Act 2017,* does not contain a temperature limit in Table 5-13 *Indicators and Objectives for Port Phillip Bay.* However, *Table 5-18 Weight of Evidence in Toxicant Risk Scoring System* provides a pertinent risk assessment framework, summarised in Table 8-3. The risk rankings for toxicants are considered applicable to physical stressors such as temperature.

Table 8-3. Risk Assessment Scoring in EPA Environment Reference Standard

Line of Evidence	Risk Ranking		
	High	**Medium**	**Low**
Marine	Significant and	Significant and	No significant effects on

ecology	high effects on abundance and diversity	moderate effects on abundance and diversity	abundance and diversity
Other lines of evidence	Significantly different from control and high effect size	Significantly different from control and moderate effect size	Not significantly different from control
Weight of evidence assessment	High risk of significant adverse effects	Medium risk of significant adverse effects	Low risk of adverse effects – meets objectives for protection of environmental values

Measurements and analyses that are presented in this marine assessment and used in the risk ranking are as follows:

- Monthly surveys of the abundance and species distribution of phytoplankton, zooplankton and ichthyoplankton in Corio Bay;
- Mapping and assessment of seabed habitat and ecological condition;
- Surveys of infauna abundance and species distribution;
- Targeted survey of seagrass under refinery plumes and in Ramsar site; and
- Model predictions of temperature changes, and comparison of the predictions to threshold limits derived from ANZECC 1992 (summarised in Table 8-2).

The evidence for infauna and seagrass indicates no significant adverse long-term effects of the refinery plume on abundance and diversity of seagrass or algae.

For the risk ranking in Table 8-3, it is concluded that the temperature plumes with the proposal would pose a **low risk** based on the following evidence:

- No detectible change in seagrass beds along the shore of the refinery;
- Temperature plumes are well under the ANZG threshold in Ramsar site and does not extend into Limeburners Bay; and
- No significant effects on abundance and diversity of plankton, pelagic species, infauna, water birds or other components of the marine food chain.

8.12 Conclusions of Impact Assessment on Ramsar Site

Examination of the plots showing plumes of temperature show the following:

- The existing warm plumes extend along the shore of Corio Bay but do not enter Limeburners Bay, and are well under the ANZG threshold of +/- 2 ^{o}C before the boundary of the Ramsar site, as shown in Figure 8-18; and
- Future plumes with the project will not affect the Ramsar site or its ecology.

The conclusions from the assessment of potential impacts on the Ramsar site are listed in Table 8-4, together with appropriate mitigation and monitoring recommendations.

Table 8-4. Summary of Assessment of Impact on Temperature

Critical processes and services	Conclusion of Assessment	Mitigation and Monitoring
Wetland bathymetry	No impact in intertidal mudflat area	No action needed
Geomorphology	No impact on sedimentation patterns	No action needed
Marine invertebrates	No effect on invertebrates in Ramsar site or on abundance of zooplankton or infauna as food supply in Ramsar site.	No action needed
Seagrass	No loss or change in condition of seagrass in Ramsar site due to any of the existing or future plumes.	No action needed Note: Seagrass monitoring recommended for outside Ramsar site
Mangroves	No impact on mangroves.	No action needed
Saltmarsh	No impact on saltmarsh.	No action needed
Water birds	No apparent effect as water birds continue to occupy and feed in the plume zone.	No action needed
Threatened bird species	Addressed by Aecom, but no significant impact pathway from temperature plume.	No action needed
Migratory birds	Addressed by Aecom, but no significant impact pathway from temperature plume. No change in zooplankton availability.	No action needed
Threatened fish species	No effect. Recreational fishing popular in the plume and in Limeburners Bay.	No action needed

8.13 Biotope Complexes Potentially Affected by Thermal Plumes

The existing thermal plumes from the refinery discharges occupy the littoral and shallow sublittoral zones along the shoreline in front of the refinery. Biotope complexes (as per the DELWP FeAST tool) that are potentially affected are:

- ba2.7 Littoral seagrass beds
- ba5.8 Sublittoral seagrass beds
- ba2 Littoral sediment (small patches among seagrass)
- ba5 Sublittoral sediment (small patches among seagrass)
- ba5.b Non-reef sediment epibenthos

The possible future cool thermal plume from the diffuser which would be used in the event that the FSRU discharge was not used in the refinery during a maintenance period would occupy the seabed in the dredged channel. Biotope complexes that are potentially affected are:

- ba5.3 Sublittoral mud

The possible future warm thermal plume with closed loop operation of the FSRU would extend from the seabed to the water surface in the port above the dredged channel. Biotope complexes that are potentially affected are:

- ba5.3 Sublittoral mud
- Plankton communities
- Pelagic communities.

In this section, the pressure being assessed is the change in seawater temperature. Scales for the frequency and intensity of this pressure have been defined by DELWP and are summarised in Table 8-5.

Table 8-5. Defined Scales for Parameters in Environmental Risk Assessment

Parameter	Very poor	Poor	Affected	Good
Frequency	**Permanent**	**Frequent =** *3 times per year*	**Regular =** *1 per year*	**Occasional =** *1 per 5 years*
Intensity	**High (*3) =** *ecosystem functional change*	***Medium (2) =*** *communities shift a distinct level*	***Low (1) =*** *noticeable change but not significant*	***Very Low (0) =*** *no significant effect*
Tolerance/ resistance	**Very Low (2)** (>75 %)	**Low (3)** (25- 75 %)	**Medium (4)** (25 %)	**High (5)** No significant effect
Recovery	**Very Low (2)** (>25 years)	**Low (3)** (10- 25 years)	**Medium (4)** (2-10 years)	**High (5)** (<2 years)

For each plume, and for each biotope complex, the parameter values have been assessed and are listed, with reasoning, in Table 8-6, Table 8-7 and Table 8-8.

Table 8-6. Environmental Risk Assessment for Existing Thermal Plume

Biotope Complex	Marine Ecology Assessment				Evidence Assessment	Risk Ranking
	Frequency	Intensity	Tolerance	Recovery		
Existing Thermal Plume along shoreline in front of refinery						
ba2.7 Littoral seagrass beds	Permanent	Very low = no effect	High tolerance to temperature rise	Medium – in 2-10 years	Survey of seagrass beds found no detectible change with existing plumes	Negligible Risk
ba5.8 Sublittoral seagrass beds	Permanent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Survey of seagrass beds found no detectible change with existing plumes	Negligible Risk
ba2 Littoral sediment (small patches among seagrass)	Permanent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Infauna have life cycles of months and are tolerant of temperature change	Negligible Risk
ba5 Sublittoral sediment (small patches among seagrass)	Permanent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Infauna have life cycles of months and are tolerant of temperature change	Negligible Risk
ba5.b Non-reef sediment epibenthos	Permanent	Low = noticeable but not significant	High tolerance to temperature rise	Medium – in 2-10 years	Survey of seagrass beds found no detectible change with existing plumes	Negligible Risk
Plankton and pelagic communities	Permanent	Low = noticeable but not significant	High tolerance to temperature rise	High – in < 2 years	Plankton surveys show rapid regrowth is the plume. Pelagics are mobile and can avoid plume.	Negligible Risk
The location of the thermal plume varies with the tide, and extends from the water line to about 300 m offshore in shallow water. The plume is 1 to 1.5 m deep. Littoral and shallow sublittoral seagrass beds naturally experience large diurnal variations in temperature that exceed the plume temperature (except in the defined mixing zones). Surveys show seagrass communities were healthy with no detectible variation in condition with changes in temperature which have been occurring as a result of refinery operation for 65 years. Possible that growing season may be slightly extended by higher water temperature in sublittoral. Sea urchins are grazing vigorously in the outer edge of seagrass and causing significant loss of seagrass. Turbidity from land drainage affects seagrass.						

Table 8-7. Environmental Risk Assessment for Cooler Diffuser Plume

Biotope Complex	Marine Ecology Assessment				Evidence Assessment	Risk Ranking
	Frequency	Intensity	Tolerance	Recovery		
Possible future cool thermal plume from the diffuser						
ba5.3 Sublittoral mud	Frequent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Infauna have life cycles of months and are tolerant of temperature change	Negligible Risk
Plankton communities	Frequent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Extensive plankton surveys found no significant effect of existing thermal discharges. Plume will be deep and away from photic zone	No Risk
Pelagic communities.	Frequent	Low = noticeable but not significant	High tolerance to temperature rise	High – in < 2 years	Mobile community and can easily avoid plume if desired. Very small zone of effect on seabed and in water column	No Risk
The location of the possible future cool thermal plume from the diffuser is on the seabed and in a 3 m layer above the seabed. The plume is approximately 10 m below the surface. The temperature change is less than 0.5^{o}C and within the ANZG limit. Infauna have life cycles of months and are tolerant of temperature change. Extensive plankton surveys found no significant effect of existing thermal discharges from the refinery. The cooler plume would be in a deep layer and away from photic zone. Plankton are in the upper part of the water column and adapted to larger diurnal variations in temperature from natural processes. Very small temperature change in the diluted plume, so effects may be minor to negligible. Pelagic communities are mobile and can easily avoid plume if desired.						

Table 8-8. Environmental Risk Assessment for Warmer Closed Loop Plume

Biotope Complex	Marine Ecology Assessment				Evidence Assessment	Risk Ranking
	Frequency	Intensity	Tolerance	Recovery		
Possible future warm thermal plume with closed loop operation of the FSRU						
ba5.3 Sublittoral mud	Frequent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Infauna have life cycles of months and are tolerant of temperature change	Negligible Risk
Plankton communities	Frequent	Very low = no effect	High tolerance to temperature rise	High – in < 2 years	Extensive plankton surveys found no significant effect of existing thermal discharges. Plume will be deep and away from photic zone	Negligible Risk
Pelagic communities.	Frequent	Low = noticeable but not significant	High tolerance to temperature rise	High – in < 2 years	Mobile community and can easily avoid plume if desired. Very small zone of effect on seabed and in water column	Negligible Risk
The location of the possible future warm thermal plume from closed loop operation would occupy a small area in the port at the rear of the FSRU from the seabed to the sea surface. The temperature change is less than 0.5^{o}C and within the ANZG limit except for a very small mixing zone. Infauna have life cycles of months and are tolerant of temperature change. Extensive plankton surveys found no significant effect of existing thermal discharges. Plume will be deep and away from photic zone. Plankton are in upper part of water column and adapted to larger diurnal variations in temperature from natural processes. Pelagic communities are mobile and can easily avoid plume if desired. Small temperature change in the diluted plume.						

8.14 Conclusions

The largest temperature changes occur with the existing discharge arrangements from the refinery (without the proposed project) and have been occurring in north Corio Bay for the last 60 years. Surveys of the seagrass beds under the plumes do not detect any significant change due to the plumes. This provides an empirical basis for assessing the effects of temperature changes in Corio Bay and indicates that the warm water refinery discharges (and associated chlorine discharges) are not creating adverse impacts.

The temperature rise in the existing plumes outside the mixing zone is modest at 2 ^{o}C in relation to the daily variation in temperatures experienced by biota in the littoral zone (10 ^{o}C) and shallow sublittoral zones (1.6 ^{o}C to 5 ^{o}C).

The proposal would involve reuse of the FSRU discharge in the refinery for cooling purposes and result in a considerable reduction in temperature in the refinery discharge plumes. Implementation of the proposal would substantially reduce the temperature rise in the refinery discharges, and therefore the extent of the thermal plumes along the shore. This would be the usual mode of operation of the proposal.

Discharge through the diffuser is not anticipated to be a common situation and would only occur when the refinery was not operational such as during maintenance periods. When discharge of cooler water from the FSRU through the diffuser occurs, there would be high dilution of the discharge (20:1, see Section 6)and the resulting diluted plume would have a temperature difference of less than -0.6 ^{o}C. The diluted plume would be approximately 3 m thick and located within the dredged port area at the bottom of the water column, well away from the photic zone. The temperature change is well within the ANZG limit of +/- 2 ^{o}C and within the more stringent limit of +/- 1 ^{o}C for deeper water. Infauna in the sediments on the seabed in the port are tolerant of a small temperature change.

Discharge of warm water from closed loop operations is not anticipated to be a common situation, as this is not the preferred FSRU operating mode. When it does occur, there would be high dilution of the discharge so that the resulting diluted plume has a temperature rise of less than 0.8 ^{o}C. The diluted plume would be in a very small area at the rear of the FSRU within the port. The temperature change is within the ANZG limit except in a very small mixing zone.

The assessment recognizes that, except in the defined mixing zones, the biotope complexes are exposed to natural diurnal variations in temperature that exceed the temperature changes due to the discharge plumes.

Based on the assessment of the DELWP risk factors, and the weight of evidence from monitoring, surveys and published literature and reports, the existing thermal plume, and the possible future thermal plumes are classified as "*Negligible Risk*" under the DELWP risk matrix and "*Low Risk*" under the EPA risk matrix.

9 Chlorine Assessment

This section provides an assessment of the potential marine impacts associated with the discharge of chlorine that would be used to control biofouling in the FSRU during operation of the proposed Viva Energy Gas Terminal Project. The proposal is that, usually, the discharge from the FSRU would be directed to the refinery where the flow would be reused as cooling water. In that scenario, there would be no change in the concentration or rate of chlorine discharge from the refinery from conditions that have existed for over 60 years.

As described in Section 1, the FSRU may on occasions operate in a closed loop scenario, whereby a portion of the LNG would be re-gasified using LNG-fired boilers on the FSRU. The warm seawater from closed loop operation contains residual chlorine and would be discharged from pipes at the rear of the FSRU.

A third scenario is the backup discharge arrangement that would be used during refinery maintenance periods. As full reuse of the FSRU discharge in the refinery would not be possible during that period, the FSRU would discharge directly to Corio Bay via the diffuser located under the new pier.

The environmental effects of the discharge of chlorine are assessed in this section. In each scenario, the chlorine would be discharged at low concentrations to Corio Bay where it would be converted by natural chemical transformations back to sodium chloride (natural sea salt) with minor concentrations of other compounds, primarily bromoform, which also exists naturally in the marine environment.

9.1 Chlorine Addition in the FSRU and the Refinery

For many years, the Geelong Refinery has been using seawater from Corio Bay for cooling water purposes. Refinery processes generate heat, and this is transferred to the seawater in a series of heat exchangers in the refinery. The discharge is regulated by the EPA.

Chlorine at a concentration of about 0.5 mg/L is added to the seawater as it enters the refinery to control biofouling (accumulation of microorganisms, plants, algae, or small animals) in the pipes, pumps and heat exchangers. For many years, the chlorine was produced by electrolysis, where the passage of an electrical current separated the salt in seawater (sodium chloride) into chlorine and sodium ions. In recent years, a chlorine solution has been used, based on an electrolysis process away from the refinery site.

The electrolysis technology would be used to add chlorine to the seawater entering the FSRU and for the same purpose – to control biofouling. An average of 0.5 mg/L of chlorine would be added to the seawater entering the FSRU. Most of the chlorine and chlorine-produced oxidants (CPO) would convert back to natural salts through chemical changes during passage through the heat exchanger. The seawater leaving the FSRU would have a residual CPO concentration averaging 0.1 mg/L. The flow sequence and chlorine levels are shown in Figure 8-1.

The proposed and preferred FSRU operating mode for this project is open loop regasification i.e., using seawater as the heat source to convert LNG back to a gas. Seawater would be drawn from Corio Bay into the FSRU through the sea chests in the FSRU hull and circulated through heat exchangers to vaporise the LNG to a gas

using some of the heat in the seawater. This would cool the seawater by about 7 ºC. At maximum capacity, the daily seawater intake to the FSRU would be 350 ML/d. Seawater from the FSRU regasification process would be piped to the refinery for use as cooling water (and as a replacement for seawater currently extracted from Corio Bay) and then discharged back to Corio Bay via the existing refinery discharge points. The seawater would be piped from the FSRU to the existing refinery seawater inlet channel and additional chlorine would be added in the refinery to bring the chlorine concentration up to 0.5 mg/L (the same level as currently used).

The chlorine and CPO concentrations decline during passage through the refinery pipes and heat exchangers to less than 0.02 mg/L. The average chlorine concentration in the refinery discharge would remain at 0.06 mg/L with the operation of the FSRU.

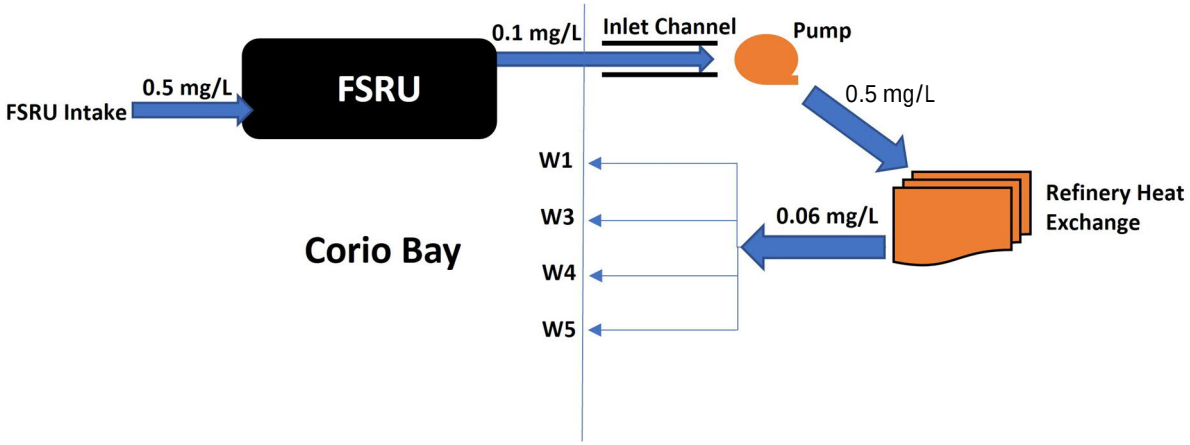


Figure 9-1. Schematic Diagram of Water Flow and Chlorine Addition

The key feature of the proposed project is that the chlorine level in the refinery discharges **with** the FSRU would be the same as now, **without** the FSRU.

The flow and chlorine levels with the proposal are documented in Table 9-1 where is it apparent that the present discharges totalling 350 ML/d contain 20 kg/d of residual chlorine. The future discharges would also total 350 ML/d and contain 20 kg/d of residual chlorine.

Table 9-1. Schedule of Discharge Points with Flow and Chlorine Rise

Discharge Point	Type	Unit	Existing Situation	Future Peak	Future Average
W1	Flow	ML/d	228	228	228
	Chlorine	mg/L	0.06	0.06	0.06
W3	Flow	ML/d	2	2	2
	Chlorine	mg/L	0.18	0.18	0.18
W4	Flow	ML/d	35	35	35
	Chlorine	mg/L	0.06	0.06	0.06
W5	Flow	ML/d	85	85	85
	Chlorine	mg/L	0.05	0.05	0.05

Discharge Point	Type	Unit	Existing Situation	Future Peak	Future Average
All four discharges	**Flow**	**ML/d**	**350**	**350**	**350**
	Chlorine	**kg/d**	**20**	**20**	**20**

As noted above, two other discharge scenarios could occur in addition to the preferred operation - either FSRU discharge of cooler water from the diffuser or FSRU discharge of warmer water in closed loop mode of operation. Discharge in these other scenarios would occur in the port area and therefore affect different marine communities than the plume formed along the foreshore by the four existing refinery discharges.

Direct discharges from the FSRU, either to the refinery or from the proposed diffuser under the new pier, or from ports on the FSRU (if the FSRU operates in closed loop mode i.e., using gas-fired boilers to warm the LNG) would have a chlorine concentration (as CPO) of up to 0.1 mg/L (100 µg/L). The maximum chlorine concentration is based on information provided by potential FSRU operators. Ballast water also is discharged periodically. It undergoes 2 weeks of storage, and there is more chlorine decay, so the concentration of CPO in the ballast water discharge would be 0.02 mg/L (20 µg/L).

The amount of seawater used by the FSRU would vary each day depending on the demand for gas. Peak gas production occurs in cold winter months. As stated above, the maximum seawater extracted for peak gas production would be 350 ML/d, the average rate would be 250 ML/d and the minimum rate would be approximately 120 ML/d. The difference between the seawater volume piped from the FSRU to the refinery inlet and the refinery seawater requirement of 350 ML/d would continue to be drawn up the refinery inlet channel.

9.2 Seawater Chemistry

Seawater contains a range of elements and compounds at concentrations much higher than in freshwater (see Table 9-2). Apart from the hydrogen and oxygen in H_2O, or pure water, the most abundant element in seawater is chlorine, normally present as the ion chloride. Sodium is the next most common element, followed by other metals (calcium, potassium, strontium), oxidised compounds (sulfate, carbonate, bicarbonate), other halogens (bromine, fluorine and iodine) and non-metals (carbon and boron). These elements and compounds are dissolved and are known as ‘salts’ in water. Together the salts and water make seawater. Table salt is ‘sodium chloride’, which is a solid form of the most common salt present in seawater.

Table 9-2. Composition of Seawater

Element (as ion)	Concentration in seawater, mg/L
Chloride	19,160
Sodium	10,500
Magnesium	1,280

Element (as ion)	Concentration in seawater, mg/L
Sulfate	2,680
Calcium	410
Potassium	380
Bromide	65
Carbon (inorganic)	36
Strontium	13
Boron	4
Fluoride	1

Marine biota present today have evolved in the presence of chloride and other salts. They are accustomed to exposure to chlorine and bromine as ions (chloride) and a range of compounds. Chlorine as dissolved hypochlorite can be easily produced from seawater by electron transfer from chloride. Hypochlorite reacts quickly with the bromide in seawater to create a wide range of brominated oxidants (hypobromite) and other compounds, while the chlorine returns to the salt form (sodium chloride). These reactions form the basis of the natural halogen cycle in the marine environment (see Figure 9-2).

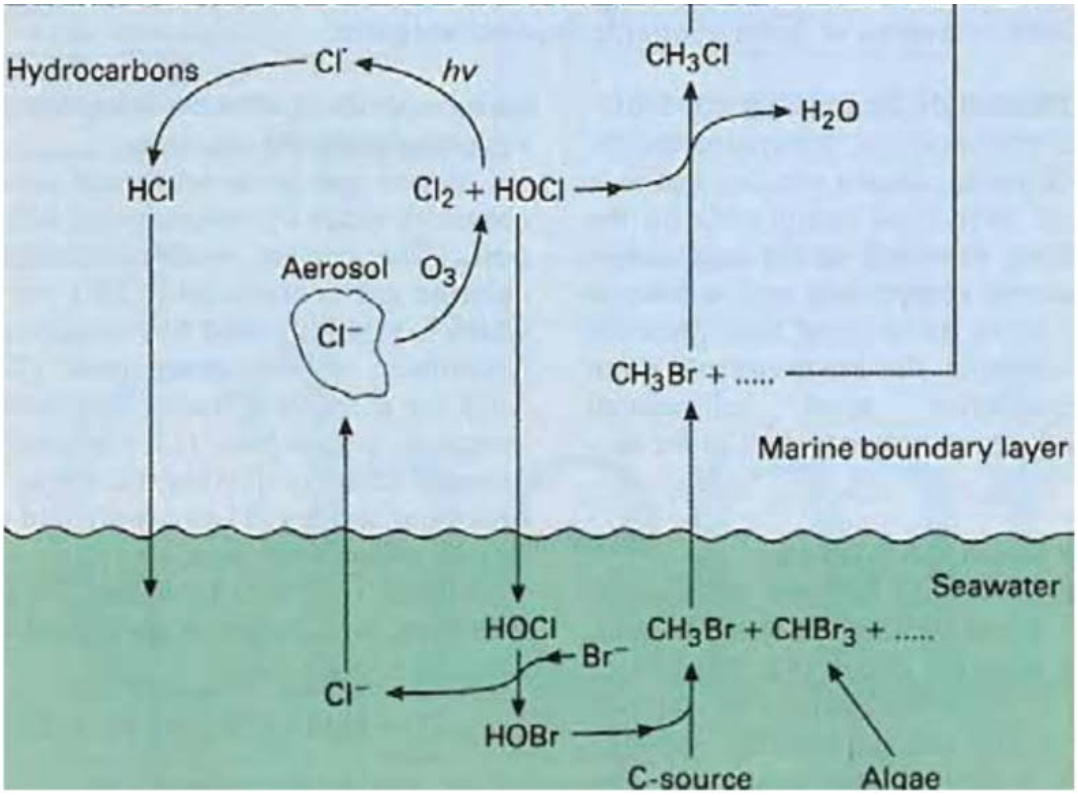


Figure 9-2. The Natural Halogen Cycle in the Marine Environment
(Jenner and Wither 2011)

Brominated compounds are produced naturally by a range of marine biota, notably marine algae (see Figure 9-2). While these compounds may be toxic to freshwater biota, they are part of life in the marine environment.

Many marine seaweeds and microalgae produce bromoform (it smells like chlorine bleach). Bromoform (or tribromomethane, $CHBr_3$) is one of the most common bromine compounds in the marine environment. It has been found to suppress methane production in cattle. Consequently, the seaweed *Asparagopsis* is being grown to supplement the diet of cows to reduce methane production on a large scale. *Asparagopsis* and other macroalgae are common on seagrasses in Corio Bay, Port Phillip Bay and Western Port Bay (see photos in Figure 9-3).

Tribromophenol ($C_6H_3Br_3O$ or TBP) is another bromine compound produced by brown and red algae that are common the Victorian Bays. The edible flesh of many species of Australian ocean fishes contain natural concentrations of TBP, which is responsible for the natural 'ocean flavour' of seafoods and has been considered for addition to prawn farm ponds to provide a more natural tasting product (Whitfield et al., 1998).

Marine biota can regulate (accumulate or depurate) the concentration of these chemicals. The concentrations of bromophenols are naturally high in many marine invertebrates, including burrowing marine worms in Australia with TBP concentrations commonly naturally ranging from 2 µg/kg to more than 8,000 µg/kg (Whitfield et al, 1999b). After exposure to high concentrations, they can lower the concentrations in their bodies within hours or days. Consequently, marine biota are far less sensitive to chlorine and bromine than their freshwater ecological equivalents (Lebaron et al 2019).



Figure 9-3. Algae on seagrasses, Corio Bay left, Asparagopsis in Western Port

9.3 Behaviour of Chlorine Produced Oxidants in Seawater

As a preface to the assessment of marine impacts arising from residual chlorine in the seawater discharge, it is important to explain how chlorine products are formed from seawater salts and how these products return almost entirely to seawater salts.

Chlorine is used to prevent biological growth in the seawater cooling system at the refinery. Chlorine can be added as sodium hypochlorite liquid or by passing seawater through an electrolysis cell that converts the chloride naturally present in seawater to chlorine gas, which dissociates instantaneously to hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). The hypochlorite ion ($OCl^{-)}$ is the main equilibrium product in seawater.

$$Cl_2 + 2OH^- \rightarrow OCl^- + Cl^- + H_2O$$

The hypochlorite rapidly reacts with natural bromide salt (Br-) in seawater to create hypobromous acid (OBr^-) while the chlorine component of the hypochlorite returns to the original chloride ion (Cl^-).

$$OCl^- + Br^- \rightarrow OBr^- + Cl^-$$

This series of reactions is rapid and occurs within 10 seconds (Jenner et al. 1997). Bromine is a weaker oxidant than chlorine but is effective in preventing biofouling in heat exchangers (or in disinfecting saltwater swimming pools). The antifouling and oxidative capacity of electrolysed seawater is therefore largely due to hypobromite rather than hypochlorite.

The chlorine and bromine oxidation chemicals used to prevent biological growth in seawater are referred to as chlorine produced oxidants (CPO). CPO are often referred to as total residual chlorine oxidants or simply residual chlorine, with concentrations expressed as mg/L or µg/L chlorine for consistency with the original form of the oxidant and its analytical measure.

Other products of seawater chlorination are known as chlorination-produced by-products (CPB). They represent less than 6 % of the chlorine concentration initially produced (Jenner and Wither 2011). Most of the CPB are present as trihalomethanes (THM) and most THM are tribromomethane or 'bromoform' (Abdel-Wahab, 2011, Boudjellaba et al, 2016, Jenner and Wither, 2011, Satpathy et al, 2010).

Bromoform occurs naturally in seawater at around 1 to 3 µg/L as a result of natural production by marine macro-algae and micro-algae found in all coastal marine environments (USEPA, 2012, Boudjellaba et al, 2016, Gribble, 2012). The toxicity of chlorine-derived chemicals in seawater includes CPO and THM but is measured as the concentration of CPO simply in terms of chlorine concentration.

9.4 Chlorine Decay Over Time

CPO concentration reduces quickly with time due to inorganic reduction reactions and volatilisation to the atmosphere (ANZECC 2000, CEE 2018b, CSIRO 2019, Jenner and Wither 2011, Saeed et al. 2015, USEPA 2017, Wahab 2012). The rate of reduction of chlorine is faster at high salinity and high temperature, with reduction of initial concentration by 70 % to 85 % in seawater within 5 minutes of initial production.

Figure 9-4 shows the rate of chlorine decay as a function of salinity (left panel) and temperature (right panel). There is slow decay in freshwater and fast decay in seawater. Zeng et al. (2009) showed that at 15 °C, an initial residual chlorine concentration of 2.35 mg/L in seawater reduced to approximately 0.8 mg/L in less than 1 minute (see Figure 9-4). This reduction resulted from the oxidation of bromide to hypobromous acid, at a rate that is too fast to measure. This was followed by a slower decomposition of the CPO over 15 mins to 0.5 mg/L and almost to zero in 30 – 40 min.

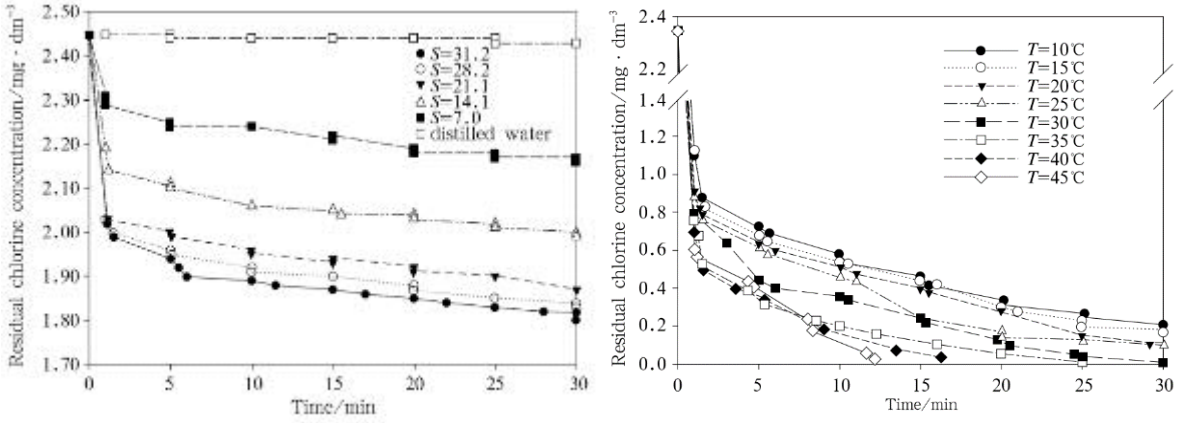


Figure 9-4. Reduction in CPO Concentration with Time (Zeng *et al* 2009)

The electrolysis process on the FSRU would produce an initial CPO concentration of 0.5 mg/L. This concentration would decay rapidly in the pipe network to less than 0.2 mg/L and by the time the flow has passed through pumps, pipes and heat exchangers, the residual chlorine concentration in all seawater discharges is warranted by the FSRU supplier to be a maximum of 0.1 mg/L. Thus, all near-field and regional model predictions in this study are based on a chlorine concentration of 0.1 mg/L in all seawater discharges direct from the FSRU except ballast water, which would have a residual chlorine concentration after prolonged storage averaging 0.02 mg/L. The refinery discharges have extra decay and chlorine levels of 0.018 to 0.006 mg/L.

Small biota in the FSRU pipes would be subjected to a continuous dose of chlorine in the range of 0.1 mg/L to 0.5 mg/L (depending on the position of the biota in the pipe network).

The effect of a continuous low dose of chlorine over many hours is to damage the organism and thus prevent growth.

The hydrodynamic model calculations in this study take into account the decay of chlorine with time due to chemical reactions and volatilisation. Decay processes in seawater would result in total loss of CPO from the initial production over a period of hours in well-mixed aerobic seawater (CEE 2018b, Saeed et al. 2015, Water Technology 2017). There will be no accumulation of chlorine in Corio Bay.

The rate of chlorine decay with time was measured by Dr Ian Wallis of CEE and a chemist from ALS (a NATA-certified laboratory). The decay tests were conducted using seawater from Corio Bay at the St Helens Park pier. Various concentrations of chlorine in the range of 0.5 to 1.4 mg/L were dosed into 20 L of seawater.

The concentration of chlorine in the water was measured by the ALS chemist every 5 minutes using the DPD method to monitor the rate of decay until no chlorine could be detected. Four initial doses of chlorine used: 0.55 mg/L, 0.59 mg/L, 0.61 mg/L and 1.41 mg/L. According to ANZ Standard 5667.1:1998, residual chlorine samples have a maximum 5-minute holding time (due to the rapid decay rate).

The results of the decay tests are plotted in Figure 9-5. They show that with an initial chlorine concentration of around 0.55 to 0.61 mg/L, the chlorine rapidly reacts with the bromine in seawater and has dissipated to very low concentrations in approximately one hour. With a higher initial chlorine concentration of 1.41 mg/L the chlorine decayed by 50% in about half an hour and by 90 % in two hours.

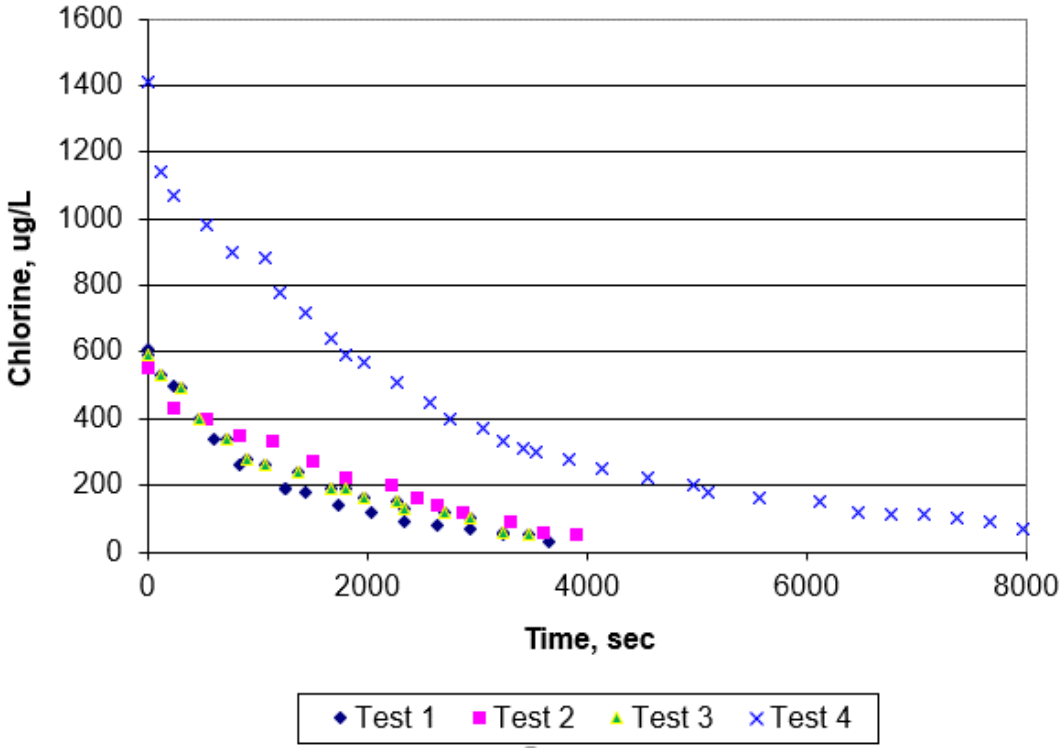


Figure 9-5. Decay of Chlorine in Tests beside Corio Bay (CEE, 2021)

(Note: DPD method measures chlorine-produced oxidants; tests meet AS 5667.1:1998)

Previous laboratory experiments by CEE on chlorine decay in Sydney showed a 50 % decay rate in approximately 1 hour. The experiments by Zeng et al. (2009 showed a 40 % decay rate in approximately 1 hour (see Table 9-3).

For the hydrodynamic modelling simulations of chlorine plumes, a conservative chlorine decay rate of a 40 % decay each hour was used, with a sensitivity simulation using the measured 50 % decay each hour.

9.5 Limit or Guideline Value of Chlorine in the Marine Environment

A Guideline Value for chlorine was obtained from consideration of the Victorian EPA *Environment Reference Standard* (ERS), the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG) and a recent CSIRO paper specifically addressing the chlorine limit in marine waters (Batley and Simpson, 2020).

9.5.1 EPA Environment Reference Standard

The new *Environment Protection Act* 2017 came into effect on 1 July 2021 and substantially amended the environment protection framework, including adopting a new *general environmental duty* and introducing a new permissions scheme including a development licence, operating licence, permits and registrations.

The *Environment Reference Standard* is a fundamental component of the *Environment Protection Act 2017.* Table 5-18 of the *Environment Reference Standard* provides a series of criteria that define ***low risk to ecological biodiversity***. There is no specific limit listed for chlorine. However, for defining low risks to marine ecosystems, key criteria are listed as:

- Concentration of toxicity test values meets 95 % species protection levels;
- No significant effects on abundance or diversity;

- Bioaccumulation not significantly different from control; and
- Low risk of adverse effects.

9.5.2 Water Quality Guideline (ANZG 2018) for Chlorine

The ANZG have been developed and refined over years in a scientifically rigorous process with review and consultation. The ANZG provide generic trigger values *(Default Guideline Values*) and procedures to develop site-specific *Guideline Values* for the protection of aquatic ecosystems.

The ANZG and an associated document (Warne et al. 2018) define the procedure to develop *Guideline Values* (GV) for protection of ecosystems based on all available toxicity test results for any particular chemical. This procedure is based on the use of species sensitivity distributions of chronic toxicity data for at least five species and is applicable to developing short-term GV for the discharge of chlorine produced oxidants (CPO) to the marine environment.

The ANZG listed a chronic Guideline Value for chlorine in freshwater of 3 µg/L (ANZG 2018), but no Guideline Value for chlorine in marine waters (as at October 2021), although the freshwater limit was suggested as an interim limit for marine waters.

9.5.3 Chlorine Guideline Value

Batley and Simpson (2020) published a Guideline Value for chlorine in seawater in 2020. They noted that derivation of a water quality guideline value for chlorine is complicated by the fact that chlorine is highly reactive in seawater, first hydrolyzing and then rapidly oxidizing bromide. Because these reactions are rapid, chlorine or hypochlorite do not pose a direct toxicity risk; but their reaction products could. The toxicity from their reaction products can be related to the original chlorine concentration.

Batley and Simpson noted that chlorine in seawater is short-lived and nonpersistent due to dispersion, volatilization and degradation. The rapid decay rate is demonstrated in the experiments described above (see Figure 9-5).

The derivation of guideline values for CPO in marine waters by Batley and Simpson followed the procedures outlined by Warne et al. (2018) as used in the *Australia and New Zealand Guidelines for Fresh and Marine Water Quality*. Because of the high reactivity of chlorine, and with the lifetime of the reaction products being in the order of several hours at most with no persistence or accumulation in the environment, they considered it was appropriate to develop and apply a short-term guideline value rather than one based on longer term chronic effects.

Guideline Value for Chlorine is Conservative

The guideline value derived by Batley and Simpson is conservative where it is based on toxicity testing with the chlorine continuously renewed over a long duration (48 or 96 hours in most tests). Continuous renewal also avoids the problem of chlorine decay.

In comparison, the CPO concentration in the plume in Corio Bay declines with time (decay due to oxidative reactions) and distance (due to mixing). While there is a continuous discharge of chlorine to Corio Bay from the existing refinery cooling water, once the plumes escape the proximity of the discharge, they mix with seawater and the ratio of residual CPO/seawater declines in the plume.

On the other hand, in the laboratory tests with continuous renewal of chlorine, the toxicity effects are due to chlorine and the concentration is constant. In the real world, the toxicity is predominantly due to bromine. The oxidation products from bromine are much less toxic than those from chlorine (e.g. Dinnel et al. 1981). A review of the toxicity of chloroform and bromoform showed that the effects of chloroform on algae and fish are typically seen only at high concentrations, orders of magnitude above those for hypochlorite toxicity (UK Marine Special Areas of Conservation 2019). The 50 per cent Lethal Concentration (LC50 – the concentration required to kill 50 % of a test population) for larval survival of an oyster was 2,000, 1,000, and 100 µg/L, respectively, for chloroform, bromoform, and bromate. These authors noted that chloroform and bromoform were both lost from solution by volatilisation.

Bromine Products are less Toxic than Chlorine

Data from short-term (mostly 48-hour or 96-hour) toxicity tests in marine waters with renewal of chlorine (except for one test) are summarised in the paper by Batley and Simpson (2020) as these were used to develop the chlorine guideline value. The exposure period to chlorine in the tests was mostly 96 hours, but some tests with a lesser exposure time were included. Using data from the tests, Batley and Simpson plotted a species sensitivity distribution (SSD) to determine 99%, 95% and 90% species protection.

For the resulting Burrilioz distribution of best fit, the threshold CPO concentrations were:

- For 99 % species protection, CPO of 3.7 µg/L;
- **For 95 % species protection, CPO of 12 µg/L; and**
- For 90 % species protection, CPO of 21 µg/L.

Batley and Simpson applied a further conversion factor of 0.6 to convert the LC50 concentrations from the SSD to a *No Effect or Low Effect* (LC10) concentration. As shown in Table 9-3, application of this factor resulted in a draft guideline value for protection of 95 % of species (applicable to a modified environment such as Corio Bay) of 7.2 µg/L. This marine impact assessment report has used this draft guideline value of 7.2 µg/L to assess the impacts of chlorine discharges. The plots of chlorine plumes shown later in this section, have contours corresponding to 7.2 µg/L to delineate the zone of potential impact.

In applying these conservative guideline values in field situations, Batley and Simpson suggest that the GV applies over a period of 12 or 24 hours. Chlorine concentrations can reduce to below these values within a mixing zone both through dilution and decay (dissociation). Further reduction in chlorine concentration is inevitable, due to dispersion, volatilisation and degradation.

Table 9-3. Schedule of Discharge Points with Flow and Chlorine Rise

Protection	All data	Guideline Value	Local sea urchins
99 %	3.7 µg/L	2.2 µg/L	11 µg/L
95 %	12 µg/L	7.2 µg/L	17 µg/L
90 %	21 µg/L	13 µg/L	21 µg/L

Local Sea Urchin Tests

The most sensitive species in the SSD were Canadian sea urchins, with impacts on fertilization apparently occurring at 5 and 6 µg/L as CPO (Dinnel et al. 1981). These tests were conducted before the rapid decay of chlorine was appreciated, so there is some doubt about the actual chlorine concentrations used in the tests.

An odd feature of the Dinnel et al sea urchin tests are that the "*chlorine was allowed to react with seawater for 24 and 48 hours"* prior to mixing the seawater with the sperm. Yet from the chlorine decay rates quoted in Section 9-4, it is obvious that there would be zero chlorine or other oxidants remaining after 24 hours. There is a question about whether the chlorine levels reported for these tests are accurate, and whether or not unfiltered seawater was used in the tests (as suspended solids in unfiltered seawater reduce fertilisation success). It is desirable to repeat them with a continuous flow apparatus and filtered seawater, where the chlorine level is known and constant.

The Canadian Council of Ministers of the Environment (1999) considered these tests but decided they were not acceptable for use in deriving a chlorine limit due to reservations with respect to the analytical methodologies and testing protocols.

The toxicity of chlorine oxidants in seawater on the Australian sea urchin *Heliocidaris tuberculata* was tested by Ecotox Services Australia, following NATA accredited methods, in Sydney (CEE 2018). The Ecotox tests used a hypochlorite stock concentration of 2 mg freeCl_2/L diluted down to specified concentrations in filtered seawater, with the actual concentrations being measured within 10 minutes of each test. The measured chlorine concentrations in the test preparations were well-within the commercial range of the analytical method. The sea urchins were collected at South Maroubra, NSW.

The Exotox results established that fertilisation of the Australian sea urchins was not affected by chorine oxidant concentrations below 38 µg/L. This is a factor of five higher than the EC50s for the northeastern Pacific urchins tested by Dinnel et al 1981. The EC50 of the Ecotox results is 133 µg/L, a factor of fifteen higher than the EC50 for the Canadian sea urchins.

The results of the Australian sea urchin tests are more rigorously documented and representative of echinoderm sensitivity than the early tests on the North Pacific species. The results of the Australian sea urchin tests are consistent with the observation of substantial numbers of sea urchins living within the plume in Corio Bay in a habitat exposed to CPO concentrations of 5 to 10 µg/L (see Figure 9-6).



Figure 9-6. Sea Urchins in Corio Bay under the Refinery Plume

If the 2018 test results for the Australian sea urchin tests are substituted for the 1981 sea urchin tests, and the species sensitivity distribution is re-plotted using Burrlioz software (same method as recommended by Warne et a, 2018l) the chlorine concentrations corresponding to 99 %, 95 % and 90 % species protection can be obtained. Applying a factor of 0.5 to convert from LC50 to LC10 results, the CPO concentration for 95 % species protection would be **17 µg/L**. It is apparent that the draft guideline value for chlorine in marine waters is very sensitive to the results of the 1981 tests for Canadian sea urchins.

Summary

In summary, there is currently no ANZG Guideline Value for chlorine in marine waters (as at October 2021).

Batley and Simpson were engaged by CEE to develop a draft GV and have recommended a **GV of 7.2 µg/L**. This recommendation is currently being reviewed by the State and Territory environmental agencies. It reflects a conservative value, and it is used in this report as the measure of the extent of potential impact of CPO (chlorine).

The Guideline Value or limit for chlorine in seawater is based on continuous flow tests using chlorine whereas the actual exposure in marine waters (except, perhaps in mixing zones) is to bromine, which is known to be much less toxic than chlorine (Batley and Simpson, 2020). Therefore, a large safety factor has already been included in deriving the acute chlorine guideline limit and compliance with the conservative short-term guideline values also is protective against chronic effects of chlorine-produced oxidants on biota.

9.6 Methodology for Predicting Chlorine Plumes.

As described in Section 6, the extent of the plumes produced by the discharges associated with the four existing refinery discharges (W1, W3, W4 and W5) were estimated using the following methodology:

- Near-field hydrodynamic modelling of each plume to the point where the plume connects to the 20 m grid cells in the regional hydrodynamic model;
- Regional hydrodynamic model of Corio Bay with tides and currents simulated on a 20 m by 20 m by 1 m deep 3-D grid, with a time step of 5 minutes.
- Chlorine decay was simulated by a chlorine decay rate of a 40 % decay in 1 hour.

In the regional model, the extent and magnitude of temperature and chlorine are simulated simultaneously. This allows the effects of buoyant horizontal spreading of the plume to be simulated, as well as the reduced vertical dispersion due to the stratification between the warmer plume and the cooler underlying seawater (see plots of stratification in Section 8).

The regional model stores the chlorine concentration in each grid cell every 10-minutes over a six-month simulation. From the set of concentrations, percentiles of chlorine concentration are calculated and plotted as contours in the figures that follow.

The median or 50 percentile concentration is plotted as this closely matches the requirement for a “short term” chlorine limit, which Batley and Simson advised should be considered to apply to the **average concentration over a tide cycle**. To some extent, this matches the variations in chlorine concentration that occur in a laboratory toxicity test where the chlorine concentration is regularly renewed. In a flow through-test, the chlorine concentration is held approximately constant for 48 or 96 hours, although even then there must be some variation in chlorine concentration during the test.



Figure 9-7. Australian Salmon, Seagrass and algae in Outlet W5 (15 Sept 2021)

9.7 Chlorine Plumes for Existing Situation

The **existing situation** is the continued operation of the refinery with the four existing seawater discharges into Corio Bay in front of the refinery. Figure 9-8 shows the predicted 50-percentile CPO concentration at the surface for the existing discharges. The plumes are warm and form a shallow layer on the water surface. The plumes

extend 500 m along the shore from W1 and 800 m along the shore from W4 and W5, but the extent is well short of the entrance to Limeburners Bay and the Ramsar site.

The three CPO contours are 7.2 µg/L (the GV), 5.4 µg/L and 3.6 µg/L (half the GV). In each case, the plume is confined to within approximately 200 m of the shoreline. Beyond this, the chlorine concentrations in the plume deplete rapidly because of the chlorine decay with time.

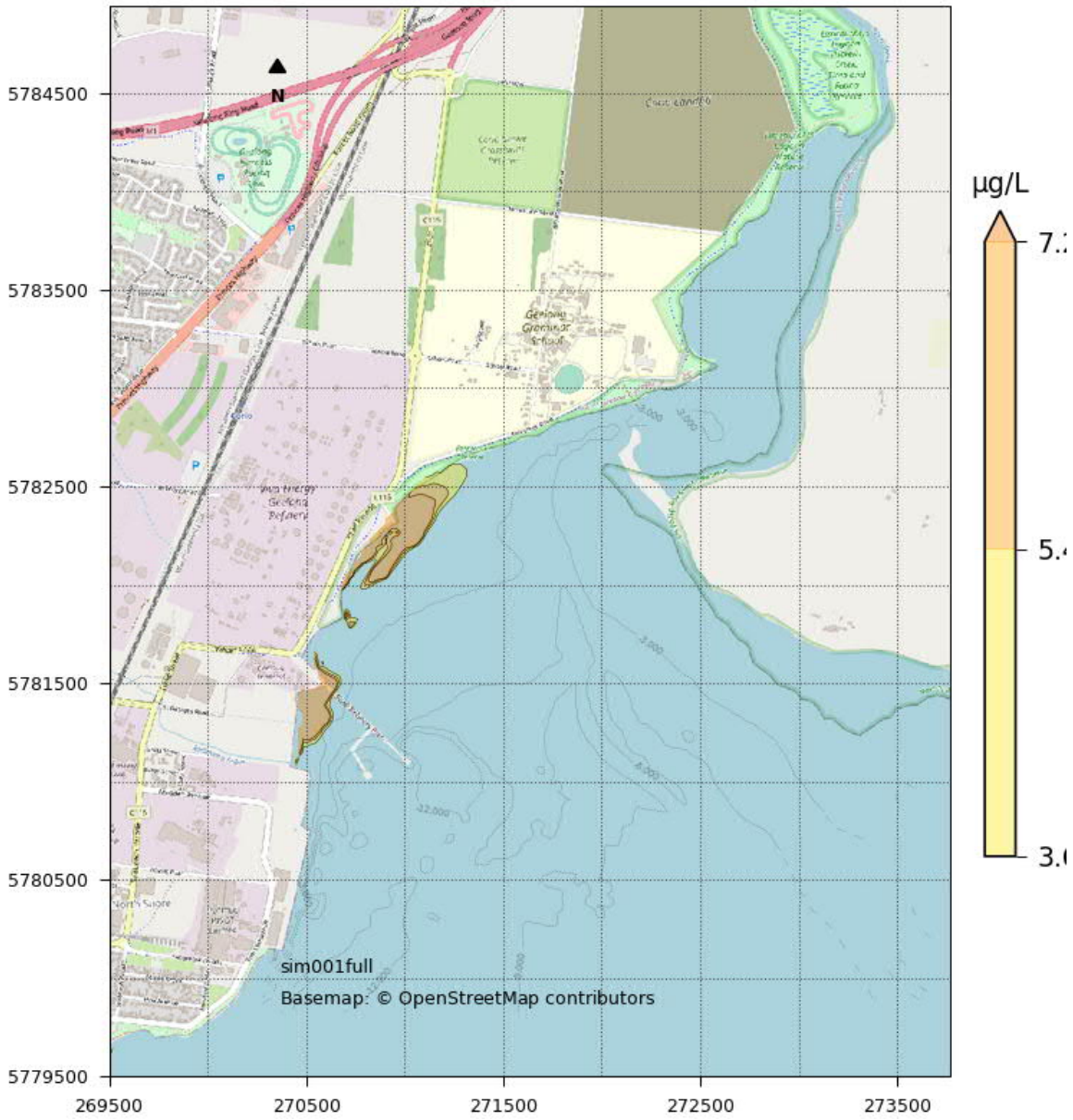


Figure 9-8. Predicted 50-percentile Chlorine Plumes for Existing Situation

In summary, the CPO plume **for the existing situation** is located in shallow water near the shore in front of the refinery and does not reach Limeburners Bay or the Ramsar site.

9.8 Chlorine Plumes for Future Situation – Peak Flow

The **future situation with peak flow** involves the FSRU using 350 ML/d of seawater and transferring this flow to the refinery inlet for use as cooling water. The refinery would add chlorine to bring the concentration up to the current intake chlorine concentration of 0.5 mg/L. The seawater would be returned to Corio Bay through the

four existing refinery discharge points with **the same** residual chlorine concentrations as now.

Figure 9-9 shows the predicted 50-percentile CPO concentration for the future situation. The pattern and CPO concentrations are **essentially the same** as the existing situation, as the same volume of seawater and concentrations of residual chlorine would be discharged. There is a minor effect of reduced plume spreading due to the lower temperature of the discharge plumes than at present, as discussed in Section 8.

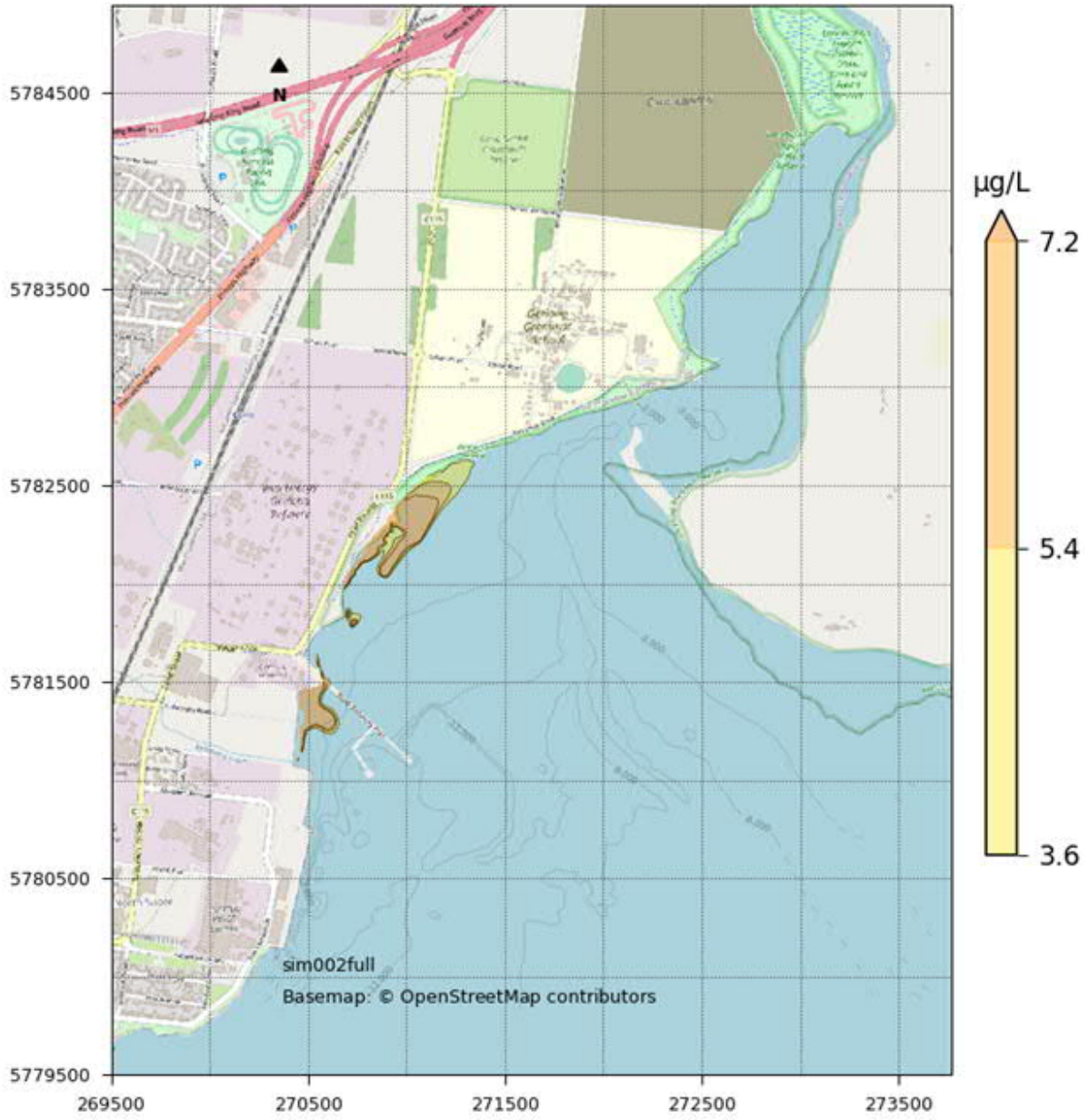


Figure 9-9. Predicted 50-Percentile Chlorine plumes for Future Peak Flow

9.9 Chlorine Plumes for Future Situation – Average Flow

The **future situation with average flow** involves the FSRU using 250 ML/d of seawater and transferring this flow to the refinery inlet. The refinery would extract another 100 ML/d of seawater through the existing intake and add chlorine to bring the level up to their current intake chlorine concentration of 0.5 mg/L. The seawater

would be returned to Corio Bay through the four existing refinery discharge points with the same residual chlorine concentrations as now.

Figure 9-10 shows the predicted 50-percentile CPO concentration for the future average flow scenario. The plume concentration pattern is very similar to the existing pattern, as would be expected as the same load of chlorine is discharged with the same flow rates. The plume does not extend to Limeburners Lagoon or to the Ramsar site.

The plume **at average production** extends a similar distance offshore and along the shore as the existing plume and does not extend to Limeburners Lagoon or to the Ramsar site.

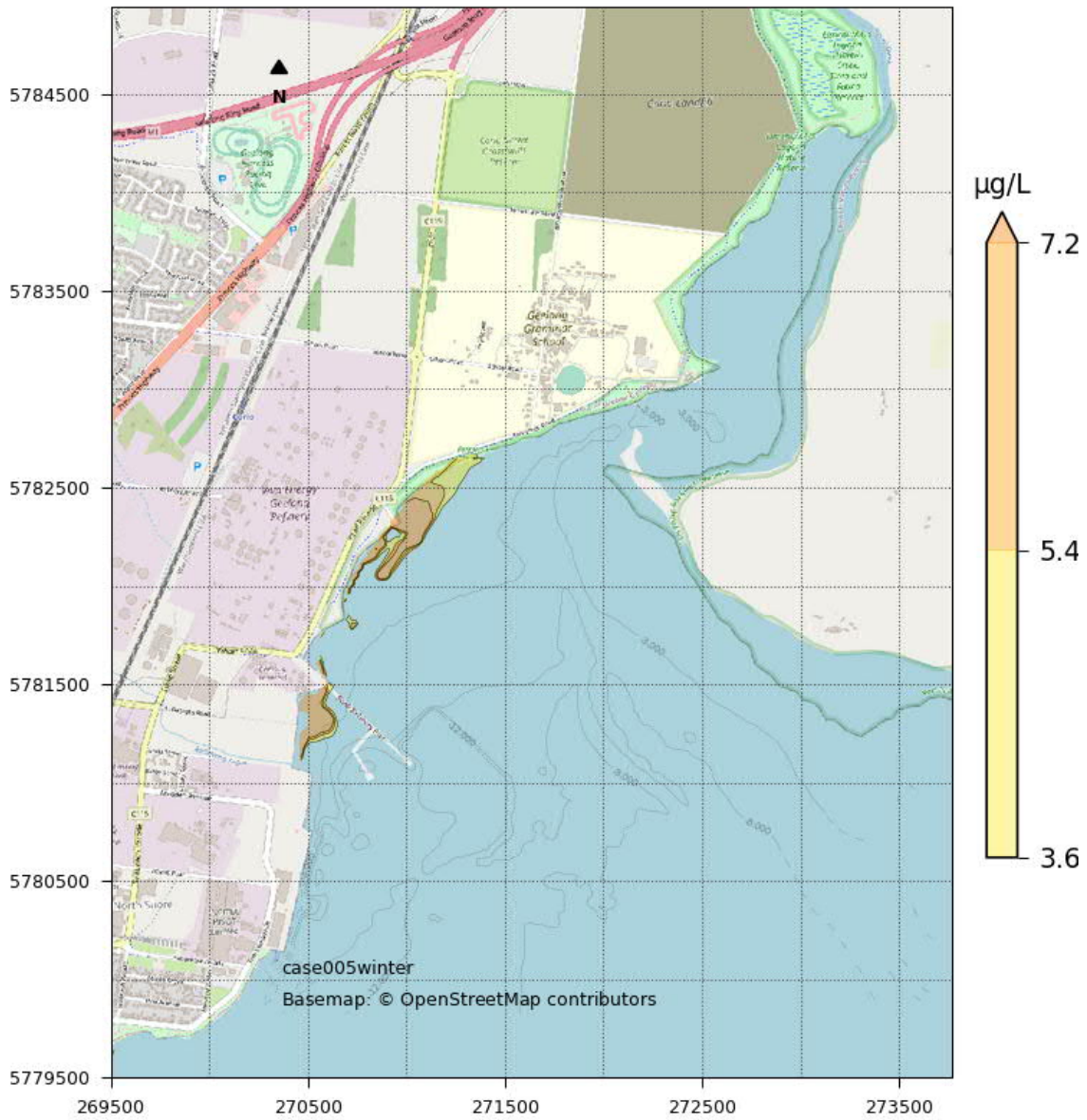


Figure 9-10. 50-percentile Chlorine Change for Future Average Flow

9.10 Chlorine Plumes for Future Situation – Diffuser Discharge

A further scenario was modelled in the event that the refinery was closed for maintenance or other reasons and the FSRU discharge water was not able to be used in the refinery for cooling purposes. Current refinery maintenance generally

involves a partial shutdown. In the event of a partial or full shutdown, the cooler seawater from the FSRU (7 ºC below ambient temperature) would be discharged through a 300 m long diffuser installed under the new pier. There would be no discharge from the refinery.

The discharge from the diffuser would dilute by 20:1 as a result of the mixing caused by the high velocity discharge jets along the diffuser (see discussion of near-field modelling in Section 6). Initial dilution of 20:1 reduces the chlorine level from 100 µg/L to 5 µg/L. Figure 9-11 shows the predicted 50-percentile CPO concentration at the seabed (as the cooler seawater would sink) for this scenario. The whole of the plume on the seabed would have a CPO concentration below 5.4 µg/L, well within the GV for chlorine in marine waters. This plume is well away from the Ramsar site.

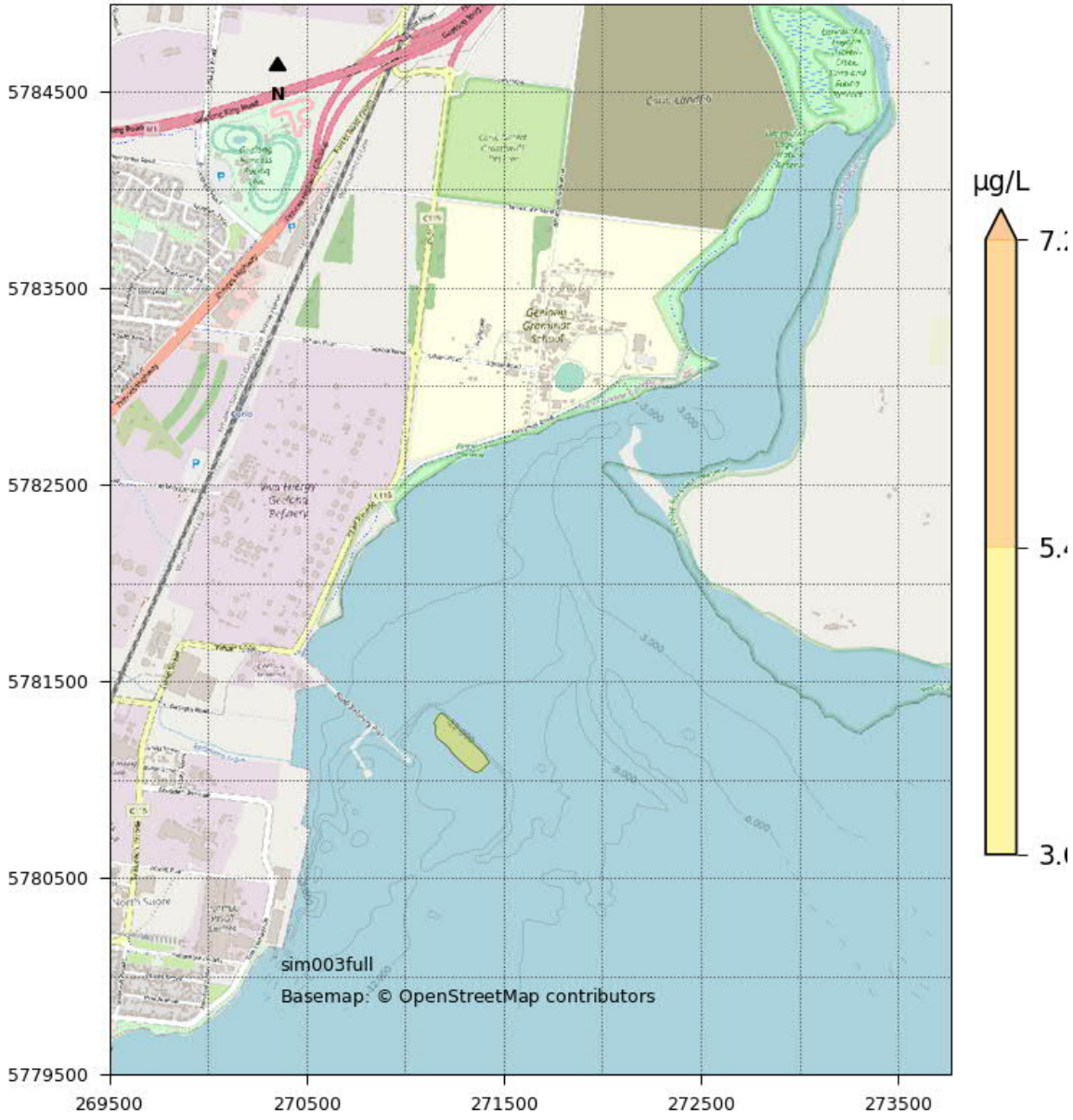


Figure 9-11. 50-percentile Chlorine Change for Peak Diffuser Discharge

9.11 Chlorine Plumes for Average Flow - Diffuser Discharge

This scenario is for 250 ML/d with all FSRU seawater discharged from the diffuser under the new pier. The diffuser is 300 m long however, during the average flow

scenario only 240 m of the diffuser would be in operation to maintain a high port velocity.

Figure 9-12 shows the predicted 50-percentile CPO concentration at the seabed for this scenario. The plume for this scenario has chlorine concentrations in the range of 4 to 5 µg/L and encompasses an area of 3 ha on the seabed. The plume spreads out in the deep waters of the channel, but the extent is limited by the decay of chlorine compounds in the plume. The plume is well away from Limeburners Bay and the Ramsar site.

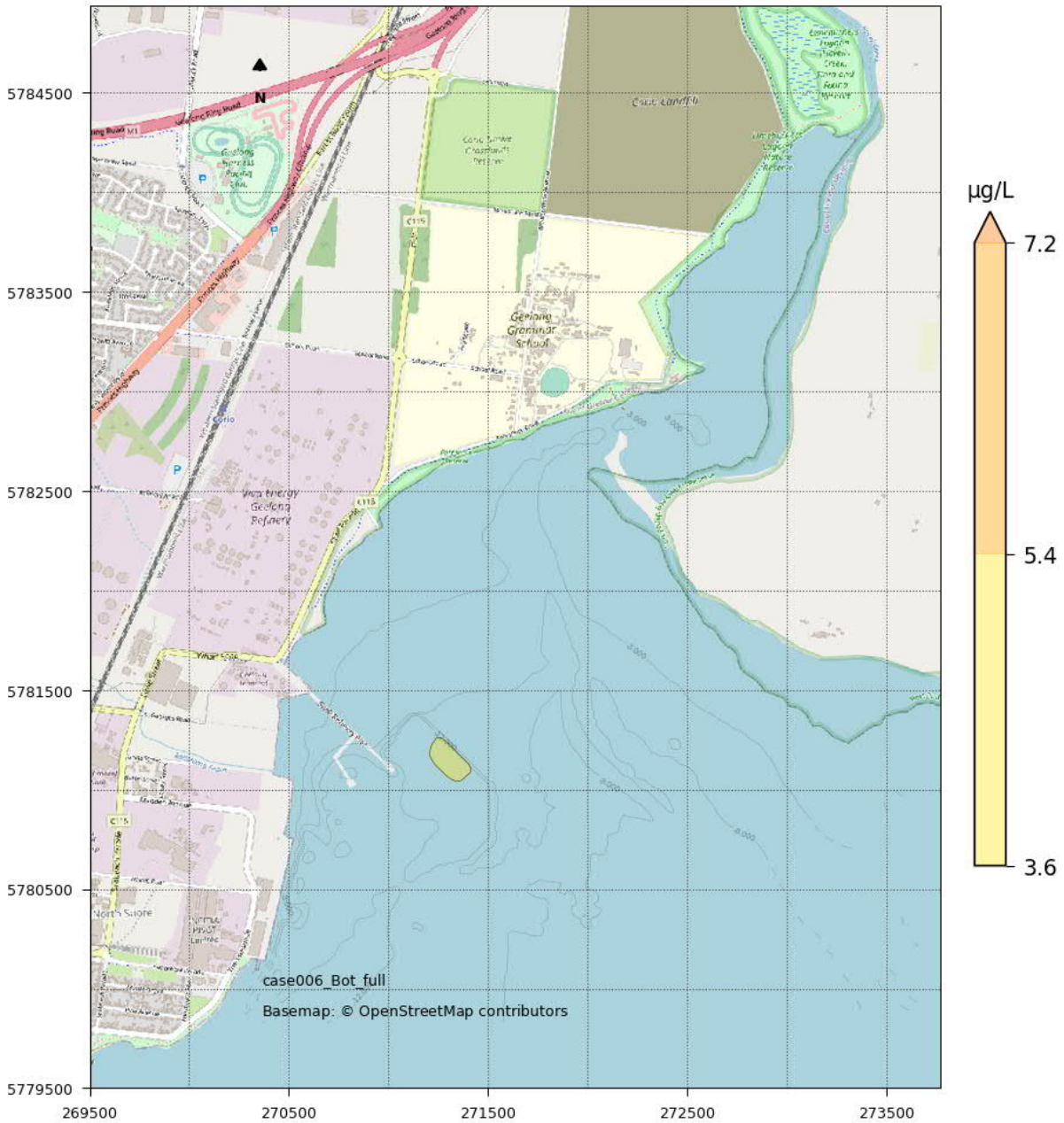


Figure 9-12. 50-percentile Chlorine Change for Average Diffuser Discharge

9.12 Chlorine Plumes for Future Closed Loop Discharge

The proposed and preferred method of operation of the FSRU for the project is the open loop mode with transfer of the cooled seawater from the FSRU to the refinery as previously described. However, the FSRU can also operate in closed loop mode (at the cost of additional GHG and air emissions as LNG is used to fuel the boilers). In closed loop, a small quality of warm water would be discharged to Corio Bay. The chlorine impacts associated with closed loop mode were assessed.

The warm plume generated by closed loop operation would be discharged with residual chlorine through two small pipes at the rear of the FSRU (see Section 6). Figure 9-13 shows the predicted 50-percentile CPO concentration at the surface for future peak flow in closed loop operation. The maximum CPO concentration is less than 5 µg/L. The plume does not extend to Limeburners Bay or to the Ramsar site.

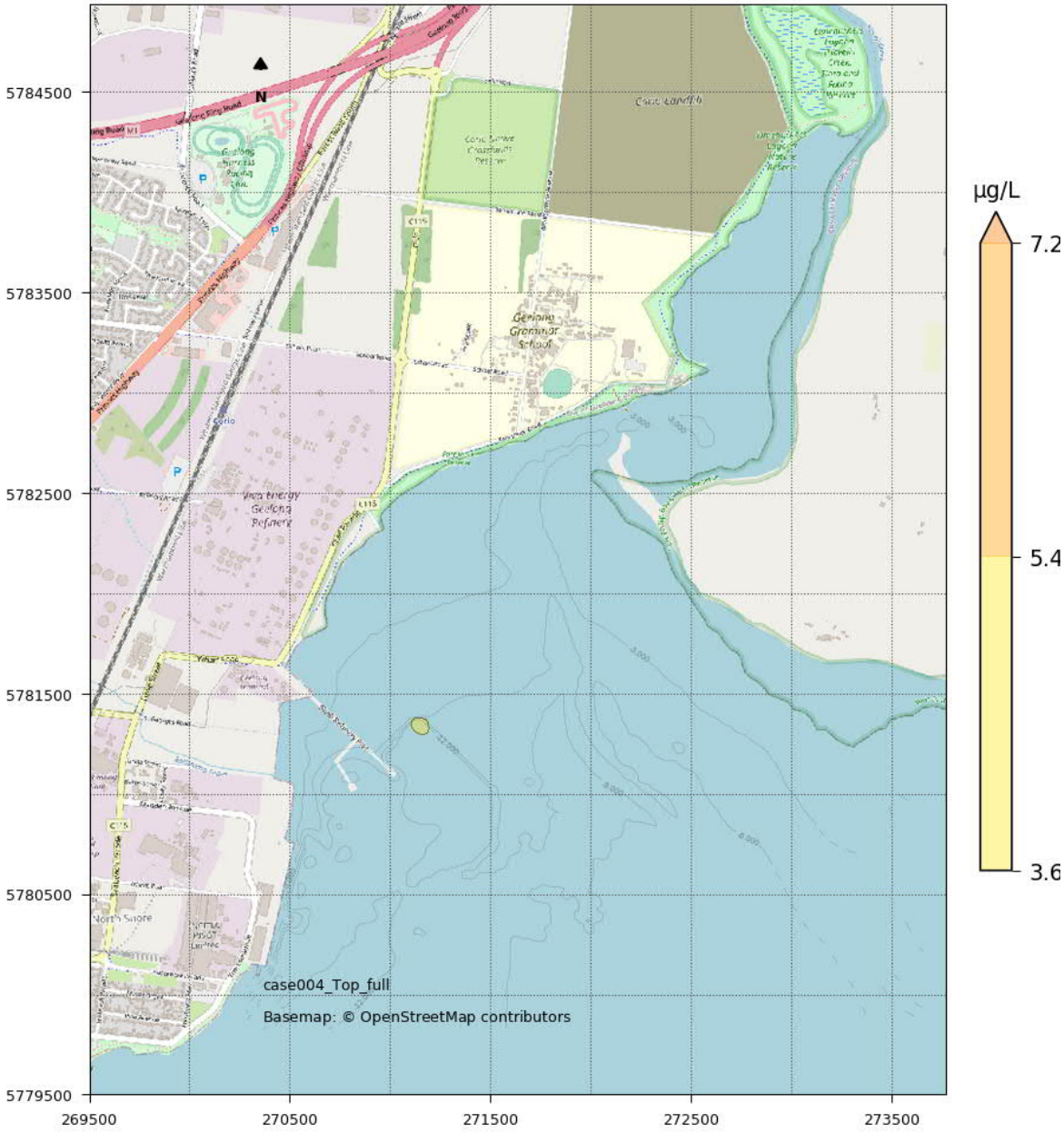


Figure 9-13. 50-percentile Chlorine for Future Closed Loop Discharge

9.13 Sensitivity Assessment of Chlorine Decay Rate

The computer modelling of chlorine plumes was carried out using a conservative 40 % decay per hour, based on previous literature tests.

In calibrating the model, it was noted that the predicted chlorine contours were sensitive to the decay rate. This sensitivity study examined the implications of using the 50 % per hour chlorine decay rate measured in Corio Bay.

Figure 9-15 shows the tidally-averaged chlorine concentrations for two cases: (1) using 40 % decay per hour (upper panel); and (2) using 50 % decay per hour (lower panel). The contours in the figures are 3.6 µg/L; 5.4 µg/L and 7.2 µg/L (the GV) of chlorine. The grid spacing in the plots is 500 m.

The faster decay rate reduces the spatial extent of the contours. In particular, the extent of the 3.6 µg/L in the plume along the shore to the north is reduced by 200 m. The plumes at discharge points W1 and W3 are only marginally smaller, as the dispersion rate exceeds the decay rate.

Overall, the results are similar for the two cases, although the area of the plumes inside the various contours decrease with the higher decay rate, as would be expected.

No Accumulation in Corio Bay

At the 50 % per hour decay rate for chlorine that was measured in Corio Bay (see Section 9-4), an initial chlorine concentration of 20 µg/L would decay to the background level (of about 1 µg/L – see discussion of natural bromoform) in 4.3 hours.

Even starting with an initial chlorine concentration of 100 µg/L, the plume would decay to the background level of 1 µg/L in 6.6 hours – without dispersion. Including the extra effect of the typical rate of dispersion in Corio Bay, the plume would decline from an initial chlorine concentration of 100 µg/L to the background level of 1 µg/L in 2 to 3 hours. As mentioned above, there is no risk of accumulation of chlorine in Corio Bay.

Conclusions on Chlorine Decay

The two major conclusions that are drawn from the plots of the chlorine contours in Figure 9-15 are:

1. For the reasonable rate of chlorine decay rates, the chlorine concentration at the Ramsar site is well under the conservative chlorine GV for marine waters, and no direct impact from any of the existing or future chlorine discharges occurs in Limeburners Bay or the Ramsar site;
2. Chlorine decay processes in seawater result in total loss of CPO from the initial production over a period of hours in well-mixed aerobic seawater (CEE 2018b, Saeed et al. 2015, Water Technology 2017). There will be no accumulation of chlorine in Corio Bay.

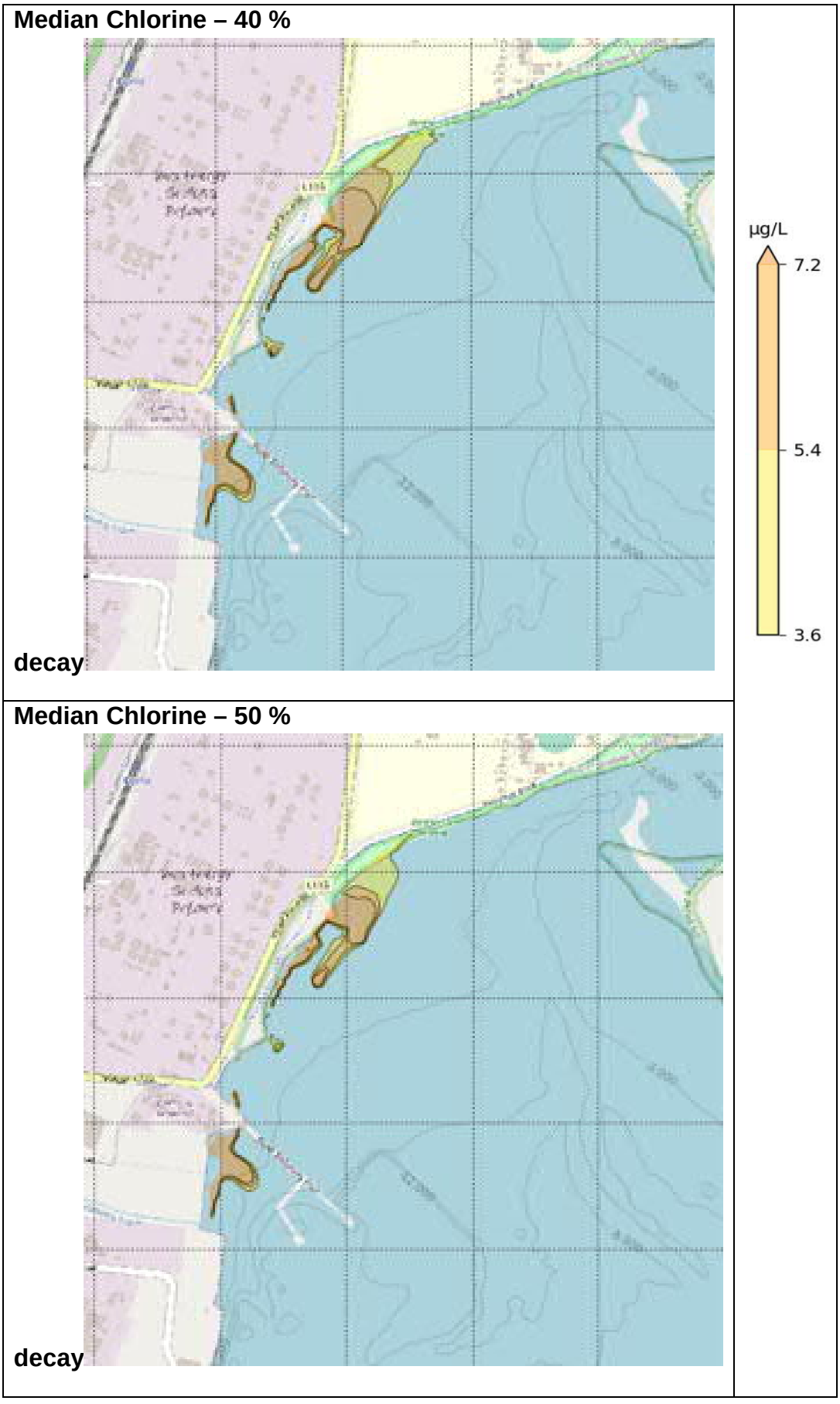


Figure 9-14. Sensitivity Study of Chlorine Decay Rate

9.14 Measurement of Chlorine Accumulation in Mussels

Products of seawater chlorination other than oxidants are known as chlorination-produced by-products (CPB). They represent less than 6% of the chlorine concentration initially produced (Jenner and Wither 2011). Most of the CPB are present as trihalomethanes (THM), and most THM are tribromomethane or 'bromoform' (Abdel-Wahab 2011, Boudjellaba et al. 2016, Jenner and Wither 2011, Satpathy et al. 2010).

Bromoform occurs naturally in seawater at around 1 to 3 µg/L as a result of natural production by marine macro-algae and micro-algae found in all coastal marine environments (USEPA 2012, Boudjellaba et al. 2016, Gribble 2012). The toxicity of chlorine-derived chemicals in seawater includes CPO and THM but is measured relative to the concentration of CPO or chlorine concentration.

To investigate whether the existing chlorine discharge from the refinery was producing significant levels of residual chemicals in marine life, mussels were collected from six sites in north Corio Bay in August 2021 and analysed for a wide range of chlorine residuals including THMs, haloacetic acids and bromophenols. Figure 9-15 shows the locations of the mussel samples. The sites include Refinery Pier and directly within the dispersing plume as well as samples from navigational markers around the dredged channel and two reference sites further out in the Bay.

Six mussel samples of approximately the same size were taken from piles at each site and placed in bags with appropriate labels. Each bag was held in a chilled esky and delivered directly to the Leeder Analytical Lab with the Chain of Custody forms for analysis of four THMs, six haloacetic acids and two bromophenols.



Figure 9-15. Locations of Mussel Samples in Corio Bay

Table 9-4 lists the results of the mussel analyses for sites M1, M2 and M3 (the three sites closest to the refinery). The mussels from Site M1 were analysed in duplicate as a quality check. Blank samples and spiked samples were also analysed, with satisfactory results in the laboratory report (Leeder Analytical report, 2021).

Table 9-4. Analytical Results of THM in Mussel Samples

Leeder Analytical

Leeder Analytical Report No: L210318
Analytical Results

Matrix: Mussel		Leeder ID	L210318-1	L210318-1	L210318-2	L210318-3
		Client Id	M-1 9-08-2021	M-1 9-08-2021	M-2 9-08-2021	M-3 9-08-2021
ANALYTE	CAS No	PQL		Duplicate		
LA-87 Trihalomethanes (THMs)						
Dichlorobromoethane	75-27-4	0.01	nd	nd	nd	nd
Dibromochloromethane	124-48-1	0.01	nd	nd	nd	nd
Tribromomethane	75-25-2	0.01	nd	nd	nd	nd
Trichloromethane	67-66-3	0.01	nd	nd	nd	nd
LA-48 Haloacetic Acids						
Bromoacetic acid	79-08-3	0.05	nd	nd	nd	nd
Bromochloroacetic acid	5589-96-8	0.05	nd	nd	nd	nd
Chloroacetic acid	79-11-8	0.05	nd	nd	nd	nd
Dibromoacetic acid	631-64-1	0.05	nd	nd	nd	nd
Dichloroacetic acid	79-43-6	0.05	nd	nd	nd	nd
Trichloroacetic acid	76-03-9	0.1	nd	nd	nd	nd
BROMOPHENOLS						
2,4,6-tribromophenol	118-79-6	0.02	nd	nd	nd	nd
2,4,6-tribromoanisole	607-99-8	0.02	nd	nd	nd	nd

Results are expressed as mg/kg on an as received basis.

nd - not detected, less than practical quantitation limit (PQL).

The results for mussels from Sites M1, M2 and M3 show no detectible levels of THMs, haloacetic acids and bromophenols in the mussels. The same results were obtained for mussels from Sites M4, M5 and M6. From these results, it is concluded that the chlorine discharged from the refinery decays or is volatilised in a short period, and there is no accumulation of toxic by-products in mussels or, by inference, other marine life in Corio Bay.

9.15 Assessment of Impact of Chlorine Discharge

This section provides an assessment of the effects of the existing and predicted chlorine discharge on marine biota and ecological diversity. In making the assessment, the following points were considered.

Future Refinery Discharges Have the Same Chlorine Concentrations

The refinery has been operating for over 60 years with essentially the same discharges of chlorine. The operations and discharges are regulated by the EPA. The intended operating procedure is to transfer the seawater from the FSRU to the refinery inlet. The proposal would make **no change to the discharge of chlorine** from the refinery under normal operating conditions. The discharges from the refinery would have the same flow rates and chlorine levels as now (and as have occurred over the past 60 years).

In summary, the proposal would involve recycling the FSRU seawater discharge through the refinery and there would be no significant change in the amount of chlorine discharged or in the pattern of the plumes in Corio Bay along the shore in front of the refinery. The predicted chlorine plumes in Figures 9-5, 9-6 and 9-7 show that there would be minimal change in the chlorine concentration pattern with the FSRU in operation compared to the current refinery discharges.

Cumulative Impacts Considered

The cumulative effects of temperature change and chlorine concentration are considered, as the discharges from the refinery have a temperature increase as well as a residual chlorine concentration. However, with the implementation of reusing the cooler FSRU seawater in the refinery cooling water system, the warm temperature in the existing refinery discharge plumes would decrease by between 5 ^{o}C to 7 ^{o}C, so the existing effects of the warmer temperature change would be reduced. The chlorine discharge would remain the same. Thus, the combined stress due to temperature and chlorine would be reduced in the future compared to the current and historical situations.

Different Zones Affected by Different Discharges

Taking the existing conditions as the base, there would be no change in conditions along the shoreline of north Corio Bay. There would be additional discharge locations with the proposal, both in the port area, involving the backup discharge location of the diffuser under the new pier and the discharge pipes on the FSRU for closed loop operation. These two discharge points would need an EPA operating licence.

The two alternative discharge scenarios, either cooled FSRU seawater discharged from a diffuser under the new pier extension or warm FSRU seawater discharged in closed loop mode, produce dilute chlorine plumes in the shipping channel and therefore affect different marine communities than the plume along the foreshore.

The near-field plume that would result from the diffuser discharge is described in Section 6. Normally the plume would flow south from the pier, under the FSRU and into the deep channel serving refinery pier. Beyond a plume mixing zone, the chlorine concentrations are below the conservative GV for CPO of 7.2 µg/L and well under 17 µg/L.

Similarly, for the closed loop discharge, the plume beyond a short mixing zone would have chlorine concentrations below the conservative GV for CPO of 7.2 µg/L and well under 17 µg/L.

Outcomes for GV and Alternative Limit for Chlorine

As described in Section 9-5, the conservative **GV for CPO is 7.2 µg/L,** averaged over 24 hours, based on the SSD that included laboratory toxicity test results for overseas sea urchins. However, field surveys show that sea urchins are breeding at and above this chlorine concentration in the chlorine plume in Corio Bay. For this and other reasons set out above, if the 1981 laboratory tests for Canadian sea urchins are replaced by more recent tests of a local sea urchin, the limit for assessing impacts of CPO in Corio Bay could be 17 µg/L.

For the more stringent default GV of 7.2 µg/L:

- Almost all the plumes outside the existing mixing zones meet this GV.
- Diluted fields from diffuser discharge or closed loop discharge meet this GV.

For the alternative limit of 17 µg/L:

- All the plumes outside the existing mixing zones meet this limit
- Diluted fields from diffuser discharge or closed loop discharge meet this limit.

Summary of Impact Assessment for Chlorine

The assessment of impacts generally examines the **change** in impacts between the project and the base case. It is apparent from the comparison of the existing discharge situation for the project with seawater reused in the refinery is that there would be no change in the extent of the plumes or the concentrations of chlorine in Corio Bay. On this basis, the impact of the chlorine discharge component of the proposal from the refinery outlets is negligible.

The usual proposed mode of operation would involve no change in the seawater withdrawal rate of 350 ML/d, no change in the discharge rate of 350 ML/d and no change in the chlorine concentration at the four existing discharge points. There is essentially **no impact** (or no change in impact from that occurring for over 60 years).

Two backup discharge arrangements have also been assessed. One involves closed loop operation, whereby LNG is used to heat and regasify the LNG. In that event, a warm seawater flow would be discharged from the rear of the FSRU, with a peak chlorine level at the surface of 5 µg/L (outside the main refinery plume). The second backup operation involves discharge from the diffuser under the new pier when the refinery is not operating. In that event, a cool chlorine flow would be discharged from the 600 m length of the diffuser under the new pier with a peak chlorine level at the seabed of 4 µg/L (in the field beyond the plume).

In practice, Viva Energy would seek to maximise the use of open loop operation with transfer of the cooler FSRU water to the refinery intake. This arrangement will reduce the heat differential of the existing discharge and will increase the heat transfer efficiency of the cooling water system in the refinery. The result will be a benefit to the environment and an economic benefit to the refinery. Also, Viva Energy will seek to minimize **closed loop** operations, as this uses an additional 2.5 % of LNG in FSRU regasification, and imposes extra operating costs.

Nonetheless, the impact assessment takes into account the effects of the three modes of chlorine discharge, with the results of the assessment shown in Table 9-5 for Corio Bay (outside of the mixing zones).

Table 9-5. Summary of Impact Assessment for All Chlorine Discharges

Marine Community	Finding of Impact Assessment
Phytoplankton	No change from existing – CPO levels unchanged in refinery plumes. Extra plumes below GV and site-specific limit.
Zooplankton	No change from existing – CPO levels unchanged in refinery plumes. Extra plumes below GV and site-specific limit.
Fish larvae	No change from existing – CPO levels unchanged in refinery plumes. Extra plumes below GV and site-specific limit.
Seagrass	No change with proposal - levels well under site-specific limit Evidence shows plumes are already tolerated. Shoreline plume stops if backup diffuser discharge used.
Primary productivity	Negligible change with proposal – see Section 10
Small fish	No change from existing – CPO levels unchanged in refinery plumes. Extra plumes below GV and site-specific limit. Evidence shows plumes are readily tolerated
Large fish	No change from existing – CPO levels unchanged in refinery plumes. Extra plumes below GV and site-specific limit. Evidence shows plumes are readily tolerated
Infauna	No impact from diluted fields from closed loop or diffuser discharges. Chlorine levels well under site-specific limit.
Marine mammals	No change with proposal – levels well under site-specific limit Evidence shows plumes are readily tolerated
Seabirds	No change of plumes near Ramsar site with proposal. Chlorine levels well under GV and site-specific limit No change in food supply or extent of habitat
Migratory birds	No change with proposal – no change in food supply or availability of habitat
Limeburners Bay	No change with proposal – all plumes well away from Bay

No Accumulation of Chlorine in Corio Bay

As set out in Section 9-13, at the 50 % per hour decay rate for chlorine that was measured in Corio Bay (see Section 9-4), an initial chlorine concentration of 20 µg/L would decay to the background level (of 1 µg/L – see discussion of natural bromoform) in 4.3 hours. There is no risk of accumulation of chlorine in Corio Bay.

Similarly, as set out in Section 9-14, there is no accumulation of toxic by-products in mussels or, by inference, other marine life in Corio Bay.

9.16 Risk Assessment

EPA Environment Reference Standard

The *Environment Reference Standard* does not set a specific limit for chlorine in *Table 5 -13 Indicators and Objectives for Port Phillip Bay.* However, *Table 5-18 Weight of Evidence in Toxicant Risk Scoring System* provides a pertinent risk assessment framework for assessment of the impacts of chlorine as summarised in Table 9-6.

Table 9-6. EPA Environment Reference Standard Risk Ratings

Line of Evidence	Risk Ranking		
	High	**Medium**	**Low**
Marine ecology	Significant and high effects on abundance and diversity	Significant and moderate effects on abundance and diversity	No significant effects on abundance and diversity
Other lines of evidence	Significantly different from control and high effect size	Significantly different from control and moderate effect size	Not significantly different from control
Weight of evidence assessment	High risk of significant adverse effects	Medium risk of significant adverse effects	Low risk of adverse effects – meets objectives for protection of environmental values

Measurements and analyses that are presented in this marine assessment to provide site-specific evidence and are used in the risk ranking include:

- Monthly surveys of the abundance and species distribution of phytoplankton, zooplankton and ichthyoplankton in Corio Bay, including a site at the refinery intake, sites throughout Corio Bay and sites in Port Phillip Bay;
- Mapping and assessment of seabed habitat and conditions on transects throughout Corio Bay;
- Surveys of infauna abundance and species distribution at sites in Corio Bay and Port Phillip Bay;
- Analysis of extensive monitoring data from various Port Phillip Bay studies;
- Targeted survey of seagrass under refinery plumes and in Ramsar site;
- Experimental studies of chlorine decay rate in Corio Bay; and
- Analysis of mussels to verify that chlorine discharged from the refinery decays or is volatilised in a short period, and there is no accumulation of toxic by-products in mussels.

Field Studies of Effects of Plumes on Seagrass Abundance and Diversity

The benthic habitat and associated biological communities along 49 transects in north Corio Bay using HD underwater imagery were surveyed to document the seabed characteristics in Corio Bay including more intensive investigations close to the project area. A total of 6,345 images were analysed. The observed habitat included predominantly soft seabed ranging from sand and shell around the bay perimeter, to fine muds in the more extensive deeper parts of the bay. The associated ecological communities comprised seagrasses with macroalgae on shallow soft seabed, and microalgae (microphytobenthos) and burrowing invertebrates (bioturbation) on deeper soft seabed.

The composition of the seabed observed in the towed transect paths was consistent with previous descriptions and mapped distributions in Corio Bay. The seabed in the central area of Corio Bay was generally muds (a mixture of clays and silts, with very low sand content), while the seabed around the perimeter was more variable with sandy muds, muddy sands and sand with shell.

The outcomes of the CEE 2021 benthic habitat survey are summarised in maps in Section 4 overlayed on Port Phillip Bay Biotopes from Seamaps Australia (Lucieer et al. 2017) allowing a direct comparison with previous studies.

A further detailed set of surveys was made of the seabed in zones where the predicted chlorine concentration in the shoreline plume ranged from 2 µg/L to 8 µg/L, to provide empirical evidence of the effects of temperature and chlorine on seagrass. The survey tracks are shown in Figure 9-16. A summary of the results of the survey is presented in Table 9-7 Full details with photographs and interpretation are found in a separate technical report (CEE_f, 2021).



Figure 9-16. Towed Camera Tracks for Plume Study

The colour in squares indicate presence of a biotope, while no colour indicates absence. The strength of the colour indicates the proportion of the seabed along each track with the listed environmental character.

Table 9-7. Summary of Ecological Character on Seabed

Biotope	Track 1	Track 2	Track 3	Track 4	Track 5	Track 6	Track 7
Seagrass-dense							
Seagrass-medium							
Seagrass-sparse							
Seagrass & Brown Algae							
Brown filamentous algae-dense							
Brown filamentous algae-medium							
Brown filamentous algae-sparse							
Sea urchins							
Bare seabed							

Dense and medium density seagrass meadow was found on all survey tracks. While the distribution of seagrass is affected by sediment movement and patches of bare seabed, the seagrass condition did not correlate with the progressive reduction in chlorine and temperature with distance from the refinery discharge outlets. The extent and condition of seagrass is apparent in Figure 9-17. There is a narrow patch along the shore in shallow water, then a strip of mostly bare seabed, and then sparse seagrass and brown algae in greater depths. Seagrass in similar condition was recorded on all transects.

Brown filamentous algae was strongly associated with medium and dense seagrass. Either dense or medium density brown algae was seen on all transects. The survey observations show that the seabed characteristics are variable over short distances but there was no consistent variation with distance along the plume. There was no evidence that seagrass or algae are adversely affected by the existing refinery plumes.

Sea urchins were seen in large numbers, consuming seagrass on tracks 2 and 3. These urchins are in the zone of higher chlorine concentration. Other sea urchins were observed in the Ramsar site in the north of the Bay, where chlorine concentrations are at background, noting that there is a low background concentration of bromoform produced by marine algae (Goodwin et al, 1997; Stemmler, 2019). Sea urchins were observed in high numbers in other parts of Corio Bay including seagrass beds in Stingaree Bay and near Point Henry. The observations suggest that sea urchins are not affected by persistent chlorine at 6 µg/L (the concentration in the plume at track 3).

As described in Section 5, the areas of Corio Bay seabed occupied by seagrass beds varies from year to year, although there is always a substantial amount of seabed with seagrass in Corio Bay, particularly along the north coast and in the south-east corner.

The area of subtidal seagrass along the shore in front of the refinery totals 40 ha and is about 4 per cent of the total area of seagrass in Corio Bay of 1,100 ha.

The most extensive the seagrass beds are in Stingaree Bay in south Corio Bay (410 ha), with a further substantial area of seagrass in Limeburners Bay and along the north shore (320 ha). The remainder of the seagrass is in the shallow entrance area, or a narrow band along the western coastline.

The *Marine and Coastal Ecosystem Accounting – Port Phillip Bay (DELWP, 2016)* reported 3,280 ha of seagrass in Corio Bay and Outer Harbour out of a total of 7,140 ha in Port Phillip Bay as a whole. Thus, Corio Bay contains almost as much seagrass as the rest of Port Phillip Bay. The different seagrass beds in Port Phillip Bay are genetically similar, which suggests regular transmission of seeds propagules from one zone to another.

In assessing the impact of the combined temperature and chlorine plumes, it was noted that the refinery has been operating for over 60 years with essentially the same discharges of chlorine and temperature. Any adverse effects should be evident by now.

The proposal is to make no change to the discharge of chlorine from the refinery under normal operating conditions. The proposal is to decrease the excess temperature of the discharges from the refinery, to close to ambient temperature.

The intended operating procedure is to transfer seawater from the FSRU to the refinery for reuse in the cooling water system. The discharges from the refinery would have the same flow rates and chlorine levels as now (and as has occurred over the past 50 years). The future chlorine load discharged to Corio Bay would be the same as now.

In summary, the proposal would involve recycling the FSRU seawater discharge through the refinery and there would be no significant change in the amount of chlorine discharged or in the pattern of the plumes in Corio Bay along the shore of the refinery.

In summary, the evidence shows no significant effects on abundance and diversity of seagrass or algae, and conditions under the refinery plumes are not significantly different from reference sites in Corio Bay.

Referring to the ERS risk ranking in Table 9-6, it is concluded that the proposal represents a **low risk** based on the following evidence:

- Outside the existing licensed mixing zones, the temperature and chlorine levels meet the stringent GV of 7.2 µg/L and are always well under the limit of 17 µg/L;
- Beds of dense and medium seagrass are evident in the zone which has been exposed to the refinery plumes for over 60 years;
- There is no observable trend in algae or seagrass conditions with distance from the refinery outlets but the chlorine concentration decrease with distance;
- Seagrass beds along the shore in front of the refinery are comparable in density and condition to seagrass beds in the Ramsar site; and

Seagrass condition is affected more by sea urchins and land runoff than by the refinery discharge plumes.

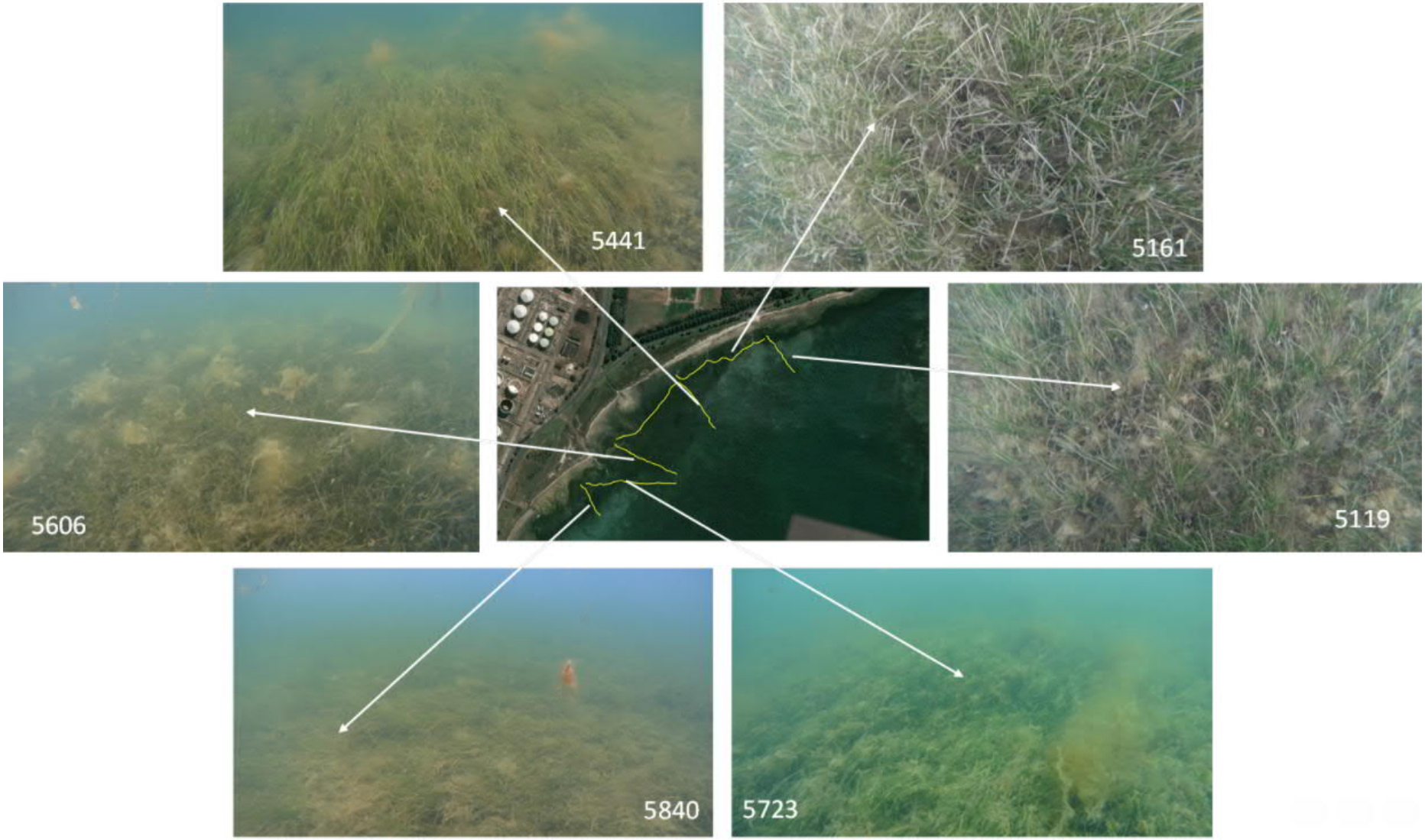


Figure 9-17. Video Images of Seagrass on Plume Survey Tracks

The existing refinery plumes occupy the intertidal or littoral zones (during high tides) and shallow subtidal (sublittoral) zones along the shoreline in front of the refinery. Based on the DELWP classification system, the Biotope complexes that could be potentially affected are:

- ba2.7 Littoral (intertidal) seagrass beds;
- ba5.8 Sublittoral (submerged) seagrass beds;
- ba2 Littoral sediment (patches among seagrass);
- ba5 Sublittoral sediment (patches among seagrass); and
- ba5.b Non-reef sediment epibenthos.

As outlined earlier, recycling of the FSRU seawater discharge through the refinery as cooling water and subsequent discharge through the existing refinery outlets, would result in plumes comparable to those experienced now (but with lower excess temperature).

The possible future plumes from the diffuser (proposed to be seldom used) would occupy the seabed in the dredged channel. Biotope complexes that would be potentially affected by the diffuser plumes are:

- ba5.3 Sublittoral mud

The possible future plume with closed loop operation of the FSRU (where water is recycled through the FSRU for the regasification process) would extend from the seabed to the water surface in the port above the dredged channel. Biotope complexes that would be potentially affected are:

- ba5.3 Sublittoral mud
- Plankton communities
- Pelagic communities.

Table 9-8 lists the conclusions from the assessment of potential impacts on critical processes and services in the Ramsar site, based on the evidence from the field studies and computer modelling presented in this impact assessment report.

Table 9-8. Summary of Assessment of Impact of Chlorine

Critical processes and services	Conclusion of Assessment	Mitigation and Monitoring
Wetland bathymetry	No impact in intertidal mudflat area	No action needed
Geomorphology	No impact on sedimentation patterns	No action needed
Marine invertebrates	No effect on invertebrates in Ramsar site. Possibly an effect on invertebrates under the plume, but this has not been demonstrated.	No action needed Note: Infauna monitoring recommended for north, south and within the dredging zone
Seagrass	No loss of seagrass in Ramsar site. Possibly a minor effect on seagrass under the plume with possibly a	No action needed Note: Seagrass monitoring

Critical processes and services	Conclusion of Assessment	Mitigation and Monitoring
	longer growing season. However, field surveys did not show this.	recommended for near the dredging zone
Mangroves	No impact on mangroves	No action needed
Saltmarsh	No impact on saltmarsh	No action needed
Water birds	No apparent effect as water birds continue to occupy and feed in the plume zone	No action needed
Threatened bird species	Addressed by AECOM, but no significant impact pathway from chlorine plume	No action needed
Migratory birds	Addressed by AECOM, but no significant impact pathway from chlorine plume. No change in zooplankton availability	No action needed
Threatened fish species	No effect. Recreational fishing popular in the plume.	No action needed

Impacts on primary productivity are assessed in Section 10. There is no area of Corio Bay outside the mixing zones with a chlorine level above the limit of 17 µg/L. The evidence from field surveys and recreational fishing shows that the existing chlorine plumes are well-tolerated, and the proposal would not make any change to the chlorine plume along the shore that has existed for over 60 years.

In this section, the pressure being assessed is the change in chlorine oxidants in seawater. Scales for the frequency and intensity of this pressure have been defined by DELWP and are summarised in Table 9-9.

Table 9-9. Defined Scales for Parameters in Environmental Risk Assessment

Parameter	Classification			
	Very poor	**Poor**	**Affected**	**Good**
Frequency	**Permanent**	**Frequent =** *3 times per year*	**Regular =** *1 per year*	**Occasional =** *1 per 5 years*
Intensity	**High (*3*) =** *ecosystem functional change*	***Medium (2) =*** *communities shift a distinct level*	***Low (1) =*** *noticeable change but not significant*	***Very Low (0) =*** *no significant effect*
Tolerance/ sensitivity	**Very Low (2)** (>75 %)	**Low (3)** (25- 75 %)	**Medium (4)** (25 %)	**High (5)** No significant effect
Recovery	**Very Low (2)** (>25 years)	**Low (3)** (10- 25 years)	**Medium (4)** (2-10 years)	**High (5)** (<2 years)

For each plume, and for each biotope complex, the parameter values have been assessed and are listed, with reasoning, in Table 9-10, Table 9-11 and Table 9-12.

The temperature changes are less than the daily natural variation in seawater temperature. For the refinery plume, the chlorine concentration outside the existing mixing zones is generally less than the GV of 7.2 µg/L and well under the limit of 17 µg/L. For the diffuser plume and the closed loop plume, the chlorine concentration in each is less than 5 µg/L and within the GV of 7.2 µg/L

Table 9-10. Environmental Risk Assessment for Existing Chlorine Plume

Biotope Complex	Marine Ecology Assessment				Evidence Assessment	Risk Ranking
	Frequency	Intensity	Tolerance	Recovery		
Existing Plume along shoreline in front of refinery						
ba2.7 Littoral seagrass beds	Permanent	Very low = no effect	High tolerance to chlorine and temperature rise	Medium – in 2-10 years	Survey of seagrass beds found no detectible change with existing plume	Low Risk
ba5.8 Sublittoral seagrass beds	Permanent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Survey of seagrass beds found no detectible change with existing plume	Low Risk
ba2 Littoral sediment (small patches among seagrass)	Permanent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Existing infauna have life cycles of months and appear tolerant of existing chlorine and temperature change	Low Risk
ba5 Sublittoral sediment (small patches among seagrass)	Permanent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Existing infauna have life cycles of months and appear tolerant of existing chlorine and temperature change	Low Risk
ba5.b Non-reef sediment epibenthos	Permanent	Low = noticeable but not significant	High tolerance to chlorine and temperature rise	Medium – in 2-10 years	Seabed photos showed no detectible change with plume exposure pathway	Low Risk
The location of the shoreline plume varies with the tide, and extends from the water line to about 300 m offshore in shallow water. The plume would be 1 to 1.5 m deep. Littoral and shallow sublittoral seagrass beds naturally experience large diurnal variations in temperature that exceed the plume temperature (except in the defined mixing zones). Surveys shows seagrass communities in north Corio Bay are healthy with no detectible variation in condition due to the existing plume. Possible that the seagrass growing season may be slightly extended by higher water temperature in sublittoral zone. Sea urchins are grazing vigorously in the outer edge of seagrass and causing significant loss. Turbidity and nutrients from land drainage affects seagrass.						

Table 9-11. Environmental Risk Assessment for Cooler Plume from Diffuser

Biotope Complex	Marine Ecology Assessment				Evidence Assessment	Risk Ranking
	Frequency	Intensity	Tolerance	Recovery		
Possible future cool plume from the diffuser						
ba5.3 Sublittoral mud	Occasional but classed as Frequent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Infauna have life cycles of months and are tolerant of temperature change	Low Risk
Plankton communities	Occasional but classed as Frequent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Extensive plankton surveys found no significant effect of existing plume. Diffuser plume will be deep and occupy an insignificant (<5%) proportion of the water column habitat	Low Risk
Pelagic communities.	Occasional but classed as Frequent	Low = noticeable but not significant	High tolerance to chlorine and temperature rise	High – in < 2 years	Mobile community and can easily avoid plume if desired. Very small zone of effect on seabed and in water column	Low Risk
The location of the possible future plume from the diffuser is on the seabed and in a 3 m layer above the seabed. The plume is approximately 10 m below the surface. The temperature change is less than 0.5 ^{o}C and the chlorine concentration is less than 5 µg/L – both are within the GV limit. Infauna have life cycles of months and are tolerant of temperature change. The chlorine level is under the GV for chlorine. Extensive plankton surveys found no significant effect of existing thermal discharges. Cooler plume would be in deep layer and away from photic zone. Plankton are in upper part of water column and adapted to larger diurnal variations in temperature from natural processes. Pelagic communities are mobile and can easily avoid plume if desired. Very small temperature change in the diluted plume.						

Table 9-12. Environmental Risk Assessment for Warmer Future Plume

Possible future plume with closed loop operation of the FSRU						
ba5.3 Sublittoral mud	Occasional to Frequent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Infauna have life cycles of months and are tolerant of temperature change. Plume will occupy a small, dredged portion of seabed habitat	Negligible Risk
Plankton communities	Occasional to Frequent	Very low = no effect	High tolerance to chlorine and temperature rise	High – in < 2 years	Extensive plankton surveys found no significant effect of existing thermal discharges. Plume will be deep and away from photic zone	Negligible Risk
Pelagic communities.	Occasional to Frequent	Low = noticeable but not significant	High tolerance to chlorine and temperature rise	High – in < 2 years	Mobile community and can easily avoid plume if desired. Relatively small and weak plume on seabed	Negligible Risk
The location of the possible future warm thermal plume from closed loop operation would occupy a small zone in the port at the rear of the FSRU from about 7 m below the surface to the seabed. The temperature change on the seabed would be less than 0.5 ^{o}C and within the GV limit except for the very small zone of the plume from the discharge ports to the seabed. The chlorine concentration is less than 5 µg/L and within the GV of 7.2 µg/L. Infauna can have life cycles of months. Plankton are in upper part of water column and adapted to larger diurnal variations in temperature from natural processes. Pelagic communities are mobile and can easily avoid plume if desired. Small temperature change in the diluted plume.						

9.17 Conclusions

The refinery commenced operation in 1954 and has been operating for 65 years. Surveys of the seagrass beds under the existing discharge plumes did not detect any significant change correlating with the plumes. Seagrass was abundant in close proximity to the discharges and along the whole length of the plumes. This provides an empirical basis for determining that the effects of chlorine and temperature changes on seagrass in Corio Bay are negligible.

There would not be any change from the existing pattern of chlorine concentrations in the shoreline plume as a result of the proposed project.

The proposal would involve reuse of the FSRU discharge in the refinery for cooling purposes and thus, the discharge of chlorine would remain the same at each of the refinery discharge points compared to the existing arrangement. Therefore, there will be no significant change in the size of the chlorine plumes when the seawater from the FSRU regasification process is discharged through the refinery.

The chlorine concentration in the existing plumes outside the existing mixing zones is 5 µg/L and is within the stringent Default Guideline Value of 7.2 µg/L for chlorine. The chlorine plume is well away from Limeburners Bay and the Ramsar site.

The temperature rise in the existing plumes is modest outside the mixing zone at 2 ^{o}C. This is small in comparison to the diurnal variation in temperatures experienced by biota in the littoral zone (10 ^{o}C) and shallow sublittoral zones (1.6 ^{o}C to 5 ^{o}C).

Discharge through the diffuser is not anticipated to be a common situation and would only occur when the refinery was not operational such as during maintenance periods. Even so, when discharge from the diffuser occurs, there would be high dilution of the discharge and the resulting plume would have a chlorine concentration of 5 µg/L and a temperature rise of less than 0.5 ^{o}C. The diluted plume would be approximately 3 m thick and at the bottom of the water column, well away from the photic zone. The chlorine concentration and temperature change would be within the stringent GV for chlorine and within the natural diurnal variation for temperature. Infauna are tolerant of temperature change. Fish are mobile and can avoid the plumes.

Discharge of warm water from closed loop operations is not anticipated to be a common situation. Even so, when it occurs, there would be high dilution of the discharge so that the resulting plume has a chlorine concentration of 5 µg/L and a temperature rise of less than 0.5 ^{o}C. The diluted plume would be in a very small zone at the rear of the FSRU within the port. The chlorine concentration and temperature change are within the GV.

Based on the assessment of the EPA risk factors, and the weight of evidence from monitoring, surveys and published literature and reports, the existing thermal and chlorine plumes, and the possible future thermal and chlorine plumes associated with the proposed project, are classified as "**Low Risk**" under the EPA risk matrix. As such, and based on field surveys and empirical evidence, it is concluded that the proposed temperature and chlorine discharges associated with the project will have minimal impact on the marine environment.

10 Plankton and Productivity Assessment

This section provides an assessment of the potential impacts of the construction and operations stages of the proposed project on plankton and productivity in Corio Bay. As background to this assessment, existing environmental conditions and field studies of plankton in Corio Bay are described in Section 5.

10.1 Construction and Operations

The project would involve the following construction activities as shown in Figure 10-1 and described in Section 1:

- Dredging an area of 12 ha and removing approximately 490,000 m^3 of sediment to create a berth for the FSRU and a turning basin for LNG carriers:
- Extension of the existing Refinery Pier with a new 570 m long pier;
- Installing a pipe to transfer seawater from the FSRU to the refinery intake; and
- Construction and removal of a temporary loadout facility (20 m by 13 m) at Lascelles Wharf to load out pier extension construction materials.

The assessment of construction impacts is based on the following duration of activities:

1. Dredging period of 5 to 10 weeks, depending on size of dredge, but 8 weeks is most likely:
2. Construction period for new pier of 12 months, including 3 months for installation of piles, with temporary loadout facility in place for duration of the pier extension construction; and
3. Excavation for seawater transfer pipe from Refinery Pier to the refinery seawater intake over 2 weeks.

The project would involve the following operations activities as described in earlier sections and in Section 1. Seawater would be drawn into the FSRU and used to heat LNG, thereby cooling the seawater. The cooler seawater would be piped from the FSRU to the refinery seawater intake for reuse within the refinery and replace the seawater that currently is drawn from Corio Bay for use in the refinery.

The refinery uses 350 ML/d of seawater. At peak production, the FSRU would use 350 ML/d of seawater and hence supply all the seawater used in the refinery. No seawater would be taken in through the refinery inlet channel. At average production, the FSRU would use 250 ML/d of seawater and supply this seawater to the refinery with the extra 100 ML/d taken in through the refinery inlet channel.

In summary, in the operation of the proposal:

- The volume of seawater extracted from Corio Bay would remain at 350 ML/d;
- All seawater used in the FSRU would be normally reused in the refinery;
- The volume of seawater discharged from the refinery would remain at 350 ML/d;
- Only when the refinery is offline for maintenance (which seldom occurs) would seawater be discharged directly into Corio Bay from the FSRU. In that event,

the discharge from the FSRU would be through the diffuser located under the new pier extension at a dilution of 20:1.

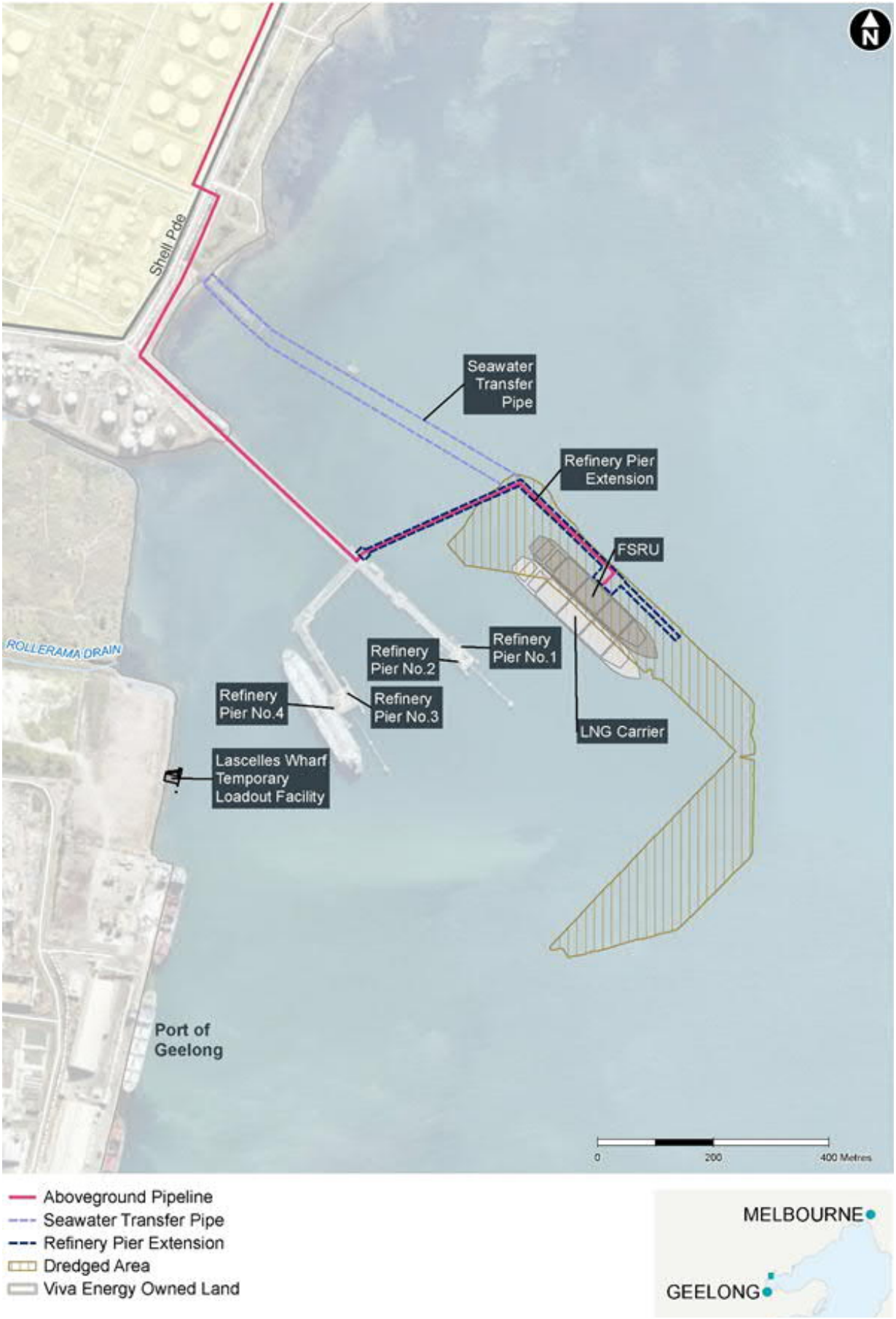


Figure 10-1. Components to be Constructed or Moored in the Project

10.2 Primary Production in Corio Bay

This section of the marine assessment report addresses the potential impacts of construction and operation on primary production (conversion of carbon dioxide to marine plant tissues) in Corio Bay. Section 7 addresses the impacts of dredging on biotopes in Corio Bay.

Almost all aquatic ecosystems depend on cycling of carbon, nitrogen and phosphorous. These basic elements are converted into plant tissue by photosynthesis. This process is carried out in aquatic ecosystems by microscopic plants in the water column (phytoplankton) and on the seabed (microphytobenthos or 'MPB' and large marine plants on the seabed including seagrasses and seaweeds (or macroalgae).

Table 10-1 lists the estimated annual primary production of Port Phillip Bay and Corio Bay, expressed in tonnes of carbon fixed per annum (tC/yr). The production amounts for Port Phillip Bay were estimated by Parslow and Murray (2012) as nitrogen (tN/yr) and converted to tonnes of carbon per year (tC/yr) for this assessment using the Redfield ratio of 106:16 for C:N in marine organic material. The Corio Bay estimates for phytoplankton were derived from the ratio of the area of Corio Bay (43 km^2) to Port Phillip Bay (1,950 km^2).

The Corio Bay estimates for MPB were derived from the distribution of microphytobenthos biomass on surface sediments in Port Phillip Bay (Beardall and Light 1996, Edmunds, et al, 2004).

The Corio Bay estimates for seagrass were derived from the area of seagrass in Corio Bay of 1,050 ha (excluding the seagrass in Outer Harbour, which is counted under Port Phillip Bay), in relation to the total area of seagrass in Port Phillip Bay of 7,140 ha (Eigenraam et al, 2016).

The Corio Bay estimates for seaweeds were derived from the area of seaweeds in Corio Bay of 950 ha in relation to the total area of seaweeds in Port Phillip Bay of 7,000 ha (Eigenraam et al, 2016).

Table 10-1. Estimated Primary Production in Port Phillip Bay and Corio Bay

Primary Producer	Unit	Port Phillip Bay	Corio Bay	Percentage of Corio Bay
Phytoplankton	tC/yr	200,000	4,400	42%
MPB	tC/yr	80,000	1,200	11%
Seagrass	tC/yr	25,000	4,000	38%
Seaweeds	tC/yr	10,000	1,000	9%
Total production	tC/yr	315,000	10,600	100%

It can be seen in Table 10-1 that the total primary productivity of Corio Bay is 10,600 tC/yr, which is 3.4 % of the primary production in Port Phillip Bay (both numbers being recognised as estimates of long-term averages). Phytoplankton and seagrass are the major contributors, each providing about 40 % of total productivity.

MPB and seaweeds are smaller contributors, each providing about 10 % of total primary productivity in Corio Bay (the inner bay excluding Outer Harbour). The

following sections establish the extent to which this primary production could be affected by construction and operation of the proposed project.

10.3 Transport and Circulation in Corio Bay

The movement of planktonic marine organisms in Corio Bay depends on the currents and mixing patterns generated by tides, winds and other processes.

As part of this study, currents in the project area were measured during two current meter deployments. The summer deployment was for 56 days from December 2019 to February 2020 at a location north of Refinery Pier and 100 m offshore from the refinery cooling water inlet. The autumn deployment was for 30 days from April to May 2021, at a deeper site near Refinery Pier.

The median current speed in the **summer deployment** was 0.045 m/s. This corresponds to a water movement of 650 m in an average tide cycle. The highest current speed recorded was 0.16 m/s to the south-west. Analysis of water movement showed varying north and south water movement, depending on wind patterns, with a resultant net water movement to the north. There was very little net water movement over the first 30 days of metering. Then there was a period of sustained south-west winds with a net northward water movement of 1.2 km/d for a week.

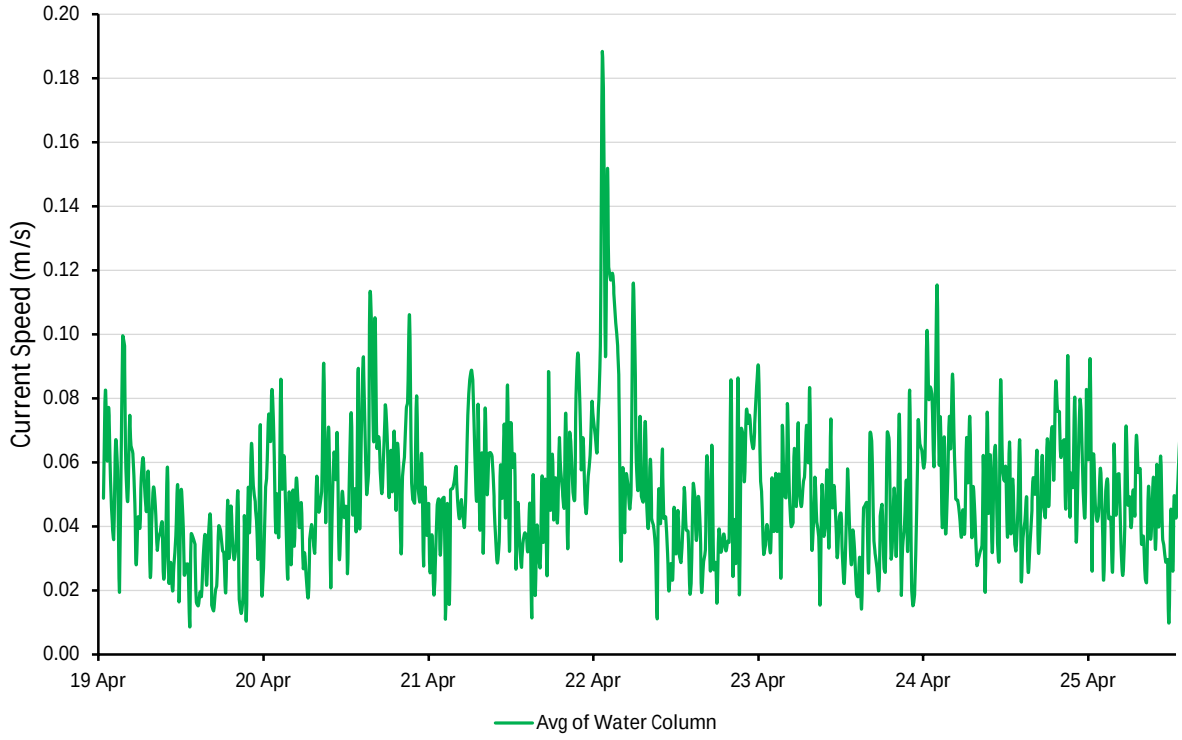


Figure 10-2. Current Speed vs Time During Autumn Deployment

The median current speed in the **autumn deployment** was also 0.045 m/s. The highest current speed recorded during the period was 0.19 m/s to the south-east. Figure 10-2 shows the recorded current speed for the period from 19 to 26 April 2021.

The data show a regular tidal pattern with periodic ebb and flood tidal currents, and occasional bursts of stronger currents at times of strong winds. Lowest speeds occur at slack water between the tides.

Analysis of the autumn measurements show that the deeper currents were slowly moving to the west, while the shallower currents were moving to the east. This reflects a surface wind-driven current to the east, which produces a small circulation within the water column.

Figure 10-3 shows the daily north-south water movement at the autumn current meter site. The average water movement recorded in a day is 0.3 km which corresponds to a water movement of 0.3 cm/s (or only 12 m/hour). The movement is dominated by northly currents which support the clockwise current circulation in Corio Bay where water enters the Bay through the deep channel (the Hopetoun Channel), and then circulates in a clockwise fashion to return to Port Phillip Bay in the north-east of the Corio Bay, near Point Lillias (PPB Study, 1973). The plot shows that water can move up to 1 km north in a day, but typically only moves a smaller distance. Plots for east-west and summer are in Section 5.4.5.

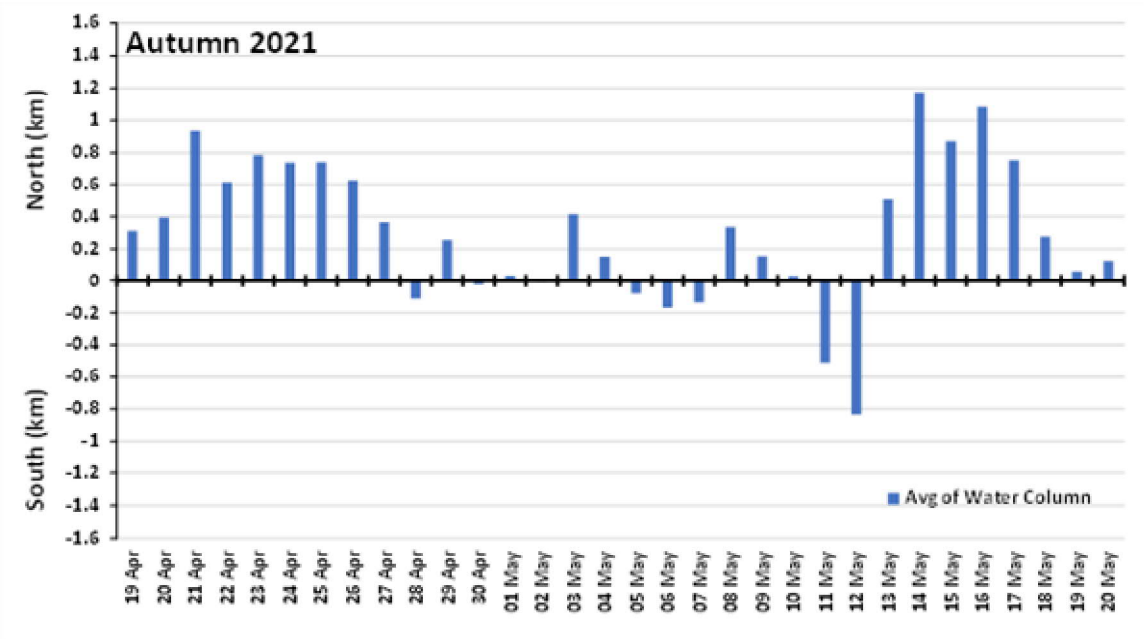


Figure 10-3. North-South Water Movement During Autumn

Overall, the current meter results show:

- Generally weak currents:
- An underlying tidal component, but a larger wind-driven component:
- Many days with a net water movement of only 100 to 400 m/day;
- Most days have a net water movement to the north
- A few days with a net water movement to the south;
- Some days have negligible net water movement – just a small back and forth movement with the tides.

The current meter records were used to calibrate and verify currents and water movement in the regional hydrodynamic model, as described in Section 6.

10.4 Transport Patterns Predicted by Regional Model

The movement and dispersion of plankton and larvae in Corio Bay, and out into Port Phillip Bay, was assessed by tracking neutrally-buoyant particles using the hydrodynamic model of Corio Bay. The modelling examined the dispersion of larvae

from various sites in Corio Bay, including the Ramsar site in north Corio Bay and representative fish-spawning areas in north and south Corio Bay, and the potential for entrainment of plankton and larvae into the existing refinery intake and the proposed FSRU intake.

The three areas examined in the dispersion simulations were:

1. Ramsar site along north coast of Corio Bay (including Limeburners Bay):
2. Fish spawning area in north Corio Bay; and
3. Fish spawning breeding area in south Corio Bay.

For this report, the eastern boundary of Corio Bay is the line connecting Point Lillias to Point Henry – this assumes that the Outer Harbour is in Port Phillip Bay. This means that 8 % of the Ramsar site stretching across the shoreline of north Corio Bay is considered to be in Port Phillip Bay.

Methodology in Dispersion Simulations

The simulation of particle dispersion started with 10,844 neutrally buoyant particles equally spaced over the defined area (e.g., the Ramsar site) at 10 cm above the seabed. The particles then moved laterally and vertically in the water depending on the currents in response to the tide, wind and other hydrodynamic processes.

The position of each particle was calculated every 20 seconds (the model time step) based on the currents and the location of each particle was recorded every 2 hours. Note that in 2 hours at the median current speed of 0.045 m/s, the particles would move 320 m, so the trajectories of the particles between the 2-hour output intervals are represented by linear interpolation between sequential locations.

The particle locations over time were analysed to determine how many of the released particles would reach selected areas in Corio Bay, or move out to Port Phillip Bay. The counts were made at 7, 14, and 28 days after release of the particles and, as a sensitivity check, repeated for releases at high tide and low tide. The particle movement model enables an assessment of how many particles make their way to Port Phillip Bay or to the south part of Corio Bay and allows the entrainment of plankton in the intake of the refinery or the FSRU to be assessed.

Results for Dispersion of Particles from Ramsar Site

Figure 10-4 shows the Ramsar site in north Corio Bay (depicted by the red outline), within which the particles were released, and the seven locations (depicted as A to G in Figure 10-4) where particles were counted. Location A represents the refinery intake. Location B represents the FSRU intake. The other locations were examined to assess the movement and dispersion of particles (or plankton or fish larvae) throughout north Corio Bay.



Figure 10-4. Ramsar Site and Counting Locations A to G

To define the entrainment zone for the 350 ML/d refinery intake (A), an intake zone of 50 x 50 m in area was used extending from the water surface to 2 m below the surface. To define the entrainment zone for the 350 ML/d FSRU intake (B), an intake zone of 50 x 50 m in area was used extending from 10 m to 12 m below the surface (representing the seawater intake zone for the sea chests on the FSRU).

The remaining counting locations (C, E F and G) were spread around north Corio Bay and location D was placed in Port Phillip Bay to the east of the Ramsar site to measure the movement of particles from the Ramsar site into Port Phillip Bay in an equivalent way. At each of these sites, a surface box of the same volume - 50 m x 50 m x 2 m deep - was used to count particles in the same manner as for sites A and B.

The movement of the particles at 7, 14 and 28 days after release from the Ramsar site is illustrated in Figure 10-5. The results show that the particles disperse widely from their initial release within the Ramsar site. Note that particles continue in existence for 28 days whereas phytoplankton divide every 1 or 2 days and zooplankton have a life cycle of 7 to 28 days. The phytoplankton entrained at the refinery after 7 days developed locally, but their forebears passed through the Ramsar site.

At release, 92 % of the particles started in north Corio Bay in the Ramsar site and the other 8 % started in Port Phillip Bay (at the eastern end of the Ramsar site). Some particles remained in the waters of Limeburners Bay, which is part of the Ramsar site, 28 days after release.

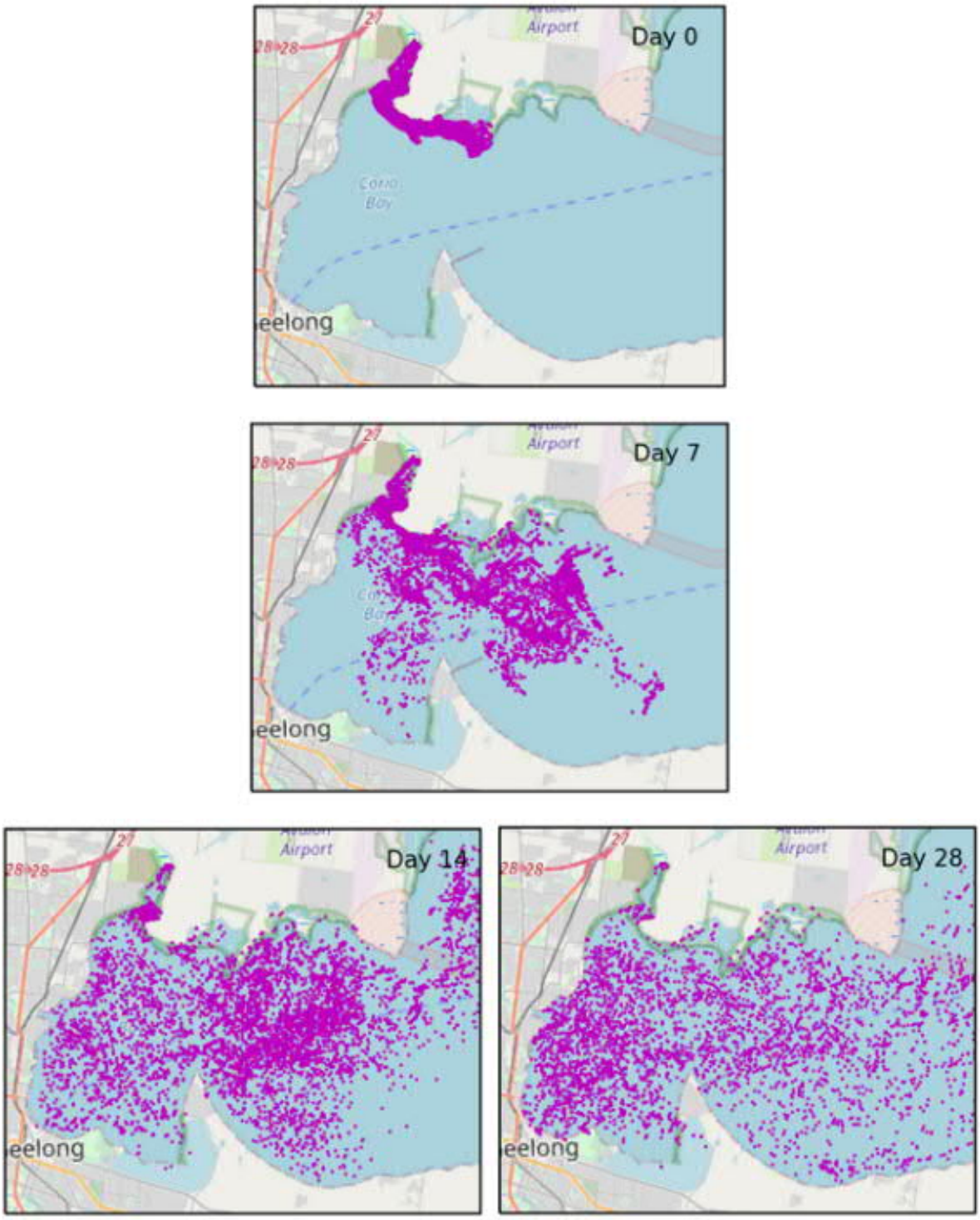


Figure 10-5. Distribution of Particles after 0, 7, 14 and 28 days.

After 7 days the particles had moved mostly eastward into Port Phillip Bay, with a smaller proportion moving down into the south-east part of Corio Bay. Only 42 % of the particles remained in Corio Bay, of which 39 % were in north Corio Bay and 3 % were in south Corio Bay (an east-west line divides Corio Bay in half). This indicates that approximately half the particles in the Ramsar site move east out of Corio Bay into Port Phillip Bay in the first 7 days after release. Many particles remained in north Corio Bay, largely near the Ramsar site, with very few down the west coast of the Bay.

This pattern of particle movement matches the observed current patterns, where there is a net northerly current near the western shore of Corio Bay and a slow clockwise circulation in Corio Bay.

After 14 days from release, there was an even wider distribution of particles. Only 25 % remained in Corio Bay, with 51 % moving into Port Phillip Bay. The particle model simulation emphasises the rapid transport of particles from the Ramsar site into Port Phillip Bay.

The particles that remained in Corio Bay after 14 days were more evenly spread between north Corio Bay (14 %) and south Corio Bay (11 %). Also, after 14 days, the particles were evenly spread over Port Phillip Bay.

After 28 days from release, there were more particles in Port Phillip Bay than in Corio Bay, and a small percentage (2 %) of particles had reached south Corio Bay after travelling back into Corio Bay from Port Phillip Bay. After 28 days, there were more particles from the Ramsar site release in south Corio Bay (17 %) than in north Corio Bay (9 %).

Table 10-2 lists the proportion of particles released from the Ramsar site in north Corio Bay, south Corio Bay and Port Phillip Bay at various times after release. It can be seen that Corio Bay and Port Phillip Bay waters are interlinked, with a high degree of exchange in 14 days. For zooplankton, which have a life cycle of 2 to 4 weeks, there is a considerable mixing of the populations in the two bays, which explains why the two populations are so similar.

It can also be inferred that (1) a majority of fish larvae that might spawn in the Ramsar area (including in Limeburners Bay) move to Port Phillip Bay or south Corio Bay and (2) that a majority of larvae entering Corio Bay from Port Phillip will initially enter the south of Corio Bay and move through the south of the Bay, before eventually reaching north Corio Bay.

Table 10-2. Percentage of Particles from Ramsar Area in Various Regions

Days after release	Percentage in Corio Bay	Percentage in North Corio Bay	Percentage in South Corio Bay	Percentage in Port Phillip Bay
0	92 %	92 %	0 %	8 %
7	42 %	39 %	3 %	16 %
14	25 %	14 %	11 %	51 %
28	27 %	9 %	17 %	47 %

Table 10-3 and Table 10-4 show the proportion of particles entrained into the boxes at sites A to G with release of particles in the Ramsar site at high tide and low tide, respectively. The results illustrate that the entrainment percentages are less than 0.5 %, apart from site D in Port Phillip Bay east of the Ramsar site and perhaps site C in the east of Corio Bay. Note that the plankton have birth and death cycles along the path of a particle. These results confirm the most common path for movement of particles (and by inference, fish larvae) from the Ramsar site is into Port Phillip Bay.

Table 10-3. Entrainment Calculations for Ramsar Site Release at High Tide

Days since release	Percent Entrained into 50 x 50 x 1 m box						
	A Refinery	B FSRU	C	D	E	F	G
7 days	0.00 %	0.00 %	0.12%	1.24%	0.06%	0.03%	0.0%
14 days	0.01 %	0.06 %	0.17%	1.70%	0.11%	0.06%	0.01%
28 days	0.11 %	0.25 %	0.47%	2.05%	0.29%	0.30%	0.20%

It is apparent that the proportion of particles from the Ramsar site entrained by the refinery inlet or the proposed FSRU intake is very small – no more than 0.27 per cent in 28 days. This is a very small proportion of the natural rate of reproduction of phytoplankton and zooplankton and confirms the seawater intake has negligible effect on plankton populations on Corio Bay.

Table 10-4. Entrainment Calculations for Ramsar Site Release at Low Tide

Days since release	Percent Entrained into 50 x 50 x 1 m box						
	A Refinery	B FSRU	C	D	E	F	G
7 days	0.00 %	0.00 %	0.23%	1.15%	0.09%	0.03%	0.0%
14 days	0.01 %	0.06 %	0.27%	1.55%	0.15%	0.08%	0.02%
28 days	0.13 %	0.27 %	0.62%	1.92%	0.34%	0.32%	0.26%

There is zero entrainment of plankton from the Ramsar site in 7 days at sites A (refinery intake) and B (FSRU intake). As noted above in the discussion on currents, many days have a net water movement of only 100 to 300 m/day, and this is mostly to the north, as there are few days with a net water movement to the south. Plankton mostly have a short life cycle (a day or so) and plankton entrained at the intakes are **developing locally and not coming from the Ramsar site.**

Zooplankton have a life cycle of around 14 days and the results show that entrainment rates are negligible (less than 0.1 %) in relation to natural factors (> 99 % loss). The majority of the zooplankton entrained at the intakes are developing locally – although a very small proportion could come from the Ramsar zone.

The majority of fish larvae from the Ramsar site including Limeburners Bay are dispersed into Port Phillip Bay and the potential entrainment after 28 days is less than 0.5%, which is very small in comparison with natural predation and other losses. In conclusion, the current seawater intake has negligible effect on plankton populations in Corio Bay and the proposed intake also would have negligible impact.

Results for Dispersion of Particles from North Corio Bay

Another particle model simulation examined the dispersion of particles from a large area in north Corio Bay (depicted by the blue square in Figure 10-6). The same seven locations in the region (depicted as A to G in Figure 10-4) were used to count particles.

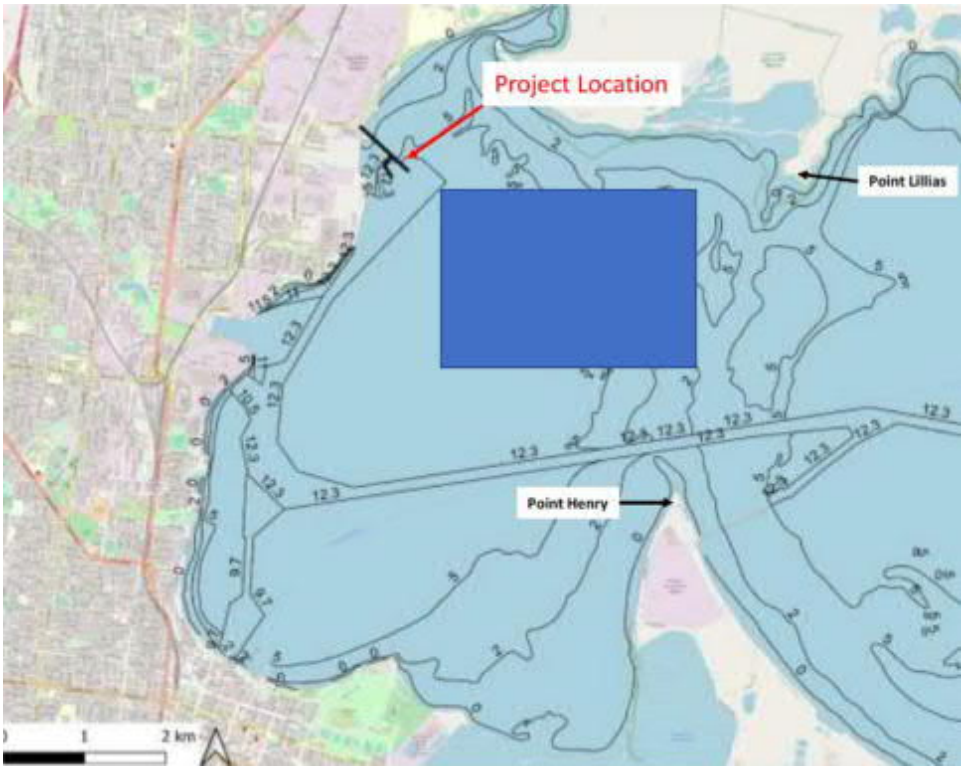


Figure 10-6. Particle Release Area in Northern Corio Bay

Initially, all the particles were spread uniformly within the blue box shown in Figure 10-6. The movement of the particles released from the north Corio Bay area over the 28-day period of model simulations is illustrated in Figure 10-7. The results show that the particles disperse widely from their initial release in north Corio Bay.

After 7 days, many of the particles had moved eastward into Port Phillip Bay and spread north and south in Corio Bay. The particles tended to stay on the east side of Corio Bay, with very little movement to the west coast of the Bay.

After 14 days, there was a widespread distribution of particles in Corio Bay and Port Phillip Bay. The particle model simulation shows the rapid transport of particles from north Corio Bay into Port Phillip Bay.

After 28 days, there were more particles in Port Phillip Bay than in Corio Bay, and the distribution of particles in Corio Bay reflected the clockwise circulation of water in the Bay, so a large percentage of particles moved up the western coast of Corio Bay.

It can be seen that Corio Bay and Port Phillip Bay waters are interlinked, with a high degree of exchange in 14 days. For zooplankton, which have a life cycle of 2 to 4 weeks, there is a considerable mixing of the populations in the two bays, which explains why the zooplankton populations in Corio Bay are similar to those in Port Phillip Bay.

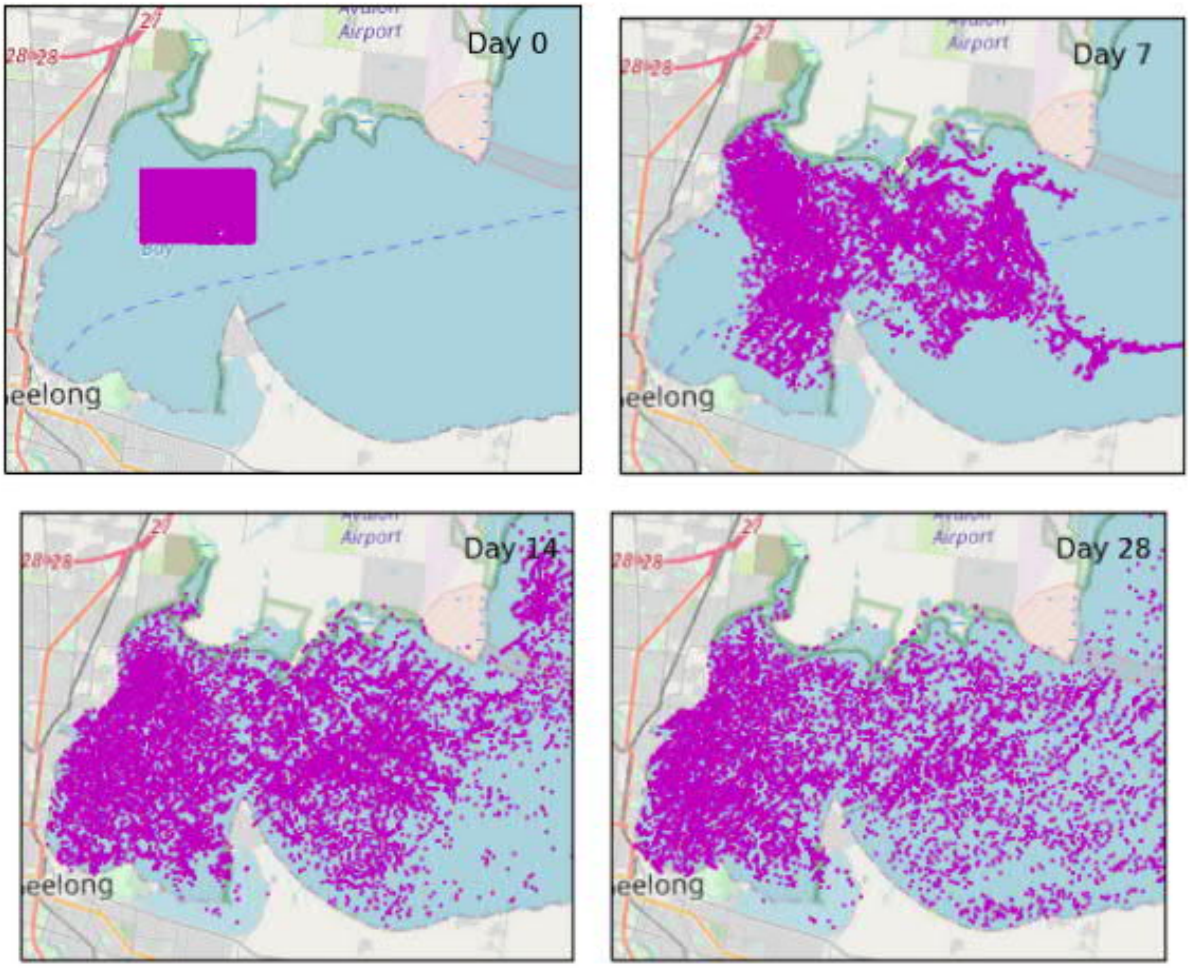


Figure 10-7. Distribution of Particles after 0, 7, 14 and 28 days.

Table 10-5 shows the proportion of particles entrained into the boxes at sites A to G with release of particles in north Corio Bay at low tide. The results illustrate that the entrainment percentages are low for sites A, B, E and G, which are on the western side of Corio Bay, and high at sites C, D and F, which are on the eastern side of Corio Bay or in Port Phillip Bay.

Table 10-5. Entrainment for Northern Corio Bay Release at Low Tide

Days since release	Percent Entrained into 50 x 50 x 1 m box						
	A Refinery	B FSRU	C	D	E	F	G
7 days	0.05 %	0.10 %	2.2 %	0.65 %	0.06 %	1.1%	0.01 %
14 days	0.18 %	0.36 %	2.4 %	0.93 %	0.23 %	1.4 %	0.07 %
28 days	0.34 %	0.66 %	2.9 %	1.15 %	0.43 %	1.8 %	0.42 %

There is low entrainment of plankton from north Corio Bay in 7 days at sites A (refinery intake) and B (FSRU intake). Phytoplankton mostly have a short life cycle (a day or so) and plankton entrained at these sites are developing locally. Zooplankton have a life cycle of around 2 to 4 weeks and the results show that entrainment rates are negligible (less than 0.4 %) in relation to natural factors (> 99 % loss).

Results for Dispersion of Particles from South Corio Bay

A third particle model simulation examined the dispersion of particles from a large area in south Corio Bay (depicted by the blue square in Figure 10-8), indicative of the south fish breeding zone in Corio Bay. The same seven locations in the region (depicted as A to G in Figure 10-4) were used to count particles.

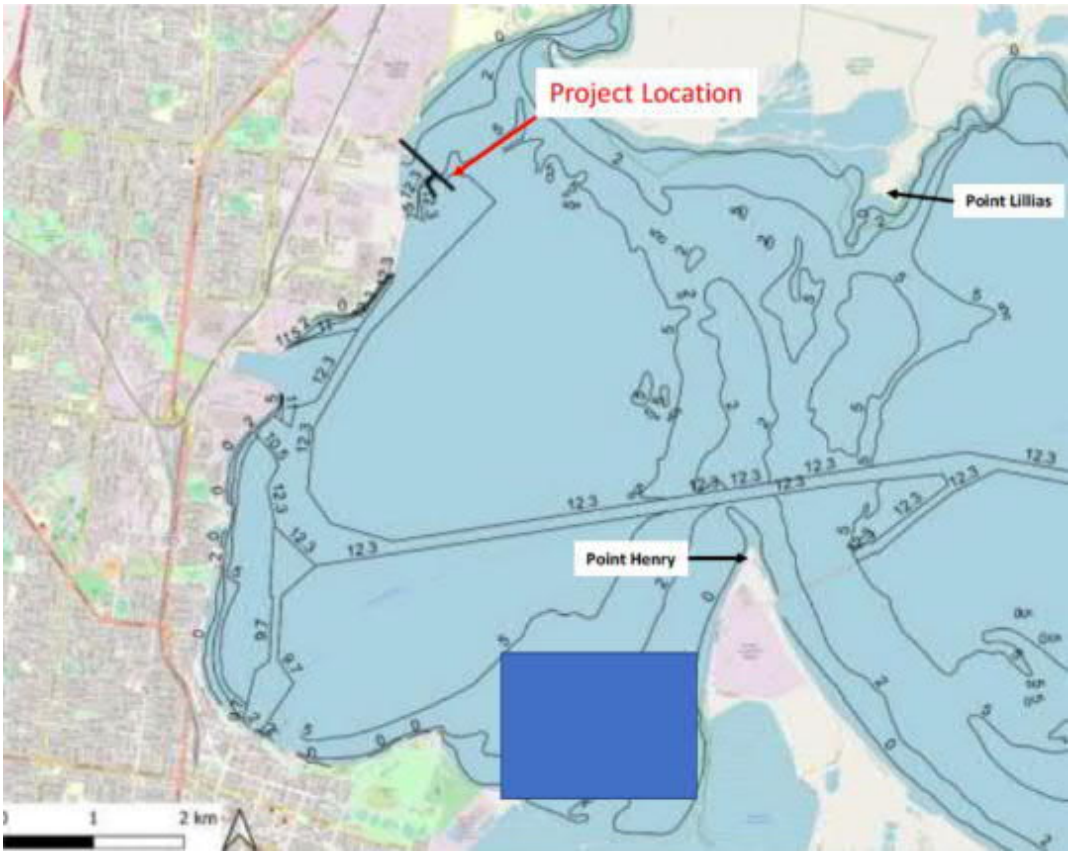


Figure 10-8. Particle Release Area in Southern Corio Bay

Initially, all the particles were spread within the blue box in south Corio Bay. The movement of the particles over 28-days is illustrated in Figure 10-9. The results show that the particles dispersed widely from their initial release.

After 7 days the particles had spread around south Corio Bay and a few had moved to Port Phillip Bay. However, after 7 days, most of the particles were still close to the release area.

After 14 days, there was a wide distribution of particles in Corio Bay and more particles in Port Phillip Bay. The particle model simulation emphasises the slow transport of particles from south Corio Bay into Port Phillip Bay, with most particles released from the south site remaining within Corio Bay for 14 days after release.

After 28 days, there are many particles in Port Phillip Bay, but most were still in Corio Bay, and they were well-distributed throughout Corio Bay.

These results illustrate that there is a longer residence time in Corio Bay for larvae starting in the south area than larvae starting in the north area, or in the Ramsar Site.

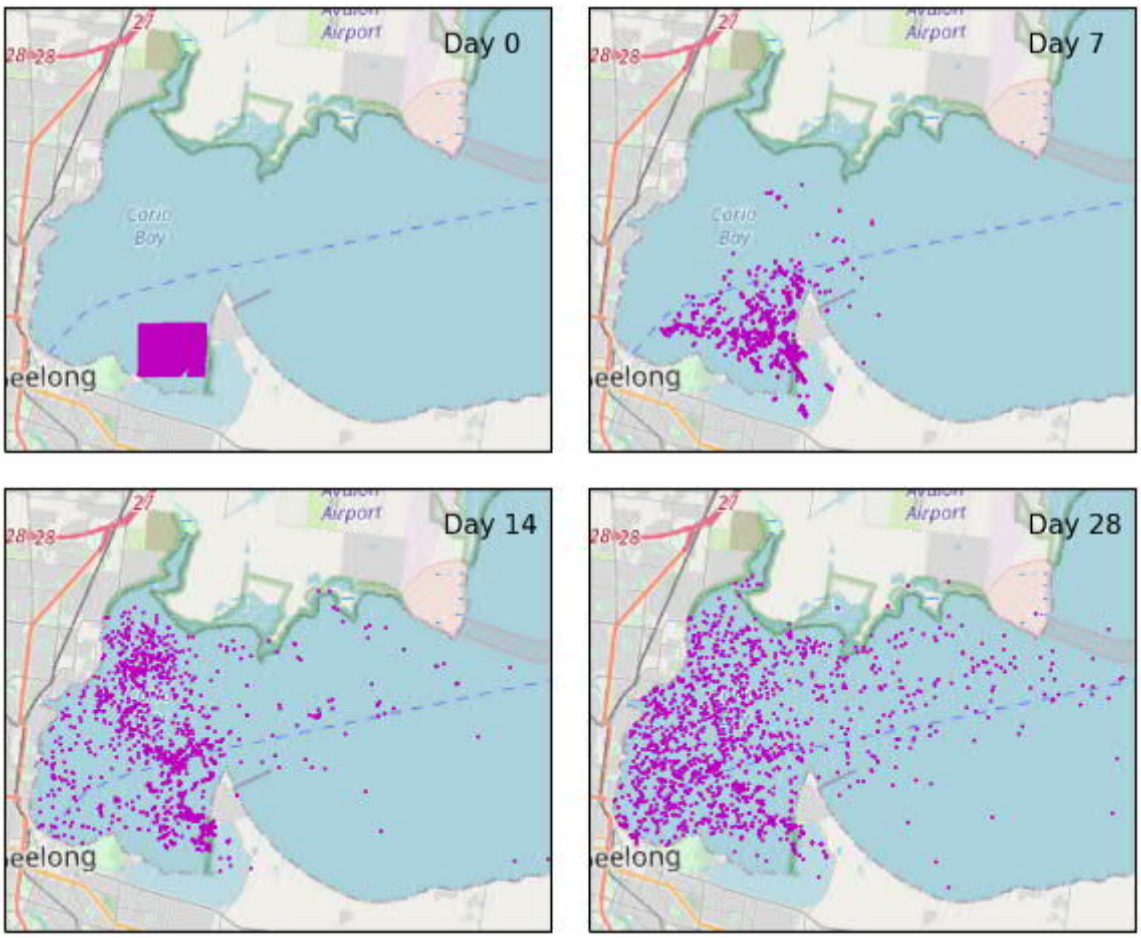


Figure 10-9. Distribution of Particles after 0, 7, 14 and 28 days.

Figure 10-6 shows the proportion of particles entrained into the boxes at sites A to G with release of particles in south Corio Bay at low tide. The results illustrate that the entrainment percentages are low for all sites.

Table 10-6. Entrainment for Southern Corio Bay Release at Low Tide

Days since release	Percent Entrained into 50 x 50 x 1 m box						
	A Refinery	B FSRU	C	D	E	F	G
7 days	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %	0.00 %
14 days	0.00 %	0.06 %	0.02 %	0.00 %	0.00 %	0.02 %	0.03 %
28 days	0.10 %	0.39 %	0.21 %	0.04 %	0.07 %	0.27 %	0.14 %

There is zero entrainment of plankton from south Corio Bay in 7 days at sites A (refinery intake) and B (FSRU intake). Plankton mostly have a short life cycle (a day or so) and plankton entrained at the intake sites are developing locally and not coming from south Corio Bay. Zooplankton have a life cycle of around 2 to 4 weeks and the results show that entrainment rates are negligible (less than 0.1 %) in relation to natural factors (> 99 % loss). In conclusion, the refinery seawater intake has negligible effect on plankton populations from the Ramsar site, north Corio Bay or south Corio Bay, and the proposed FSRU intake also would have negligible impact on plankton.

10.5 Phytoplankton in Corio Bay

Phytoplankton are microscopic plants that photosynthesize and one of the key sources of primary production in Corio Bay.

Phytoplankton were sampled monthly from October 2020 to October 2021 in the project field studies at ten sites in Corio Bay during spring and summer. One site was located in the existing refinery seawater inlet channel. The other nine sites were located around Corio Bay as shown in Figure 10-10. The distribution of sites aimed to cover the different habitats in Corio Bay and the adjacent waters of Port Phillip Bay.

Three of the sites are located in north Corio Bay - one near Refinery Pier, one near the Ramsar site and one at the EPA Corio Bay monitoring site. Three sites were located in south Corio Bay and three sites in the "Outer Harbour" – which represent reference sites to compare the phytoplankton communities in Corio Bay with those in the Geelong Arm segment of Port Phillip Bay.



Figure 10-10. Locations of Offshore Sampling Sites

As described in Section 5, depth-integrated sampling methods appropriate for Corio Bay were used, similar to those used in the Victorian Marine Biotoxin Management Plan (e.g. Fisheries Victoria 2017; EPA *Victoria Marine Monitoring Program*).

At the refinery seawater inlet, highest phytoplankton abundance occurred in spring and summer. Over the sampling period from October 2020 to October 2021, the phytoplankton abundance averaged 620,000 cells/L at the Inlet site. Diatoms were the most common phytoplankton group.

While the mean (average) number of phytoplankton at the inlet was 620,000 cells per litre (cells/L), the median was 520,000 cells/L. The abundance of phytoplankton ranged from 100,000 cells/L in winter to 1,700,000 cells/L in December 2020.

Figure 10-11 compares the average phytoplankton concentration (in cells per litre) recorded in the refinery seawater inlet (green bars) with the average of the three sites in the Corio North region (blue bars). The results show that the total counts in samples from the offshore sites were very similar to those at the inlet site for most phytoplankton groups. The inlet site had slightly lower average concentrations of diatoms of around 570,000 cells/L compared to Corio North which averaged 710,000 cells/L.

Diatoms were the most abundant group, making up 54 % of all phytoplankton. The next most abundant groups were dinoflagellates at 19 % and cryptophytes at 13 %. The abundance of diatoms peaked in December 2020. The abundance of diatoms subsequently steadily decreased to a minimum average of 45,000 cells/L, compared to the lowest abundance at the EPA site of 31,000 cells/L and highest abundance at the Point Abeona site of 64,000 cells/L.

The results show that counts of samples from the inlet site are similar to, and provide a good representation of, the plankton community in north Corio Bay. The counts at the Inlet site were similar to the offshore sites in north Corio Bay which demonstrates that the intake of seawater at the refinery is not affecting the phytoplankton populations.

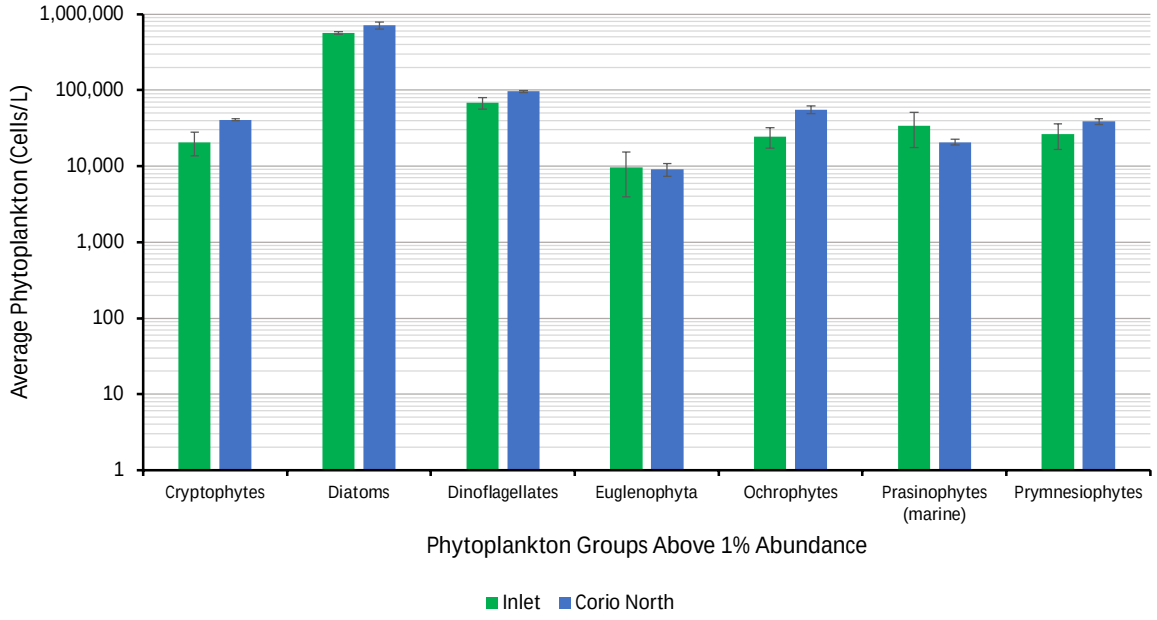


Figure 10-11. Average Phytoplankton Counts at Inlet and North Corio Bay Sites

(Mean± standard deviation)

There is a spring maximum in phytoplankton species richness. In spring 2020, the species richness was high at approximately 80 different species. Over the summer months, the species richness at all sites decreased to approximately 30 species.

Figure 10-12 compares the total phytoplankton counts for sites in north Corio Bay and sites in south Corio Bay. For most of the phytoplankton groups, the results show that the counts in both regions are very similar. This means that the field studies of phytoplankton showed that the spatial distribution is consistent over Corio Bay. This

finding reflects the even distribution of particles over Corio Bay from the various release points, as described earlier.

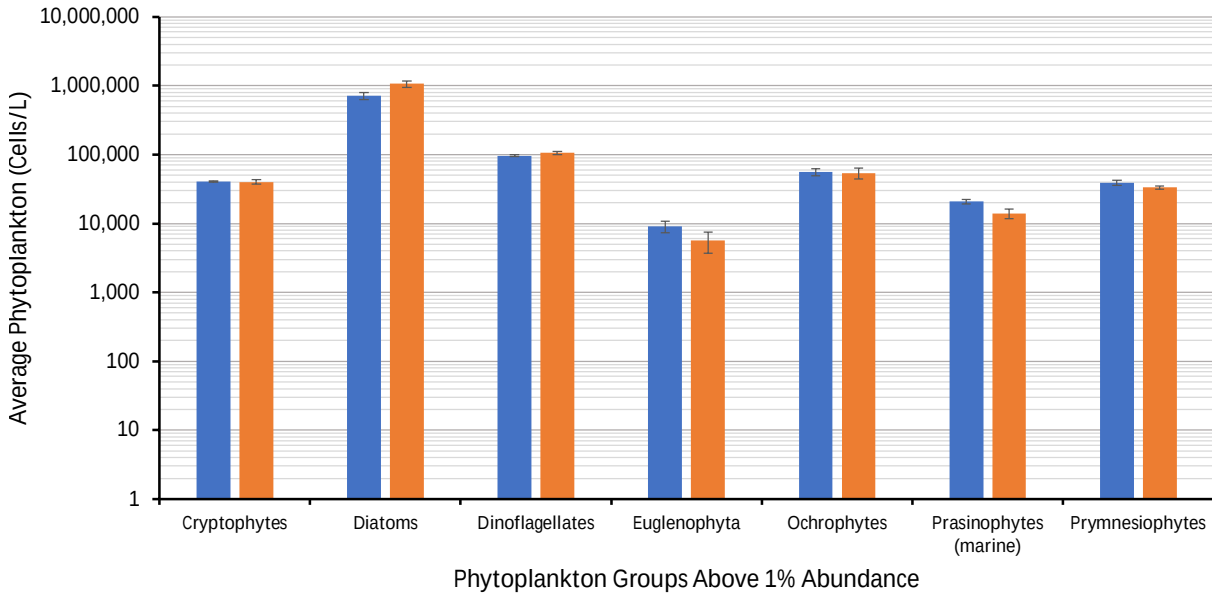


Figure 10-12. Average Phytoplankton Level in north Corio Bay and south Corio Bay

While the diatom abundances in the north and south of Corio Bay were similar, Section 5 of this report shows that diatom abundance in the Geelong Arm was around 2,500,000 cells/L. It appears that diatoms may be responding to the large nutrient input from the Western Treatment Plant east of Point Wilson in the Geelong Arm.

Figure 10-13 shows a time series of the major plankton groups at the three north Corio Bay sites from November 2020 to June 2021. There is high variability in plankton abundance at all sites as plankton numbers can increase rapidly in favourable conditions or decrease rapidly in unfavourable conditions.

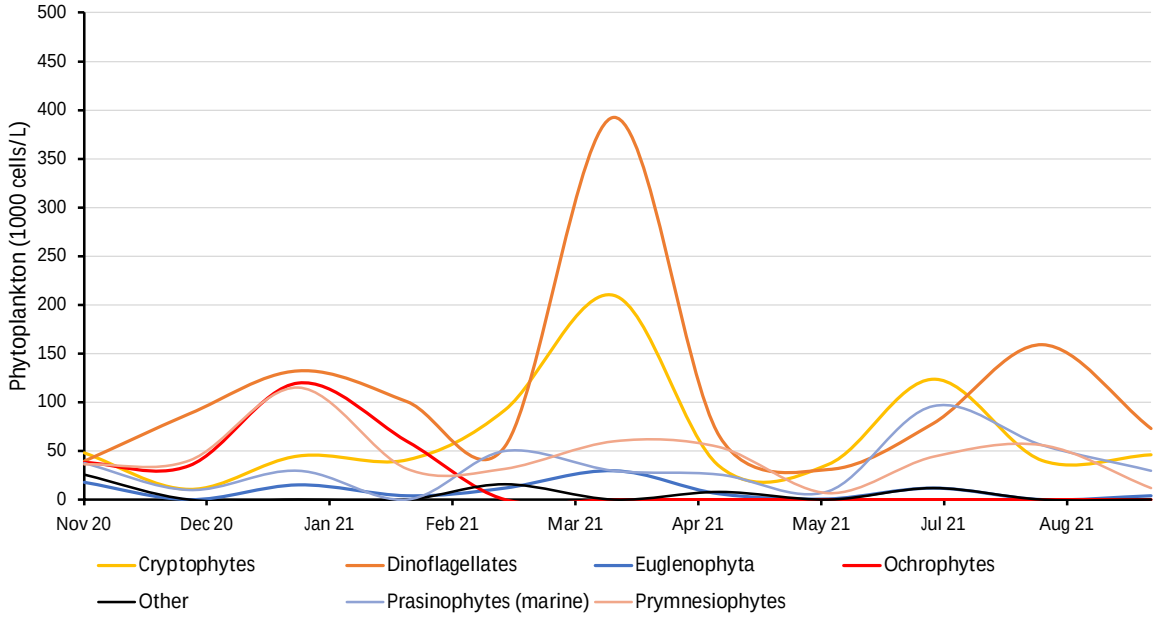


Figure 10-13. Time Series Phytoplankton Abundance in North Corio Bay

The plot confirms that dominance of the phytoplankton community by diatoms is consistent over most of the year. A seasonal pattern of higher abundances in late spring, summer and early autumn is most obvious in diatom numbers, with a spike in diatom abundance in December 2020. The other phytoplankton groups were more consistent in concentration across the time period, indicating that grazing by zooplankton over the spring and summer may be a more significant pressure on these groups than on diatoms.

Comparison with Longer Term EPA Monitoring

Plankton count data from EPA's Corio Bay monitoring site over the period 2012 to 2020 were examined to provide long-term, time-series context to the Corio Bay data collected for the project. A time series of total phytoplankton for the years 2012 to 2020 for the Corio Bay EPA monitoring site is shown in Figure 10-14.

The EPA surveys over eight years show a median phytoplankton count of 354,000 cells/L and a mean of 643,000 cells/L. For comparison, the CEE surveys in 2020-2021 showed a median phytoplankton count of 520,000 cells/L and a mean (average) of 620,000 cells/L. It is considered that the data gathered during the CEE surveys in 2020-2021 corresponds well with the phytoplankton data collected by the EPA in the same or nearby locations in Corio Bay.

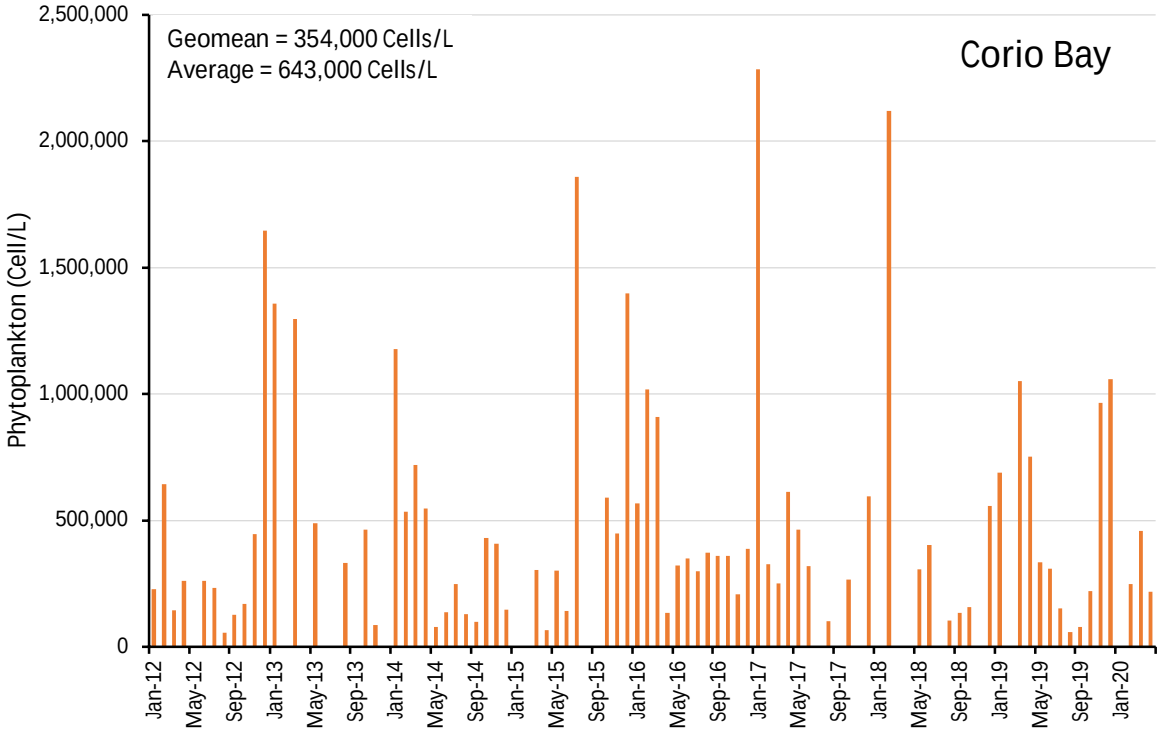


Figure 10-14. Time Series of EPA Phytoplankton Data for Corio Bay

Figure 10-15 shows the major phytoplankton species at the EPA Corio Bay monitoring site from October to December 2020. A comparison of the major phytoplankton species at the EPA site 1 (October to December) and the north Corio Bay sites shows very similar phytoplankton abundance and composition at the two sites. The December bloom in diatom numbers at the north Corio Bay sites is also apparent in the EPA monitoring.

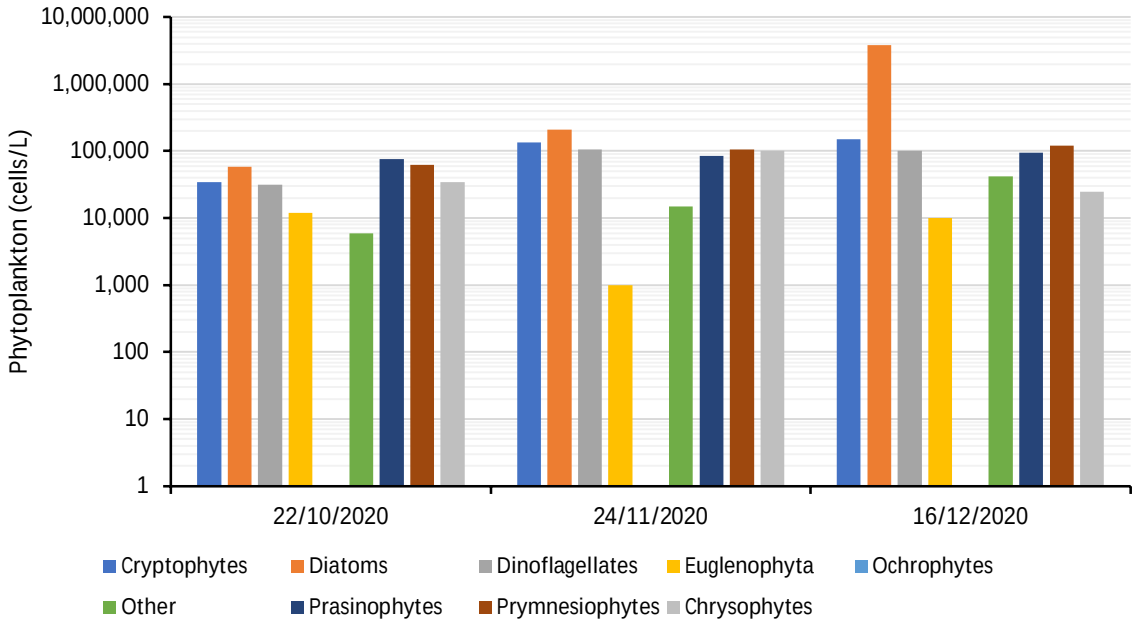


Figure 10-15. Phytoplankton Composition at EPA Site in Corio Bay

Outcomes for Primary Productivity from Phytoplankton

The outcomes of the field studies and analysis of phytoplankton in Corio Bay, as it applies to an estimation of the effects of the project on primary productivity, are summarised below.

- Phytoplankton abundance and species richness is evenly distributed over Corio Bay. The intake of seawater at the refinery is not affecting the phytoplankton populations in Corio Bay.
- On a day-by-day basis, which corresponds to the life cycle for phytoplankton of 1 to 2 days, water movement in Corio Bay is relatively small (200 to 400 m/d). Thus, although there is mixing over the bay on the scale of weeks, the plankton collected in the refinery seawater inlet developed locally – within a few hundred metres of the inlet.
- Phytoplankton numbers respond to light availability (strong growth in spring) and nutrients (higher abundance near Werribee Western Treatment Plant nutrient input).
- Numbers can increase dramatically when conditions are favourable (reported to be a 30 % increase in a day). There is a thirty-fold increase in diatom numbers between November and December (see Figure 9-14). Therefore, it can be expected that phytoplankton numbers will recover quickly from adverse local conditions during construction such as dredging.
- The refinery discharges have been operating for 65 years. Based on the monitoring data, the phytoplankton numbers near the refinery seawater inlet (and thus near the refinery discharge points) are very similar to elsewhere in north Corio Bay. Thus, there is no apparent adverse effect of the existing discharge on phytoplankton populations from either chlorine or temperature.

10.6 Impact of Change of Intake Location on Entrainment

The earlier sections discussing particle tracking results have shown that very small proportions of particles that are entrained into the refinery inlet, or the proposed FSRU intake, come from the Ramsar site or south Corio Bay or north Corio Bay (see Table 10-7 for a summary of the particle tracking results). The great majority of particles (more than 99 %) entrained into the existing refinery inlet or the proposed future FSRU inlet come from the remainder of the Bay.

This section examines the source of plankton entrained into the two inlets and the implications on (1) plankton abundance in Corio Bay and consequent ecological impacts; (2) availability of food for migratory birds in the Ramsar site; and (3) the survival and distribution of fish larvae in Corio Bay and Port Phillip Bay.

Table 10-7. Sources of Plankton Entrained into Refinery and FSRU Intakes

Days since release	Ramsar Sie		North Bay Site		South Bay Site		Remainder of Bay	
	A Refinery	B FSRU	A Refinery	B FSRU	A Refinery	B FSRU	A Refinery	B FSRU
7 days	0.00 %	0.00 %	0.05 %	0.10 %	0.00 %	0.00%	99.95 %	99.90 %
14 days	0.01 %	0.06 %	0.18 %	0.36 %	0.00 %	0.06 %	99.81 %	99.52 %
28 days	0.12 %	0.26 %	0.34 %	0.66 %	0.10 %	0.39 %	99.44 %	98.69 %

Impact on Phytoplankton in Corio Bay

As noted in Section 10-5, the abundance and species richness of phytoplankton were similar over the sites in north Corio Bay. Therefore, the number of phytoplankton entrained into the refinery inlet is about the same, on average, as the number that would be entrained into the FSRU inlet. However, the plankton entering the two inlets come from somewhat different zones.

As described in Section 5, the inshore current meter (summer deployment) recorded a mean current speed of 0.044 m/s, which corresponds to a tidal excursion of 630 m north and 630 m south of the meter. It is assumed these excursions also apply to the refinery inlet. Underlying currents are tidal, with added excursions in response to prolonged strong winds. The average wind-driven excursion was 800 m/day to the north and 400 m/day to the south. There was very little movement recorded to the east and a lot (average of 1500 m/day) to the west, reflecting the flow into the refinery inlet as recorded by the inshore current meter (sited near the inlet).

Figure 8-9 (predicted temperature plumes for existing situation) shows that the plume from discharge point W1, south of the refinery inlet, extends about 500 m offshore, and then travels to the north. This path has been confirmed by CEE field studies.

At times of weak winds and average tides, which is about half the time, the seawater entering the refinery inlet comes from a zone that extends about 500 m north and 700 m south of the inlet, including the diluted flow from W1 most of the time, and from the shoreline to around 500 m offshore.

At times of strong winds, the intake zone extends to around 1,200 m to the south, or 800 m to the north, or 800 m offshore, depending on the wind direction.

The intake zone for the refinery inlet described above defines the source of phytoplankton in the day before entering the intake channel. As phytoplankton have

a life cycle of 1 to 2 days, the great majority of the phytoplankton entering the refinery inlet come from within this intake zone.

The particle model predictions in Table 10-7 show that even for a long-lasting phytoplankton with a life cycle of 7 days, none of them could reach the inlet zone from the Ramsar Site in 7 days. With the usual phytoplankton life cycle of 2 days, they would undergo 14 life cycles on the journey from the Ramsar Site to the refinery intake zone.

The intake zone for the FSRU inlet is similar but 700 m further offshore. As described in Section 5, the offshore current meter (autumn deployment) recorded a mean current speed of 0.05 m/s, which corresponds to an excursion of 700 m north and 700 m south of the meter. The average wind-driven excursion was 450 m/day to the north, 50 m/day to the south, 300 m to the east and 50 m/day to the west.

At times of weak winds and average tides, which is about half the time, the seawater entering the refinery inlet comes from an intake zone that extends about 700 m north and 700 m south of the inlet and about 250 m to 900 m offshore.

At times of strong winds, the FSRU intake zone would extend to 1,200 m to the south, or 800 m to the north, depending on the wind direction.

The great majority of the phytoplankton entering the FSRU would come from within this intake zone. None come from the Ramsar Site within 7 days (see Table 10-7), although a small proportion of the phytoplankton that originated in (or passed through) the Ramsar Site appear to be heading towards the intakes after 4 days of simulations (even though the majority are headed out into Port Phillip Bay) as illustrated in Figure 10-16 (upper panel).

The consequence of the project would be to move the zone from which plankton are captured in the intake from close to the western shore (0 to 800 m from shore for the refinery intake) to the port zone (250 m to 900 m from shore for the FSRU intake). However, phytoplankton numbers in the intake zones remain the same as now.

The reduction in phytoplankton numbers occurs in the discharge zone as around 50 % of the phytoplankton are not viable after passing through the heat exchanger. The 3-fold dilution over 3 hours brings the count up to 83 % of the original while regrowth over 3 hours increases the count to around 95 % of the original (phytoplankton growth rate from *Port Phillip Integrated Model*, Murray et al, 1997).

In summary, changing the location of the seawater intake would move the zone of intake further from shore, but with no change in phytoplankton counts in that zone. There is a zone extending 300 m or so from the discharge points with lower phytoplankton counts. This zone would not change for the proposal with continued discharge from the existing refinery outlets. However, this zone would move to the channel in the port (see Figures 8-14 and 8-15) when the discharge is from the diffuser. Overall, phytoplankton abundance in Corio Bay would not be reduced by the proposal.

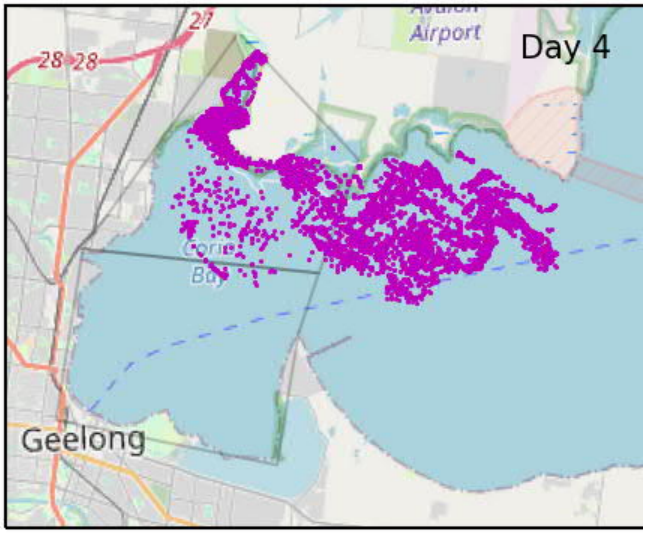
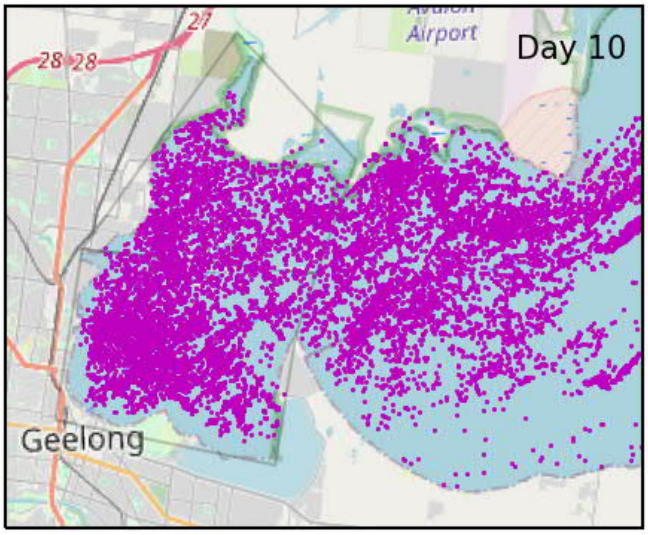
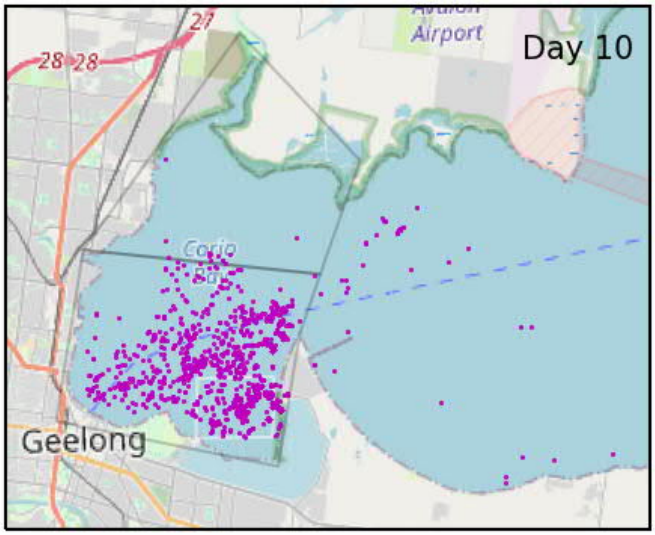
From Ramsar Site	
From North Bay Site	
From South Bay Site	

Figure 10-16. Distribution of Particles after 4 and 10 Days from Release

Impact on Zooplankton in Corio Bay

As noted in Section 5-10, the abundance of zooplankton is similar over the sites in north Corio Bay at 1,500 cells/m^3 (median count over study period), but lower at the refinery inlet (at 1,300 cells/m^3 probably because of high losses of zooplankton in the heat exchangers. The abundance is higher in the east of the Bay at 1,900 cells/m^3 (reflecting higher phytoplankton population resulting from nutrient supply at Werribee).

Therefore, the number of zooplankton entrained into the FSRU inlet would be larger, on average, than the number now entrained into the refinery inlet, as the zooplankton entering the two inlets come from somewhat different zones.

The north Bay site is closer to the FSRU intake than the refinery intake and therefore will be the source of more zooplankton. As listed in Table 10-7, with the change to the FSRU intake, the proportion of zooplankton originating from the Ramsar site is predicted to increase from 0.01 % to 0.06 %, with a similar increase from the south Bay site and a larger change from the north Bay site of 0.18 % to 0.36 %. However, Figure 10-16 shows that after 10 days, zooplankton from the north Bay site are spread throughout Corio Bay and this distribution pattern will continue.

These increases are very minor in relation to the natural loss rate for zooplankton of about 5 % per day (Port Phillip Bay Study, 1977) and are of no ecological significance, but simply reflect the movement of the zone of intake.

Zooplankton eat phytoplankton and are in turn eaten by small fish. They have a life cycle of around 2 weeks, and therefore zooplankton entering the intakes can come from a larger intake zone than phytoplankton. In addition, the zooplankton population has a slower growth rate (20 % to 50 % per day, Mitchell, 1977) and therefore is slower to recover to original numbers in the discharge plume.

The reduced numbers in the discharge plumes is the process of ecological significance. It is assumed that the loss of viability of zooplankton in the heat exchangers is around 100 %. The 3-fold dilution of the plume over 3 hours brings the count up to 67 % of the original while regrowth over 3 hours would increase the count to around 80 % of the original count (at median zooplankton growth rate from *Port Phillip Integrated Model*, Murray et al, 1997). By the time the refinery plume reaches the Ramsar site, the zooplankton count would have recovered to around 92 % of the original count. This is the same situation as occurs in the discharge plume at present.

The zooplankton damaged in the heat exchanger will be consumed by living zooplankton or small fish in the discharge plume. The residual small organic particles will settle and be consumed by detritus feeders, returning the nutrients and carbon to the natural cycles in Corio Bay.

In summary, changing the location of the seawater intake would move the zone of intake further from shore, but with no change in zooplankton abundance in Corio Bay. There would be a zone extending 700 m or so in the plumes from the discharge points with lower zooplankton counts. This zone has been present for the last 65 years and will not change as the proposal involves continued discharge from the existing refinery outlets. The plume zone would move to the channel in the port (see Figures 8-14 and 8-15) when the discharge is from the diffuser.

Impact on Ichthyoplankton in Corio Bay

As noted in Section 5-12, the abundance of ichthyoplankton is strongly seasonal, with peak numbers in spring (around 10 cells/m^3) at all sites in Corio Bay. The

ichthyoplankton samples were dominated by fish eggs, which float in the water column and therefore behave is a similar manner to phytoplankton. The main fish larvae species identified were Australian Anchovy and Gobies.

Over the year, the median numbers of ichthyoplankton were the same at all sites in Corio Bay (around 4 cells/m^3). Therefore, the number of ichthyoplankton entrained into the FSRU inlet would be the same, on average, as the number that is entrained into the refinery inlet, even though the ichthyoplankton entering the two inlets come from somewhat different zones.

Gobies are sedentary, bottom dwelling fish comprising a range of species that are widely spread in bays and coastal environments. They typically breed in spring and larvae comprise a major component of the ichthyoplankton in bays, such as Port Phillip, Corio and Western Port Bays. Gobies lay 200-2000 eggs about every 20 days between August and December. The eggs hatch and commence feeding in four days. Only 1 in 10,000 eggs survives to become an adult breeding goby – the others are consumed by larger zooplankton and the small fish in Corio Bay and Port Phillip Bay.

Anchovies are highly mobile planktivorous fish that are generally found close to the sea surface in bays such as Corio Port Phillip and Western Port and open coastal waters including Bass Strait. They typically breed in spring and summer and larvae may comprise a significant component of the ichthyoplankton in bays and open coastal waters. Anchovies lay around 1000 eggs about every 15 days between August and December. The eggs hatch and commence feeding in a day or so. Only 1 in 40,000 eggs survives to become an adult breeding anchovy – the others have the same fate as goby eggs. Overall, fish eggs have a loss rate of 99.99 %.

The change in the intake zone is predicted to make a marginal increase in the number of ichthyoplankton entrained into the FSRU inlet from the Ramsar site, south Bay and north Bay, and a marginal decrease in the number of ichthyoplankton entrained into the FSRU inlet from the west coast of Corio Bay. Given the distribution of seagrass beds in the Bay (as shown in Section 5), the net effect is expected to be an increase – equivalent to increasing predation from these zones from 0.56 % to 1.31 % in 28 days.

The main factors reducing the fish larvae population are starvation and predation (approximately equal proportions, according Reynolds, 2002 and Shann et al, 2008). About 99 % of fish eggs and larvae die in the month after hatching (Kawano, 2017). However, as a consequence of the reduced numbers of fish larvae in the discharge plume, that batch has a higher relative survival rate, because there is less predation pressure (larvae are more widely spaced) and improved food availability per larvae.

The extra loss in the refinery/FSRU from 0.5 % (including biological feedback) to 1.7 % (no feedback) is very small. The smaller estimate is more likely. Even so, in comparison to the natural loss rate of 99.99 % the estimated increase is very minor, As for zooplankton, the ichthyoplankton damaged in the heat exchanger will be consumed by living zooplankton or small fish in the discharge plume, or by detritus feeders, returning the nutrients and carbon to the natural cycles in Corio Bay.

In summary, changing the location of the seawater intake would move the zone of intake further from shore, but with no change in ichthyoplankton counts in that zone. The zone extending from the discharge points would have fewer ichthyoplankton – estimated to be about 0.5 %. The effect would be local, as most larvae would

continue to be transported by the currents into Port Phillip Bay, as shown in Figures 10-5 and 10-7.

10.7 Microphytobenthos in Corio Bay

Microphytobenthos (MPB) are a small algal group that occupy the surface of marine sediments. Depending on physical and ecological conditions, MPB may grow on seabed sediment from about 2 m to 12 m depth (Cahoon 1999). Most MPB communities are dominated by diatoms, but blue-green algae and flagellate groups including euglenoids and dinoflagellates may also occur. MPB were visible on the surface of sediments in towed camera surveys (see images below) and are also present to several centimetres below the surface (Cahoon 1999, Light and Beardall 1998).

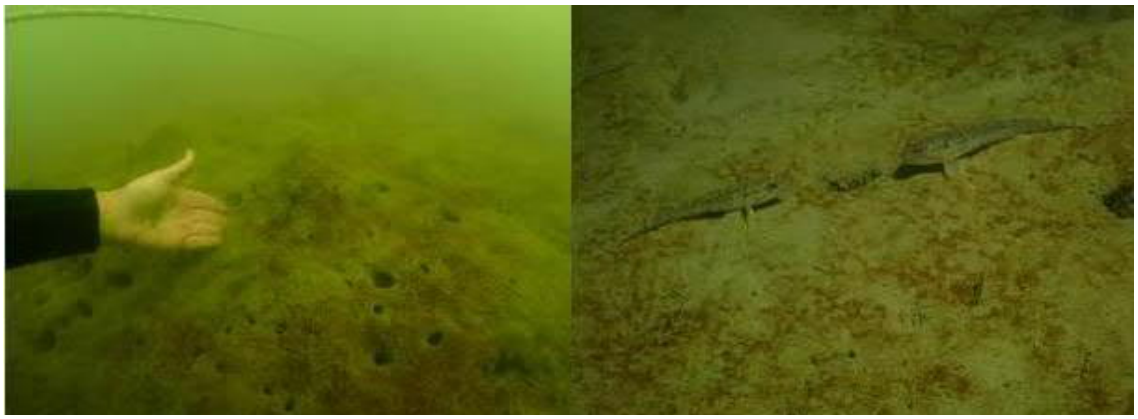


Figure 10-17. Example of MPB in Corio Bay

Studies in Port Phillip Bay and elsewhere have shown that MPB add to primary production (Axelrad, Hickman and Gibbs 1979; Cahoon 1999, Light and Woelkerling 1992; Beardall and Light 1997; Rysgaard, Christensen and Nielsen 1995, Edmunds et al, 2004, Light and Beardall 1998). Edmunds et al (2004) published a map showing the distribution of MPB in Port Phillip Bay, including Corio Bay (see Figure 10-18). There are six regions of high primary productivity (regions with > 50 mg chlorophyll-a/m^2) in the region, including two shallow areas in Corio Bay, both just offshore of seagrass.

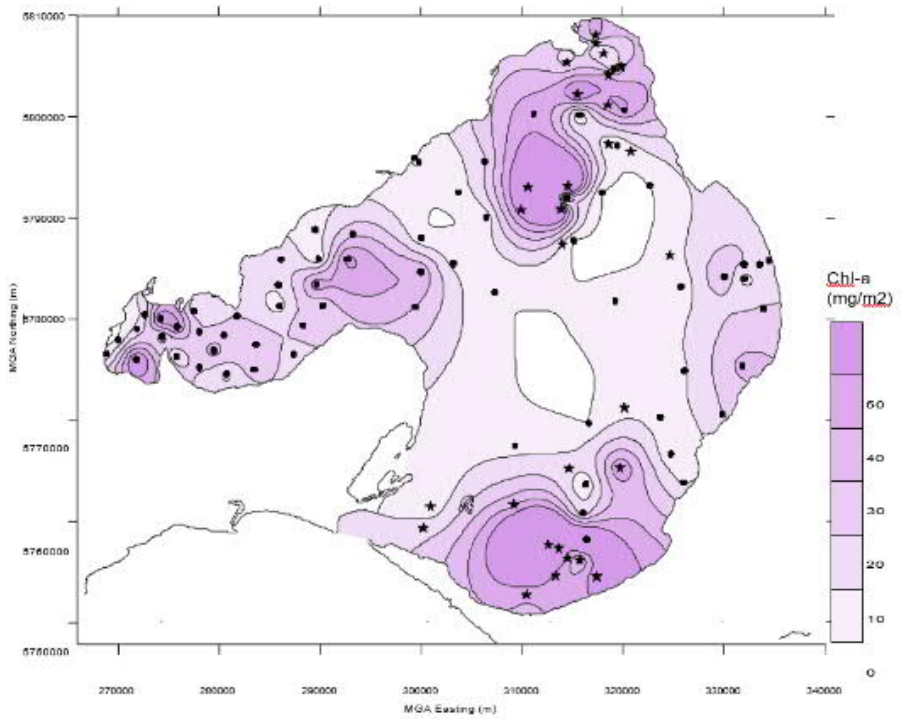


Figure 10-18. MPB Distribution in Port Phillip Bay and Corio Bay

Implications for Primary Productivity from Phytoplankton

The implications of the MPB distribution in Corio Bay, as it applies to an estimation of the effects of the project on primary productivity, are as follows:

- Although MPB levels are high in the north-east and south-east of the Bay, they are low near the proposed project site (around 12 mg Cl-a/m^2);
- MPB production varies seasonally (with light intensity) and with depth (being lower in greater depths).

10.8 Seagrass and Macroalgae Distribution in Corio Bay

The pilot ecosystem accounts for Port Phillip Bay (DELWP, 2016) show the distribution of seagrass and seaweed in five segments of Port Phillip Bay, including the Corio Segment. It is important to note that the Corio Segment includes all of Corio Bay, the Outer Harbour, the western arm of Port Phillip Bay and all the waters up to Williamstown, so it extends well beyond “Corio Bay” as described in this assessment.

As listed in Table 10-8, the Corio Segment contains 3,280 ha of seagrass which is 46 % of the seagrass in Port Phillip Bay. The Corio Segment contains 7,087 ha of seaweed which is 99 % of the seaweed in Port Phillip Bay. However, much of this seagrass and seaweed is not in Corio Bay itself, but along the shore of the Bellarine Peninsula and the north-western shore of Port Phillip Bay from Port Lillias to Williamstown.

Table 10-8. Areas of Habitat Complex in Port Phillip Bay Segments

Broad habitat	Habitat complex	Central	Corio	Exchange	Hobsons	Interfidal	Total
Sublittoral sediment	Mud	69,923	3,391	7,393	3,922	234	84,863
	Muddy sand	8,935	5,898	10,656	3,872	8	29,369
	Sand	5,800	11,064	23,458	6,921	312	47,555
	Seagrass	1	3,280	3,524	123	209	7,138
	Seaweed		7,087	352	431	14	7,884
	Silty mud	141	9,737	2,113	905	28	12,925
Sublittoral sediment total		84,800	40,457	47,498	16,175	804	189,734

Examination of the areas of seagrass and seaweeds mapped by DELWP in Coastkit shows that Corio Bay contains 1,050 ha of seagrass which is 15 % of the seagrass in Port Phillip Bay, and 7,087 ha of seaweed which is 99 % of the seaweed in Port Phillip Bay. Studies of the distribution of seagrasses for this project have shown that the relatively turbid waters of Corio Bay limit the depth range of dense Zostera seagrass.

The Port Phillip Bay Environmental Study (CSIRO, 1996) estimated that there are 64 species of Chlorophytes (green algae) in the Bay, 109 species of Phaeophyta (brown algae) and 276 species of Rhodophyta (red algae). In comparison, there are only 12 species of seagrass.

The distribution of the various macroalgae in Corio Bay is known to be associated with sediment type, wave action, light availability, nutrient availability, salinity, currents and temperature. Some taxa are found mainly in the calmer waters of Corio Bay and on the western and north coasts of Port Phillip Bay, while other taxa are ubiquitous.

The distribution of seaweeds in Corio Bay can be predicted from three physical factors: wave exposure, seabed character and available light.

Where seagrasses have colonised shallow waters, brown algae are found seasonally at medium density in the same areas, co-existing with the seagrasses (see photo in Figure 10-19). A reasonable estimate is that seaweeds occupy half the area of seagrass for half of the year.



Figure 10-19. Brown Algae Growing with *Halophilia* Seagrass in Corio Bay

In Corio Bay, medium density seagrass is restricted to a depth of less than approximately 5 m with sparse growth extending to 5.9 m (see Section 5). Beyond that depth, there is very sparse growth of *Caulerpa sedoides* over much of the muddy seabed (see Figure 10-20) and patches of unattached filamentous algae. At an equivalent density of biomass, the area of seaweed in Corio Bay is estimated at 250 ha.

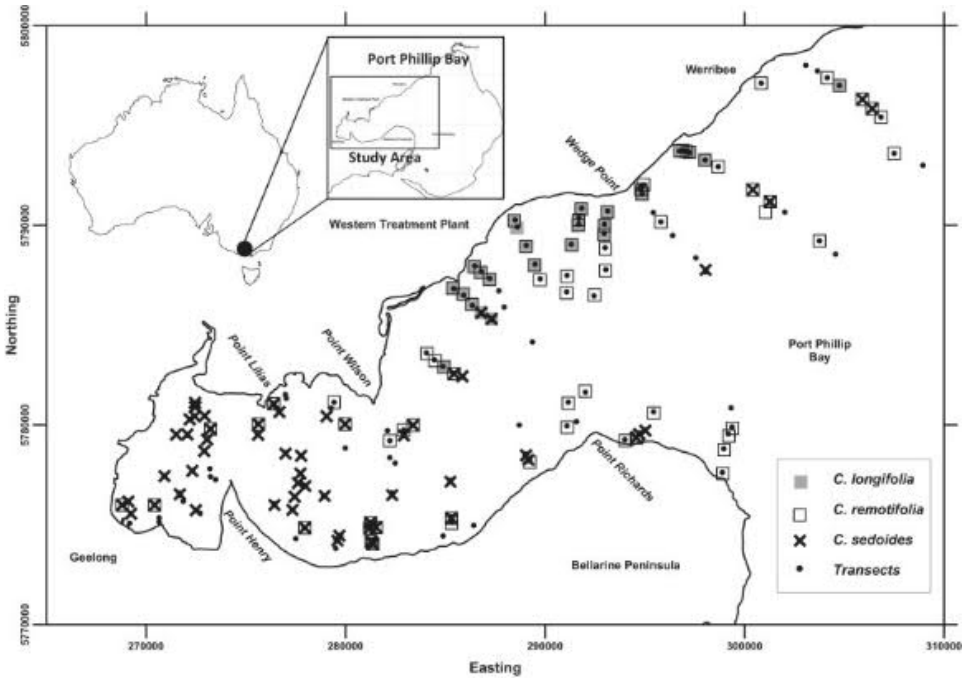


Figure 10-20. Distribution of *Caulerpa Sedoides* in Corio Bay

10.9 Assessment of Impacts of Construction

The impacts of construction on primary productivity assessed in this section are:

- Removal of 12 ha of seabed (over a dredging period of 8 weeks):
- Turbidity from dredging operations (during the 8 weeks of dredging):
- Excavation for seawater transfer pipe from Refinery Pier to the refinery seawater inlet over 2 weeks;
- Local change from soft seabed to hard structure habitat of the new pier; and
- Reduced light under the temporary loadout facility at Lascelles Wharf.

Areas Impacted

Figure 10-21 shows the 12 ha area of seabed that would be removed (the area by the pier with the red outline) and the 550 m long by 8 m wide trench (0.5 ha) that would be excavated in the seabed from the new pier to the refinery intake for the seawater transfer pipe (solid red line) to convey seawater from the FSRU to the refinery seawater inlet. Figure 10-21 also shows the predicted suspended solids (SS) plume on the seabed during the dredging program. The 20 mg/L median SS contour encloses an area of 40 ha (orange – including most of the 12 ha being dredged) and the 5 mg/L median SS contour encloses an area of 160 ha (pink). The extent of the plume is smaller at the water surface. Section 7 of this assessment described the hydrodynamic model used to predict the extent of the SS plumes.



Figure 10-21. Predicted Impact Area from Proposed Dredging in Corio Bay

Table 10-9 summarises the areas of marine habitat affected by construction activities.

Table 10-9. Areas of Habitat Impacted During Construction

Primary Producer	Corio Bay area in ha	Dredged, ha	High SS, ha	Low SS, ha
Phytoplankton	4,300	-	40	160
MPB	2,000	12	10	100
Seagrass	1,060	0.0065[a]	0	30
Seaweeds	250	7	10	25

Note a: 65 m^2 of seagrass under temporary loadout facility

The basis for the areas shown in the table is as follows.

- Total dredged seabed area of 12 ha. MPB would be removed with sediment during dredging but would recolonise the dredged area over the six months following completion of dredging. They are likely to be at low density at the dredged depth (13 m). The dredged area does not contain seagrass but has a sparse cover of unattached filamentous seaweeds which would be removed during dredging.
- Dredging would cause elevated suspended solids (SS) for approximately 8 weeks around the dredging area (see Section 7 for a detailed description of the modelling of suspended solids and turbidity). Phytoplankton would pass through the area with ambient currents. Dredging would have minor impact on phytoplankton, although there will be lower light transmission and hence lower plankton productivity is expected in areas with higher turbidity during dredging.
- MPB and seaweed productivity also would be reduced in the area of elevated turbidity over the 8 weeks of dredging, but is expected to recover outside the dredged area over the six months from completion of dredging.
- *Zostera* seagrass grows to a maximum depth of around 3.5 m in the northwest of Corio Bay and *Halophila* extends to around 5.5 m depth. The SS footprint is unlikely to reach into an area of Corio Bay occupied by *Zostera,* so it would be unaffected by dredging. The SS plume footprint northward of the pier may temporarily reach the outer boundaries of *Halophila* patches. The area impacted is a minor proportion of the *Halophila* beds in Corio Bay and the affected areas are expected to recover within 12 months of completion of dredging.

Table 10-10 shows the impacts on primary productivity from the construction activities, based on the areas listed in Table 10-8.

Table 10-10. Estimated Change in Primary Production - Construction

Primary Producer	Corio Bay tC/yr	Reduction in area, %	Reduction in productivity, tC/yr
Phytoplankton	4,400	0.6 %	26
MPB	1,200	0.8 %	10
Seagrass	4,000	0.4 %	17

Primary Producer	Corio Bay tC/yr	Reduction in area, %	Reduction in productivity, tC/yr
Seaweeds	1,000	1.5 %	15
Total production	**10,600**		**68**

It can be seen in Table 10-10 that the total primary productivity of Corio Bay could be reduced by 68 tC/yr in the year of construction, due to the increased turbidity over an 8-week period. This is equivalent to 0.6 % of the productivity for the year, and within the range of natural variability from month-to-month-and year-to-year.

The temporary loadout facility would be removed at the end of the construction period and the small area of seagrass under the temporary loadout facility (65 m^2) would recover when full light conditions return. No long-term change in productivity is expected from phytoplankton or seagrass outside the zone of short-term higher turbidity due to dredging.

10.10 Assessment of Impact of Operations

The construction impacts of the project outlined in the previous section occur over the construction period whereas the operational impacts occur over the life of the project.

Discharge Plumes from Refinery

For many years, the refinery at Geelong has been using seawater from Corio Bay as cooling water. Refinery processes generate heat, and this is transferred to the seawater in a series of heat exchangers in the refinery. The warmer seawater is returned to Corio Bay via four licensed discharge points (W1, W3, W4 and W5). The combined plume travels over the seagrass beds next to the shore in front of the refinery.

The proposed gas terminal involves an FSRU continuously moored at Refinery Pier. The FSRU would convert LNG back to a gaseous state (a process known as regasification) using seawater as the heat source. The cooled seawater from the FSRU regasification system (at 7 °C below ambient temperature) would be piped to the refinery seawater inlet for reuse within the refinery and would replace the seawater currently pumped in by the refinery. The seawater from the refinery would continue to be discharged back to Corio Bay via the four existing discharge points.

Implementation of the proposal would substantially reduce the temperature rise in the refinery discharges based on reuse of the colder water from the FSRU, and therefore, reduce the extent of the thermal plume along the shore (refer to Section 8 for detailed discussion on temperature effects). However, the existing chlorine concentration pattern in the plume from the refinery discharges would continue (refer to Section 9 for a detailed discussion on chlorine).

In summary:

- No change in the seawater intake or discharge rates (remain at 350 ML/d):
- Location of the seawater intake from Corio Bay would move from the refinery inlet channel to the FSRU;
- Temperature of the refinery discharges would decrease by 7 ^oC and be within 1 to 2 ^oC of ambient; and

- No change in the chlorine concentrations in the refinery discharges.

The current operation takes 350 ML/d of seawater into the refinery each day and from 60 to 80 per cent of the phytoplankton in the discharge are not viable. There is no change in total nitrogen or total phosphorus – the same amounts of nutrients are discharged as taken in. Field studies show that there is rapid growth of phytoplankton in the discharge plumes. In the 2 to 3 hours of travel from outlet W1 to the refinery inlet channel, the combined effects of plankton recovery, plankton division and mixing with adjacent seawater increases the phytoplankton counts in the discharge plume back to the counts at the inlet.

The project will not result in any change in the existing load or pattern of residual chlorine in the shoreline plume. The current discharges have been in place for 50 years. Surveys of the seagrass beds under the plumes have shown there is no detectable change in seagrass condition due to the plumes.

The chlorine concentration in the existing plumes, outside the licenced mixing zone, is a maximum of 5 µg/L which is within the stringent ANZG Guideline limit of 7.2 µg/L for chlorine (refer to Section 9 for detailed discussion on chlorine).

No impact of the existing shoreline plume on primary productivity can be identified. As discussed in Section 9, the chlorine concentration that causes toxic effects on algae is many times higher than the chlorine levels in the refinery plumes, and seagrass grows prolifically in close proximity to all the refinery discharges.

Direct Discharge from FSRU through Diffuser

In the event that the refinery is closed for maintenance or some other reason and the FSRU discharge was not able to be used in the refinery, the seawater flow from the FSRU would be discharged through a 300 m long diffuser installed under the new pier. In this situation, the discharge would be colder than ambient.

The discharge from the diffuser would be diluted by 20:1 as a result of the mixing caused by the high velocity discharge jets along the diffuser (refer to discussion of near-field modelling in Section 6). Figure 10-22 shows the predicted chlorine produced oxidants (CPO) concentration at the seabed for this scenario. The entire plume on the seabed would have a CPO concentration below 5.4 µg/L, well within the GV for chlorine of 7.2 µg/L in marine waters. The temperature difference in the plume on the seabed is less than 0.5 ^{o}C.



Figure 10-22. Chlorine Field with Peak Diffuser Discharge

Viva advised that the refinery is never fully shut down during maintenance activities so there would still be some level of seawater intake and discharge during these periods. Thus, peak discharge through the proposed diffuser is not anticipated to be a common situation. Even so, if it does occur, modelling shows that there would be very high dilution of the discharge so that the resulting plume has a chlorine concentration of less than 5 µg/L. The diluted plume would be approximately 3 m thick and at the bottom of the water column as it is a cold-water discharge and would be well away from the photic zone. The chlorine concentration and temperature change are within the ANZG limits.

Areas Impacted by Operation of the Project

Table 10-11 summarises the areas of marine habitat affected by operation of the proposed project.

Table 10-11. Areas of Habitat Impacted During Operations

Primary Producer	Corio Bay area in ha	Shoreline Plume, ha	Diffuser Plume, ha	New Habitat, ha
Phytoplankton	4,300	30	0	1.2[a]
MPB	2,000	0	0	12[b]
Seagrass	1,060	30	0	-
Seaweeds	250	15	0	-

Note a: Area of piles for new pier. Note b: Dredged seabed

The basis for the areas shown in the table is as follows.

- The shoreline plume from the refinery discharges has existed for 50 years so any productivity changes due to this plume have occurred many years ago. Surveys of the seagrass beds under the plumes have shown there is no detectable change in seagrass condition due to the plumes. There is a possibility that the warm plume increases the growing season for seagrass and hence increases productivity.
- There is no part of the diffuser plume where the plume temperature increase exceeds the 25 to 75 percentile natural temperature variation and/or the chlorine concentration exceeds the ANZG GV of 7.2 µg/L.
- MPB is present in waters from 5 to 12 m depth and is unaffected by the shoreline plume or the diffuser plume. However, the MPB in the dredged area of 12 ha will be at 13 m depth and have much lower productivity than at the current depth of 5 to 8 m.
- The new pier would have approximately 200 steel piles averaging 1 m in diameter and a typical length of 9 m from the water surface to the seabed. This would create a 0.7 ha zone of hard seabed, which will be colonized by filter feeding organisms. In addition, the top of the HDPE pipe from the FSRU to the refinery inlet will be at around seabed level, and 0.5 ha would be colonised by filter feeding organisms.

Table 10-12 shows the impacts on primary productivity from long-term operations, based on the areas listed in Table 10-9.

Table 10-12. Estimated Change in Primary Production in Corio Bay - Operations

Primary Producer	Corio Bay tC/yr	Reduction in area, %	Reduction in productivity, tC/yr	Comment
Phytoplankton	4,400	-	-[a]	Already occurred
MPB	1,200	0.6 %[b]	7[b]	Dredged area
Seagrass	4,000	-	-	Already occurred
Seaweeds	1,000	-	-	Already occurred
Total production	**10,600**		**7**	

Note a: Assume no extra predation from marine organisms on piles.
Note b. Due to 12 ha being dredged to create deep berth and swing basin

It can be seen in Table 10-10 that the estimated reduction in primary productivity of Corio Bay due to operations is 7 tC/yr due to the loss of MPB on the dredged seabed. This is equivalent to 0.07 % of the annual productivity, and within the range of natural variability from month-to-month-and year-to-year.

It can be anticipated that the growth of filter feeders on the new pier piles could result in a small increase in predation of phytoplankton. On an area basis, this would correspond to a 0.0003 % change, but this effect may be balanced by extra growth in local phytoplankton populations.

Surveys of the seagrass beds under the plumes do not detect any significant change in seagrass density or condition due to the existing refinery shoreline plumes which have been occurring for more than 50 years. As the proposed discharges from the project have the same residual chlorine concentrations and lower temperatures, it is very likely that there would be minimal change in seagrass or seaweed productivity under the shoreline plumes when the project is operational, as there is little change from existing conditions.

It is likely that the impacts would be lower than the effects of sea urchins grazing on the seagrass or runoff from the land, and certainly less than the year-to-year variation in the cover of seagrass.

Impact of New Pier Arm

The piles of the new pier arm would provide artificial habitat for growth of macroalgae and a range of invertebrates (including introduced species such as *Sabella spallanzani* and *Undaria pinnatifida*) as do existing piers and jetties in Corio Bay. The range of species to colonise the new pier are widely represented on artificial structures and reefs around Corio Bay and Port Phillip Bay. Piles at the refinery comprise timber wrapped in polyethylene or jacketed in concrete, steel and HDPE jacketed steel piles. The overhead decks provide a shaded environment, and the piles create a refuge for small fish, which are otherwise dispersed. The new refinery pier would be one of many artificial structures in Corio Bay. The presence of turbid plumes from dredging may temporarily change the structure of the communities on the existing piles, but biota will rapidly recover or recolonise the old and new structures.

EPA Environment Reference Standard Risk Ranking

Applying the risk ranking set out in the EPA *Environment Reference Standard,* it is considered that the weight of evidence from monitoring, surveys and published literature and reports shows that the existing shoreline plume can be ranked as “Low Risk” under the EPA matrix (see Table 10-13) except within the defined mixing zones.

Table 10-13. Risk Ranking Using EPA Environment Reference Standard

Line of Evidence	Risk Ranking		
	High	**Medium**	**Low**
Marine ecology	Significant and high effects on abundance and diversity	Significant and moderate effects on abundance and diversity	No significant effects on abundance and diversity
Other lines of evidence	Significantly different from control and high effect size	Significantly different from control and moderate effect size	Not significantly different from control
Weight of evidence assessment	High risk of significant adverse effects	Medium risk of significant adverse effects	Low risk of adverse effects – meets objectives for protection of environmental values

As noted above, there is no part of the diffuser plume where the plume temperature exceeds the 25 to 75 percentile natural temperature variation and/or the chlorine concentration exceeds the ANZG GV of 7.2 ug/L. Therefore, it is concluded that the diffuser plume will not cause any detectible reduction in primary productivity in Corio Bay. As noted above, surveys of the seagrass beds under the plumes do not detect any significant change in seagrass density or condition due to the existing refinery shoreline plumes which have been occurring for more than 60 years.

10.11 Conclusions

The total primary productivity of Corio Bay is estimated to be about 10,600 tC/yr, which is approximately 3.4 % of the primary production in Port Phillip Bay (both numbers being recognized as estimates of long-term averages). Phytoplankton and seagrass are the major contributors, each providing about 40 % of total productivity in Corio Bay. MPB and seaweeds are smaller contributors, each providing about 10 % of total primary productivity.

Simulations using a particle tracking model showed that the majority of fish larvae from the Ramsar site, including Limeburners Bay, are dispersed into Port Phillip Bay, and the potential entrainment into the refinery intake after 28 days is less than 0.5%, which is very small in comparison with natural predation and other losses. The number of plankton entrained by the FSRU would be the same as now entrained at the refinery intake. The only difference is that there would be a minor change in the areas from which the plankton come.

During construction of the proposal, the primary productivity of Corio Bay could be reduced by 68 tC/yr in the year of construction (0.6 %), due to the increased turbidity in the area of dredging over a period of 8 weeks.

During operations, the primary productivity of Corio Bay could be reduced by 7 tC/yr (0.07 %), due to the increased depth in the dredged seabed reducing MPB growth. There will not be any change from current conditions in the existing productivity of other areas.

The existing shoreline plume has been occurring for over 50 years, with no detectible impact on seagrass beds. Surveys of the seagrass beds under the plumes do not detect any significant change due to the plumes. The chlorine concentration in the existing plumes outside the licenced mixing zone at 5 µg/L is within the stringent ANZG Guideline Value of 7.2 µg/L for chlorine. The temperature rise in the existing plumes is modest outside the EPA licensed mixing zone of 2 ^{o}C is modest compared to the diurnal variation in temperatures experienced by biota in the littoral zone (10 ^{o}C) and shallow sublittoral zones (1.6 ^{o}C to 5 ^{o}C).

Implementation of the proposed project would substantially reduce the temperature rise in the existing refinery discharges as a result of reuse of the cold-water discharge from the FSRU, which would reduce the extent of the thermal plume along the shore.

Discharge through the diffuser is not anticipated to be a common situation and would only occur when the refinery is not operational due to maintenance or other reasons. Even so, when discharge of cooler seawater from the FSRU occurs, there would be very high dilution of the discharge and the resulting plume would have a chlorine concentration of less than 5 µg/L and a temperature rise of less than 0.5 ^{o}C. The diluted plume would be approximately 3 m thick and at the bottom of the water column, well away from the photic zone. The chlorine concentration and temperature

change are within the ANZG limits. It is concluded that the diffuser plume would not cause any detectible reduction in primary productivity in Corio Bay.

Based on the assessment of the EPA risk factors, and the weight of evidence from monitoring, surveys and published literature and reports, the existing refinery plume, and the possible future discharge plumes are classified as “Low Risk” under the EPA matrix.

11 Additional Marine Impact Assessment

This section is an extension of the marine impact assessment. In Section 4.5 there was a screening of risks to identify the more significant potential impacts associated with the project that required in-depth investigations to supplement existing information.

11.1 Summary of Screening Risk Assessment

The more significant marine issues identified in the initial risk screening were associated with: (1) dredging of 490,000 m^3 of sediment; (2) continuation of long-term discharge of chlorine to north Corio Bay; (3) the effects of long-term discharge of warmer or cooler seawater to Corio Bay; and (4) the effects of construction and operations activities on primary productivity. The results and findings of the studies, modelling and assessment of potential impacts associated with these issues are presented in earlier Sections of this report (Sections 7, 8, 9 and 10).

A number of other potential impacts to the marine environment were identified in the initial screening process (refer to Tables 11-1 and 11-2) and they are addressed in this report as follows:

1. Entrapment and entrainment in seawater intake system
2. Deepening of 12 ha of soft sediment habitat
3. Additional hard substrate pier habitat
4. Spills of fuel and chemicals
5. Extra light
6. Extra underwater noise
7. Vessel striking wildlife
8. Effects on penguins, dolphins and whales
9. Turbidity from tugs
10. Vessel grounding
11. Imported pests.

Table 11-1 and Table 11-2 reproduce the risk screening tables in Section 4 for construction (including dredging) and operations stages of the project. These tables include the potential impacts identified in Section 4 and show the section where each potential impact is discussed. The rows which are highlighted in a pale blue show the potential issues which are analysed in this section.

Table 11-1. Schedule of Potential Marine Environment Issues - Construction

Characteristics – Issue		***Impact pathway***	***Addressed***
Hydrodynamic conditions			
	Extra deep berth / swing basin zone	Dredging	Section 7
	Sediment accumulation	Dredging	Section 7
	Construction noise	Dredging and piling	Section 7
	Light from vessels	All marine construction	Section 11

Characteristics – Issue		*Impact pathway*	*Addressed*
Chemical conditions			
	Turbidity reduces light	Dredging	Section 7
	Turbidity causing smothering	Dredging	Section 7
	Release of contaminants	Dredging	Section 7
	Release of nutrients	Dredging	Section 7
	Reduction in dissolved oxygen	Dredging	Section 7
	Spills during construction	All marine construction	Section 11
Ecological processes			
	Removal of seabed habitat	Dredging	Section 7
	Addition of pier habitat	Pier construction	Section 11
	Introduced pests	All marine construction	Section 11
	Vessel strike	Dredging	Section 11
Ecological communities			
	Intertidal	Dredging	Section 7
	Subtidal – in photic zone	Dredging	Section 7
	Subtidal – below photic zone	Dredging	Section 7
	Pelagic and demersal fish	Dredging	Section 7
Matters of conservation significance			
	Seagrass and communities	Dredging	Section 12
	Shell/rubble with H banksii	Dredging	Section 12
	Migratory waders	Dredging	Section 12
	Saltmarsh	Dredging	Section 12
	Iconic species	Dredging	Section 12

Table 11-2. Schedule of Potential Marine Environment Issues – Operations

Characteristics – Issue		*Impact pathway*	*Addressed*
Hydrodynamic conditions			
	Entrainment current near FSRU	FSRU	Section 11
	Discharge current near diffuser	Diffuser	Section 8 and 9
	Operations noise	FSRU and LNG tanker	Section 11
	Light from vessels	FSRU and LNG tanker	Section 11
Chemical conditions			
	Chlorine discharge from refinery	FSRU and refinery	Section 9
	Chlorine discharge from FSRU	FSRU	Section 9
	Chlorine in ballast water	FSRU	Section 9
	Reduced temperature in plumes	FSRU and diffuser	Section 8
	Cold plume from diffuser	FSRU and refinery	Section 8
	Turbidity from tugs	LNG tanker movements	Section 11
	Spills during operations	FSRU and LNG tanker	Section 11

Characteristics – Issue		*Impact pathway*	*Addressed*
	Grounding of tanker	LNG tanker	Section 11
Ecological processes			
	Capture by entrapment	FSRU	Section 10
	Capture by entrainment	FSRU	Section 10
	Organics released in discharge	FSRU	Section 8 and 9
	Introduced pests	LNG tanker	Section 11
	Vessel strike	LNG tanker	Section 11
Ecological communities			
	Intertidal	Warm discharge plumes	Section 8
	Subtidal – in photic zone	Chlorine in plumes	Section 9
	Subtidal – below photic zone	Cool discharge plume	Section 8
	Pelagic and demersal fish	Intake and discharge	Section 11
Matters of conservation significance			
	Seagrass and communities	Warm discharge plumes	Section 8
	Shell/rubble with H banksii	Warm discharge plumes	Section 8
	Migratory waders	Warm discharge plumes	Section 8
	Saltmarsh	Warm discharge plumes	Section 8
	Iconic species	Intake and discharge	Section 10

11.2 Entrapment and Entrainment

The Geelong Refinery currently uses approximately 350,000 ML/d of seawater from Corio Bay for cooling. The existing inlet channel for the refinery extends for 120 m into Corio Bay (see Figure 11-1). The structure is 11 m wide at the mouth and narrows progressively to 7 m at the shore. At the mouth, the depth of water in the channel ranges from approximately 3 m at high tide to 2 m at low tide. Thus, the inflow current at the mouth averages 0.10 m/s through the tidal cycle and 0.15 m/s in the channel.

This corresponds to good practice to minimise capture of fish in the intake. Anecdotal reports from refinery operators are that fish are seldom captured on the intake screens, although seaweed and seagrass are an issue, particularly after storms. During fieldwork conducted for the project, small fish were observed swimming in all directions in the channel, easily out-swimming the net inward drift in the channel.

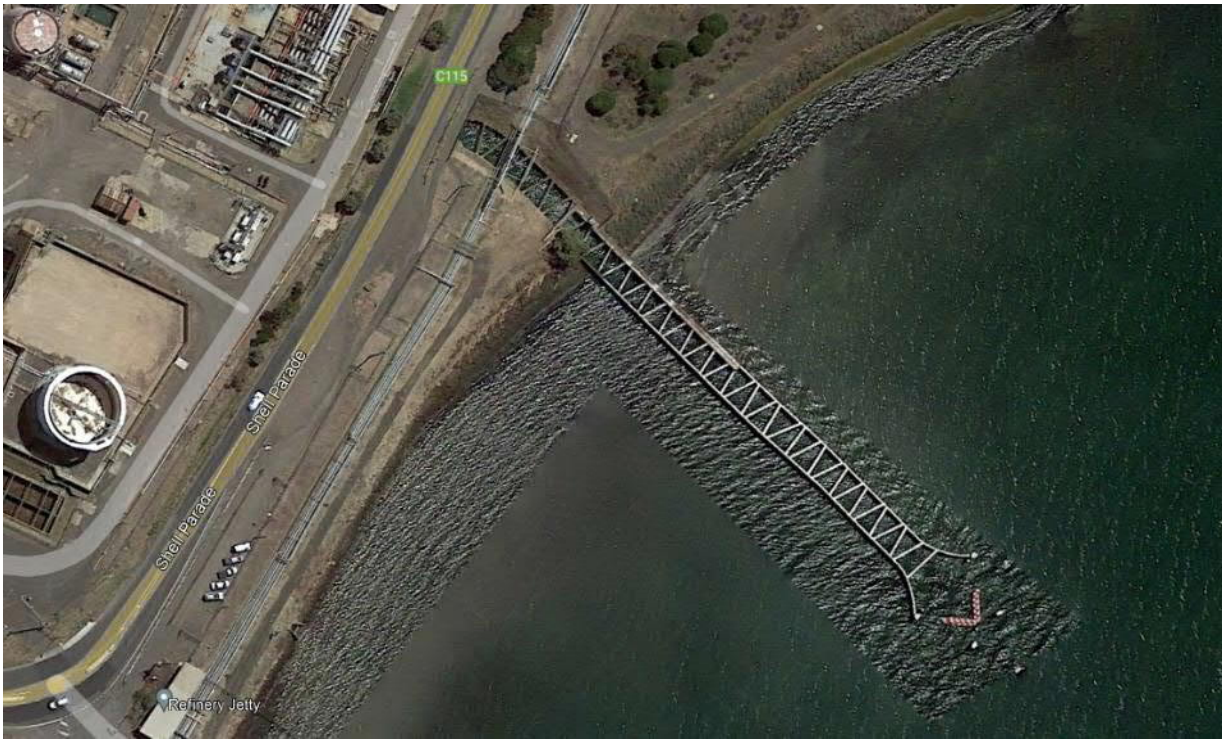


Figure 11-1. Existing Refinery Cooling Water Intake

This intake velocity complies with the requirements set out by the US EPA in 2004 for the design of cooling water intake structures. The US EPA guideline requires that the intake velocity should allow the escape of most species of fish at their different life stages. The data suggest that a 0.5 ft/s (0.15 m/s) velocity would protect 96 percent of the tested fish (see Figure 11-2) and is the value adopted by US EPA.

This mitigation measure was adopted for the Victorian Desalination Plant in Wonthaggi and is included as a proposed mitigation measure for the seawater intake on the FSRU on this project. The measure would minimise the capture of small and large fish or other free-swimming biota (e.g., birds, squid) moving in the shipping channel near the FSRU intake, and provide the same level of protection as the existing refinery intake.

The intake on the FSRU should also have a screen with apertures less than 100 mm. This would prevent large objects and seaweed from being carried into the seawater cooling system.

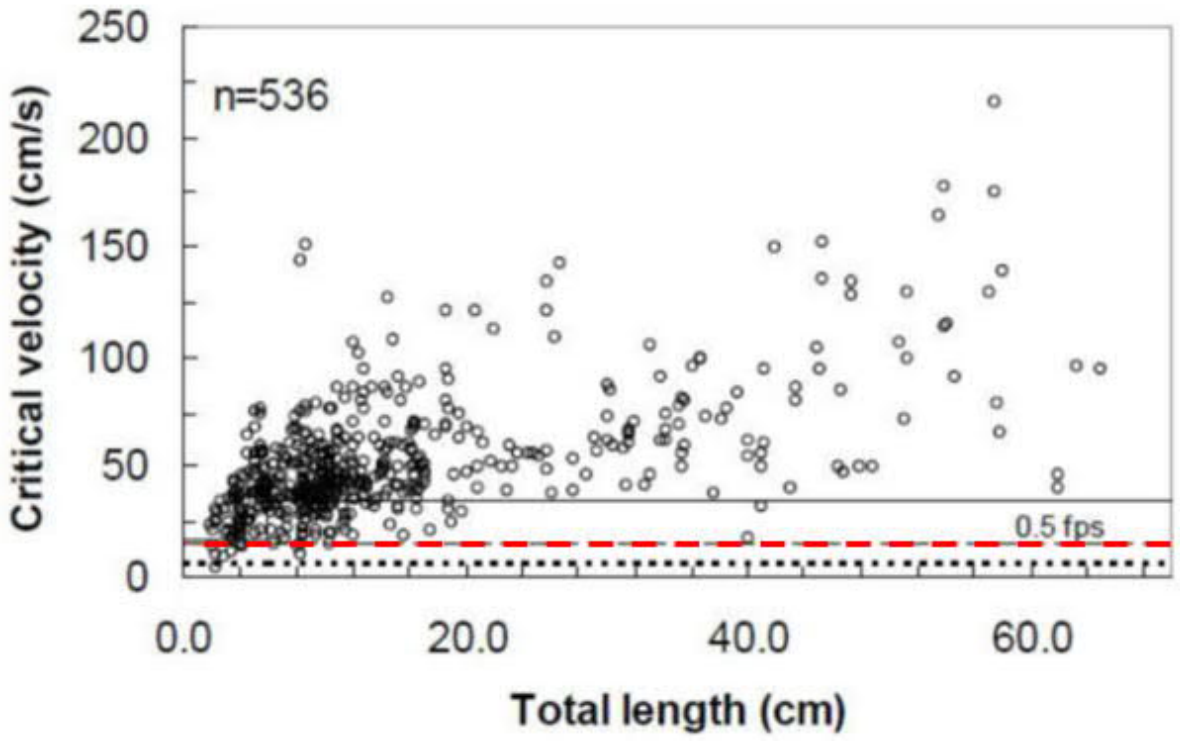


Figure 11-2. Relationship between Fish Size and Swimming Velocity

The potential for entrainment of plankton is examined in detail in Section 10. To assess potential impacts, the movement of paarticles in Corio Bay was modelled as part of the EES marine investigations. Particles represent plankton or fish larvae. For particles released at the Ramsar site, it is shown that no (zero percent) are entrained in the refinery intake, or would be entrained in the FSRU intake in the 7 days after release. This confirms that the existing seawater intake has (or the FSRU intake would have) negligible effect on plankton or fish populations in Corio Bay.

At 14 days after release, only 0.01 % of particles would be entrained by the refinery inlet and 0.06 % would be entrained by the FSRU inlet. Zooplankton have a life cycle of around 14 days and the results show that entrainment rates are negligible (under 0.1 %) when compared with natural factors (> 99 % loss).

At 28 days after release, only 0.12 % of particles would be entrained by the refinery inlet and 0.26 % would be entrained by the FSRU inlet. The majority of fish larvae from the Ramsar site, including from Limeburners Bay, are dispersed into Port Phillip Bay and the potential entrainment after 28 days is very small in comparison with natural predation and other losses. In conclusion, the current seawater intake has negligible effect on phytoplankton, zooplankton and fish larvae populations in Corio Bay and the proposed FSRU intake also would have negligible impact.

The fate of phytoplankton drawn into the refinery intake was investigated by direct sampling trials from the intake and outlet channels on three occasions. On average, the three tests showed that approximately half the phytoplankton survived in a viable condition (principally the more robust diatoms). Phytoplankton sampling at the inlet showed that the phytoplankton population had recovered to the original abundance. This finding demonstrates that the non-viable plankton in the discharge are quickly consumed and the equilibrium population re-establishes. This is understandable, as the cooling water process does not add or subtract any nutrients or organic carbon – these materials are available in the discharge for recycling and regrowth.

11.3 Removal of Soft Sediment Habitat

As described in detail in Section 10, 490,000 m^3 of soft sediment will be dredged over an area of 12 ha to create a new berth for the FSRU and a vessel turning basin. The seabed depth will increase from the existing 4 to 8 m to a greater depth range of 12.7 m to 13.1 m (below LAT). The likely impacts would be:

- With the increased depth, the MPB (microphotobenthos) that develops on the seabed in the dredged area will receive less light. Due to the reduction in light and the periodic disturbance by ship and tug movements, the productivity assessment (see Section 10) assumes there is complete loss of primary production from MPB over 12 ha (from the estimated 2,000 ha of MPB cover on muddy sediments in Corio Bay).
- The existing sediments at 4 to 8 m depth are mostly soft silt or clay, whereas the sediments at the base of the dredged basin are likely to be hard clay, with a shallow layer of fine silt. In response to the change in sediment characteristics, there will be a shift in the infauna community (as discussed in Section 10). The change would occur for 12 ha (from the approximately 3,000 ha) of muddy seabed in Corio Bay.
- It can be seen in Section 10 that the estimated reduction in primary productivity of Corio Bay due to operations is 7 tC/yr) due to the loss of MBP in the dredged seabed. This is equivalent to 0.07 % of the annual productivity, and within the range of natural variability from month-to-month-and year-to-year.

The impact of removal of soft seabed habitat quantified above is considered to be minor to negligible in the context of the existing ecological systems of Corio Bay.

11.4 Addition of Pier Habitat

The proposal involves the construction of a permanent extension to Refinery Pier as well as the construction of a temporary wharf on the shoreline to the south-west which will be used for crew and barge loading to construct the new Refinery Pier arm.

Both new piers involve pile driving. The pier arm would be supported by sets of steel piles at approximately 50 m spacings while the temporary wharf will be supported by around 6 piles and includes a floating section for crew transfer. Pile driving will create noise impacts which is addressed in a separate report.

Pier piles support a wide variety of marine growth and provide habitat for different species from those found in soft sediment. It is expected that the additional pier structures would attract the same assemblage of marine growth as the current piers and seawalls in Corio Bay.

Based on observations of CEE-diver-biologists under existing piers and seawalls in Corio Bay (CEE 2018) and Port Phillip Bay (CEE 2019, 2021), the new pier arm will be colonised by a range of encrusting invertebrates and seaweeds, and provide habitat for small fish including gobies, blennies, triplefins, spiny globe fish and pipefish.

A range of introduced pest species have been common in Corio Bay for decades. Species including the fan worm Sabella *spallanzani* and Japanese kelp *Undaria pinnatifida* would also be likely to colonise the pier from established populations throughout Corio Bay.

The additional hard substrate habitat provided by the piles is approximately 1.2 ha, which is small in the context of existing hard surfaces in Corio Bay. The net effect is, overall, considered neither positive nor negative.

The seabed characteristics around the temporary wharf is varied over the different depths. At the edge of the rocky man0made shoreline the depth drops to around 2 m of a few meters laterally and then falls away quickly into the previously dredged channel.

CEE conducted tower camera analysis of the area which determined that seagrass was the dominate seabed habitat up to around depths of approximately 8m (LAT). From 0 m to around 2 m the seabed is dominated by Zostera while from 4 m to 8 m the seabed is dominated by Halophila. There is some crossover where both Zostera and Halophila were present. Once the seagrass ends at around 8 m depth the seabed consists of mud which is covered in a light layer of MPB. Figure 11-3 provides a modelled image of seabed habitats around the are of the temporary wharf.

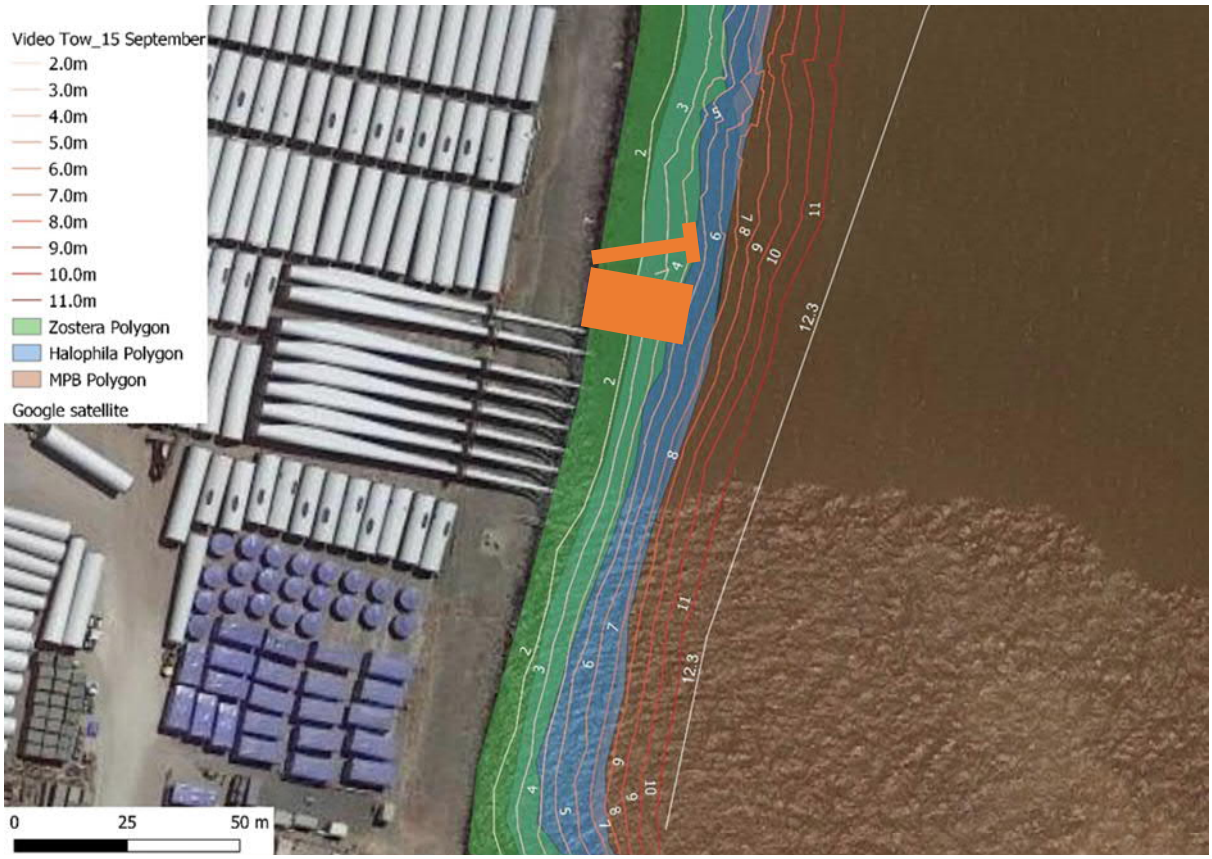


Figure 11-3. Seabed Characteristics by the Temporary Wharf

The extension to refinery pier will be positioned to the north of the existing refinery Pier and will be located in an area which has been marked for dredging down to a depth of 12.3 m (LAT) t match the rest of the channel. This area is covered by Corio Bay muds which currently contains a layer of MPB. The MPB will be removed via dredging but will likely return quickly. Figure 11-4 provides a nap of the location of the pier extension over Corio Bay biotopes from CoastKit 2021.

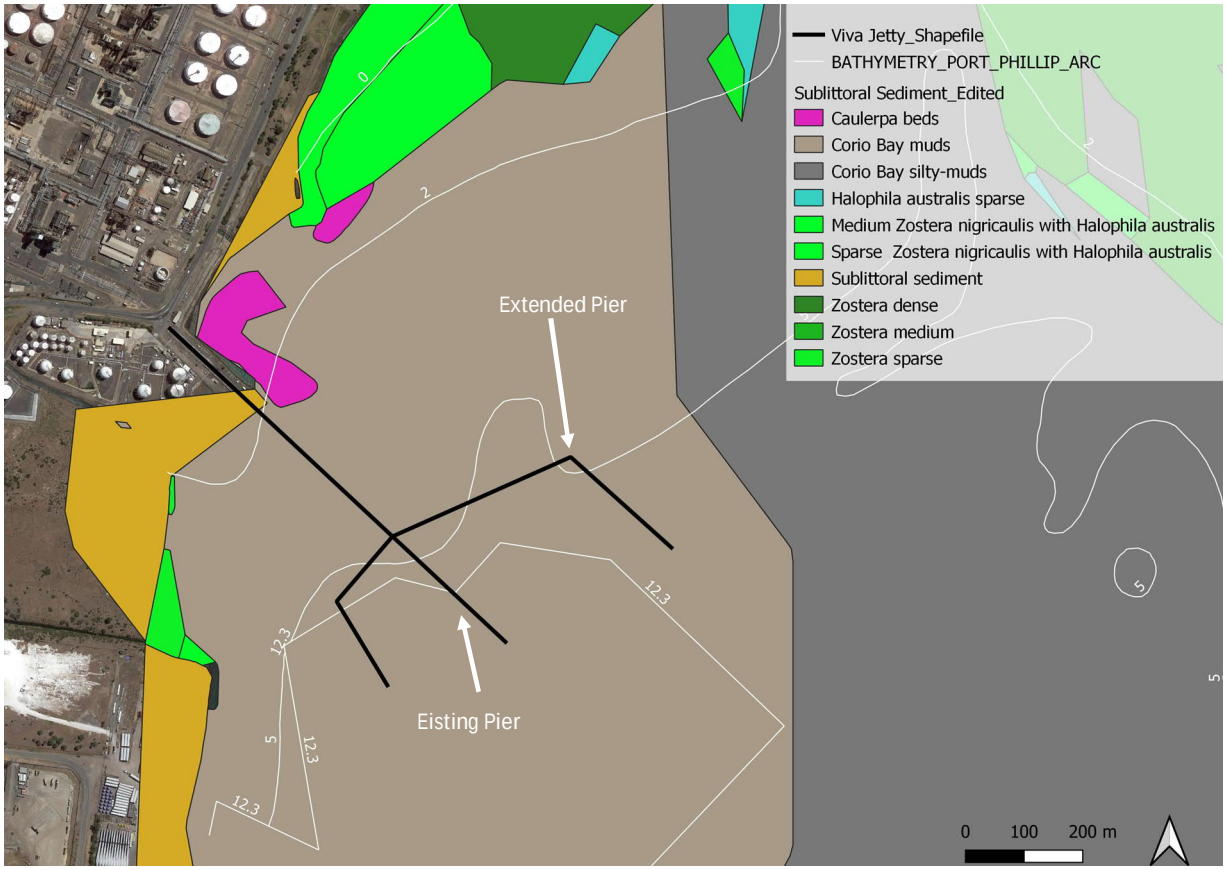


Figure 11-4. Seabed Characteristics around the Pier Extension

11.5 Spills of Fuel and Chemicals

The Port of Geelong has over 600 ships arriving and departing each year from 2 bulk berths south of Corio Quay, 5 berths at the Corio Quay precinct, 3 berths at Lascelles Wharf and 4 existing berths at Refinery Pier. Many more small boats used for recreational activities are launched from numerous boat ramps around Corio Bay or moored at recreational facilities at Limeburners Cove, Royal Geelong Yacht Club and public moorings at Western Beach.

There are regular deliveries of crude oil for processing in the refinery and tankers taking on various types of fuel for delivery elsewhere in Australia and overseas. Bulk and break-bulk freight carriers deliver or load a range of freight at the other wharves and piers in north-western Corio Bay. The Victoria-Tasmania ferry service is planning to move its Victorian terminal to Corio Quay, Geelong.

The FSRU holds only a few chemicals on board, including 200 L of boiler water additive (eg, Ameroyal), 350 L of cleaning liquid (eg, Envirocare 370), 350 L of rust inhibitor (eg, Liquide) and 1,200 L of paints and thinners).

There is at present, and has been for decades, a potential for spills of oil, fuel and chemicals in north Corio Bay. Viva Energy advised that there had not been a significant spill at the port in at least the last 30 years, and none were recorded before that. The consequences of an oil or other spill are well understood and can be mitigated by the spill management plan in place. LNG carriers are more modern vessels, fuelled by LNG and carry less oil and fuel than existing ships (and carry much less oil than existing tankers) using Corio Bay. Hence, the environmental

consequences of a spill in Corio Bay from an LNG carrier are less than from other vessels (such as oil tankers).

However, there would be a marginal increase in the *likelihood* of a spill due to the increased number of shipping movements. The increase of 5 per cent in the number of shipping movements from 600 to approximately 640 is expected to increase the likelihood of a spill by around 3 per cent after allowing for the efficiencies of shipping management and safety measures incorporated into new LNG carriers.

As another comparison, Port Phillip Bay has around 4,000 large vessels using ports. Thus, the increase in likelihood of a spill in Port Phillip Bay from the 45 LNG carriers is approximately 1 per cent.

Despite the minor increase in shipping movements, the overall likelihood of a spill would be low. LNG carriers have multiple layers of effective protection to prevent spills and losses of containment. The safety measures that provide the layers of protection include:

- Experienced pilot on board the vessel;
- Use of four tug vessels during transit in the shipping channel;
- Double hull design and construction;
- Storage tanks set back from the inner hull by insulating material;
- Sophisticated ship controls ensuring effective manoeuvrability;
- Port operations managing vessels within the shipping channel.

The principal actions to limit and mitigate the effects of spills of fuel and chemicals are:

- Rigorous procedures to minimize the likelihood of a spill:
- Planned and effective spill response plan; and
- Availability of boats, trained personnel and equipment to effectively deploy booms, skimmers, temporary storage systems and dispersants as required.

Viva Energy Spill Management Plan

As an established refinery that has been receiving and handling large quantities of oils and diesel for many years, Viva Energy has developed and tested effective methods for preventing, controlling and dealing with small and large spills in Corio Bay.

Preventing Oil Spills from Refinery Pier

Viva Energy has well-established protocols to minimize the likelihood of a spill. These involve:

1. Checking that all drains and sumps are sealed and do not leak into the bay.
2. Maintaining all loading arms, loading and discharge hoses in good order.
3. Checking that all surface water drainage valves on Berth 3 and 4 are closed whilst a ship is loading or discharging.
4. Pumping out pier sumps and collection vessels regularly to prevent overflowing.

5. Before any cargo movement between ship and shore commences, the ship must have all its scuppers plugged and drip trays in position. Sea and overboard discharge valves are to be closed and lashed.
6. Checking that all manifolds have a fitted blind flange; all back valves are closed, and dry break couplers are clean and functional.
7. On commencement of loading or discharging, ensuring that manifold pressure does not exceed defined limits (10 bar for hoses, 12 bar for loading arms) to minimize the likelihood of a hose rupture or leak.
8. Stop pumping immediately if the pressure exceeds the above operating pressure and have the ship and/or shoreline pumps and lines checked.
9. If the pressure on any hose exceeds 12 bar the hose must be taken out of service and tested.
10. Only operating transfers when all these requirements are satisfied.

Viva Energy Spill Response Plan

Viva Energy has developed a response plan for spills that occur in Corio Bay. The plan involves a tiered system to categorise different spill levels with requiring a different response. The tiers are listed in Table 11-3 from the Viva Energy *Oil Spill Response Plan*.

Table 11-3. Viva Energy Oil Spill Response Plan – Tiers of Response

International Description	TIER 1			TIER 2		TIER 3
OSCP Description - Category - Lower Size Limit - Upper Size Limit	TIER 1A Very Minor - 100 litres	TIER 1B Minor > 100 litres 1 tonne	TIER 1C Small > 1 tonne 10 tonnes	TIER 2A Medium > 10 tonnes 100 tonnes	TIER 2B Large > 100 tonnes 1000 tonnes	TIER 3 Major > 1000 tonnes -
Activate OSCP?	Yes	Yes	Yes	Yes	Yes	Yes
Shell Response Team	Shell Team A	Shell Team B	Shell Team C	Shell Team C	Shell Team C	Shell Team C
Combat Agency	Shell	Shell	Shell	VCA	VCA	VCA
Statutory Agency	Toll (VCA)	Toll (VCA)	Toll (VCA)	Victorian Oil Spill Controller	Victorian Oil Spill Controller	Victorian Oil Spill Controller
Support Coordination	-	PPMPC	PPMPC	PPMPC/ VMPC	VMPC/ NATPLAN	VMPC/ NATPLAN/ DISPLAN
Required Resources: Regional Resources - Shell Geelong - AMOSC - Toll - Mobil State Resources National Resources International Res.	✓	✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓

Toll GeelongPort (Toll); Victorian Channel Authority (VCA); Port Philip Marine Pollution Committee (PPMPC); Victorian Marine Pollution Committee (VMPC).

Response Plan for Minor Spill:

The VCA Incident Controller is responsible for managing the *Regional Oil Spill Response Plan* in Corio Bay.

Minor spills are classified by the VCA as those which can be handled by Viva Energy or the contractor (currently Toll) either locally (up to 1 t) or by the resources of the Corio Bay Region (up to 10 t). In response to a minor spill, the VCA Incident Controller will monitor the spill response and assist the VCA Operations Officer and liaise with relevant agencies as needed. The VCA Operations Officer is responsible for the operations to respond to an oil pollution incident.

Response Plan for Major Spill

In response to a major spill, the VCA Incident Controller will:

- Establish the Operations Centre at Geelong
- Mobilise a Planning Officer, Operations Officer, Logistic Officer
- Direct the activities of the VCA, Toll and Viva Energy response team engaged in the containment and clean-up operations.
- Direct the Toll response team in the deployment of booms, skimmers and temporary floating storage systems from the Toll stockpile of equipment.
- Arrange for dispersant application if required.
- Liaise with government departments and the oil industry as required.
- Activate OSSM and Coastal Resource Atlas.
- Invoke the State Plan if required.
- Coordinate transfer of any recovered oil to shore facilities.

Example 1 – Consequences of Spill from Hydraulic Hoses

Dredging and the construction of the new pier would involve the use of a fleet of offshore equipment using a range of hydraulic devices. The most common spills in construction involve breaks in hydraulic hoses. This can be mitigated by regular checks and preventative maintenance to old or worn hoses remaining in use.

Breaks in hydraulic hoses typically release a relatively small volume of hydraulic fluid. According to the Material Safety Data Sheet (MSDS) for hydraulic fluid, it has a 96-hour lethal concentration (LC50) of more than 1000 mg/l (*Oncorhynchus mykiss*) and a 48-hour median effect concentration (EC50) of more than 1000 mg/l (*Daphnia magna*)[1]. If a spill of hydraulic fluid did occur, the hydraulic fluid would spread and be diluted in the currents underneath the pier. Within a few minutes, the fluid would mix with over 10 m^3 of seawater and the mixture would be below the LC50 and EC50 values listed above. There could be a localised adverse effect of the spill but no long-term effect.

The FSRU is expected to be carrying approximately 500 m^3 of diesel and around 200 m^3 of other lubrication oils. The LNG carriers will have around 2,000 m^3 of diesel and 200 m^3 of lubrication oils, as well as boiler water additives, cleaning liquids, rust inhibitor, paints and thinners.

Example 2 – Consequences of Spill of Diesel from FSRU or LNG carrier

The FSRU operates on LNG but carries up to 800 t of diesel as a backup fuel and as a pilot fuel for the generators running on gas and maintenance activities. The FSRU is permanently moored, and so the only risk of a spill is due to a collision with an LNG carrier or another vessel visiting Refinery Pier (or a nearby jetty).

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[1] The median effect concentration (EC50) is the concentration of a substance in an environmental medium expected to produce a certain effect in 50 per cent of test organisms in a given population under a defined set of conditions. The Lethal Concentration 50 (LC50) is the concentration of a substance in water causing a death (50% of the tested population) to aquatic life. The EC50 and the LC50 are often used in ecotoxicology as an indicator of the toxicity of a compound to the environment.

The carriers have six diesel tanks at different locations in the vessel, spaced over about 100 m length of the vessel, with volumes when full of approximately 250 tonnes to 1,000 tonnes. Normally the tanks are less than half full.

The FSRU and LNG vessels are double-hull vessels, the fuel storage tanks are separated from the hull by either ballast tanks or cofferdams (void spaces). There is no point on the vessel where tanks (or the LNG cargo) are in direct contact with the outer hull of the vessel. For a significant loss of diesel to occur, the outer and inner hull of the vessel would have to be breached at the point where a storage tank is located on the vessel. In the unlikely event of this happening, there are also multiple bunker tanks meaning that fuel can be transferred to intact tanks and it would be improbable that a large complement of diesel fuel would be lost. Overall, the potential risk for a large spill of diesel is considered to be very unlikely.

Taking account of the spread of storage tanks, it was assumed that only one tank would be ruptured and the maximum credible spill is 30 tonnes of diesel over a period of three hours from a breached diesel storage tank. A leak at a smaller rate is much more likely.

Given the weak tidal currents in Corio Bay, the typical size of the slick would be about 500 m long and 300 m wide within 2 hours. By this time, spill management operations should be occurring to contain and collect the spill.

Diesel spreads rapidly over the surface. Some evaporates, but most mixes into the surface water layer. The concentration in the slick would exceed 1000 mg/L. According to the Material Safety Data Sheet (MSDS) for diesel fluid, it has a 72-hour effect concentration (EC50) of 22 mg/L for algae, 65 mg/L for fish and 210 mg/L for daphnia. While EC50 concentrations are higher for short-term events, major short-term effects would occur to biota within the area of the plume

The extent of adverse impacts would depend on the rate of leakage, the time before leakage was stopped, the response time to deploy a boom and skimmer and the weather. In favourable weather, the spill could be contained in the port area.

In unfavourable weather, the spill would travel, most likely to the north in the prevailing currents. Some damage to the seagrass and seaweed on the refinery shore could occur, depending on whether the spill occurred at high or low tide. Within a kilometre, and before the boundary of the Ramsar site, the residual concentration would be down to 50 mg/L, without including the reduction due to spill skimming, which would not cause short term impacts at a distance.

Minor short-term effects are expected within a distance of 1 km. Beyond this distance, there should be no visible slick, and little effect on birds or intertidal biota. The effects are likely to persist for up to 1 km from the spill for weeks to months. Longer term, there should be full recovery.

Thus, the estimated effects of the maximum credible spill would occur within 1 km of the site of the FSRU. There have not been large spills in Corio Bay.

The Port of Geelong regularly handles vessels carrying heavy fuel oil. Spills of heavy oil also spread over the water surface, evaporate slowly and tend to form a sticky surface emulsion of oil, entrained water and floatable objects. Thus, compared to a spill of diesel, heavy fuel oil spills could cause more adverse effects on intertidal mudflats and seagrass. The area impacted would depend on the time and duration of the spill in relation to tides and wind patterns. Whatever the tidal and wind conditions,

a major spill would cause substantial adverse impacts over a shoreline distance of a kilometre. Hence, a heavy fuel oil spill would have greatest consequence on the marine ecosystem. It is important to note that LNG carriers do not carry heavy fuel oil and this type of spill would not be an issue associated with the project.

As described above, a spill of diesel from an LNG carrier due to collision would have more severe consequences than the hydraulic hose failure example cited earlier in this section. However, the likelihood of a spill from a collision is significantly lower, as the FSRU and LNG vessels are double-hull vessels, the fuel storage tanks are separated from the hull by either ballast tanks or cofferdams (void spaces) and there is no point on the vessel where diesel tanks (or the LNG cargo) are in direct contact with the outer hull of the vessel. There is also discussion in the Safety section about how LNG carrier movements will be managed to avoid other ships in the channel.

Additionally, port operations control the movement of vessels within the shipping channel. Ships are only able to move with the Harbour Master's authorisation, helping to minimise the likelihood of any potential collision.

Vessel grounding is addressed in a later section.

11.6 Additional Light from the Project

This section discusses the potential for light spill effects on marine biota and a result of additional of light sources on the FSRU and the new pier. Technical Report D: *Terrestrial ecology impact* assessment by AECOM examines the effects of extra light on migratory birds and shorebirds in the Ramsar wetland.



Figure 11-5. Bright Lights on Refinery and Geelong Port Area

The existing Viva Energy refinery and the urban Geelong shoreline are substantial existing sources of light (see Figure 11-5). Oil refineries require extensive lighting as a safety measure and to ensure that tall structures and stacks are visible to aircraft. To reduce circadian disturbances for workers, lighting guidelines for refineries include restrictions on blue light at night. All lighting must be explosion proof to meet safety standards.

The recently released Commonwealth Draft National Light Pollution Guidelines for Wildlife (DEE, 2019) provide discussion mostly specific to marine turtles, seabirds and migratory shorebirds. Lighting is known to affect turtle breeding behaviour. Lighting for an extended period influences marine fauna including fish and other pelagic species (e.g., zooplankton, squid, and larval fish) that are attracted to light. This can in turn, encourage predatory fish behaviour and may assist penguins, which are visual predators, to catch fish at night.

As well as the Viva Energy refinery, there is existing lighting along the whole of the western shore and half the southern shore of Corio Bay from port facilities, urban Geelong, shoreline roads, buildings and recreational facilities, cars on roads, offshore piers and marinas. An example of the existing pier lighting is shown in Figure 11-6.



Figure 11-6. Light Spill at Refinery Pier

Minimum lighting is required on the FSRU and LNG carriers for safety purposes and for navigation. All vessels in Australian waters must comply with the navigation safety requirements prescribed within the *Navigation Act 2012* and the associated Marine Orders concerning workplace safety equipment (e.g., lighting) and navigation.

There are hundreds of elevated lights on the foreshore around Corio Bay. The additional light spill contributed by the FSRU and LNG carrier is shown in the light spill calculation report (Appendix A of Technical Report J: *Landscape and visual impact assessment*) as a distance of less than 140 m from the vessel. Other vessels using Refinery Pier or other berths in the Port of Geelong may illuminate a similar area when in port.

Best practice will be used in the design of the lights on the new pier, including AS 4282: 2019 *Control of the Obtrusive Effects of Outdoor Lighting* and the *National Light Pollution Guidelines for Wildlife* (Jan 2020). The guidelines apply to new projects where wildlife could be affected by artificial light to ensure that wildlife is not disrupted or displaced from habitat, and able to forage and disperse.

Given the existing levels of light, the minor increase in artificial light and application of best practice to the design of new lighting, it is considered that the adverse effects of extra lighting on marine biota would be negligible*.*

11.7 Underwater Noise

A separate assessment of the potential impacts of underwater noise generated by FSRU operations on marine fauna receptors has been carried out by Jasco and is appended to this report at Appendix A3: Underwater noise impact assessment.

Background underwater noise in north Corio Bay was monitored for 37 days. The largest source of underwater noise is vessel noise. There was a faint dusk and dawn invertebrate chorus, with the primary contributor being snapping shrimp, and a significant storm event was recorded. The ambient noise level in the project area is high and adding other noise sources (from project-related activities) will increase levels only in the vicinity of these activities.

The impact ranges assessed in the JASCO report indicate the onset of behavioural responses of little or no ecological relevance unless animals are very close to construction and only become more severe if animals are close to the sound source(s). Acoustic masking is assumed to occur at the same ranges as (ecologically relevant) behavioural responses.

The mitigation measures recommended by JASCO will reduce the noise emitted by the construction activities and in future operations and reduce the extent and range of noise-induced impacts.

The mitigation measures will reduce or even eliminate the risk of behavioural responses except for the immediate vicinity of the activities. The primary mitigation method involves selecting equipment for pile driving that produces the least noise necessary to complete the work. Secondary noise mitigation methods can include reducing sound at the source. Due to the existing acoustic condition, it is very likely that the animals are already accustomed (habituated) to living in a noisy environment and those individuals more sensitive to noise have long left the area.

The findings of this impact assessment conducted by Jasco concluded that the proposed construction of the new pier extension and operations of the FSRU at the new berth would contribute to the soundscape in the Port of Geelong but not change the ecological character or reduce the biodiversity of this environment.

None of the species listed as endangered or vulnerable under the EPBC Act (Southern right whales, Humpback whales and Australian sea lions) nor species listed under the FFG Act (such as sharks) or little penguins would be impacted by the planned operations of the project.

Mitigation measures are proposed for pier construction to reduce potential noise impacts will be included in the Construction EMP.

11.8 Vessels Striking Wildlife

Vessel strike refers to an event in which a vessel in motion connects with marine fauna causing injury or death. Deaths usually arise from strikes with vessels such as cargo ships, tankers or large yachts. The main victims of vessel strike are usually whales, and in the waters of Victoria, the main species at risk are humpback whales and Southern Right Whales.

According to Peel et al (2018), there were 87 whale strikes (all species of whales) by ships reported in Australian waters between 1997 and 2017. Figure 11-7 shows that almost half (39 strikes) involved Humpback whales and 10 involved Southern Right whales (Peel, 2018).

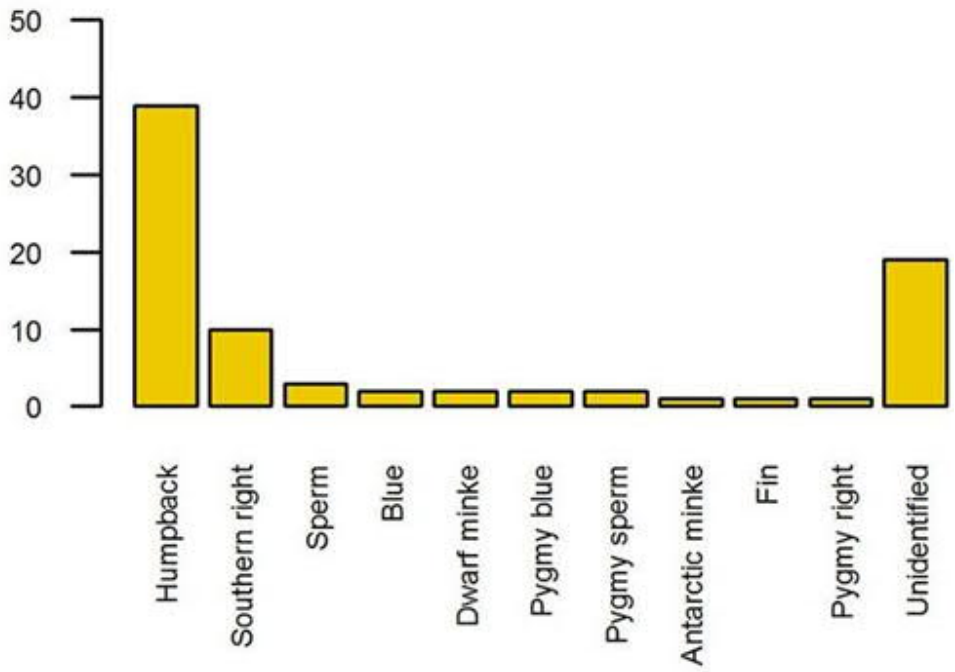


Figure 11-7. Number of Whale Strikes in Australian Waters 1997 to 2015

Around 400 to 600 whales are observed along the Victorian coast between Barwon Heads and Cape Patterson each year, mostly Humpback whales, but also about ten Southern Right Whales and occasional killer whales. Approximately twenty whales are seen each year just inside the entrance to Port Phillip Bay and an average of five whales per year venture into Port Phillip Bay beyond Dromana.

Given the shallow bathymetry of Corio Bay, it is not visited by larger whales such as Killer whales, Blue whales or Southern Right whales. Corio Bay is not known as an important area for large marine mammals as it is not an established breeding or feeding ground for whales.

Figure 11-8 shows the vessel strike rate for each state between 1997 and 2015 (DoEE, 2017). According to the data, Victoria has the lowest rate of reported vessel strikes with 3 strikes in 18 years while Queensland is the highest at around 35 strikes in 18 years.

This corresponds to 1 whale strike in Victorian waters every 6 years. Many whale strikes are by small ships - private boats, fishing vessels and even whale spotting vessels (DoEE, 2017, Peel et al, 2016 and Jensen et al, 2004).



Figure 11-8. Number of Whale Strikes in State Waters 1997 to 2015

Jensen et al, (2004) indicated that tankers make up for about 10 per cent of whale strikes. Thus, commercial tankers could be considered to be involved in only 1 whale strike in Victorian waters every 300 years.

This corresponds to 1 whale strike in Victorian waters every 6 years. Most whale strikes are by other ships - private boats, fishing vessels and even whale spotting vessels (DoEE, 2017, Peel et al, 2016 and Jensen et al, 2004). Jensen et al, (2004) indicated that tankers make up for about 10 per cent of whale strikes. In Victorian waters, commercial tankers could be involved in only 1 whale strike every 300 years.

Humpback whales are along the eastern and western coasts of Australia (QLD, NSW and WA) and most of the strikes for Humpback whales occur to the north of Victoria. Southern Right whales are along the southern coast (WA, SA and VIC) most of the strikes for Southern Right whales occur on the south coast of Australia.

Figure 11-9 shows the vessel strike rate for each state between 1997 and 2015 (DoEE, 2017). According to the data, Victoria has the lowest rate of reported vessel strikes with 3 strikes in 18 years while Queensland is the highest at around 35 strikes in 18 years.



Figure 11-9. Number of Whale Strikes in State Waters 1997 to 2015

Over the 20-year period, there is one whale strike per 100,000 commercial vessels. Assuming an average of 20 LNG carriers per year visit Corio Bay over a period of 25 years, there will be an extra 500 vessels. If all vessels have an equal potential for causing a whale strike, the likely potential impact is an additional 500 / 100,000 = 0.005 whale strikes – i.e. a probability of 1 in 200 over the 25-year period (any species of whale). These whale strikes are very unlikely to occur in Corio Bay but could occur in Bass Strait or anywhere along the coast of Australia.

The total number of humpback whales in Australian waters has increased considerably from around 1,000 individuals in 1962 to around 40,000 at present. Therefore, a loss of a single humpback whale, although very unfortunate, would not affect the species population dynamics.

There is a small population of Southern Right whales – perhaps only 300 individuals – that is increasing slowly. The waters east of Warrnambool (Logans Beach) are a nursery area for Southern Right whales. It is suggested that it may be the only nursery area in Australian waters. Other aggregation areas are from Portland to Port Campbell. These sites are all distant from Corio Bay and the project would have no impact on this species other than potential for a LNG carrier strike in the event that a cargo was traversing these waters.

Peel (2018) considers that the population of Southern Right whales appears to be recovering and indicates that vessel strikes are more likely a welfare issue than a population issue. Nonetheless, a precautionary approach with implementation of all practical mitigation measures is warranted.

In summary, LNG carriers increase the typical number of large vessels using Victorian coastal waters from around 3,600/yr to around 3,640/yr. If a linear extrapolation is used, this could increase the whale strike from 1 in 6 years to 1.01 in 6 years, which is well under the anticipated whale population growth rate of about 6.8 per cent/yr (*Conservation Management Plan for Southern Right Whale*, 2011).

The National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna (DEE, 2017) lists three main mitigation measures - keeping vessels away from whales, slowing vessel speeds and avoidance manoeuvres. All of these

measures would be implemented for LNG carriers in or approaching Port Phillip Bay and Corio Bay.



Figure 11-10. Killer Whales at Port Phillip Heads

(photo Karen Pecar, Two Bay Whales Project)

11.9 Effects on Penguins, Seals and Dolphins

Port Phillip Bay and Corio Bay may be visited from time to time by dolphin species such as the common dolphin (*Delphinus delphis)* and the common bottlenose dolphin (*Tursiops truncatus*). The bottlenose dolphin is more likely in Port Phillip than the common dolphin, which is more common in open waters. The existence of the Burrunan dolphin *Tursiops australis* as a species separate from T *truncatus* is not currently recognized by the International Committee for Taxonomy, but the local population of bottlenose dolphins are well-known in southern Port Phillip Bay and they move all around Port Phillip Bay and into Corio Bay.

Solitary or small groups of fur seals live for short periods of their life in Port Phillip Bay. The seals do not breed in the Bay but are often found on many of the navigation beacons (e.g., Popes Eye, South Channel Fort and South Channel Marker) and smaller structures and buoys (*Commissioner for Environmental Sustainability Victoria*, 2021). They seem to prefer sites around Port Phillip Heads, but individuals are often sighted in other parts of Port Phillip and into Corio Bay (see example in Figure 11-11).



Figure 11-11. Seals Resting on Ship Moored in Port Phillip Bay

The nearest penguin breeding colony to Corio Bay is the breakwater at St Kilda in Port Phillip Bay. Penguins are habituated to a wide range of human-related activities including boating, shipping, dredging and industrial activities. The penguins from St Kilda feed in shipping channels between St Kilda harbour and Williamstown, and also disperse widely in Port Phillip Bay following schools of anchovies and pilchards.

Penguins from Phillip Island colonies feed in Port Phillip Bay in autumn and winter and may range into Corio Bay. While there is not an established colony of penguins in Corio Bay, individuals or small groups of penguins may enter the bay from time to time to feed on anchovies.

The Minister's assessment of the Channel Deepening Program (CDP), which involved dredging 16,000,000 m^3 of sediment in Port Phillip Bay, concluded that "*The effects of the CDP on fish, listed fish, penguins, cetaceans and birds are short term, and will not affect long term population viability, and are acceptable. Recovery is predicted within one to two years following completion of CDP*".

Penguins, seals and dolphins from Port Phillip Bay visit Corio Bay from time to time. They are habituated to shipping and other human activities, including dredging. They are a very mobile animals and could easily avoid the proposed dredging zone for the project over the 8 weeks period in which it would occur. Similarly, these species could readily avoid the pier construction area for the proposed 12-month construction period. Thus, the potential impacts of the proposal on penguins, seals and dolphins are considered to be negligible.

11.10 Turbidity from Tugs

The wake from tugboats operating in the shipping basins causes local turbidity as sediments from the seabed are eroded and dispersed. Currently, at Refinery Pier, approximately 280 vessels come into berth each year with an average of two tugs per vessel. This means that there are around 1,120 tug operations each year near Refinery Pier at present. The addition of an FSRU means that up to an additional 45 vessels would be brought to the pier each year, meaning an additional 80 tugs to bring LNG tankers into port and 80 to take them out of port. This represents an increase of 14 per cent.

The tugs operate mainly in the dredged channels that are maintained to a minimum depth of 12.2 m depth (chart datum). The depths in the adjacent waters range from around 5 m to 9 m (chart datum). Therefore, the sediments re-suspended by the tugs will be from the bottom of the channel and will settle within the channel.

An assessment of propeller wash from tugs concluded that the depth of scour was 2 mm over a maximum area of 0.2 ha, so the amount of sediment suspended was about 8 t per tug mobilisation (AMOG, 2010). This corresponds to an estimated maximum re-suspension of 640 t per year (from the 80 occasions).

In contrast, the estimated sediment input to Port Phillip Bay from the land catchments and shoreline erosion is around 50,000 t/yr (PPBES, 1996). No data is available for Corio Bay, but it is known that there is high turbidity and suspended solids levels in the nearshore waters of north Corio Bay each time there is a storm.

The sediment resuspended by tugs would settle within approximately 100 m of the tug operations, with the sediment transport determined by the tidal currents (and would be generally longshore). The sediment re-suspended by tugs at 14 m depth would not be carried by currents to the nearest seagrass areas which are at much shallower depths.

In summary, tugs re-suspend sediment and this has been occurring at the Port of Geelong for many years. Seagrass areas are well away from the operating zone for tugs and the re-suspended sediment settles well before reaching the seagrass areas. Effects on phytoplankton are transitory and minor. Overall, the effects of turbidity from tugs associated with the project would be localised and minor.

11.11 Vessel Grounding

Three vessels have grounded at Port Phillip Heads over the last 20 years. This is a frequency of 1 grounding per 30,000 vessel transits. Groundings in Port Phillip Bay in recent years include the *Mirande* which grounded on 28 June 2001, the oil Carrier *Desh Rakshal* on 4 January 2006, the container ship *Francoise Gilot* on 9 May 2008 and the Carriers *Bow Singapore* on 19 August 2016 (ATSB, 2001, ATSB 2006, ATSB 2008, ATSB 2016).

None of the vessel groundings that have occurred in previous years have occurred in the channels in Corio Bay. There was a collision between the *Reliance Trader* berthing at Corio Quay North No 1a with *Anangel Apollo* berthed at Corio Quay North No 3. There was damage but not an oil spill.

LNG carriers will be under the control of a local pilot and will be assisted by tugs when entering and leaving Port Phillip Bay and Corio Bay. During passage, LNG carriers will draw up to 12 m water depth, depending on the load. The shipping lanes in Corio Bay are maintained to a minimum depth of 12.3 m depth and comprise clay and silt.

In the event that an LNG carrier turned from the axis of the channel, it would ground on the side of the channel. From there, it could be pulled free by tugs on a subsequent high tide, most likely without damage to the vessel or any leaks.

Vessels entering and leaving Corio Bay have defined speed limits, which reduce the potential issues related to vessel navigation including grounding. While in the Hopetown channel, vessel have a maximum speed of 12 knots and a minimum speed of 7 knots (VRCA, 2018).

The seabed along the shipping channel is not vegetated as it is too deep to provide light for plants such as seagrasses and there is no rocky seabed for attachment of macroalgae. Much of the seabed is mobile and invertebrate fauna is sparse. Temporary disturbance of these habitats due to vessel grounding would have minimal effect on biodiversity values in Corio Bay.

The consequences of an LNG carrier grounding on the edge of the channel would most likely be minor as the vessel has a double hull protecting from spills and the vessel could be returned to the channel on the following high tide.

11.12 Imported Pests

Marine pest introduction to Australian waters from shipping is rigorously managed by the Commonwealth Department of Agriculture and Water through the implementation of the National Plan for Marine Pest Biosecurity 2018-2023 (DAW 2018). It is well known that Port Phillip Bay and Corio Bay have an established community of introduced marine pests Introduced marine species in Port Phillip were thoroughly investigated in 1997 and reported in *Marine Biological Invasions of Port Phillip Bay Victoria*, CRIMP Technical Report #20 (1999).

A summary of the finding of this report is provided in Section 5.19 in the existing marine ecological context section of this report. One of the first introduced marine species to Victoria was the European shore crab *Carcinus maenus* in Port Phillip Bay as early as 1856 (Waters 1996). Recently, the first known occurrences of two key pest species in Victoria were the Japanese kelp *Undaria pinnatifida* at Point Wilson in 1996 (Campbell and Burridge 1998) and the European fan worm Sabella *spallanzani* in Corio Bay in 1992 (Carey and Watson 1992).

Agriculture Victoria estimates that Port Phillip Bay currently has at least 100 confirmed records of introduced and 61 cryptogenic marine pests with possibly more than 300 species of unknown origin. Many of these are likely to occur in Corio Bay.

The project has the potential to introduce pest species into the bay attached to the hull of an international project vessel or in the ballast water of the LNG carrier. The potential impact of marine pest introduction to Corio Bay or Port Phillip Bay is the same for all international vessels entering the ports. The likelihood of introducing pest species into Corio Bay from the project relates to the change in the number of vessels and the risk profiles of the individual vessels (ports of origin, vessel design, vessel purpose, hull antifoul management systems). There are expected to be up to an additional 40 vessels entering the bay each year as part of the project to supply LNG to the FSRU.

LNG carriers are in high demand internationally compared to many other bulk carrying vessels. Their economic performance relies on efficiency at sea and short port stays. Hence, there is an economic driver for clean, efficient hulls to be maintained and for minimal duration in ports (Lewis 2019). As discussed above, Port Phillip Bay is a

potential source of many introduced species including marine pest species to Corio Bay.

There are well-established measures to control and minimise the introduction of marine pests. These include:

- Carriers have antifoul coating to prevent the encrusting of biota on the hull;
- Vessels from certain ports will be cleaned before entry is allowed;
- International vessels will empty ballast water in accordance with the latest version of the Australian Ballast Water Management Requirements (DAWR, 2017);
- If an imported pest is identified or suspected, then the vessel will be managed in accordance with biosecurity requirements of the Biosecurity Act 2015; and
- Vessel management activities will adhere to the *National System for the Prevention and Management of Marine Pest Incursions.*

Based on the use of these measures, the additional 45 vessels entering the port each year would not pose a significant increase in the potential for pest species to enter Corio Bay and no further mitigation measures associated with the project are considered to be required.

11.13 Conclusions on Additional Marine Impacts

This section provides an assessment of ten additional issues that could result in adverse environmental impacts over and above the primary issues associated with marine discharges discussed earlier in this report. The impacts associated with each of the additional issues have been assessed and appropriate mitigation measures have been defined. A summary of the impact assessment for these potential impacts and the mitigation measures is provided in Table 11-4.

Table 11-4. Summary of Additional Impact Assessment

Additional potential impacts	Impact Assessment	Mitigation
Entrapment and Entrainment	Potential entrapment and entrainment without mitigation	Limit intake velocity; Screen on intake
Removal of Soft Sediment Habitat	Impacts are minor to negligible	No additional mitigation measures recommended
Addition of Pier Habitat	Small positive and negative impacts	No additional mitigation measures recommended
Spills of Fuel and Chemicals	Medium	Comprehensive spill management plan and equipment

Additional potential impacts	Impact Assessment	Mitigation
Extra Light	Localised impact	Best practice measures in design of lighting
Underwater Noise	Localised impact	Best practice mitigation measures in piling
Turbidity from Tugs	No significant impact	No additional mitigation measures recommended
Vessels Striking Wildlife	Very low probability	Implement statutory measures
Vessel Grounding	Low probability and expect minor environmental impacts	Use pilots
Imported Pests	Has been a significant impact already. Need to implement all mitigation measures	Implement statutory measures and best practice

References:

USEPA (2004). National Pollutant Discharge Elimination System: Final Regulations Addressing Cooling Water Intake Structures for New Facilities; Final Rule. Federal Register. Part II. Environmental Protection Agency 40 CFR Parts 9, 122, 123, 124 and 125.

12 Assessment of Impacts on Ramsar Site

12.1 Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site

The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site is located along the western side of Port Phillip Bay and covers six separate areas including the northern shore of Corio Bay, Limeburners Bay, the former Cheetham salt works near Point Wilson, Avalon, another salt works near Point Cook, the sewage treatment ponds at Werribee, Lake Connewarre, Swan Bay, Mud Islands and the coastal strip and seagrass beds along Point Wilson to Limeburners Bay. Figure 12-1 shows the location of the six separate components of this Ramsar site (highlighted in light blue).

The six sites have a total area of 22,650 hectares and each has a different set of environmental characteristics including freshwater wetlands, estuaries, intertidal shoreline, sub-tidal seabed, inland wetlands and the Western Treatment Plant wastewater treatment facility (DWELP, 2018). Ramsar wetlands are diverse, represent a range of habitats and environmental conditions, and are not necessarily natural or 'pristine' environments.

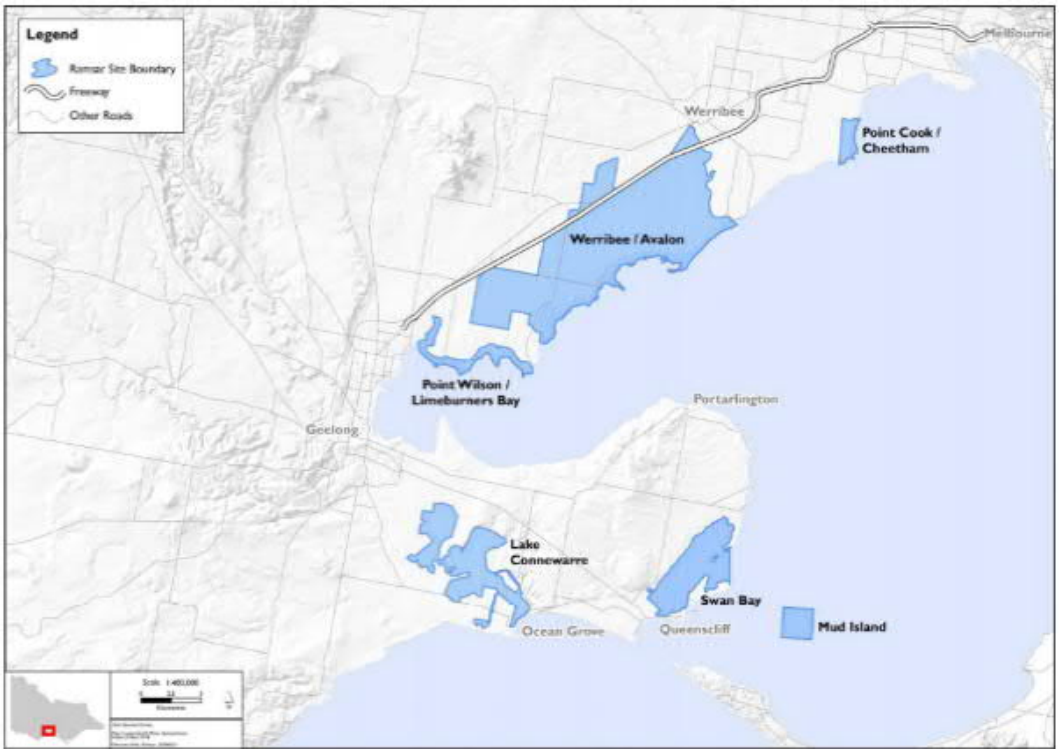


Figure 12-1. Port Phillip Bay and Bellarine Peninsula Ramsar Site

The area of interest in regard to the project is *Point Wilson / Limeburners Bay*– coastal areas west of Point Wilson and Limeburners Bay, including coastal areas between Point Wilson and Limeburners Bay Estuary but excluding Avalon Saltworks. The boundary of the Ramsar Site is the 2 m depth contour and various points on land (L to V in Figure 12-2). (see Figure 12-2). The Ramsar site is 1.3 km north of the proposed FSRU and Refinery Pier extension and Limeburners Bay is 1.6 km north of the project site.



Figure 12-2. Ramsar Site between Limeburners Bay and Point Wilson

12.2 Purpose of this Section

The purpose of this section of the marine impact assessment is to characterise and assess potential impacts on the Ramsar site from the construction and operation of the regasification project. Sections 7 to 9 of this report assessed the magnitude and extent of impacts on the Corio Bay environment from dredging and the discharge of chlorine and seawater with higher or lower temperature associated with the proposed FSRU. Section 10 assessed the impacts on primary productivity of Corio Bay and, by extension, the marine food chain in Corio Bay.

Section 11 provides an assessment of ten additional impacts associated with the project that could result in averse environmental impacts – entrapment and entrainment; removal of soft sediment habitat; addition of pier habitat; spills of fuel and chemicals; extra light; underwater noise; turbidity from tugs; vessels striking wildlife; vessel grounding and imported marine pests. Each issue is assessed, and appropriate mitigation measures are defined.

This section assesses the potential for adverse effects on the components, processes and services (CPS) that characterise the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site (DELWP 2018). The assessment considers marine issues and the implications for migratory and shorebirds that feed in the intertidal zone. A separate terrestrial ecology report by AECOM addresses ecological assets which occur on land (Technical Report D: *Terrestrial ecology impact assessment*).

The potential for impacts on the Ramsar site is assessed in the context of existing pressures and climate change. Section 4 of this report outlined current trends in temperature rise and sea level rise in Corio Bay. This section identifies and recommends mitigation measures to avoid, minimise and manage potential impacts which will inform the development of an Environmental Management Framework (EMF) for the project.

12.3 Local Environment Context of Ramsar Site

The Ramsar site situated along the north of Corio Bay (west of Point Wilson) occupies an area of about 480 ha, including Limeburners Bay and the Avalon Coastal Reserve. In Corio Bay, the site extends out to the 2 m depth contour (see Figure 12-2).

The main freshwater input to the Ramsar site is via Hovells Creek, which flows through the township of Lara and discharges into Limeburners Bay (see Figure 12-3). Lara has a population of 17,000 and is a growing suburb of the City of Greater Geelong. The Lara region is the driest in southern Victoria because of the Otway Ranges' rain shadow and receives an average of only 425 mm/yr of rainfall. As a consequence, flow in Hovells Creek is ephemeral. The average discharge is around 13,000 ML/yr. However, the discharge varies greatly from year to year – 2018 was a dry year with a creek discharge of 7,000 ML whereas the following year 2019 was a wet year with a creek discharge of 56,000 ML.



Figure 12-3. Environmental Context of Ramsar Site in north Corio Bay

The land to the east of Limeburners Bay is used for cropping and is ploughed most years. Most of the land at Avalon, between the Princes Highway and the Ramsar Site, is used for a combination of grazing and cropping. The Avalon Airport occupies a large site to the north of the Ramsar site. There is a large quarry between the airfield and the Ramsar site. There is a row of houses on the Avalon foreshore (see Figure 12-4), a boat ramp and parking for visitors.



Figure 12-4. Houses on Avalon Foreshore Road and Historical Foreshore

Figure 12-4 also shows the position of the foreshore from 1989 to 2019 (from DELWP, 2020). The plotted foreshore lines indicate that there has been accretion of sand at each end of the residential strip, with the shore moving outwards approximately 20 m.

The DELWP foreshore analysis shows the foreshore along most of the Ramsar site is accreting slowly, with the shore moving offshore from 0.2 to 0.4 m/yr in Limeburners Bay, around 0.4 m/yr along the foreshore from the refinery to Limeburners Bay, and from 0.2 to 1.3 m/yr along most of the Avalon foreshore.

There also are changes in the offshore depth contours. Section 4 of this report documents the large changes in the seagrass cover from year to year in north Corio Bay which coincide with small changes in the seabed profile.

Local measurements of the effects of climate change are presented in Section 4. Sea level in eastern Australia, including in Corio Bay, has been rising at a steady rate for a long period due to climate change. Records of tide levels from 1880 show that sea level has risen 220 mm over 140 years at a rate averaging 1.6 mm/yr. Figure 4-3 shows the sea level at Geelong has been rising at 1.6 mm/yr from 1966 to 2020. The annual rise in sea level is projected to increase (IPCC, 2021).

Seawater temperature in Corio Bay has been rising at a steady rate in parallel with the rise in air temperature. Figure 4-6 shows that there has been a 1.5 °C increase in average annual temperature in the 80 years to 2021. Thus, aquatic biota in Corio Bay have been adjusting to the same rise in water temperature.

In summary, this description of the environmental context of the Ramsar Site has identified several existing stresses, including agricultural activities in the catchment, urban development at Lara, the houses on Avalon foreshore, the Geelong Port and associated industrial development, imported marine pests, climate change and recreational activities including boating and fishing.

12.4 Wetland Criteria for Ramsar Site

The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula site was nominated for Ramsar listing in 1982 on the basis of four of the eight wetland criteria at the time including *"Representative Wetlands" (DELWP 2018).*

Criteria 2 – A wetland should be considered internationally important if it supports vulnerable, endangered or critically endangered species or threatened ecological communities.

The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula site meets the criteria as it has one vulnerable, endangered and critically endangered community (saltmarsh) as well as an additional 12 fauna species (DELWP, 2018). Table 12-1 lists each of the communities and fauna species as well as the list they are protected under.

Table 12-1. Protected Species and Habitats

Name	Type	Protection List
Coastal Saltmarsh	Community	EPBC
Australasian bittern	Fauna	EPBC and IUCN
Australian fairy tern	Fauna	EPBC
Bar-tailed godwit	Fauna	EPBC and IUCN
Curlew sandpiper	Fauna	EPBC and IUCN
Eastern curlew	Fauna	EPBC and IUCN
Great knot	Fauna	EPBC and IUCN
Hooded plover	Fauna	EPBC
Lesser sand plover	Fauna	EPBC
Red knot	Fauna	EPBC and IUCN
Orange-bellied parrot	Fauna	EPBC and IUCN
Australian grayling	Fauna	EPBC and IUCN
Growing grass frog	Fauna	EPBC and IUCN

Criterion 3 – A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.

The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula site is home to a total of 130 water bird species which is most likely related to the diversity of the habitats at the site. The site hosts water birds across all defined functional groups representing a higher diversity compared with sites which only host birds from some of the groups.

Criterion 4 – A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their lifecycles or provides refuge during adverse conditions.

The Ramsar site supports a wide variety of domestic and international water birds including over 35 waterbirds, including 20 species that migrate internationally. The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula site provides habitat, feeding grounds and breeding grounds for around 49 species of waterbirds.

Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.

There are many birds using the site, with the lagoons of the Western Treatment Plant being a focus for bird populations. Waterbird counts in the site are also consistently higher than 80,000 (DELWP, 2018).

Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

There are twelve species which meet this criterion including:

• Australasian shoveler	• Double-banded plover
• Australian fairy tern	• Hoary-headed grebe
• Australian shelduck	• Musk duck
• Blue billed duck	• Pink-eared duck
• Chestnut teal	• Red-necked stint
• Curlew sandpiper	• Sharp-tailed sandpiper.

Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.

The Ramsar site provides habitat, feeding grounds and spawning grounds for many species of fish with varying levels of ecological importance. Swan Bay in particular is a known feeding ground for over 50 fish species.

Limeburners Bay has mangroves and saltmarsh zones that provide habitat for small and juvenile fish (Crinall and Hindell 2004; Hindell and Jenkins 2004). The estuarine area of Limeburners Bay is likely to be a spawning habitat for Black Bream and also a migration pathway for the Southern Shortfin Eel.

As discussed in Section 5 of this report, the main fish species of conservation significance are the syngnathids (pipefish and seahorses), School Shark and possibly Australian Mudfish. There are no records of the marine larval phase of Australian Mudfish (or of Australian Grayling) in Corio Bay. School Sharks breed in the Geelong Arm of Port Phillip Bay, with pups recorded from sampling near Point Wilson. School Sharks may also enter Corio Bay although none have been recorded to date.

Anchovy are recognised as an important food for many fish-eating species including seabirds and the threatened Australian Fairy Terns. Sampling of ichthyoplankton (fish eggs and larvae) in Corio Bay in 2020-21 found abundant Australian Anchovy eggs. Australian anchovies are widely distributed throughout temperate Australian coastal waters, south of the Tropic of Capricorn. Anchovies breed widely throughout Port Phillip Bay, Western Port, Bass Strait in South Australian Gulfs and shelf waters (Dimmlich and Ward 2006, Hoedt and Dimmlich 1995, Parry et al, 1999).

Implications for Marine Impact Assessment

Earlier sections of this report present the findings of detailed studies and modelling to assess the potential impacts associated with the temperature and chlorine discharges from the refinery and FSRU. The potential impacts associated with suspended solids resulting from the proposed 8-week dredging program were also assessed.

The predictions of the extent of the chlorine or temperature plumes, and the elevated suspended solids during the 8-week dredging program, show that the plumes extend to the mouth of Limeburners Bay, but not into the Bay. As such, it was concluded that chlorine, temperature and suspended solids would have no direct impacts on saltmarsh or mangroves.

12.5 Ecological Character of Ramsar Site

In order to detect change it is necessary to establish a benchmark for management and planning purposes. Ecological character descriptions (ECD) form the foundation on which a site management plan and associated monitoring and evaluation activities are based (DELWP, 2020).

Maintaining the ecological character of the Ramsar site relies on several processes. One of the key documents is the *Ecological Condition Description (ECD)* of the critical components, processes and services (often referred to as CPS) of the sites and limits of acceptable change (LAC).

Critical Components and Processes

In the 2020 *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Ecological Character Description*, ecological components are described as follows.

The basis of an ECD is the identification, description and where possible, quantification of the critical **components, processes, benefits and services** of the site. Wetlands are complex ecological systems and the complete list of physical, chemical and biological components and processes for even the simplest of wetlands would be extensive and difficult to conceptualise. It is not possible to identify and characterise every organism and all the associated abiotic attributes that are affected by, or cause effect to, that organism to describe the ecological character of a system. What is required is to identify the key components, the initial state of the systems, and the basic rules that link the key components and cause changes in state (Holland 1998). Thus, we need to identify and characterise the key or critical components, processes, benefits and services that determine the character of the site. These are the aspects of the ecology of the wetland, which, if they were to be significantly altered, would result in a significant change in the system. DEWHA (2008) suggest the minimum components, processes, benefits and services, which should be included in an ECD are those (DELWP, 2020):

1. that are important determinants of the sites unique character;
2. that are important for supporting the Ramsar criteria under which the site was listed;
3. for which change is reasonably likely to occur over short to medium time scales (less than 100years); and / or
4. that will cause significant negative consequences if change occurs.

Geomorphic Setting

Limeburners Bay Estuary – This is considered an excellent example of a complex estuary containing many features of larger estuarine systems. Its form and proximity to Melbourne make it an ideal demonstration site for the study of estuarine systems.

Nutrients

The report details the importance of nutrients and in particular nitrogen as follows: - *Nitrogen is considered to be the limiting nutrient in Port Phillip Bay with respect to phytoplankton growth in the Bay (Longmore and Hale 2006). Around the time of listing, approximately 6,000 to 9,000 tonnes of nitrogen enter the waters of Port Phillip Bay annually (Parslow et al. 1999). The major sources are the Western Treatment Plant and the Yarra River, with smaller amounts entering from other rivers, streams and drains and the atmosphere. Concentrations of nitrogen in the water column vary with distance from major sources and the waters in the Ramsar site adjacent to the Western Treatment Plant typically are higher in nitrogen than sites more distant* (DELWP, 2020).

The importance of nutrients is in their effect on primary production. Productivity in the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site is particularly important as it is the primary reason the site supports such a large number of waterbirds (Rogers et al. 2007, Parry et al. 2013). Phytoplankton and microphytobenthos are the dominant primary producers in Port Phillip Bay and this is likely to also be reflected within a number of the coastal areas of the Ramsar site Phytoplankton is the most significant primary producer in Port Phillip Bay. It forms the basis of the food chain for the Bay and there is evidence that zooplankton grazing maintains the balance of phytoplankton biomass, preventing frequent algal blooms (DELWP, 2020). Primary production by microphytobenthos biomass is one-quarter that of phytoplankton

Therefore, maintaining phytoplankton productivity at levels sufficient to sustain the food chain within the coastal areas of the Ramsar site is important for maintaining ecological character. Note that the whole of Section 10 of this assessment is directed to establishing the impact of the construction and operations stages of the proposal on primary productivity).

The role of non-phytoplankton organic carbon may also be important, particularly in areas close to the Western Treatment Plant. The wastewater treatment process results in significant loads of particulate organic carbon, which can enter the food chain directly through bacteria and detritivores (DELWP, 2020).

Investigations in the nearshore environment adjacent to the Western Treatment Plant have indicated that concentrations of organic carbon are correlated with benthic invertebrate diversity and abundance (GHD 2008). It has been suggested that particulate organic carbon is a major food source for invertebrate fauna in both the intertidal areas and within the treatment lagoons (DELWP, 2020).

Note that the clockwise circulation pattern in Corio Bay, as shown in Section 10, means that discharges from the Western Treatment Plant have a minor role in productivity in north Corio Bay, with local recirculation and recycling of nutrients having the major role.

Saltmarsh

The Ramsar Site contains a small area of saltmarsh in Limeburners Bay. The saltmarsh provides important habitat for waterbirds on low tides. At noted above, the saltmarsh is well away from the turbidity, chlorine, temperature or turbidity plumes associated with the project.

Mangroves

There is 4 ha of the mangrove *Avicennia marina* in Limeburners Bay. These trees provide habitat for both fish and invertebrates and help to stabilise the soft sediments in the area (DELWP, 2018). Some mangroves are present in Limeburners Bay however, they are well away from the extent of the turbidity, chlorine, temperature or turbidity plumes associated with the project.

Seagrass

Around the time of listing there was approximately 2500 ha of seagrass in Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site spread over three locations: (DELWP, 2020). Seagrass is another important characteristic of the Ramsar site in Limeburners Bay and across the north of Corio Bay. As described in earlier sections of this assessment, four species of seagrass are found in Corio Bay: *Zostera muelle*ri, Zostera *nigricaulis*, *Zostera tasmanica* and *Halophila australis.*

- *Zostera nigricaulis* (formerly *Heterozostera tasmanica*) – occurs only in subtidal areas where exposure to the air is limited. Prefers sand and mud sediments. The dominant seagrass in all three areas of the Ramsar site;
- *Zostera muelleri* – generally occurs in the intertidal zone, requiring periods of exposure to maintain health and growth; and
- *Halophila ovalis* – occurs on in subtidal areas and generally in deeper water than *H. nigricaulis*. Within the Ramsar site the only significant patches are within the Point Wilson area.

Waterbirds

According to the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan, there are a total of 154 water bird species within the Ramsar site (this number includes 24 species which are vagrant or where there was only 1 record). It supports around 20 species of waders from the East Asian-Australasian Flyway that are listed under the international migratory bird agreements JAMBA, CAMBA and ROKAMBA. The Ramsar site provides a feeding ground as well as a breeding ground for many of these bird species. The site is also used by protected species which include 10 birds, 1 fish and 1 frog.

A separate study of migratory birds and waterbirds in the Ramsar site has been conducted by AECOM, with a separate report (Technical Report D: *Terrestrial ecology impact assessment*).

Table 12-2 provides a list of wetland dependant bird groups which have been recorded in Corio Bay and the number of species recorded within each group. The table shows a high number of international shorebirds with around 33 species recorded.

Table 12-2. Numbers of Recorded Species in Ramsar site

Functional groups	Description	Number of species
Ducks and small grebes	Ducks and small grebes that typically are omnivorous and shallow or open water foragers.	16
Herbivores	Black swans, hens and coots that have a vegetation diet.	8
Fish eating species	Gulls, terns, cormorants, petrels, shearwaters and grebes with a diet mainly of fish.	32
Australian shorebirds	Australian resident shorebird species that feed in shallow inland waters or mud and sand flats mainly on invertebrates.	14
International shorebirds	Palaearctic shorebird species that breed in the northern hemisphere and migrate to the southern hemisphere to feed.	33
Large wading birds	Long-legged wading birds with large bills, feeding mainly in shallow water and mudflats.	17
Other	Other birds that are wetland dependent such as birds of prey (white-bellied sea eagle, swamp harrier), reed warblers and the orange-bellied parrot	10
Total		130

The Ramsar site regularly supports six species of threatened migratory birds including:

- Bar-tailed godwit (*Limosa lapponica baueri*) – Vulnerable
- Curlew sandpiper (*Calidris ferruginea*) – Critically endangered
- Eastern curlew (*Numenius madagascariensis*) – Critically endangered
- Great knot (*Calidris tenuirostris*) – Critically endangered
- Greater sand plover (*Charadrius leschenaultia*) – Vulnerable (EPBC)
- Lesser sand plover (*Charadrius mongolus*) – Vulnerable
- Red knot (*Calidris canutus*) – Endangered

Reefs

There is a small area of reef on the northern shore of Corio Bay by Point Lillias. According to Coastkit, the reefs are a small rock outcrop and a subtidal biogenic reef comprising cunjevoi beds in sand and muddy seabed. The intertidal reef provides habitat for limpets and mussels, and subtidal reefs are habitat for macroalgae and encrusting invertebrates. Intertidal reefs and isolated rock outcrops provide roosting and foraging habitat for water birds.

12.6 Limits of Acceptable Change

Limits of acceptable change are defined as "…*the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. If the particular measure or parameter moves outside the 'limits of acceptable change' this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed* (Phillips, 2006). The LAC's for the Ramsar Site as well as the critical processes and the baseline supporting evidence are shown below in Table 12-3. Table 12-3 is a reduced version of Table 17 in the Ecological Character Description (DELWP, 2020).

Table 12-3. Assessment of Limits of Acceptable Change

Critical CPS	Baseline / supporting evidence	Limit of Acceptable Change	Confidence
Hydrology	Reedy Lake was a naturally intermittent wetland with cycles of wet and dry (prior to listing as part of the Ramsar site). The near permanent water regime that was in place at the time of listing disrupted the ecological system, contributing to (among other impacts) excessive reed bed growth (Lloyd Environmental et al. 2006, Ecological Associates 2014). A more natural inundation regime that allows for wet and dry cycles has now ben instigated and forms the baseline against which the LAC is established. The artificial wetlands at Cheetham and the Western Treatment Plant are important for supporting ecological character, specifically large numbers of waterbirds.	Reedy Lake will not be continuously wet for more than 10 continuous years, or continuously dry for more than five. At least 75% of aerobic treatment lagoons at the Western Treatment Plant will contain permanent water At least 75% of the lagoons at Cheetham will contain permanent water.	Medium
Vegetation: seagrass	GIS layers indicate that in 1981 there was approximately 2500 hectares of seagrass within the Ramsar site boundary. Seagrass can be highly variable over short timeframes (Ball et al. 2014), so a LAC that accounts for longer cycles is proposed.	Seagrass extent will not fall below 1500 hectares for a period of greater than 20 continuous years.	High
Vegetation: saltmarsh	Boon et al. (2011) completed mapping of saltmarsh and mangrove communities across Victoria, with 1225 hectares of saltmarsh within the Ramsar site boundary. As natural variability of saltmarsh extent is low and the recovery of saltmarsh from disturbance is known to be slow (Saintilan 2009), the LAC is based on the 2011 extent. The LAC has been set to be consistent with that for other Victorian Ramsar sites supporting saltmarsh – a 25% decline from the time of listing. LAC for condition of saltmarsh is also desirable and Boon et al. (2011) suggested EVC benchmarks for the community. However, there is no benchmark of condition against which change could be assessed.	Total saltmarsh extent will not fall below 900 hectares.	High
Vegetation: mangroves	Boon et al. (2011) completed mapping of saltmarsh and mangrove communities across Victoria, with 52 hectares of mangroves within the Ramsar site boundary. As assessment against this LAC is likely to be via remote sensing, the LAC must be set at a level that can be detected reliably. A LAC of a 25% decline, from the time of listing, was considered to adequately represent a potential change in character.	Total mangrove extent will not fall below 40 hectares.	Moderate

Critical CPS	Baseline / supporting evidence	Limit of Acceptable Change	Confidence
Vegetation: freshwater aquatic vegetation	Management of Reedy Lake is designed to maintain a habitat mosaic of open water, emergent freshwater vegetation (reed and sedge beds), submerged vegetation (e.g. *Myriophyllum* spp.) and lignum shrubland (Ecological Associates 2014, Corangamite CMA 2015). The LAC is based on maintaining this habitat mosaic.	A habitat mosaic will be maintained at Reedy Lake that comprises open water, emergent native vegetation (sedges, rushes and reeds) and lignum shrubland with no habitat comprising more than 70 percent of the total wetland area for more than five successive years.	Moderate
Fish	The Corangamite CMA commissioned a review to develop a LAC for fish in Swan Bay (Jenkins 2020). The study indicated the following: “raw data from studies conducted from 1989 to 1992, and 1996/97 were analysed in relation to the temporal change in fish abundance, species richness and diversity. Species Richness was found to be a suitable candidate for LAC because seasonal variation is predictable and interannual variation is low. Moreover, there was relative consistency in minimum values across habitats. Fish abundance showed considerable interannual variability in addition to seasonal variability, but again was potentially suitable for LAC due to relative consistency in minimum values across habitats. In contrast, fish diversity was found not to be a suitable candidate for LAC through difficultly in interpreting the biological basis of low values. Finally, although the abundance of King George Whiting post-larvae showed high interannual variability in Swan Bay, the fact that there has been an ongoing monitoring program for post-larvae in Port Phillip Bay means that this species can also be a suitable candidate for LAC. “	A minimum of 3 fish species per standard haul of a 10 m seine net from three replicate hauls in subtidal habitats of Swan Bay; A minimum abundance of 5 fish per standard haul of a 10 m seine net from three replicate hauls in subtidal or intertidal habitats of Swan Bay;	Low

Critical CPS	Baseline / supporting evidence	Limit of Acceptable Change	Confidence
Waterbird abundance	Average annual maximum counts3 from 1981 to 1995, a 15 year period that should reflect conditions at the time of listing are as follows (mean ± standard deviation): • Total waterbirds – 185,000 ± 80,000 • Australasian waders – 3000 ± 2000 • Ducks – 60,000 ± 24,000 • Fish eating species – 4500 ± 3100 • Herbivores – 11,000 ± 9000 To account for changes in populations of migratory waders from elsewhere in the flyway, three indicator species were selected: double-banded plover (trans-Tasman migratory wader), red-necked stint (EAAF, population has increased since the time of listing) and sharp-tailed sandpiper (EAAF population has declined since the time of listing). The LAC has been established based on the proportion of the population supported at the time of listing (based on waterbird population estimates WPE2 (1977 to 1991). Average annual maximum counts for these species (1981 to 1995) were: • Double banded plover – 2.1% • Red-necked stint – 2.4% • Sharp-tailed sandpiper – 3.2% There is a high degree of variability in waterbird abundance as evidenced by the high standard deviations in the list above. To account for this variability, a sustained change of approximately 50% has been set as the LAC.	Abundance of waterbirds will not decline below the following (calculated as a rolling five-year average of maximum annual count): • Total waterbirds – 100,000 • Australasian waders – 1500 • Ducks – 30,000 • Fish eating species – 2250 • Herbivores – 6000 • Double-banded plover – 1 % • Red-necked stint – 1 % • Sharp-tailed sandpiper – 1.5 %	High
	There are several groups of waterbirds, for which annual maximum counts are too variable to derive quantitative LAC. For the gulls and large bodied wader groups this is due to variability (either actual or in terms of survey effort) of a small number of species that breed in large numbers at Mud Island (e.g. up to 50,000 pairs of silver gulls and ibis). These groups have therefore been considered under the critical process of “waterbird breeding”. In addition, waterbird counts rarely include wetland birds of prey and passerine reed inhabiting birds in a consistent manner, making the data difficult to interpret. These species have therefore been included in terms of total waterbird abundance and in the LAC for diversity.		

Critical CPS	Baseline / supporting evidence	Limit of Acceptable Change	Confidence
Waterbird diversity	A total of 130 species of wetland dependent bird have been recorded at the site (excluding vagrant observations). The average number of species within each guild is relatively stable and does not show the degree of variability of waterbird abundance at the site. The LAC for species richness has also been established for functional groups based on the following averages (1981 to 1995); and a sustained decline of greater than one standard deviation: • Total waterbirds – 76 ± 5 • Migratory waders – 23 ± 3 • Australasian waders – 11 ± 1 • Ducks – 12 ± 1 • Fish eating species – 13 ± 1 • Herbivores – 4 ± 2 • Gulls – 2 ± 0 • Large bodied waders – 9 ± 2	Diversity of waterbirds will not decline below the following (calculated as a rolling five-year average of number of species): • Total waterbirds – 70 • Migratory waders – 20 • Australasian waders – 10 • Ducks – 10 • Fish eating species – 12 • Herbivores – 2 • Gulls – 2 • Large bodied waders – 7	
Waterbird breeding	While breeding records from most locations are insufficient to establish a quantitative LAC, there is good data for pied cormorants nesting in the Western Treatment Plant, with an average of 680 nests between 2002 and 2012 (Loyn et al. 2014). Similarly, the importance of Mud Islands to waterbird breeding is well established; but historical data indicate a succession of different colonial nesting species since the 1940s (Menkhorst 2010). Whether this succession is due to altered habitat conditions or other factors, remains unknown, but commenced before the time of listing. The LAC for waterbird breeding at Mud Islands is based, therefore on supporting colonial nesting birds, with species known to regularly breed at this locations listed as presence only.	Annual breeding at Mud Islands of colonial nesting species of at least 25,000 pairs / nests. Presence of all of the following species breeding in at least three in every five years: Australian pelican, Australian pied oystercatcher, Australian white ibis, crested tern, little pied cormorant, pied cormorant, silver gull, straw-necked ibis and white-faced storm petrel. Annual breeding at Western Treatment Plant of > 300 pairs of pied cormorant.	Medium
Supports threatened species: waterbirds	The site regularly supports nine threatened waterbird species. Counts of Australasian bittern, Australian fairy tern, bar-tailed godwit, eastern curlew, great knot, hooded plover, lesser sand plover and red knot indicate moderate to low, but persistent numbers within the site. LAC is based on continued presence for these species. At the time of listing, the site regularly supported > 1 % of the population of two threatened waterbird species: • Australian fairy tern – 1.2 % • Curlew sandpiper – 3.4 % A quantitative LAC based on population estimates is established for these species.	Australasian bittern, bar-tailed godwit, eastern curlew, great knot, hooded plover, lesser sand plover and red knot recorded within the site in three out of five seasons. Abundance of waterbirds will not decline below the following (calculated as a rolling five year average of maximum annual count; percentages calculated based on Hansen et al. (2016) for migratory shorebird species and the latest Wetlands International Waterbird Population for other species): • Australian fairy tern – 0.6 % • Curlew sandpiper – 1.7 %	

Critical CPS	Baseline / supporting evidence	Limit of Acceptable Change	Confidence
Threatened species: orange-bellied parrot	Numbers of orange-bellied parrots on mainland Australia have declined in recent years. This decline is not related to factors within the Ramsar site. The LAC for orange bellied parrot is therefore related to maintaining suitable habitat and covered by the LAC for saltmarsh.	See LAC for saltmarsh.	Low
Threatened species: Australian grayling	The Australian grayling passes through the Ramsar site as part of its lifecycle but is unlikely to be easily detectable within the Ramsar site during these brief periods of migration.	Australian grayling continues to be supported in the Barwon River system.	Medium
Threatened species: Growling grass frog	This threatened species has been monitored at the Western Treatment Plant for five years. The average total frog count was 337 ± 123 (mean ± standard deviation; Ecology Partners 2008). In an attempt to incorporate the level of variability, limits are proposed based on mean ±1 standard deviation. Data from the Lake Connewarre Complex are more limited and so a LAC based on presence has been established.	At Western Treatment Plant > 200 growling grass frogs in 3 out of 5 years. Presence of growling grass frog in the Lake Connewarre complex in 3 out of 5 years.	High
Physical habitat for waterbirds	This critical service is covered by the LAC for waterbirds.	See LAC for waterbird abundance.	
Physical habitat for native fish	This critical service is largely related to the nursery habitat for native fish provided by the seagrass and saltmarsh in Swan Bay.	See LAC for seagrass and saltmarsh.	Moderate
Ecological connectivity	Keeping the connection between the ocean and freshwater areas is important for migratory fish and the water quality of estuarine systems. The fish supported by the site use these migratory routes autumn to spring (Lloyd et al. 2006).	Connectivity between the Barwon River and the Southern Ocean is not impeded between March and November for more than two consecutive years.	High

12.7 Ecological Threats

The Ramsar site faces threats to its ecological character from a variety of sources including climate change, urban development, wastewater stormwater and catchment flows, recreational activities, biological resources and invasive species (DELWP, 2020).

Climate change poses several threats to the Ramsar site including sea level rise, increased average temperature and in increase in frequency and intensity of storm activity. These stressors can potentially have an impact on the ecology of saltmarsh, mangrove and wading birds as these are heavily dependent on the frequency and depth of tidal processes (DELWP, 2020).

The population of greater Melbourne is projected to increase from 4.3 million (2013) to 7.8 million (2051). This extra urban development will increase pressure on several areas around the Ramsar Site. For the Point Wilson / Limeburners Bay section, the north shore of Corio Bay is surrounded by farmland which may be subject to urban expansion. Thus, the Corio Bay section of the Ramsar site may see increased pressure in future due to loss of wetland buffers. This can also lead to an increase in stormwater runoff inflows into the Bay adding to contaminated water levels in the Ramsar Site (DELWP, 2020).

An increase in recreational activities in the area may cause disturbance to shorebirds and nesting areas. Further, in increase in vehicles may cause damage to the intertidal zone (DELWP, 2020).

The 1997 study of imported pests found that there were 19 invasive species that were widespread in Corio Bay, as described in Section 5.20. Although the Ramsar site was not specifically surveyed, it is expected that some of those pests would be present in the Ramsar site where habitat is suitable. To avoid the introduction of any new invasive species into Corio Bay and the Ramsar site, a series of management measures are recommended for construction vessels and the ongoing visits that would be made by LNG carriers, as described in Section 12.9.5.

12.8 Available Information and Field Surveys

This marine impact assessment is based on both a review of available information on the Ramsar site and the ecological values of Corio Bay and Limeburners Bay as determined from detailed marine investigations conducted over a 12-month period in support of the EES which are listed later in this section. Information sources included:

- Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan Summary (DELWP, 2018).
- Port Phillip Bay (Western Shoreline) & Bellarine Peninsula Ramsar Site Strategic Management Plan (DSE, 2003).
- Victorian Resources Online –
    - Coastline condition
    - CoastKit (biotopes).

AECOM Shorebird Survey

Technical Report D: *Terrestrial ecology impact assessment* established a baseline of migratory shorebirds within, and adjacent to, the Ramsar Site in the summer of 2021. Migratory shorebirds were surveyed on three occasions over February and March

2021, when migratory shorebirds are visiting Australia for the southern hemisphere non-breeding season. A survey was also conducted in winter (July 2021) to capture data on birds that remain in Australian during the northern hemisphere breeding season.

The Ramsar site is recognised as important habitat for aquatic birds including waders (shorebirds), ducks, fishers (e.g., cormorants and terns), grebes, gulls, large wading birds (e.g., spoonbills and egrets) and swans. AECOM classified aquatic birds into three group as presented in Table 12-4. The table lists the main habitat and food preferences of the three groups for consideration in the marine assessment.

Table 12-4. Aquatic Bird Groups and Descriptions

Aquatic Bird Group	Description
Shorebirds (waders)	Rely on tidal mudflats for foraging at low tide and alternate habitats at high tide for extended feeding or roosting. Mudflat availability is restricted in places where the mangrove fringe is extensive. *Shorebirds predominantly feed on insects, aquatic invertebrates and small fish*.
Waterbirds	Comprise a mixed group of species which feed in intertidal areas that are not shorebirds. These include ducks, swans, ibises, herons, spoonbills and grebes. *Waterbirds predominantly feed on fish, frogs and aquatic invertebrates.*
Seabirds	Comprise species which feed on the sea surface and in the marine water column. Seabird species include gulls, gannets, terns, cormorants, penguins, pelicans and shearwaters. *Seabirds are upper trophic predators which predominantly feed on fish, but other food sources including marine invertebrates.*

Limeburners Bay (Estuary of Hovells Creek)

Limeburners Bay is an estuarine inlet at the mouth of Hovells Creek characterised by shallow water. The shorelines and sandy spits are important feeding and roosting habitat for birds. Most of Limeburners Bay is 1 to 2 m deep, and the shallow, sheltered waters encourage the growth of seagrass which provides nursery habitat for fish and important feeding habitat for birds. The entrance channel is deeper (2 m to 5 m) and there is a spit projecting out from the east bank across the mouth of Limeburners Bay. The extent, shape and position of the spit varies from decade to decade.

Figure 12-5 shows the depth contours in north Corio Bay. It can be seen that the southern boundary of the Ramsar site follows the 2 m depth contour.

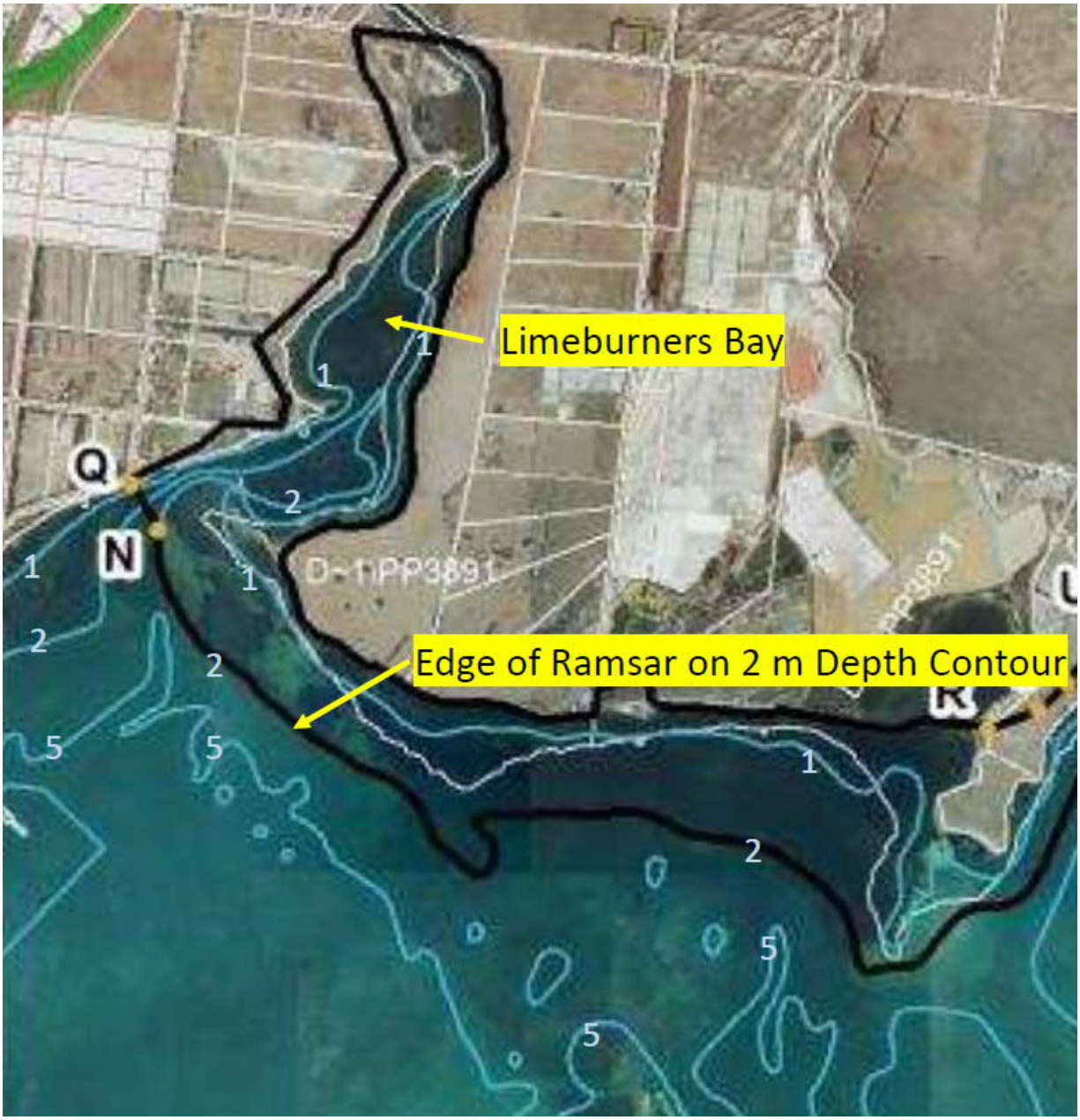


Figure 12-5. Environmental Context of Ramsar Site in North Corio Bay

Marine Field Studies

Over the period from October 2020 to October 2021, CEE conducted field studies to better understand existing marine conditions in Corio Bay. These studies aimed to developing local knowledge of marine habitats, flora, fauna, primary production and marine conditions at different times of the year and through various seasons.

Table 12-5 lists the field studies undertaken by CEE to obtain additional on-site data for the marine assessment.

Table 12-5. List of Field Studies for Marine Assessment

Field Study	Reason for Study
Plankton sampling (including phytoplankton, zooplankton and ichthyoplankton).	Plankton was sampled once a month to understand the abundances of various plankton species over a year and how the communities' changes seasonally and in respect to each other. The sampling provides evidence to production, grazing and mortality of plankton species in the localised area or Corio Bay.
Water quality sampling	Water quality was sampled monthly to see how certain parameters such as temperature, salinity and dissolved oxygen change seasonally. This helps define the water column characteristics in terms of stratification, how well mixed the Bay is and how well the water can support life.
Water temperature measurements	Water temperature was recorded via two temperature loggers constantly at various depths. The water temperature was recorded to see how temperature changed both hourly, daily and yearly and to determine what variations the habitats are normally exposed to under existing conditions.
Light attenuation measurements	Two PAR loggers were constantly logging underwater light for a period of 3 months. The data was used to calculate light attenuation in the water column.
Current measurements	Currents were recorded constantly for 1 month via an ADCP placed to the north of Refinery Pier. Current data assists with modelling which is used to understand hydrodynamics of the Bay and track particle movement in the water column over time.
Seabed video tows	Initial seabed video tows were done over two days coving all of Corio Bay but focussing on the project area of north Corio Bay. The video tows were aimed at assessing the seabed habitats and confirming the boundaries of important biotopes.
Mussel sampling	Mussel sampling occurred once where mussels were taken from several places in Corio Bay from structures. The mussels were sent to Leeder Analytical to be analysed for tribromomethane accumulation.
Additional seabed video tows	Further video tows were done, focussing on the seagrass which dominated the shoreline by the refinery and into Limeburners Bay to assess the impact of the existing plume on seagrasses.
Infauna sampling	Infauna sampling was conducted at several sites throughout the Bay using a grab. The samples were sent for infauna identification.

12.9 Assessment of Impacts on Character of Ramsar Site

The initial risk screening conducted to inform EES studies identified the following impact pathways for marine ecology impacts on the Ramsar Site:

- Plumes of turbid water generated during dredging impacting on environmentally sensitive areas within Corio Bay.
- Changes to the availability of food for water birds;
- Changes to water quality (chlorine) and temperature (seawater discharge).
- Operational activities (including noise and lighting) impacting marine fauna.
- Introduction/spread of imported species during construction or operations from vessels;

This section assesses the specific potential impacts on the ecological values of the Ramsar site in north Corio Bay/Limeburners Bay. Measures to manage or mitigate the potential impacts are identified where needed. Any ecological impacts that remain following the adoption and implementation of those measures (residual impacts) are outlined.

Dredging and Sediment Mobilisation

The pathway for an impact of dredging on the Ramsar site is an increase in turbidity and light attenuation over the seagrass beds within the Ramsar site boundary. A large proportion of the seabed in the Ramsar site has sediments and water depth suitable for seagrass. As documented previously, much of the subtidal seabed in the site is covered by seagrass. Retaining healthy seagrass is essential to meet the ecological functions of the Site with respect to fish nursery and habitat, as well as a wide range of other marine organisms.

A second consequence of an increase in turbidity and light attenuation in the waters of the Ramsar site is a reduction in phytoplankton populations with flow-on effects in the marine food chain such as reduced zooplankton numbers (as they feed on phytoplankton), and reduced populations of small fish (as they feed on zooplankton).

Turbidity is a measure of water clarity and has been measured by the EPA in mid-Corio Bay since 2014. In Corio Bay, the turbidity has averaged around 1 NTU with a recorded peak of 7 NTU. Turbidity peaks result from storms or from phytoplankton blooms.

Light attenuation was measured by CEE in Corio Bay over May-June 2021 near the Ramsar site. The light attenuation coefficient (K_d) ranged from 0.6 to 0.8 m^{-1} with an average of 0.75 m^{-1}. This is marginally higher than light antennation values measured in Port Phillip Bay, indicating natural turbidity in Corio Bay is marginally higher than in Port Phillip Bay.

The average k_d value measured in Corio Bay of 0.75 m^{-1} corresponds to an average or background SS (suspended solids) concentration of 5 mg/L.

The area predicted to be impacted by proposed dredging is shown in Figure 12-5. The red outline indicates the 12 ha area of seabed that will be dredged. The orange indicates the area predicted to be affected by 20 mg/L median suspended solids (40 ha) and the pink indicates 5 mg/l median suspended solids (160 ha). As noted above, the background level of suspended solids is 5 mg/L (median) and this

increases regularly up to around 12 to 20 mg/L when waves re-suspend sediment near the shore.

The boundary of the Ramsar site is the 2 m depth contour. Figure 12-6 shows that the median 5 mg/L suspended solids contour would not extend into the Ramsar site, although there is a localised part of the Ramsar site that would experience an increase in median suspended solids concentration of around 1 mg/L.

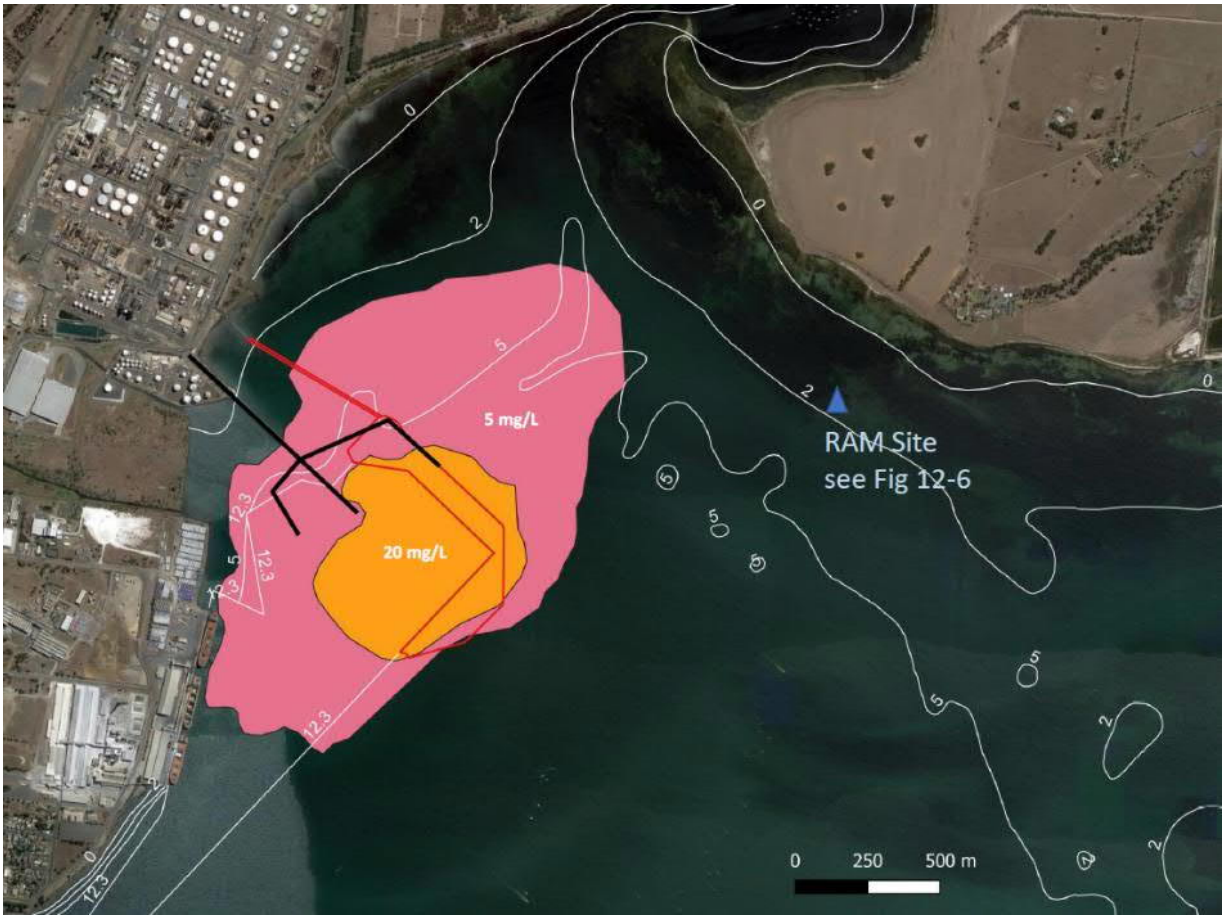


Figure 12-6. Predicted Area of Impact from Proposed Dredging

As discussed in Section 7, storms occurring during the dredging would increase the net current to the north and carry turbid waters from the dredging area into the Ramsar site. Figure 12-7 shows the predicted time series of surface suspended solids (SS) over the 8 weeks of dredging (if it occurred in Aug-Sept 2020) at a point on the boundary of the Ramsar Site (RAM).

The blue line in Figure 12-7 shows the instantaneous SS concentration. Peak SS concentration is 12 mg/L for a few hours, which is comparable to existing conditions during storms. The pink line shows the 5-day moving average SS concentration, which ranges from 0 to 3 mg/L (peak of 1 NTU). The green line shows the 8-week average, which is under 1 mg/L or less than 0.3 NTU. Turbidity increases in the Ramsar site are quite minor. The light attenuation coefficient would increase from 0.75 m^{-1} to 0.85 m^{-1} based on the 8-week average and up to 1.1 m^{-1} for the peak 5-days.

The predicted increases in turbidity occur for short periods within a limited 8-week period. They may have a minor effect in slowing seagrass growth and productivity for a day or two, but the impact would be too small to be measured and of no ecological consequence.

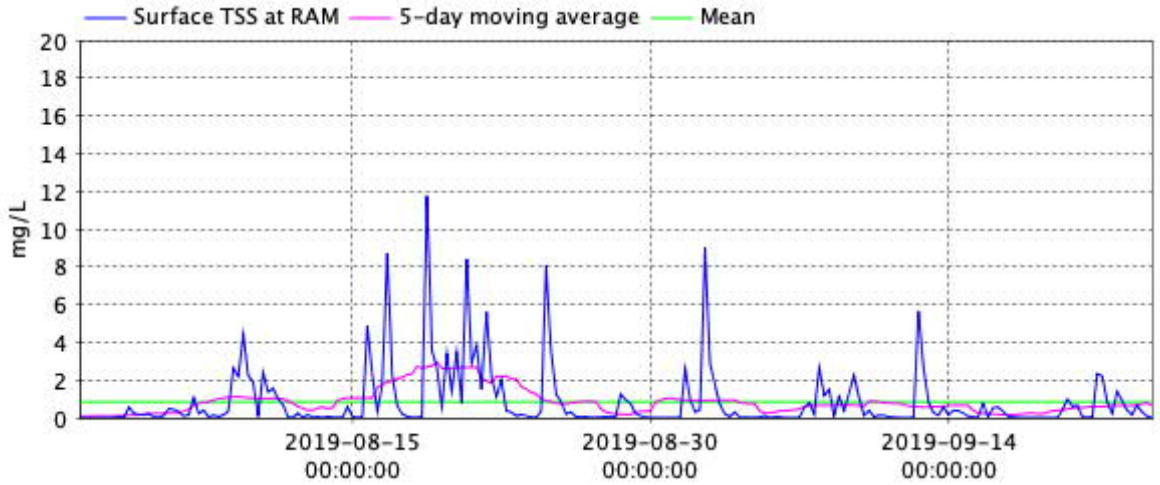


Figure 12-7. Time Series of SS at Ramsar Site (RAM)– Aug – Sept

A key issue related to the proposed 8-week dredging program is the timing, in particular, whether there are some months or seasons that should be avoided to maintain potential environmental impacts at acceptable levels. Several species of fish are more vulnerable during particular seasons, as most of the early lifecycle (eggs, larvae, juveniles) are concentrated in a particular habitat type or a specific geographic region.

The potential for restricting dredging at specific times was informed by the information provided in the Victorian EPA *Best Practice Guidelines for Dredging* (EPA Publ 691, 2001). The main habitat types in the Ramsar site are soft sediments seagrass and estuaries. The Ramsar site in Corio Bay has a large area of seagrass habitats, a medium area of soft sediment habitat and a small area of estuarine habitat.

Key fish species that occur in each habitat are listed in Table 12-6. The months in which each species may be particularly vulnerable to site-specific impacts also are summarised in Table 12-6. The proposed dredging will take place over 8 weeks, and it would have least impact on fish spawning and development in the Ramsar site if the dredging avoided the spring season (Sept-Oct-Nov, as highlighted in Table 10-5). The activities within the blue rectangle will be unaffected if there is no dredging in spring, and these activities constitute a majority of the breeding/larvae dispersion months. Thus, a recommended mitigation measure is to carry out dredging in summer, autumn or winter, but not in spring.

There is wide variation in the tolerance of turbidity by juvenile fish that migrate through estuaries, but most species have a wide tolerance (Rowe and Dean 1998). Fish in seagrass habitat are possibly less tolerant to turbidity, although it is noted that there is elevated turbidity in the Ramsar seagrass beds about every 2 to 3 weeks, when storms stir up sediment near the shore. Fish populations are not likely to be seriously impacted by the dredging, but as a precautionary measure, dredging should

be programmed to occur in autumn, winter or summer but avoiding spring months if possible.

The effects of metals and nutrients released during dredging is assessed in Section 7 of this report. The resulting metal concentrations are within acceptable levels close to the dredging zone and there will be negligible increase in metal concentrations in the Ramsar site.

Table 12-6. Assessment of Non-dredging Period to Protect Fish

	Jan	Feb	Mar	Apr	May	Jun	Jul	Au	Sep	Oct	Nov	Dec
Seagrass habitats												
King George whiting	J							J	J	J	J	J
Southern sea garfish	J									E	E	J
Southern calamari									E	E		
Yank flathead										E	E	E
Yellow-eyed mullet*	E										E	E
Estuarine habitats												
Black bream										E	E	E
Broad-finned galaxias					L?	L?	L?		J	J	J	
Common galaxias						A	A?	A		J	J	
Long-finned eel	A+J	A+J	J	J	J							A
Short-finned eel	A	A			J	J	J					A
Southern anchovy	E	E	E							E	E	E
Spotted galaxias	J				L?	L?				J	J	J
Soft-sediment habitats												
Greenback flounder						E	E	E	E	E		
Long-snouted				E	E	E	E	E	E	E		
Flounder												
Sand flathead									E	E		

E=Eggs, L=Larvae, J=Juvenile, A=Adult

Section 7 shows that the release of total nitrogen over an 8-week dredging period would be 70 kg. This is around 0.03 % of the total nitrogen in Corio Bay. It is possible that there could be a small, localised phytoplankton bloom shortly after dredging ceases. Monitoring of phytoplankton is recommended to trigger any management measures. However, this would not alter the ecological character of the Ramsar site as such blooms occur periodically due to natural events.

Entrainment

The impact assessment for entrainment of plankton or larvae from the Ramsar site in the existing refinery intake or the proposed FSRU seawater intake is examined in Section 10 using a particle tracking model, where the movement of particles released in the waters of the Ramsar site are tracked for 7, 14 and 28 days.

The results show that the particles disperse widely from their initial release within the Ramsar site.

There is zero entrainment of plankton from the Ramsar site in 7 days at sites A (refinery intake) and B (FSRU intake). Plankton mostly have a short life cycle (a day or so) and plankton entrained at these sites are developing locally and not coming from the Ramsar site.

Zooplankton have a life cycle of around 14 days and the results show that entrainment rates are negligible (less than 0.1 %) when compared to natural factors (> 99 % loss). Therefore, there will be negligible impact on food availability for shorebirds that eat zooplankton, or animals that consume zooplankton.

The majority of fish larvae from the Ramsar site including Limeburners Bay are dispersed into Port Phillip Bay and the potential entrainment after 28 days is less than 0.5%, which is very small in comparison with natural predation and other losses. In conclusion, the current refinery seawater intake has negligible effect on plankton populations in Corio Bay and the proposed FSRU intake also would have negligible impact.

Potential impacts on seaweeds will be localised and of short (8-week) duration and therefore very unlikely to affect the availability of food for migratory shorebirds or other waterbirds. Seagrasses are addressed in Section 12.8.6.

Cooling Water Discharges

The impact assessment for cooling water discharges is examined in Section 8 of this report for chlorine in the discharges and Section 9 for temperature in the discharges. The existing warm plumes formed by the discharges from the refinery travel to the north and reach the mouth of the Limeburners Bay, but within the acceptable temperature limit derived in Section 8. As indicated in Sections 8 and 9 of this report, any plumes formed by direct discharges from the FSRU (cooled seawater via the diffuser, ballast water or heated seawater released in open loop operations) are well away from the Ramsar site.

The project will reduce the temperature in the refinery discharge and therefore ensure there is no effect of temperature on the Ramsar site.

Future chlorine levels in the discharges to Corio Bay from the refinery with the FSRU discharge water being recycled through the refinery will be the same as currently discharged from the refinery operations. Therefore, there will not be any additional, or any change in environmental impact associated with the project.

The existing shoreline plume formed from the four refinery discharges has been occurring for over 50 years with no detectible impact on seagrass beds near the refinery or in the Ramsar site. Surveys of the seagrass beds under the plumes do not detect any significant change due to the plumes. The chlorine concentration in the existing plumes outside the licenced mixing zone at 5 µg/L is within the stringent Guideline Value of 7.2 µg/L for chlorine.

Future temperature increments above ambient in the discharges to Corio Bay from the refinery with the project will be from 5 to 7 ^{o}C smaller than now. The temperature rise in the existing plumes outside the EPA licenced mixing zone of 2 ^{o}C is modest compared to the diurnal variation in temperatures experienced by biota in the littoral zone (10 ^{o}C) and shallow sublittoral zones (1.6 ^{o}C to 5 ^{o}C). The temperature rise in the future plumes with the project will be much smaller in extent.

Additional Noise, Vibration and Light

The impact assessment for additional noise, vibration and light is examined in Section 11 of this report. The Ramsar site is too distant from the construction zone or the operations area for any fauna to experience any direct impacts from additional noise, vibration or light.

The associated AECOM report on terrestrial ecology addresses the effects of noise, vibration and light on water birds.

Indirect effects may involve avoidance reactions by fish and marine mammals close to the construction zone, during the period of dredging and pier construction. There would remain large marine corridors for these species to access the Ramsar site, and it is considered that there will not be any adverse impact from noise, vibration or lighting.

Introduction of Pest Species

The impact assessment for importation of pest species is examined in Section 11 of this report. It is documented that Port Phillip Bay currently has at least 100 confirmed records of introduced and 61 cryptogenic marine pests with possibly more than 300 species of unknown origin (Agriculture Victoria, 1999). Many of these are likely to occur in Corio Bay.

Introduced marine species in Port Phillip were thoroughly investigated in 1997 and reported in *Marine Biological Invasions of Port Phillip Bay Victoria*, CRIMP Technical Report #20 (1999). A summary of the finding of this report is provided in Section 5.19 in the existing marine ecological context section of this report.

The project risk of introducing further introduced species into the bay is via these species attached to the hull of an international project vessel or in ballast of the LNG carriers. The consequence of a marine pest introduction to Corio Bay or Port Phillip Bay is the same for all international vessels entering the ports.

Marine pest introduction to Australian waters from shipping is rigorously managed by the Commonwealth Department of Agriculture and Water through the implementation of the National Plan for Marine Pest Biosecurity 2018-2023 (DAW, 2018). There are well-established measures to control and minimise the introduction of marine pests these days and they must continue to be implemented by all vessels involved in the construction or operation (LNG carriers) of the project.

Impact on Area of Seagrass

The assessment of the *limits of acceptable change* in Section 12.6 showed that maintaining the area of healthy seagrass is an important indicator of ecological condition in the Ramsar site.

The most extensive seagrass in the Ramsar site, *Zostera nigricaulis,* grows to approximately 3.5 m water depth. Growth of this species is seasonal, with strongest growth in spring and relatively dormancy over winter. Consequently, it is susceptible to light reduction in spring and can tolerate substantial reduction in light over winter (Bulthuis 1985). If dredging does not occur in spring, then there will be no impact on early seasonal growth.

The assessment of potential impacts in this section concludes that there will be no reduction in the area of seagrass in the Ramsar site. The predicted increases in turbidity occur for short periods within an limited 8-week period. They may have a

minor effect in slowing seagrass growth and productivity for a day or two, but the impact would be too small to be measured and of no ecological consequence.

12.10 Summary

The main potential impacts addressed in this section are for direct impacts of chlorine, temperature and turbidity on seagrass habitat and fish breeding and dispersal, and indirect impacts on the habitat or food supply for waterbirds in the context of the Ramsar site. Other causes of indirect impacts to be considered are spills of fuel and chemicals; extra light; underwater noise and imported pests.

The conclusions from the assessment of potential impacts on the Ramsar site are listed in Table 12-7, together with appropriate mitigation and monitoring recommendations.

Table 12-7. Summary of Assessment of Impact on Ramsar Site

Critical processes and services	Conclusion of Assessment	Mitigation and Monitoring
Wetland bathymetry	No change in intertidal mudflat area	No mitigation needed
Geomorphology	No significant change in sedimentation patterns	No mitigation needed
Marine invertebrates	Chlorine and temperature plumes below Guideline limits well before Ramsar site, so no effect in Ramsar site	No mitigation needed Note: Infauna monitoring recommended for closer to dredging site
Seagrass	No loss of seagrass in Ramsar site	No mitigation needed Note: Seagrass monitoring recommended for boundary of Ramsar site
Mangroves	No effect – no loss of mangroves	No mitigation needed
Saltmarsh	No effect – no loss of saltmarsh	No mitigation needed
Fish	Minor change in entrainment of fish eggs and larvae. No effects on adults.	No mitigation needed
Water bird abundance and diversity	No effect due to dredging or operation of FSRU	No mitigation needed
Water bird breeding	No effect due to dredging or operation of FSRU	No mitigation needed
Threatened bird species	Addressed by AECOM report, but no significant impact pathway from marine operations	No mitigation needed
Migratory birds	No significant impact pathway from marine operations. No change in zooplankton abundance. (See AECOM Report for land impacts).	No mitigation needed
Threatened fish species	No effect	No mitigation needed

Critical processes and services	Conclusion of Assessment	Mitigation and Monitoring
Physical Habitat – waterbirds and native fish	No effect	No mitigation
Ecological Connectivity	No effect	No mitigation

13 Combined stresses and Integrated Risk Assessment

Cumulative impacts of the Project are assessed in this section in relation to:

- Combined stresses during construction;
- Combined temperature and chlorine (in seawater discharge) stresses;
- Combined plume, shading and seabed scour stresses;
- Combined Project and other port stresses;
- Combined Project and catchment development stresses; and
- Combined Project and climate change stresses.

13.1 Combined Stresses during Construction

Construction would proceed through a sequence of dredging (over 8-weeks) followed by pier construction stages (over 12 months), with no overlap between stages. However, cumulative effects of construction would result from overlapping footprints and corresponding environmental recovery times for the impact pathways described in previous sections.

The existing refinery would continue to operate during construction, so some construction stressors (principally dredging) may add to the existing operations stressors. Existing shipping operations will continue next to the dredging. However, the high turbidity zone from dredging will largely occupy the port zone or the adjacent seabed, which are already modified areas that were previously dredged.

The potential overlap for turbidity plumes from dredging and the dispersion pathways of seawater temperature and chlorine discharge from the existing refinery operation on marine environmental values was considered. The discharge plumes from the existing facility have been modelled and validated for temperature in Section 8 and chlorine in Section 9. Turbidity from the dredging activities has been reliably modelled and monitoring and mitigation measures have been listed previously in Section 7. There may be some overlap in the extremities of each plume under episodes of strong and persistent onshore winds. However, the strength and duration of the combination of the stressors (particularly turbidity) on these occasions is unlikely to be undetectable from background concentrations. The key environmental receptor in these areas would be shallow water seagrasses. A key outcome of the turbidity monitoring and management program would be to protect seagrass beds from the effects of turbidity. This would ensure potentially detrimental combined effects of stressors on seagrasses are avoided.

13.2 Combined Temperature and Chlorine Stresses

The stress from the plume formed by the four refinery discharges is due to the combined effects of chlorine (or chlorine-produced oxidants at very low concentrations – see discussion in Section 8) and a temperature warmer than ambient. The proposed project would mean that discharge water plumes would be around 3 °C warmer than ambient rather than up to 10 °C in the existing conditions. This results in a reduction in the extent of the warm plume in Corio Bay. The temperature change is within the range of the natural variation in seawater temperature in shallow water.

Chlorine is discharged from the four discharge points with a maximum licenced output of 20 kg/d. The proposed project will not change the total chlorine output which means the chlorine plume will remain the same. This stress has been in existence for almost 50 years. The existing chlorine stress is well under the site-specific limit of 17 µg/L and, outside the mixing zones, less than the GV of 7.2 µg/L.

The field observations of the condition of the seagrass under the plume, and the associated seaweed, show no observable adverse effects from the combination of the stressors in operations.

13.3 Combined Plume, Shading and Seabed Scour Stresses

The FSRU and LNG carrier would occupy an area of 3 ha and, at different times of the day, would shade an area of 4 to 5 ha. Within this local zone there would be combined stresses due to discharge from the diffuser (when it operates), CPO, shading and scour of sediments (periodically due to tugs).

Shading is expected to be a significant stress within the defined areas of the turbidity plumes during construction and beneath new piers and vessels during operation. Shading would reduce the light in the lower water column. The combination of the presence of a vessel and occasional cooler water plumes on the seabed would potentially reduce the food supply to infauna in the 3 ha of seabed below the vessels.

The field studies of the infauna community in different areas of Corio Bay observed that there was lower infauna abundance in the deeper channel seabed, which was attributed to the change in sediment character from soft silty sediment to hard clay. There may also be a superimposed effect of ship scour and tug scour from vessel movement along the channels.

It is considered very likely that there would be an altered infauna population in the 12 ha of seabed deepened by dredging and subject to the combined stresses listed above.

13.4 Combined Project and Other Port Stresses

The projected 45 LNG carriers would add up to an extra 95 ship movements each year to the current 1,200 ship movements in the main channels of the Port of Geelong. As there are currently an average of 4 ship movements per day, the effects of this increase are expected to be very minor.

There also would be an increased likelihood of spills, as discussed in Section 11 and addressed by a mitigation measure earlier in this Section of the marine assessment.

13.5 Combined Noise and Light Stresses

Appendix A-3: Underwater Noise Impact Assessment to this Technical Report A: *Marine ecology and water quality impact assessment* discusses the existing underwater soundscape of Corio Bay and assesses the impacts of noise generated during construction and operation of the project. The noise report concludes that the existing soundscape in north Corio Bay is noisy due to the area being an industrialised port zone. Animals in the area would be accustomed to the existing soundscape and project-related underwater noise would result in temporary and localised impacts. Animals may avoid the immediate area during construction, although they would return after construction has been completed. Dolphins and other marine mammals are regularly observed in close proximity to existing ships and

it is expected that the continuously moored FSRU would have little effect on marine animal behaviour.

Noise would be noticeable from dredging, although there have been many previous dredging programs in Corio Bay and Port Phillip Bay, with no long-term adverse effects from dredging noise recorded. Mitigation measures, including 'soft-start' piling, are recommended for inclusion in the CEMP to minimise extraneous noise during construction of the pier extension.

Appendix A: Light Spill Impact Assessment of Technical Report J: *Landscape and visual impact assessment* discusses potential cumulative light spill impacts from existing light sources in the industrialised port zone and assesses the impacts of project light sources that would be in addition to the existing light sources. The project site is adjacent to the refinery and Port of Geelong, which are brightly lit. The Geelong CBD adjacent to Corio Bay also is a major source of light affecting the nearshore waters. The light spill assessment concludes that the project would not result in significant impacts as a result of cumulative light spill.

It is noted that the noise stresses would occur mostly during the construction phase of the project whereas light stress (from the pier extension and the FSRU and LNG carriers) would occur during the operations stage of the project. Thus, peak noise and peak light stresses would not overlap.

13.6 Climate Change Stresses

Section 5 notes that sea level in Corio Bay has increased by about 1.6 mm/yr since 1965 and the seawater temperature has increased by 1.5 ^{o}C since 1942.

Steadily increasing sea level and seawater temperature increases over coming decades will have significant impacts on Corio Bay, particularly on the mangroves and saltmarsh in Limeburners Bay. These impacts will mostly occur around the perimeter of the Bay and be separate from the very minor effects of the project in the deeper channel near the new berth.

Implementation of the proposal would involve either a reduction in the temperature increase above ambient in the plume along the refinery shoreline, or a small reduction in temperature on the seabed near the diffusers. The lower temperatures operate in the opposite direction to the rising temperature due to climate change, and thus there would not be increased temperature stress due to the project and climate change.

Climate change would result in slightly deeper water in Corio Bay, but would not affect the operation of the FSRU, which floats. Deeper water would slightly increase dilution. For example, an increase in MSL of 40 mm (2 mm/yr for 20 years) would increase the dilution of the plumes by about 0.2 %. Infauna are unlikely to be affected by rising sea level.

13.7 Outcomes from Integrated Risk Assessment

The outcomes from the FeAST integrated risk assessment are summarised in Table 13-1. The DELWP outcomes are precautionary, and similar to the outcomes of the screening risk assessment described in the earlier Section 4.6.

Table 13-1. Outcomes from DELWP Risk Assessment Method

Biotope Description	DELWP Outcome	CEE Outcome
Sublittoral Mud	Medium	Low
Sublittoral Seagrass	High	Low
Sublittoral Seaweed	Medium	Low
Biogenic reef	Medium	Unaffected

The CEE outcomes are based the results of field studies, computer modelling of the turbidity, chlorine and temperature plumes, and the impact assessments detailed in previous sections. Based on this site-specific understanding, the scores in the various stages can be adjusted and a refined outcome reached.

In conclusion, on the basis of a normal integrated risk assessment, it is our view that the integrated risk can be assigned a LOW rating. This matches the outcome reached when using the EPA risk evaluation table in the *Environment Reference Standard* and described in earlier sections.

14 Conclusions, Mitigation and Monitoring

14.1 Conclusions from Marine Impact Assessment

This section summarises the conclusions of the marine environment assessment for each of the items in the scoping requirements. The scoping requirements and outcomes of this marine impact assessment are listed in Table 14-1.

14.2 Summary of Mitigation Measures

A series of impact mitigation measures have been identified and developed through the impact assessment process to limit the extent of adverse effects on the marine environment. These are listed below and described in the following paragraphs.

1. Reuse seawater used by FSRU in existing refinery processes;
2. Avoid dredging in spring growth and spawning season;
3. Limit duration of turbid water overflow from hopper barges;
4. Install silt curtain between dredging and refinery intake and seagrasses;
5. Monitor turbidity at six sites during dredging, with threshold triggers and management responses;
6. Limit noise and vibration during pier construction and implement standard underwater noise impact mitigation procedures;
7. Design seawater intake to minimise entrapment
8. Locate seawater intake to minimise entrainment;
9. Design diffuser to achieve high dilution;
10. Design lighting to minimise adverse overspill;
11. Implement biosecurity measures on all vessels;
12. Manage cleaning and antifouling system on FSRU to avoid contamination;
13. Continue to use and upgrade spill management procedures;
14. Use pilots, tugs and comply with vessel speed restrictions; and
15. Minimise chlorine concentration at the discharge points.

14.2.1 Reuse Seawater used by FSRU

A key feature of the proposal is that the seawater used on the FSRU would be piped to the refinery seawater intake and be reused in the refinery. As a result, there would be

- No increase in seawater withdrawn from Corio Bay;
- No increase in seawater discharge to Corio Bay;
- No increase in chlorine discharge to Corio Bay;
- Significant reduction in temperature of plume from refinery discharge.

This is an important mitigation measure, and reuse of FSRU seawater in the refinery must be part of the project to correspond to this marine impact assessment.

14.2.2 No Dredging in Spring Season

As a precautionary measure, the 8-week dredging program should be carried out in any season except spring. Spring is the season for high growth of seagrass, and phytoplankton, and also the season when key species of fish are in larval or juvenile stages (see discussion in Section 12). Put simply, dredging in seasons other than spring would have least effect on primary productivity and fishery replenishment.

Table 14-1. Summary of Responses to Scoping Requirements for Marine Impact Assessment

Scoping Requirement	Outcome from Marine Impact Assessment
Key Issues	
Potential for adverse effects on the ecological character and biodiversity values of *the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site* including, but not limited to, the listed threatened species and terrestrial and marine conservation reserves.	The potential effects are examined in Section 7 (dredging), Section 8 (temperature change), Section 8 (chlorine), Section 10 (primary productivity), Section 11 (other impacts) and Section 12 (Ramsar critical processes and services). The modelling and assessment of the increase in turbidity in north Corio Bay during the 8-week dredging program shows there would be no incursion on turbidity into Limeburners Bay. There would be short-term events of higher turbidity from the dredging at the seagrass beds in north Corio Bay, similar to the natural variation in turbidity and within the tolerance of seagrass to turbidity, particularly over the short 8-week dredging period. The assessment shows there would be no impact from the dredging on seagrass and threatened species. The project would reduce the excess temperature in the shoreline plume from the temperature existing over the last 60 years. Elevated temperature above the threshold Guideline Value (+/- 2 ^{o}C) from the discharge points does not reach the Ramsar site or Limeburners Bay, which naturally experience larger daily variations in water temperature. The project would no change existing chlorine levels in north Corio Bay from those existing over the last 60 years. In any event, elevated chlorine does not reach the Ramsar site and is within the site-specific Guideline Value. Incremental changes in light and noise at the Ramsar site from the marine components of the project are not significant.

Scoping Requirement	Outcome from Marine Impact Assessment
Potential for indirect effects on biodiversity values including but not limited to those effects associated with changes in hydrodynamics and coastal processes, water quality (i.e., on water dependent ecosystems). Potential for significant short and long-term impacts on marine biota due to entrainment of organisms in seawater for regasification or due to variable water temperature discharges and other pollutants, including chlorine, after use for regasification. Impacts resulting from reduced availability of food for other species, resultant hydrodynamic changes and other impacts such as long-term changes to populations and distribution.	The discharges from the refinery have been in operation for over 60 years. Studies of the conditions in seagrass beds under the refinery plume show no adverse effects in comparison to seagrass beds elsewhere in Corio Bay. Chlorine concentrations are low except close to the discharge points (in mixing zones). Recreational fishers report that fishing conditions are as good (or better) in the plume as elsewhere in Corio Bay. The observations show that there is negligible long term impact from the existing discharge arrangement (see Sections 5 and 9-16). In normal operations, seawater from the FSRU would be transferred for reuse in the refinery as cooling water and there would be no change in the refinery discharges, other than a reduction in discharge temperature. The FSRU discharge does not have any effect on nutrients or dissolved oxygen or pH. In backup operations, the diluted plume from the FSRU or the diffuser would be within the port area, and well away from the Ramsar site. Chlorine and temperature levels are in all cases well within the Guideline Values. The same quantity of seawater would be extracted from Corio Bay and there would be no change in the number of plankton entrained, as studies have shown that plankton populations are much the same across north Corio Bay. Mitigation measures are recommended to minimize entrapment and entrainment. The detailed plankton studies reported in Sections 5 and 10 show that plankton populations are much the same in north and south Corio Bay, and similar in abundance and composition to the plankton in Port Phillip Bay. The studies have shown evidence of rapid recovery of phytoplankton populations within a few hours after discharge from the refinery. As there is no change in nutrient levels with the use of seawater for cooling, the population and abundance of zooplankton and fish larvae are not expected to alter, so there would be no impact on availability of food for seabirds. At the levels occurring in Corio Bay, chlorine and temperature are not the factors limiting phytoplankton growth.

Scoping Requirement	Outcome from Marine Impact Assessment
Potential for adverse effects on the marine environment from dredging and sediment mobilisation, including increased turbidity and contaminant disturbance.	Extensive studies, including modelling of suspended solids and settlement of solids, have been carried out and are reported in Section 7. There would be localized increase in turbidity during the 8-week dredging program, and a few events of higher turbidity in the Ramsar seagrass beds. There would be a small impact on primary productivity (equivalent to 0.6 % reduction in the productivity for the year) in Corio Bay during the 8-week dredging program. Recovery would be quick after dredging ceases. As noted above, the short-term events of higher turbidity in the seagrass beds in north Corio Bay are similar to the natural variation in turbidity and within the tolerance of seagrass to turbidity, particularly over only a short period. The assessment shows there would be no impact from the dredging on seagrass and threatened species. A silt curtain is recommended to protect the seagrass closest to the dredging site. To minimize short term effects during dredging, a recommended mitigation measure is to not dredge in the spring growth season. Overall, the principal effects of the dredging program would be a localised reduction in primary productivity, as detailed in Section 10, and the temporary loss of the infauna in the 12 ha dredged area, until they re-develop. Infauna sampling in nearby existing channels, which were dredged a few years ago, has shown that a viable infauna community has recolonised the seabed. It is noted that the area impacted is 12 ha out of a total area of 3,500 ha of sublittoral mud in Corio Bay. The muddy seabed will persist – but further below the water surface. In summary, the evidence of the marine impact assessment points to no significant adverse long-term effects on abundance and diversity of infauna, seagrass or plankton. A few months after dredging has been completed, conditions in the dredged areas would be the same as in the other areas of dredged channels in Corio Bay and Port Phillip Bay.
Potential for impacts resulting from increased shipping activity on marine species, including acoustic impacts and potential collisions.	The project involves an extra 40 vessels using the Port of Geelong. This would be an increase over the 600 vessels currently using the Port of Geelong each year, and the 3,300 vessels using the Port of Melbourne each year. The likelihood of impacts increases with the number of vessels, and, also, with the increasing populations of marine mammals. Standard precautions will apply.

Scoping Requirement	Outcome from Marine Impact Assessment
Potential for significant impacts on the marine environment resulting from accidental or unintended leaks or spills arising from construction works or operational activities, including unintended introduction of exotic species (e.g. through ballast water).	These impacts are assessed in Section 11. There would be a marginal increase in the likelihood of a spill due to the increased number of shipping movements. The increase of 5 per cent in the number of shipping movements from 600 to approximately 640 is expected to increase the likelihood of a spill by around 3 per cent after allowing for the efficiencies of shipping management and safety measures incorporated into new LNG carriers. Despite the minor increase in shipping movements, the overall likelihood of a spill would be low. LNG carriers have multiple layers of effective protection to prevent spills and losses of containment. The safety measures that provide the layers of protection include: • Experienced pilot on board the vessel; • Use of four tug vessels during transit in the shipping channel; • Double hull design and construction; • Storage tanks set back from the inner hull by insulating material; • Sophisticated ship controls ensuring effective manoeuvrability; • Port operations managing vessels within the shipping channel. As another comparison, Port Phillip Bay has around 4,000 large vessels using ports. Thus, the increase in likelihood of a spill in Port Phillip Bay from the 45 LNG carriers is approximately 1 per cent. The principal actions to limit and mitigate the effects of spills of fuel and chemicals are: • Rigorous procedures to minimize the likelihood of a spill: • Planned and effective spill response plan; and • Availability of boats, trained personnel and equipment to effectively deploy booms, skimmers, temporary storage systems and dispersants as required. These actions are described in Section 11.

Scoping Requirement	Outcome from Marine Impact Assessment
The potential for adverse effects on the functions, environmental values and the ecological character of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site*.	This impact assessment is made in Section 12. The main potential impacts addressed are direct impacts of chlorine, temperature and turbidity on seagrass habitat and fish breeding and dispersal, and indirect impacts on the habitat or food supply for waterbirds in the context of the Ramsar site. Other causes of indirect impacts assessed are spills of fuel and chemicals; extra light; underwater noise and imported pests. The conclusions from the assessment of potential impacts on the Ramsar site are listed in Table 12-6, together with appropriate mitigation and monitoring recommendations. No effect is expected for any of the 10 critical processes and services. As a check, monitoring is recommended for seagrass and infauna.
Likely Effects	
Assess likely direct and indirect effects of the project and alternatives on native vegetation, ecological communities and habitats for protected fauna and flora species, known or likely to occur in or adjacent to the project works, in particular any species listed under the EPBC Act, Flora and Fauna Guarantee Act or DELWP advisory lists.	The impact assessments are made in Sections 7, 8, 9, 10 and 11. It is noted that there would be a minor reduction in primary productivity during dredging, and a possible small long-term reduction in MBP productivity over 12 ha (the deeper dredged area). There would be no impact from marine construction or subsequent operations on any species listed under the EPBC Act, Flora and Fauna Guarantee Act or DELWP advisory lists, all of which are considered in the assessment.
Indirect loss of vegetation or habitat quality, that may support any listed species or other protected fauna, resulting from changes to the local hydrology (terrestrial) or hydrodynamics (marine), edge effects, habitat fragmentation, loss of connectivity, or other disturbance impacts arising from construction or operation, including noise, vibration and lights.	The extension of the existing 33 km long shipping channel by about 0.5 km would not cause any significant change in tides, currents, mixing or other hydrodynamic processes. The new pier would not be a barrier. The piles would add 1.2 ha of hard surface habitat for a range of marine animals and provide a refuge for small fish. There is no fragmentation or loss of connectivity of marine habitat. There are local noise, vibration and light effects during construction, which would be carried out subject to a range of management and mitigation measures. The extra light due to the FSRU and the LNG carriers would be minor in relation to existing lighting in Geelong and the existing refinery. Best practice would be used in the design of the lights on the new pier, including AS 4282: 2019 Control of the Obtrusive Effects of Outdoor Lighting and the National Light Pollution Guidelines for Wildlife (Jan 2020).

Scoping Requirement	Outcome from Marine Impact Assessment
Assess likely direct and indirect effects of the project on the ecological character and habitat values of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site*, including but not limited to effects of entrainment, dredging and sediment mobilisation, potential introduction of exotic organisms, wastewater discharges, other waste streams, noise, vibration and light.	This assessment is made in Section 12. The main potential impacts addressed in this section are for direct impacts of chlorine, temperature and turbidity on seagrass habitat, fish breeding and dispersal, and indirect impacts on the habitat or food supply for waterbirds in the context of the Ramsar site. Other causes of indirect impacts assessed are spills of fuel and chemicals; extra light; underwater noise and imported pests. There would be no change in the concentrations of the existing chlorine plume with the project, and the levels are below the site-specific Guideline Value. There would be a reduction in the extent of elevated temperature in the plume with the project, and the levels are below the site-specific Guideline Values. The conclusions from the assessment of potential impacts on the Ramsar site are listed in Table 12-6, together with appropriate mitigation and monitoring recommendations. No effect is expected for 10 of the 10 critical processes and services. As a check, monitoring is recommended for seagrass and infauna.
Assess likely direct and indirect effects of the project and alternatives on protected fauna and their habitat, including threatened or migratory species listed under the EPBC Act, Flora and Fauna Guarantee Act or DELWP advisory lists.	The assessments are made in Sections 7,8, 9, 10 and 11. It is noted that there would be a minor reduction in primary productivity during dredging, and a possible small reduction in MBP productivity over 12 ha (the deeper dredged area). Food needs of water birds and migratory birds were assessed and it is concluded that there will be no change in the food supply in the Ramsar habitat. There would be no impact from marine construction or subsequent operations on any species listed under the EPBC Act, Flora and Fauna Guarantee Act or DELWP advisory lists, all of which are considered in the assessment.
Assess likely cumulative effects on biodiversity-related values that might result from the project in combination with other projects or actions taking place or proposed nearby.	As set out in the Ecological Character Description for the Ramsar site (DELWP, 2020), the Point Wilson/Limeburners Bay coastal area is subject to stresses from a range of causes including: Climate change, particularly sea level rise; Nutrient inputs from Western Treatment Plant and the urban growth in the catchment, Litter (including micro-plastics); Feral animals (foxes, cats, rabbits and deer); Salt-tolerant weeds impacting saltmarsh and waterbird habitat; Recreational boats, jets skis, 4WD, motorbikes; and Duck hunting impacts to non-target species. The refinery discharges have been in place for over 60 years, so the Ramsar ecosystems and visitors are adapted to them. The view in this EES is that the impacts of the proposal on the Ramsar site are negligible whereas the impacts of the other stresses would be major over the coming decades.

Scoping Requirement	Outcome from Marine Impact Assessment
Assess the impacts of the construction and operation of the project on the Ramsar Site, particularly potential substantial and/or measurable changes to the hydrological regime, in the context of ecological character description and acceptable limits for change. Ensure a systems-based assessment with marine water quality, hydrodynamics and marine ecology studies undertaken together.	There would be no impact from marine construction or subsequent operations on the hydrological regime. Section 11 concludes the project would not have any effects that would come anywhere near an unacceptable limit for change, and the expected changes do not occur in the Ramsar area. The assessment of potential impacts on marine water quality, hydrodynamics and marine ecology involved field studies, use of existing data and a team of scientists taking an integrated approach to the assessment.
Mitigation	
Identify potential and proposed design options and measures that could avoid, minimise, mitigate or manage significant direct and indirect effects on native vegetation and any listed ecological communities or flora and fauna species and their habitat including the ecological character of the *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site* and habitat values within or adjacent to the pipeline alignment.	The recommended mitigation measures that could avoid, minimise, mitigate or manage significant direct and indirect effects on native vegetation and any listed ecological communities or flora and fauna species and their habitat are listed in Section 13.
Identify and evaluate aspects of project works and operations, and proposed design refinement options or measures, that could avoid or minimise significant effects on water, wetlands and marine environments.	The mitigation measures to minimise effects on the marine environment include: 1. Reuse seawater from FSRU in refinery; 2. Avoid dredging in spring spawning and growth season; 3. Limit duration of overflow from hopper barges; 4. Install silt curtain between dredging and refinery intake and seagrass; 5. Monitor turbidity during dredging, with threshold triggers and responses; 6. Limit noise and vibration during pier construction; 7. Design seawater intake to minimise entrapment 8. Locate seawater intake to minimise entrainment; 9. Design diffuser to achieve high dilution;

Scoping Requirement	Outcome from Marine Impact Assessment
	10. Design lighting to minimise adverse overspill; 11. Implement biosecurity measures on all vessels; 12. Manage cleaning and antifouling system on FSRU to avoid contamination; 13. Continue to use and upgrade spill management procedures; 14. Use pilots, tugs and comply with vessel speed restrictions; and 15. Minimise chlorine concentration at the discharge points
Best practice guidelines and standards must be considered when designing mitigations.	Best practice guidelines, including the Victorian Dredging Guideline, and standards were considered when designing mitigations.
Specific Impacts of Dredging on Seagrass Beds	CEE undertook extensive mapping of seagrass in the area of the project and established that no seagrass would be removed by the proposed dredging. While the maximum depth of seagrass for the whole of Corio Bay is around 4.5 m, video tows in the northwest of Corio Bay in January and February 2021 show that *Zostera* meadows were confined to depths less than around 3 m. No medium or dense *Zostera* was recorded beyond about 2.5 m. The waters that are being dredged are deeper than the extent of seagrass. The seabed surveys in north Corio Bay (see Figure 14-1) show that no seagrass would be dredged, as there is no seagrass present on that area of seabed.

Scoping Requirement	Outcome from Marine Impact Assessment
	 **Figure 14-1. Zones of Existing Seagrass in Relation to Dredging Zone**

14.2.3 Limit Duration of Overflow from Hopper Barges

To limit the extent of the turbidity plume from barges loading dredged material in Corio Bay, the overflow period for hopper barges associated with a small or medium-size backhoe dredge should be limited to 20 minutes while the overflow period for barges associated with a large size backhoe dredge should be limited to 14 minutes. This limits the sediment spill rate to below 9 kg/sec.

14.2.4 Install Silt Curtain

The simulation of the movement and dispersion of turbidity from dredging showed that during the 8-week period of dredging, there could be several days with elevated suspended solids concentrations at the refinery inlet (threatening refinery operations) and similar elevated concentrations at the seagrass beds near the shore adjacent to the refinery (see discussion in Section 7).

The effects can be mitigated by installing a temporary silt curtain between the dredging and the intake/seagrass bed. The design, installation, maintenance and removal of the silt curtain should be a component of the dredging operation.

The effectiveness of the silt curtain would be managed as part of a turbidity monitoring and management task in the Dredging Environmental Management Plan (DEMP).

14.2.5 Monitor Turbidity and Light Attenuation during Dredging

Background turbidity at the seagrass beds in Corio Bay is generally in the range of 1 to 2 NTU, with occasional peaks up to 6 NTU. Seagrass can tolerate in increase in turbidity over a short period, but not consistently elevated levels.

Turbidity and light attenuation should be monitored continuously at six sites - four sites in north Corio Bay and two sites inshore of the spoil disposal site. In Corio Bay, there should be three sites along the 3 m depth contour at the offshore boundary of the main seagrass beds, and one near the refinery intake. The following limits are proposed as thresholds for action to restrict turbidity releases:

- 12-hour concentration above 15 NTU (trigger warning);
- 24-hour concentration above 12 NTU (action required).

Actions taken would most likely involve reducing the period of overflow from barges to zero and slowing the dredging cycle of the backhoe. Monitoring, response triggers and corresponding management responses would be detailed in the DEMP.

Turbidity and light attenuation also should be monitored at two sites inshore of the dredge material disposal site, to ensure there is not shoreward movement of the plumes or fines from the dredge spoil.

14.2.6 Limit Noise and Vibration

There are well developed procedures to minimise impacts on marine mammals during piling operations or other noisy aspects of pier construction. These include marine spotters on the site, precautionary early warning signals, regular maintenance of equipment and other measures. These must be included in the Construction Environmental Management Plan.

14.2.7 Design Seawater Intake to Minimise Entrapment

As described in Section 11, the seawater intake should be designed to keep the intake velocity in the horizontal plane and at a speed below 0.15 m/s. This would minimise the capture of small and large fish or other free-swimming biota (birds, squid) moving in the shipping channel near the FSRU intake, and provide the same level of protection as the existing refinery intake.

The intake on the FSRU also would be provided with a screen with apertures less than 100 mm. This would prevent large objects and seaweed from being carried into the seawater cooling system.

14.2.8 Locate Seawater Intake to Minimise Entrainment

To ensure that a very low percentage of fish larvae are entrained in spring and summer, the seawater intake on the FSRU should be located so that it is at least 2 m below the water surface (to avoid entraining biota from near the surface) and at least 2 m above the seabed (to avoid entraining biota from near the seabed).

14.2.9 Design Diffuser to Achieve High Dilution

The near-field modelling described in Section 6 established that the diffuser would achieve an initial dilution of 20:1. This would ensure that the diluted discharge would have a chlorine concentration less than the GV and a temperature change from ambient of less than 0.4 ^{o}C.

As the diffuser would be seldom used, according to current refinery operating practices, the preliminary design for the impact assessment would need to be refined to incorporate duckbill valves to keep marine growth out of the diffuser. The final design is subject to the approval of the EPA, but it is recommended that a design requirement should be to achieve an initial dilution of 20:1.

14.2.10 Design Lighting to Minimise Adverse Overspill

Lighting is required on the FSRU and LNG carriers for safety purposes and for navigation. Best practice should be used in the design of the lights on the new pier, including AS 4282: 2019 *Control of the Obtrusive Effects of Outdoor Lighting* and the National *Light Pollution Guidelines for Wildlife* (Jan 2020). Design of the lighting on the new pier would be required to meet the guidelines.

14.2.11 Implement Biosecurity Measures on all Vessels

It is well known that Port Phillip Bay and Corio Bay have an established community of introduced marine pests, as described in Section 11. Marine pest introduction to Australian waters from shipping is managed by the Commonwealth Department of Agriculture and Water through the implementation of the *National Plan for Marine Pest Biosecurity* 2018-2023 (DAW 2018).

There are well-established measures to control and minimise the introduction of marine pests these days and all applicable measures should be implemented, including:

- Antifoul coating to prevent the encrusting of biota on the hull;
- Vessels from certain ports to be cleaned before entry;
- Manage ballast water in accordance with the *Australian Ballast Water Management Requirements* (DAWR, 2017);

- Manage vessel activities in accordance with the *National System for the Prevention and Management of Marine Pest Incursions*.

These measures would be part of the Environmental Management Plan associated with the existing refinery shipping activities.

14.2.12 Manage Cleaning and Antifouling on FSRU

The anti-foul coating on the FSRU would need to be cleaned and maintained periodically. There are established procedures to collect scrapings from the hull and prevent them from accumulating on the seabed. Only approved antifoul coatings should be used for bio-foul management.

14.2.13 Use and Upgrade Spill Management Procedures

A spill is an ever-present potential risk in Corio Bay. Viva Energy and Ports Victoria and other port managers have a well-established spill management plan as a component of the Port of Geelong Safety and Environment Management Plan (SEMP), which is a requirement of Part 6A of the Port Management Act 1995.

The mitigation measures are to continue to implement the existing spill management plan and to seek new and better monitoring procedures (eg, using continuously operating sensors fitted on the sides of jetties) for early detection of spills.

14.2.14 Use Pilots and Tugs

A risk identified in Section 1 was the grounding of a vessel, leading to a spill. The mitigation measure is to have all vessels under the control of experienced and qualified captains and pilots, and to operate only in the dredged channel or for smaller vessels, within the defined operation area. The dredge spoil transport barges and LNG carriers are to adhere to the Ports Victoria vessel speed requirements to limit the risk of whale strikes.

14.2.15 Minimise Chlorine Concentration at Discharge Points

The seawater chlorination process at the FSRU and the refinery should be managed to minimise the concentration of chlorine in the seawater discharges, consistent with good practice while also achieving the purpose of chlorination (which is to avoid internal biofouling).

14.3 Conclusions and Recommendations for Monitoring

Monitoring and associated management response is an essential part of verifying that the assumptions in the EES are justified, the actual environmental impacts are not greater than what was predicted, and that any unexpected circumstances are detected and responded to appropriately to meet the environmental responsibilities of the proponent. The final monitoring program would be designed in collaboration with a marine environmental specialist, statistician and the EPA.

The recommended components of the marine monitoring plan are as follows.

1. Monitor Turbidity and Light Attenuation during Dredging

Turbidity should be monitored continuously at four sites in north Corio Bay, with three sites along the 3 m depth contour at the offshore boundary of the main seagrass beds and one near the refinery intake. The following limits are proposed as thresholds for action to restrict turbidity releases:

- 12-hour concentration above 15 NTU (trigger warning);
- 24-hour concentration above 12 NTU (action required).

Turbidity should be monitored continuously at two sites 600 m inshore of the spoil disposal zone to confirm that there is not regular transport of turbidity from barge disposal into shallow water near Point Wilson.

Light attenuation should be monitored at the same six sites.

The extent of plumes should be monitored visually during dredging to provide real time feedback to project managers. The monitoring should commence two months prior to dredging, continue throughout the dredging period and extend for two months after dredging has been completed.

2. Monitor Seabed Biota in Dredged and Spoil Disposal Areas

Two baseline surveys should be made with a 3-month gap prior to dredging, and four post-commissioning surveys in the same locations every 3 months for 2 years of benthic fauna abundance, diversity and composition to detect any significant changes to infauna communities in the dredged area and the recovery of the spoil disposal area.

3. Monitor Phytoplankton during and after Dredging

Plankton populations should be monitored at four sites in north Corio Bay (as used in the 2020-2021 plankton surveys) before, during and after the dredging period, at two weekly intervals. The purpose is to identify if there is a bloom of toxic phytoplankton as a result of release of nitrogen or toxic algal spores during dredging.

The phytoplankton surveys should commence 4 weeks before dredging and continue for 8 weeks after dredging has been completed. The standard notifications to EPA and aquaculture should be made in the event that there is a bloom.

4. Monitor Rates and Characteristics of all Discharges. Monitoring and recording of the flow rate, temperature and residual chlorine concentration of all major discharges, excluding fire water, water curtain and ballast water, is required.

The objectives are to keep a record of all discharges, confirm that the discharge rate and chlorine concentration are within the values used in the EES (and the EPA licences) and, if not, provide the trigger for remedial action.

Detailed Dredging and other Monitoring Plans

The detailed monitoring plan during dredging and subsequent construction and operation of the project would be developed in cooperation with DELWP and the EPA as part of the application process for the MACA consent and EPA Development and Operation Licences. Consultation around the expected timeframe and intervals for long-term marine monitoring after dredging would be agreed with relevant agencies including EPA, DELWP, Barwon Water and Ports Victoria for the proposed turbidity, seabed/seagrass condition and phytoplankton studies.

References:

Abdel-Wahab A, Khodary A and , N Bensalah (2010). Formation of Trihalomethanes during Seawater Chlorination. Journal of Environmental Protection, 2010, 1, 456-465

AECOM. (2004). Port Phillip Bay Channel Deepening Project EES. Melbourne.

AECOM. (2021). Dredging and Offshore Contamination Assessment. Melbourne.

Amtstaetter, F., Tonkin, Z., O'Conner, J., Stuart, I., & Koster, W. M. (2021). Environmental Flows Stiultae the Upstream Movement of Juvenile Diadromous Fishes. Marine and Freshwater Research, 1019-1026.

ANZECC (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Vol 1. paper 4.

ANZG. (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Canberra, ACT, Australia.

Arnott, G. H., & McKinnon, A. D. (19985). The Developmental Stages of gladioferens Pectinatus. New Zealand Journal or Marine Freshwater Research, 21-42.

Atlas of Living Australia (2017). CSIRO and NCRIS. https://www.ala.org.au/ accessed September 2021.

Australian/New Zealand Standards. (1998). Water quality - Sampling guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. AS 5667.1.

Axelrad, D. M., Hickman, N. J., & Gibbs, C. F. (1979). Microalgal productivity as affected by treated sewage discharge to Port Phillip Bay. Port Phillip Bay Environmental Study Werribee Project (PO1), Environmental Studies Series Publication No. 241. Ministry for Conservation.

Ball, D., Soto-Berelov, M., & Young, P. (2014). Historical Seagrass Mapping in Port Phillip Bay, Australia. Journal of Coastal Conservation.

Batley GE and Simpson SL. (2019). Behaviour and regulation of chlorine in waters associated with the AGL Gas Import Jetty Project. CSIRO Land and Water Report EP192345, Lucas Heights, NSW, Australia, 22 pp

Beardall, J., & Light, B. (1997). Microphytobenthos in Port Phillip Bay: Distribution and Primary Productivity. Canberra: CSIRO.

Bengtsson, U., McMahon, J., Quarrell, O., rubenstein, C., David, K., greenburg, F., & Wasmuth, J. (1990). Phenotypically normal carriers of unbalanced terminal deletions of 5p transmit the deletions to offspring who display growth and developmental delay. AM J Hum Genet.

Biosecurity ACT (2015). Includes amendments up to No. 93, 2017. Compilation No. 5. Australia

Black, K. P., Longmore, A. R., Hamer, P. A., Lee, R., Swearer, S. E., and Jenkins, G. P. (2016). Linking nutrient inputs, phytoplankton composition, zooplankton

dynamics and the recruitment of pink snapper, Chrysophrys auratus, in a temperate bay. Estuarine, Coastal and Shelf Science 183, 150-162.

Blake, S. and Ball, D. (2001). Victorian Marine Habitat Database: Seagrass. Mapping of Western Port. Queenscliff, Marine and Freshwater Resources Institute.

Blake, S., & Ball, D. (2001). Seagrass Mapping of Port Phillip Bay. Marine and Freshwater Resource Institute.

Boon et al (2011). Mangroves and Coastal Saltmarsh of Victoria. Distribution, Condition, Threats and Management.

Bothelo, D. and Imberger, J., 2007.Dissolved-oxygen response to wind-inflow interactions in a stratified reservoir. Limnology and Oceanography, vol. 52 (5), pp. 2027 – 2052.

Boudjellaba D, Dron J, Revenko G Demalas C and J-L Boudenne (2016). Chlorination by-product concentration levels in seawater and fish of an industrialised bay (Gulf of Fos, France) exposed to multiple chlorinated effluents. Science of the total environment 541: 391-399

Bulthuis, D. A. (1983). Effects of in situ light reduction on density and growth of the seagrass Heterozostera tasmanica (Martins Ex Archers). . Journal of Experimental Marine Biology and Ecology, 67-91.

Bulthuis, D.A. (1983a). Effects of in Situ Light Reduction On Density and Growth of the Seagrass Heterozostera Tasmanica (Martins Ex Aschers). Den Hartog in Western Port, Victoria, Australia. Journal of Experimental Marine Biology and Ecology 67:91-103.

Bulthuis, D.A. (1983b). A report on the status of the seagrasses in Western Port in May 1983. Ministry for Conservation, Marine Science Laboratories Internal Report No. 38.

Cabaco, S., Santos, R., & Duarte, C. (2008). The Impact of Sediment Burial and Erosion on Seagrass: A Review. Estuarine, Coastal and Shelf Science, 354-366.

Cahoon, L. (1999). The role of benthic microalgae in neritic ecosystems. Oceanography and Marine Biology, 47-86.

Carey, J. M., & Watson, J. E. (1992). Benthos of the muddy bottom habitat of the Geelong Arm of Port Phillip Bay, Victoria, Australia. Victorian Naturalist, 196-202.

CCME. (1999). Canadian Environmental Quality Guidelines. Winnipeg.

CCME. (2007). A protocol for the derivation of water quality guidelines for the protection of aquatic life. Winnipeg.

CEE Pty Ltd. (2021a). CEE Technical Report for Phytoplankton Sampling in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021b). CEE Technical Report for Zooplankton Sampling in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021c). CEE Technical Report for Ichthyoplankton Sampling in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021d). CEE Technical Report for Seawater temperature and Salinity in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021e). CEE Technical Report on Infauna Sampling in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021f). CEE Technical Report on Benthic Ecological Habitats in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021g). CEE Technical Report on Current Monitoring in Corio Bay. Melbourne: AECOM.

CEE Pty Ltd. (2021h). CEE Technical Report on Light Monitoring in Corio Bay. Melbourne: AECOM.

Chan, T., Hamilton, D., Robson, B., Hodges, B. and Dallimore, C., 2002, Impacts of hydrological changes on phytoplankton succession in the Swan River, Western Australia. Estuaries, 25(6B): 1405-1415

Charlton-Robb. K, Taylor A. C, McKechnie S.W. (2015). Population genetic structure of the Burrunan dolphin (Tursiops australis) in coastal waters of south-eastern Australia: conservation implications. Conservation Genetics. Volume 16, Issue 1, pp 195–207

Coffey. (2020). Sediment Contamination Assessment - Geelong LNG Regasification Terminal Project. Melbourne.

Commonwealth of Australia. (2009). national Assessment Guidelines for Dredging. Canberra.

CRIMP. (1999). Marine Biological Invasions of Port Phillip Bay Victoria - Technical Report Number 20. Hobart: CSIRO.

Crinall, S. M., & Hindell, J. S. (2004). Assessing the use of saltmarsh flats by fish in temperate Australian embayment. Estuaries and Coasts, 728-739.

Crook, D. A., Macdonald, J. I., O'Connor, J. P., and Barry, B. (2006). Use of otolith chemistry to examine patterns of diadromy in the Australian grayling Prototroctes maraena. Journal of Fish Biology 69, 1330-1344.

CSIRO. (1996). Port Phillip Bay Environmental Study. Canberra: CSIRO.

CSIRO. (1997). Port Phillip Environmental Report - The Findings 1992 - 1996. CSIRO.

Currie, D., & Parry, G. (1999). Changes to benthic Communities Over 20 Years in Port Phillip Bay, Victoria, Australia. Marine Pollution Bulletin, 36-43.

Currie, D.R., McArthur, M.A. & Cohen, B.F. (1998). Exotic marine pests in the Port of Geelong, Victoria. Report No. 8. Marine and Freshwater Resources Institute, Queenscliff, Vic.

Dallimore, C., Hodges, B. and Imberger, J., 2003.Coupling and underflow model to a three-dimensional hydrodynamic model. Journal of Hydraulic Engineering, 129 (10), pp. 748 – 757.

DAW. (2018). National Plan for Marine Pest Biosecurity 2018-2023.

DAWE. (1999). Environment Protection and Biodiversity Act. Australia.

DAWE. (2015). Biosecurity Act. Australia.

DAWE. (2020). PFAS National Environment Management Plan 2.0. Australia.

DEE. (2019). Commonwealth Draft National Light Pollution Guidelines for Wildlife.

DELWP. (2018). Port Phillip Bay (Western Shoreline) and Bellarine Peninsula - Ramsar Site Management Plan. Melbourne: DELWP.

Department of Environment and Primary Industries. (2013). Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Boundary Description - Technical Report. Melbourne: Department of Environment and Primary Industries.

Dimmlich, W. (2010). The life history and stock assessment of anchovy , Engraulis australis, in South Australia. Adelaide: School of Earth and Environmental Sciences - university of Adelaide.

Dimmlich, W. F., & Ward, T. M. (2006). Ontogenetic shifts in the distribution and reproductive patterns of Australian Anchovy (Engrauis australis) by otolith microstructure analysis. Marine and Freshwater Research, 373-381.

Dinnel, P., Stober, Q., & Dijulio, D. (1980). Sea urchin sperm bioassay for sewage and chlorinated seawater and its relation to fish bioassays. Fisheries Research Institute - University of Washington, 29-39.

Dodd, K., & Wood, S. (2009). Sub-Tidal Ecological Risk Assessment, Shell Refinery, Corio. ERM.

DoEE (2014). Recovery Plan for the Grey Nurse Shark (Carcharias taurus), Department of Environment and Energy, Canberra.

DSEWPC. (2011). Conservation Management Plan for the Southern Right Whale. Canberra.

Edmunds, M. (2004). Port Phillip Bay Channel Deepening Study - Environmental Effects Statement: Marine Ecology Specialist Studies. Vol 11 - Impact Analysis Methods. Channel Deepening EES Volume 3 A1. Melbourne: Port Of Melbourne.

Eigenraam, M., McCormick, F., & Contreras, Z. (2016). Marine and Coastal Ecosystem Accounting: Port Phillip Bay. Melbourne: DELWP.

Environment Protection and Biodiversity Conservation ACT (1999). Incorporating ammendments as at 30 August 2019. Compliaiotn No. 53, Australia

Environment Protection and Biodiversity Conservation ACT (1999). Incorporating ammendments as at 30 August 2019. Compliaiotn No. 53, Australia

EPA (2001). Protecting the Waters of Western Port and Catchment. EPA Publication no 797. Environment Protection Authority.

EPA Vic. (2010). Baywide Water Quality Monitoring Program - Milestone Report #6. Melbourne.

EPA Vic. (2020). Environment Reference Standard. Melbourne.

EPA Vic. (2020). Report Card 2019-20. Publication number 1923. Vic, Australia.

EPA. (2001). Best Practice Guidelines for Dredging - EPA Report 691. Melbourne.

EPA. (2010). Baywide Water Quality Monitoring Report Program - Milestone Report 5. Melbourne.

Fettweis, M., Francken, F., Van den Eynde, D., Verwaest, T., Janssens, J., & Lancker, V. V. (2012). Storm Influence on SPM concentrations in a coastal turbidity maximum area with high anthropogenic impact (Southern North Sea). Continental Shelf Research, 1417-1427.

Fisheries ACT (1995). Authorised version incorporating amendments as at 1 February 2020. Authorised Version No. 095. Victoria, Australia

Flora and Fauna Guarantee Act (1988). Authorised version incorporating amendments as at 1 March 2019. Authorised version No. 045. Victoria, Australia

Foord, C., Rowe, K., & Robb, K. (2019). Cetacean biodiversity, spatial and temporal trends based on stranding records (1920 - 2016). Victoria Australia. PLoS ONE.

Fulton, W., Jenkins, G. P., and Walker, T. I. (2006). Literature review of protected and listed marine fauna of Port Phillip Bay and identification of potential impacts of channel deepening. Primary Industries Research Victoria, Internal Report No. 70, Queenscliff, Victoria, Australia.

Goodwin, K. D., North, W. J., & Lidstrom, M. E. (1997). Production of bromoform and dibromomethane by giant kelp: factors affecting release and comparison to anthropogenic bromine sources. California Institute of technology, Environmental Engineering Science, 138-178.

Gray, C., & Barnes, L. (2008). Reproduction and growth of dusky flathead (Platycephalus fuscus) in NSW estuaries. NSW Department of Primary Industries.

Gribble G.W (2012). Chapter 1—Occurrence of halogenated alkaloids. In: Knölker H.-J., editor. The Alkaloids: Chemistry and Biology. Volume 71. Academic Press; Amsterdam, The Netherlands. pp. 1–165.

Hamer, P. A., Acevedo, S., Jenkins, G. P., and Newman, A. (2011). Connectivity of a large embayment and coastal fishery: spawning aggregations in one bay source local and broad-scale fishery replenishment. Journal of Fish Biology 78, 1090-1109.

Hamer, P. A., and Jenkins, G. P. (2004). High levels of spatial and temporal recruitment variability in the temperate sparid Pagrus auratus. Marine and Freshwater Research 55, 663-673.

Hamer, P. A., Jenkins, G. P., and Gillanders, B. M. (2005). Chemical tags in otoliths indicate the importance of local and distant settlement areas to populations of a temperate sparid, Pagrus auratus. Canadian Journal of Fisheries and Aquatic Sciences 62, 623-630.

Hamer, P. A., Jenkins, G. P., and Sivakumaran, K. P. (2004). Identifying the spawning locations of King George whiting in Victorian waters: a recreational fishing based study. Fisheries Victoria Research Report Series No. 21.

Hamer, P., & Mills, K. (2017). Anglers tune in to find out why Port Phillip Bay is so Important to Snapper. Department of Economics, Jobs, Transport and Resources.

Harris, G., Batley, G., & Fox, D. (1996). Port Phillip Bay Evironmental Study: Final Report. CSIRO.

HEPA. (2020). PFAS National Environmental Management Plan 2.0. HEPA.

Hewitt, C. L., Campbell, M. L., Thresher, R. E., & Martin, R. B. (1999). Marine Biological Invasions of Port Phillip Bay, Victoria - Technical Report No. 20. Centre for Research on Introduced marine Pests.

Hillmer, I. and Imberger, J., 2007.Influence of advection on scales of ecological studies in a coastal equilibrium flow. Continental Shelf Research, 27 (1), pp. 134-153

Hindell, J. S., & Jenkins, G. P. (2004). Spatial and temporal variability in the assemblage structure of fishes associated with mangroves (Avicennia marina) and intertidal mudflats in temperate Australian embayments. Marine Biology, 385-395.

Hindell, J. S., and Jenkins, G. P. (2005). Assessing patterns of fish zonation in temperate mangroves, with emphasis on evaluating sampling artefacts. Marine Ecology-Progress Series 290, 193-205.

Hindell, J.S., Jenkins, G.P. and Keough, M.J. (2000). Evaluating the impact of predation by fish on the assemblage structure of fishes associated with seagrass (Heterozostera tasmanica) (Martens ex Ascherson) den Hartog, and unvegetated sand habitats. Journal of Experimental Marine Biology and Ecology 255: 153-174.

Hirst , A., Werner, G., Heislers, S., White, C., & Spooner, D. (2011). Port Phillip Bay Annual Trawl Sub-Program: Progress Report No. 4 . Department of Primary Industries.

Hirst, A. (2008). Baywide seagrass monitoring program: milestone report 3. Department of Primary Industries.

Hirst, A. J., Longmore, A. R., Ball, D., Cook, P. L. M., and Jenkins, G. P. (2016). Linking nitrogen sources utilised by seagrass in a temperate marine embayment to patterns of seagrass change during drought. Marine Ecology Progress Series 549, 79–88.

Hodges, Ben & Imberger, Jorg & Saggio, Angelo & Winters, K.. (2000). Modelling Basin-Scale Internal Waves in a Stratified Lake. Limnology and Oceanography. 45. 1603-1620. 10.4319/lo.2000.45.7.1603.

Hoedt, F. E., and Dimmlich, W. F. (1995). Egg and larval abundance and spawning localities of the anchovy (Engraulis australis) and pilchard (Sardinops neopilchardus) near Phillip Island, Victoria. Marine and Freshwater Research 46, 735-743.

HydroNumerics. (2022). Viva Regasification Project - Hydrodynamic Modelling Report. HydroNumerics.

Jagger, R., Kimmerer, W., & Jenkins, G. (1988). Food of the cladoceran Podon intermedius in a marine embayment. marine Ecology - Progress Series, 245-250.

Jenkins, G. (2005). The influence of climate on the fishery recruitment of a temperate, seagrass associated fish, the King George whiting, Sillaginodes punctata. Marine Ecology Progress Series, 263-271.

Jenkins, G. P. (1986). Composition, seasonality and distribution of ichthyoplankton in Port Phillip Bay, Victoria. Australian Journal of Marine and Freshwater Research 37, 507-520.

Jenkins, G. P., and King, D. (2006). Variation in larval growth can predict the recruitment of a temperate, seagrass-associated fish. Oecologia 147, 641-649.

Jenkins, G. P., Black, K. P., and Hamer, P. A. (2000). Determination of spawning areas and larval advection pathways for King George whiting in southeastern Australia using otolith microstructure and hydrodynamic modelling. I. Victoria. Marine Ecology Progress Series 199, 231-242.

Jenkins, G. P., Black, K. P., Wheatley, M. J., and Hatton, D. N. (1997a). Temporal and spatial variability in recruitment of a temperate, seagrass-associated fish is largely determined by physical processes in the pre- and post-settlement phases. Marine Ecology Progress Series 148, 23-35.

Jenkins, G. P., Hamer, P. A., Kent, J. A., Kemp, J., Sherman, C. D. H., and Fowler, A. J. (2016). Spawning sources, movement patterns, and nursery area replenishment of spawning populations of King George Whiting in south-eastern Australia — closing the life history loop. Fisheries Research and Development Corporation Final Report, Deakin, Canberra.

Jenkins, G. P., Hutchinson, N., Hamer, P. A., and Kemp, J. (2012). Fisheries Adaptation to Climate Change - Marine Biophysical Assessment of King George whiting. Fisheries Victoria Research Report Series, No. 57.

Jenkins, G. P., Kenner, T., Brown, A., and Coleman, R. (2015). Fish assemblages in locations with alternative structured habitats in an eelgrass, Zostera, dominated bay: Biodiversity value and potential for refuge. Estuarine, Coastal and Shelf Science 161, 25-37. doi:http://dx.doi.org/10.1016/j.ecss.2015.05.007

Jenkins, G. P., May, H. M. A., Wheatley, M. J., and Holloway, M. G. (1997b). Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with emphasis on commercial species. Estuarine, Coastal and Shelf Science 44, 569-588.

Jenkins, G., May, H., Wheatley, M., & Holloway, M. (1997a). Comparison of fish assemblages associated with seagrass and adjacent unvegetated habitats of Port Phillip Bay and Corner Inlet, Victoria, Australia, with emphasis on commercial species. Estuarine, Coastal and Shelf Sceince, 569-588.

Jenkins, G., Watson, G., & Hammond, L. (1993). Patterns of utilisation of seagrass (Heterozostera) dominated habitats as nursery areas by commercially important fish. Victorian institute of Marine Science.

Jenner H and A Wither (2011). Chlorination by-product in power station cooling water. Science Advisroy report. BEEMS Expert Panel. EDF Energy UK. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010001/EN010001-005166-HPC-NNBPEA-XX-000-RET-000153%201.pdf

Kilminster, K., McCahon, K., Waycott, M., Kendrick, G., Scanes, P., McKenzie, L., . . . Udy, J. (2015). Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of the Environment.

Koster, W., and Dawson, D. (2010). Investigation of Australian Grayling spawning in the Yarra and Bunyip rivers. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria.

Koster, W., Weeks, A., Dawson, D., and Hale, R. (2019). Influence of streamflow on the immigration of diadromous fishes into the Bunyip River. Unpublished Client Report for Melbourne Water. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

Kuyper, B., Palmer, C., Labuschagne, C., & Reason, C. (2018). Atmospheric bromoform at Cape Point, South Africa: An initial fixed point dataset on the african continent. Atmos. Chem. Phys, 5785-5797.

Lawson and Treloar. (1998). Port Phillip Heads - Offshore wave climate: report prepared for DNRE and Vantree Pty Ltd. Lawson and Treloar.

LeBaron, K., Mechiri, L., Richard, S., Austruy, A., Boudenne, J., & Coupe, S. (2019). Assessment of individual and mixed toxicity of bromoform, tribromoacetic-acid and 2,4,6 tribromophenol, on the embryo-larval development of Paracentrotus lividus sea urchin. Environmental Science and Pollution Research, 20573-20580.

Light, B., & Woelkerling, W. (1992). Literature and information review of the benthic flora of Port Phillip Bay, Victoria, Australia. Port Phillip Bay Environment Study Report Number 6. CSIRO.

Ling, S. D., Kriegisch, N., Woolley, B., & Reeves, S. E. (2019). Density-dependant feedbacks, hyseresis, and demogrphy of overgrazing sea urchins. Hobart: institute for marine and Antarctic Studies - University of Tasmania.

Longmore, A., & Hale, J. (2006). Supplementary Environment Effects Statement. Head Technical Report: Nutrient cycling-current conditions and impact .

Lucieer, V., Roche, M., Degrendele, K., Malik, M., Dolan, M., & Lamarche, G. (2017). User expectations for multibeam backscatter data—looking back into the future. In: Seafloor backscatter data from swath mapping echosounders: From technological development to novel applications, Marine Geophysical Research .

Murphy H.M., Jenkins, G.P., Hamer, P.A., Swearer, S.E. (2012). Interannual variation in larval survival of snapper (Chrysophrys auratus, Sparidae) is linked to diet breadth and prey availability. Canadian Journal of Fisheries and Aquatic Sciences, 69: 1340-1351.

Murphy, H. M., Jenkins, G. P., Hamer, P. A., and Swearer, S. E. (2013). Interannual variation in larval abundance and growth in snapper Chrysophrys auratus (Sparidae) is related to prey availability and temperature. Marine Ecology Progress Series 487, 151-162. doi:10.3354/meps10388

Murray, A., & Parslow, J. (1997). Port Phillip Bay Integrated Model: Final report - Technical Report No. 44. Canberra: CSIRO.

NAGD. (2009). National Assessment Guidelines for Dredging. Canberra: Commonwealth of Australia.

Neira, F. J., and Sporcic, M. I. (2002). Use of ichthyoplankton ecology to evaluate ecosystem changes: a case study in a large, semi-enclosed Australian bay. Marine and Freshwater Research 53, 339-354.

NEPC. (1999). National Environment Protectio (Assessment of Site Contamination) Measure - As amended 2013. national Environment Proection Council. Australia.

NIWA. (2004). The Role of Sediment in Keeping Seagrass Beds Healthy. Water and Atmosphere.

O'Connor, J. P. (2015). Action statement No.257 Flora and Fauna Guarantee Act 1988 Australian Grayling Prototroctes maraena. State of Victoria Department of Environment, Land, Water and Planning.

Peel, D., Smith, J., & Childerhouse, S. (2016). Historical Data on Australian Whale Vessel Strikes. CSIRO.

Peel. D, Smith. J.N, Childerhouse. S (2016). Historical Data on Australian Whale Vessel Strikes. International Whaling Commission.

Poore, G., & Rainer, S. (1974). Distribution and abundance of soft-bottom molluscs in Port Phillip Bay, Victoria, Australia. Marine and Freshwater Research.

Potouroglou, M., Bull, J. C., & Krauss, K. W. (2017). Measuring the Role of Seagrasses in regulating Sediment Surface Elevation. Sci Rep.

Quark, B., & Wallace, D. (2003). Air-sea flux of bromoform: controls, rate and implications. Global Biogeochemical Cycles.

Quark, B., Atlas, E., Petrick, G., Stroud, V., Schauffler, S., & Wallace, D. (2004). Oceanic bromoform sources for the tropical atmosphere. Geophysical Research Letters.

Robb, K., & McKechnie, S. (2014). Population genetic structure of the Burrunan dolphin (Tursiops australis) coastal waters of south-eastern Australia : conservation implications. Conservation genetics.

Romero, J., Antenucci, J. and Imberger, J., 2004.One- and three-dimensional biogeochemical simulations of two differing reservoirs. Ecological Modelling, 174 (1 – 2), pp. 143 – 160.

Rowe, D. K., & Dean, T. L. (1998). Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. Mar. Freshwater. Res., 21-29.

Rysgaard, S., Christensen, P. B., & Nielsen, L. P. (1995). Seasonal variation in nitrification and denitrification in estuarine sediment colonized by benthic microalgae and bioturbating infauna. Mar Ecol Prog Ser, 111-121.

Saeed. S, Prakash. S, Deb. N, Campbell. R, Kolluru. V, Febbo. E and Dupont. J (2015). Development of a Site-Specific Kinetic Model for Chlorine Decay and the Formation of Chlorination BY-Products in Seawater. Journal of Marine Sceience and Engineering. Vol 3. pages 772 - 792. ISSN 2077-1312

Satpathy K, Mohanty A, Sahu G, Biswas S and M Selvanayagam (2010) . Biofouling and its Control in Seawater Cooled Power Plant Cooling Water System - A Review. Open Access DOI 10.5772/9912

Silva, C., Marti, C. and Imberger, J., 2014.Physical and biological controls of algal blooms in the Río de la Plata. Environmental Fluid Mechanics, 14, pp. 1199-1228

Simpson, S. L., & Batley, G. E. (2016). Sediment Quality Assessment: A practical Guide. CSIRO.

Simpson, S., Mosley, L., Batley , G., & Shand, P. (2018). National Acid Sulphate Soils Guidance: guidelines for the Dredging of acid sulfate soils and associated dredge spoil management. Canberra: DAWR.

Sim-Smith, C. J., Jeffs, A. G., & Radford, C. A. (2013). the relationship between growth and energy storage in juvenile snapper (Chrysophrys auratus : Sparidae). Marine and Freshwater Research, 1003-1010.

Spillman, C., Imberger, J., Hamilton, D., Hipsey, M. and Romero, J., 2007.Modelling the effects of Po River discharge, internal nutrient cycling and hydrodynamics on biogeochemistry of the Northern Adriatic Sea, Journal of Marine Systems, 68 (1-2), pp. 167-200.

Stemmer, I., Hense, I., & Quark, B. (1967). Marine sources of bromoform in the global open ocean - global patterns and emissions. Biogeosciences, 1967-1981.

Stevens, J. D., and West, G. J. (1997). Investigation of school and gummy shark nursery areas in south eastern Australia. FRDC Final Report: Project 93/061.

Summerson, R., Bloomfield, N., & Arthur, T. (2019). Treated Ballast Water and its Impact on Port Water Quality - Technical Report 19.1. Department of Agriculture and Water Resources.

USEPA (2004). National Pollutant Discharge Elimination System: Final Regulations Addressing Cooling Water Intake Structures for New Facilities; Final Rule. Federal Register. Part II. Environmental Protection Agency 40 CFR Parts 9, 122, 123, 124 and 125.

USEPA. (2004). National Pollutant Discharge Elimination System: Final Regulations Addressing Cooling Water Intake Structures for New Facilities; Final Rule. Federal Register. Part II. CFR Parts 9, 122, 123, 124 and 125.

Victoria Government. (1988). Flora and Fauna Guarantee Act. Victoria, Australia.

Victorian Government. (1978). Environment Efects Act. Victoria, Australia.

Victorian Government. (1987). Planning and Environment Act. Victoria, Australia.

Victorian Government. (1995). Fisheries Act. Victoria, Australia.

Victorian Government. (2017). Environment Protection Act. Victoria, Australia.

Victorian Government. (2018). Marine and Coastal Act. Victoria, Australia.

Victorian Regional Channels Authority (2018). Vic Tides 2018 Edition 2. Victorian Regional Channels Authority

Viva Energy. (2014). Jetty Operation manual - Pollution. Viva Energy.

Viva Energy. (2018). Oil Spill Contingency Plan. Viva Energy.

Wallis (1985) Initial Dilution for Outfall Parallel to a Current.Proc. ASCE, J Hyd. Div.Prepared with Hinwood, J. B.

Wallis (2016) "Outfall Construction Using Inclined Drilling", Internat Symp onOutfall Systems, Ottawa, IAHR, pp 201-209

Water Technology (2017). Hydrodynamic & Water Quality Modelling, Western Port Bay. Report to AGL Wholesale Gas Ltd.

Zeng, J., & Jiang, Z. (2009). The decay kinetic of residual chlorine in cooling seawater simulation experiments. Acta Oceanologica Sinica - English Edition, 54-59.

Zeng, Jiangning & Jiang, Zhibing & Quanzhen, CHEN & Yijun, ZHENG. (2009). The decay kinetic of residual chlorine in cooling seawater simulation experiments. Acta Oceanologica Sinica -English Edition. 28. 54-59.

Ziska, F., Quark, B., Abrahamsson, K., Archer, S., Atlas, E., Bell, T., . . . Yokouchi, Y. (2013). Global sea-to-air flux climatology for bromoform. dibromomethane and methyl iodide. Atmos. Chem. Phys., 8915-8934.

Appendix A-1: Baseline Monitoring of Ambient Underwater Noise Environment

Viva Energy Gas Terminal Project Environment Effects Statement

JASCO Applied Sciences (Australia) Pty Ltd

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Executive Summary

This technical report provides the results of underwater acoustic monitoring conducted to support an underwater noise impact assessment (Lucke and McPherson 2021) and inform underwater acoustic modelling (Green et al. 2021) which forms part of the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

The measurement component of this program was completed to characterise the ambient environment, and to achieve this a single JASCO Autonomous Multichannel Acoustic Recorder (AMAR) was deployed in Corio Bay from Aug-Sep 2021 for a period of 37 days. The recorder collected data continuously over the frequency band of 10–32000 Hz, and thus captured the majority of anthropogenic contributions in the area, along with natural and biological contributors. These data were analysed with the goal being to present this the data in a manner that documents the baseline underwater sound conditions in Corio Bay and allows us to examine temporal variations, and to correlate with external factors that change sound levels such as weather and human activities.

The most substantial contribution to the soundscape in Corio Bay is from vessel noise occupying bands below approximately 1000 Hz, with many distinct tones related to vessel propulsion observable in the 30-200 Hz ranges of data representations such as spectrogram and percentiles. JASCO's vessel detector, optimised for larger vessels, demonstrates that these signals are present for a significant amount of time per day for the entire monitoring period.

The soundscape also includes a faint dusk and dawn invertebrate chorus, with the primary contributor likely being snapping shrimp. No automated detectors or manual review was conducted to determine the presence of marine mammals. The low tidal variation does not offer a strong contribution to the soundscape, and on occasion, a significant storm event was recorded.

The monitoring results demonstrate that when compared to long term recordings of other Australian harbours, such as Fremantle Inner Harbour (Salgado Kent et al. 2012), Corio Bay has higher median sound levels, and has a soundscape primarily defined by anthropogenic contributors, with shipping being the dominant factor.

1. Introduction

1.1. Project Overview

This technical report provides the results of underwater acoustic monitoring conducted to support an underwater noise impact assessment (Lucke and McPherson 2021) and inform underwater acoustic modelling (Green et al. 2021) which forms part of the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a gas terminal using a ship known as a floating storage and regasification unit (FSRU), which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas for the south-east Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU) and would convert LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification) as required to meet industrial, commercial, and residential customer demand. A 7 km gas transmission pipeline would transfer the gas from the FSRU to the Victorian Transmission System (VTS) at Lara.

The project would be situated adjacent to, and on, Viva Energy's Geelong Refinery, within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. Co-locating the project with the existing Geelong Refinery and within the Port of Geelong offers significant opportunity to minimise potential environmental effects and utilise several attributes that come with the port and industrial setting.

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the *Environment Effects Act 1978* (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic, and transport as well as visual amenity.

In January 2021, the project was also determined to require assessment and approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) due to the potential for the project to have a significant impact on wetlands of international importance, listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

1.2. Study Specific Introduction

The measurement component of this program was completed to characterise the ambient environment over a period of approximately one month. A single JASCO Autonomous Multichannel Acoustic Recorder (AMAR) was deployed in Corio Bay (Figure 1) from Aug-Sep 2021.

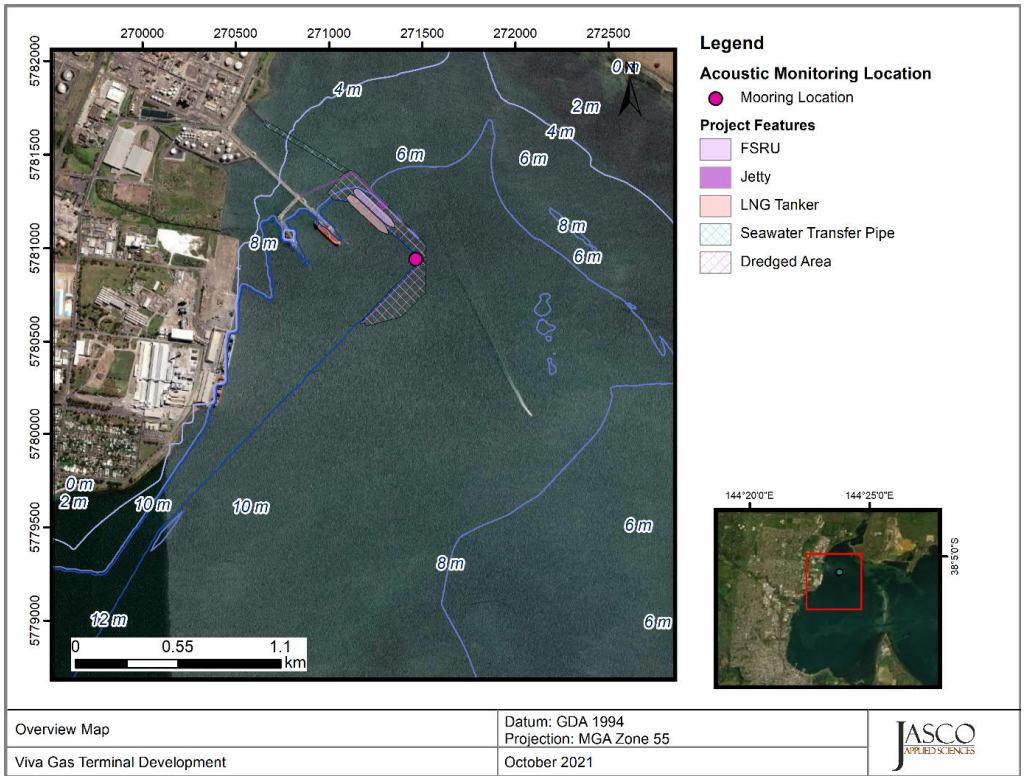


Figure 1. Map of location of the acoustic recorder and proposed project features in Corio Bay.

1.3. Changes to Sound as it Travels in the Ocean

A key question in the study of underwater sound is how a sound changes in nature as it propagates from its source to a receiver some distance away. Understanding and modelling sound propagation in the ocean is a complex topic that is the subject of numerous textbooks. This section provides a descriptive overview of key sound propagation concepts to assist with the results presented in this report. These concepts are integral to interpreting how sounds emitted by a source are transformed into those received some distance away. The sounds are transformed by 1) geometric spreading; 2) reflection, scattering and absorption at the seabed and sea surface; 3) refraction due to changes in sound speed with depth; and 4) absorption. This section does not address 3), as sound refraction plays only a minor role in shallow water.

At one extreme, the echolocation clicks of porpoises at 130 kHz travel only 500 m before becoming inaudible (Au et al. 1999). At the other extreme, sounds from fin whales (20 Hz) and low frequency energy from seismic airguns (5–100 Hz) can be detected thousands of km away under the right conditions (Nieukirk et al. 2012).

Geometric spreading losses: Sound levels from an omnidirectional point source in the water column are reduced with range, a process known as geometric spreading loss. As sound leaves the source, each spherical sound wave propagates outward and the sound energy is spread out over this ever-expanding sphere. The farther you are from the source, the lower the sound level you will receive. The received sound pressure levels at a recorder located a distance R (in m) from the source are 20log10R dB lower than the source level (SL) referenced to a standard range of 1 m. But the sound cannot spread uniformly in all directions forever. Once the waves interact with the sea surface and seabed, the spreading becomes cylindrical rather than spherical and is limited to the cylinder formed by the surface and seabed with a lower range-dependent decay of 10log10R dB. Thus, the water depth is a key factor in predicting spreading losses and thus received sound levels. These spherical and cylindrical spreading factors provide limits for quick approximations of expected levels from a

given source. In very shallow waters, sound rapidly attenuates if the water depth is less than a quarter of a wavelength (Urick 1983).

Absorption, reflection, and scattering at the sea surface and seabed: If geometric spreading were the only factor governing sound attenuation in water, then at a given distance from a source, sound levels in shallow waters would almost always be higher than those in deep waters. In shallow water, however, the sound interacts more often with the seabed and sea surface than sound travelling in deep waters, and these interactions reflect, absorb, and scatter the sounds. The sea surface behaves approximately as a pressure release boundary, where incident sound is almost completely reflected with opposite phase. As a result, the sum of the incident and reflected sounds at the sea-surface is zero. At the seabed, many types of interactions can occur depending on the composition of the bottom. Soft silt and clay bottoms absorb sound, sand and gravel bottoms tend to reflect sound like a partially reflective mirror, and some hard yet elastic bottoms, such as limestone, reflect some of the sound while absorbing some of the energy by converting the compressional waves to elastic shear waves.

Absorption by sea water: As sound travels through the ocean, some of the energy is absorbed by molecular relaxation in the seawater, which turn the acoustic energy into heat. The amount of absorption that occurs is quantified by an attenuation coefficient, expressed in units of decibels per kilometre (dB/km). This absorption coefficient depends on the temperature, salinity, pH, and pressure of the water, as well as the sound frequency. In general, the absorption coefficient increases with the square of the frequency, so low frequencies are less affected. The absorption of acoustic wave energy has a noticeable effect (>0.05 dB/km) at frequencies above 1 kHz. For example, at 10 kHz the absorption loss over 10 km distance can exceed 10 dB, as computed according to the formulae of François and Garrison (1982a, b).

1.4. Ambient Ocean Soundscape

The ambient acoustic environment, or soundscape, consists of cumulative contributions from abiotic (geophonic), biotic (biophonic), and man-made (anthrophonic) sound sources (Krause 2008). Variation in soundscape characteristics over time and space can act as proxies for geographical, biological, and anthropogenic events occurring within an environment.

In the marine environment, geophonic elements of the soundscape commonly correlate with oceanographic conditions. Increased sea state and wind speed lead to higher sound intensities across frequencies ranging from 500 Hz to 30 kHz, via sound produced by breaking waves, cavitation, surface flow noise, and pressure changes (Knudsen et al. 1948, Wenz 1962) (Figure 2). Rainfall elevates sound levels in the 1–15 kHz frequency range, via surface impacts and bubble entrainment (Heindsmann et al. 1955, Bom 1969, Scrimger et al. 1987). The specific frequency band affected by rainfall depends on rain strength and droplet size. Abiotic acoustic contributions are often unpredictable or irregular (Urick 1983). For example, significant low frequency acoustic energy can be contributed to marine soundscapes by earthquakes and sea ice movement (Urick 1974, Matsumoto et al. 2014). On the other hand, biophonic contributions often feature seasonal and diel activity patterns (Hannay et al. 2013, Erbe et al. 2017). Water movement, or flow noise, is considered to be a pseudo-noise that results from eddies and vortices forming as water flows past an acoustic receiver, and is not considered to be part of a marine soundscape (Strasberg 1979).

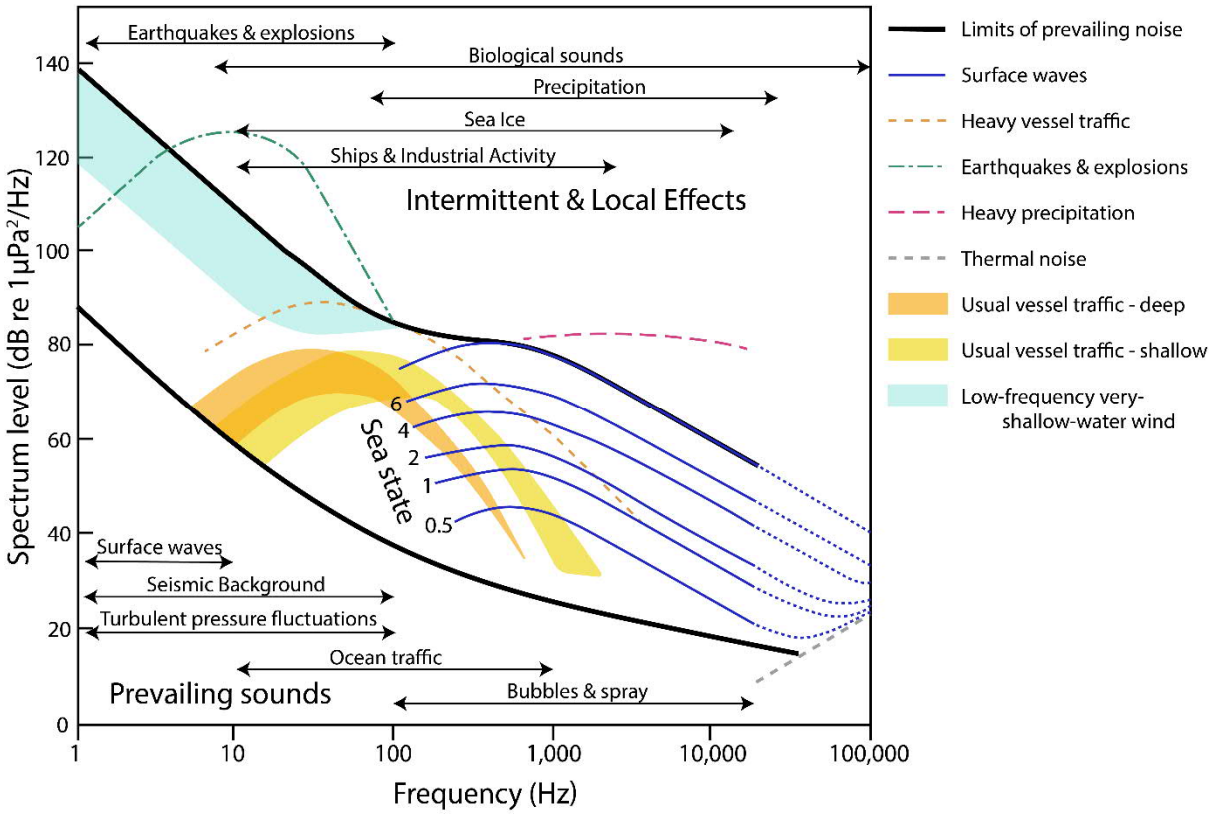


Figure 2. Wenz curves describing pressure spectral density levels of marine ambient sound from weather, wind, geologic activity, and commercial shipping (adapted from NRC 2003, based on Wenz 1962). Thick lines indicate limits of prevailing ambient sound.

1.5. Anthropogenic Contributors to the Soundscape

Anthropogenic (human-generated) sounds are relatively recent additions to soundscapes and, unlike biophonic contributors, often overlap in frequency, space, or time (Cato 1997, van Opzeeland and Boebel 2018). Anthrophonic contributors to global ocean noise include vessel traffic (commercial and recreational) at frequencies mainly in the frequency band 50–500 Hz. This sound can be a by-product of vessel operations, such as engine sound radiating through vessel hulls and cavitating propulsion systems, or it can be a product of active acoustic data collection with seismic surveys, military sonar, and depth sounding as the main contributors.

Marine construction projects involve vessel operations and project specific noise sources that can produce a range of both impulsive and non-impulsive noise. The contribution of anthropogenic sources to the ocean soundscape has increased from the 1950s to 2010, largely due to greater maritime shipping traffic (Ross 1976, Andrew et al. 2011). Oil and gas exploration with seismic airguns, marine pile driving, and oil and gas production platforms elevate sound levels over significant ranges when present (Bailey et al. 2010, Miksis-Olds and Nichols 2016, Delarue et al. 2018).The extent of seismic survey sounds has increased substantially following the expansion of oil and gas exploration into deep water, and seismic sounds have been detected across ocean basins (Nieukirk et al. 2004). Recent trends suggest that global sound levels are leveling off or potentially decreasing in some areas (Andrew et al. 2011, Miksis-Olds and Nichols 2016).

The main anthropogenic contributor to ambient sound in the present study was vessel noise. Vessels include large ships carrying goods to nearby ports, as well as smaller recreational boats. Figure 3 shows the vessel traffic over 2019 and 2020 of AIS-carrying vessels.

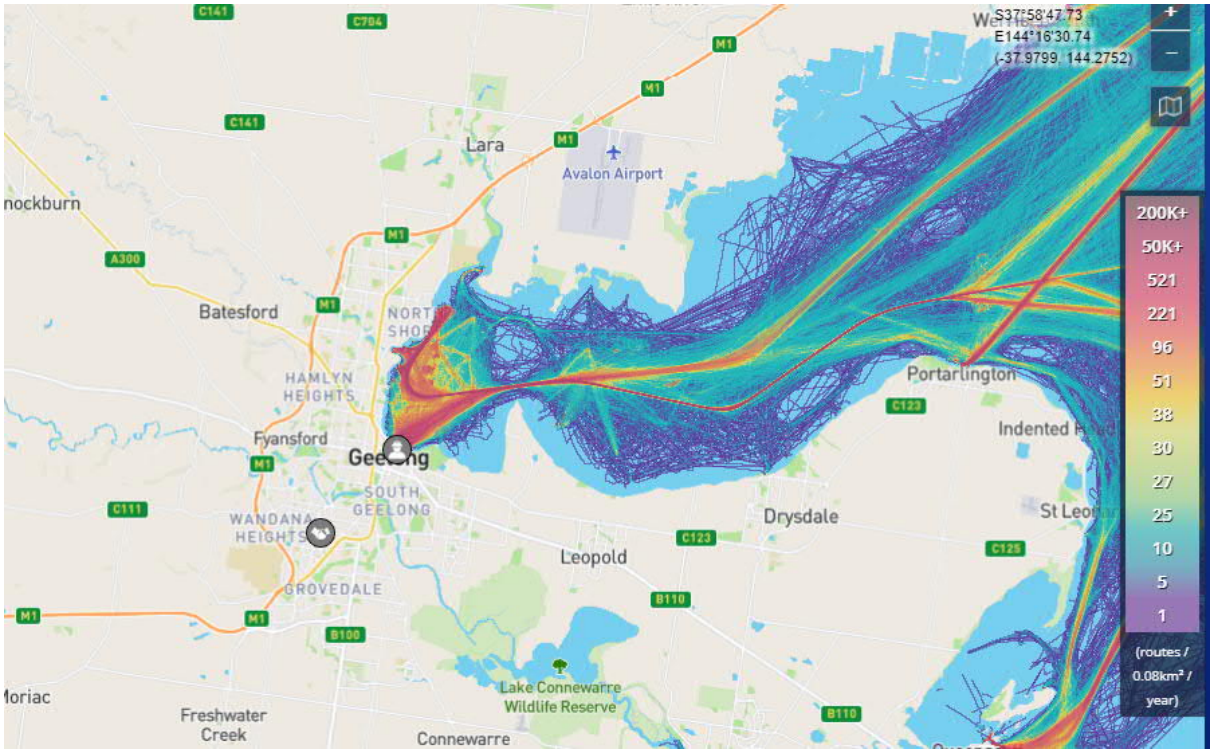


Figure 3. Vessel traffic near Geelong for 2019 and 2020. (source: marinetraffic.com; accessed 3 Nov 2021).

2. Methods

2.1. Acoustic Data Acquisition

Underwater sound was recorded with an Autonomous Multichannel Acoustic Recorder (AMAR, JASCO; Figure 4). The AMAR was fitted with an M36 omnidirectional hydrophone (GeoSpectrum Technologies Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The AMAR hydrophone was protected by a hydrophone cage, and flow shields. The AMAR recorded continuously at 64 000 samples per second for a recording bandwidth of 10 Hz to 32 kHz, storing approximately 600 Gb of data; The recording channel had 24-bit resolution with a spectral noise floor of 20 dB re 1 µPa^2/Hz. Acoustic data were stored on 1TB of internal solid-state flash memory. Appendix C provides details about the calibration procedure.



Figure 4. The Autonomous Multichannel Acoustic Recorder (AMAR; JASCO) used to measure underwater sound Geelong Harbour.

2.1.1. Deployment Locations

The AMAR was deployed at one location (Figure 1) on the 25 Aug 2021 (Table 1) with the assistance of Consulting Environmental Engineers (CEE), as due to COVID restrictions, JASCO was unable to enter Victoria from Queensland. The AMAR was retrieved as planned on 30 Sep 2021 using grappling, also by CEE, and the retrieved AMAR recorded as planned from deployment until retrieval, for an average recording duration of 37 days. Appendix A provides details about the mooring design.

The AMAR location was determined through considering proximity to the project location, the requirement to place the recorder in the deepest water possible to achieve the best quality acoustic data (less influenced by wave / wind noise at the surface), and also staying as clear of shipping lanes as possible. The Geelong Harbour Master approved the mooring location.

Table 1. Deployment details of the Autonomous Multichannel Acoustic Recorder (AMAR) deployed in Corio Bay.

Station	Latitude	Longitude	Depth (m)	Deployment Date (UTC+10)	Retrieval Date (UTC+10)	Duration (days)
1	-38.090452	144.41069	13	26 Aug 2021	30 Sep 2021	37

2.2. Automated Data Analysis

The AMAR collected approximately 600 GB of acoustic data during this study. A specialised computing platform (PAMlab; JASCO) capable of processing acoustic data hundreds of times faster than real time was used. The system performed automated analysis of total ocean noise and sounds from vessels.

2.2.1. Total Ocean Sound Levels

The data collected at Corio Bay spans approximately one month, over the frequency band of 10–32000 Hz. The goal of the total ocean sound analysis is to present this expansive data in a manner that documents the baseline underwater sound conditions in Corio Bay and allows us to examine temporal variations, and to correlate with external factors that change sound levels such as weather and human activities.

The first stage of the total sound level analysis involves computing the peak pressure level (PK) and sound pressure level (SPL) for each minute of data. This reduces the data to a manageable size without compromising the value for characterising the soundscape (ISO 2017b, Ainslie et al. 2018, Martin et al. 2019). The SPL analysis is performed by averaging 120 fast-Fourier transforms (FFTs) that each include 1 s of data with a 50% overlap and that use the Hann window to reduce spectral leakage. The 1 minute average data were stored as power spectral densities (1 Hz resolution) and summed over frequency to calculate decidecade band SPL levels. Decidecade band levels are very similar to 1/3-octave-band levels. Table B-1 lists the decidecade band frequencies, and Table B-2 lists the decade-band frequencies. The decidecade analysis sums the frequency range from the 180,000 frequencies (representing the frequency range 1 Hz to 180 kHz) in the power spectral density data to a manageable set of 43 bands that approximate the critical bandwidths of mammal hearing. The decade bands further summarize the sound levels into four frequency bands for manageability. Detailed descriptions of the acoustic metrics and decidecade analysis can be found in Appendix B.

In Section 3, the total sound levels are presented as:

- **Band-level plots:** These strip charts show the averaged received sound pressure levels as a function of time within a given frequency band. We show the total sound levels (across the entire recorded bandwidth from 10 to 32,000 Hz) and the levels in the decade bands of 10–100, 100–1000, 1000–10,000, and 10,000–32,000 Hz. The 10–100 Hz band is associated with blue whales, large shipping vessels, flow and mooring noise. Sounds within the 100–1000 Hz band are generally associated with the physical environment such as wind and wave conditions but can also include both biological and anthropogenic sources such as southern right and humpback whales, fish, nearby vessels, and pile driving. Sounds above 1000 Hz include high-frequency components of humpback whale sounds, odontocete whistles and echolocation signals, snapping shrimp, wind- and wave-generated sounds, and sounds from human sources at close range including pile driving, vessels, seismic surveys, and sonars.
- **Long-term Spectral Averages (LTSAs)**: These colour plots show power spectral density levels as a function of time (*x*-axis) and frequency (*y*-axis). The frequency axis uses a logarithmic scale, which provides equal vertical space for each decade increase in frequency and allows the reader to equally see the contributions of low and high-frequency sound sources. The LTSAs are excellent summaries of the temporal and frequency variability in the data.
- **Decidecade box-and-whisker plots**: In these figures, the ‘boxes’ represent the middle 50% of the range of sound pressure levels measured, so that the bottom of the box is the sound level 25th percentile (L_{25}) of the recorded levels, the bar in the middle of the box is the median (L_{50}), and the top of the box is the level that exceeded 75% of the data (L_{75}). The whiskers indicate the maximum and minimum range of the data.
- **Spectral density level percentiles**: The decidecade box-and-whisker plots are representations of the histogram of each band’s sound pressure levels. The power spectral density data has too many frequency bins for a similar presentation. Instead coloured lines are drawn to represent the L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles of the histograms. Shading is provided underneath these lines to provide an indication of the relative probability distribution. It is common to compare the power spectral densities to the results from Wenz (1962), which documented the variability of ambient spectral levels off the US Pacific coast as a function of frequency of measurements for a

range of weather, vessel traffic, and geologic conditions. The Wenz levels are appropriate for approximate comparisons only since the data were collected in deep water, largely before an increase in low-frequency sound levels (Andrew et al. 2011).

- **Daily sound exposure levels (SEL; $L_{E,24h}$)**: The SEL represents the total sound energy received over a 24 h period, computed as the linear sum of all 1-minute values for each day. It has become the standard metric for evaluating the probability of temporary or permanent hearing threshold shift. Long-term exposure to sound impacts an animal more severely if the sounds are within its most sensitive hearing frequency range. Therefore, during SEL analysis recorded sounds are typically filtered by the animal's auditory frequency weighting function before integrating to obtain SEL. For this analysis the 10 Hz and above SEL were computed as well as the SEL weighted by the marine mammal auditory filters (Appendix D (NMFS 2018), which are identical to the filters applied in Southall et al. (2019)). The SEL thresholds for possible hearing impacts from sound on marine mammals are provided in Appendix D, Lucke and McPherson (2021) and Green et al. (2021).

2.2.2. Vessel Noise Detection

Vessels are detected in two steps (Martin 2013):

1. Detect constant, narrowband tones produced by a vessel's propulsion system and other rotating machinery (Arveson and Vendittis 2000). These sounds are also referred to as tonals. We detect the tonals as lines in a 0.125 Hz resolution spectrogram of the data (8 s of data, Hann window, 2 s advance).
2. Assess the SPL for each minute in the 40–315 Hz shipping frequency band, which commonly contains most sound energy produced by mid-sized to large vessels. Background estimates of the shipping band SPL and system-weighted SPL are then compared to their mean values over a 12 h window, centred on the current time.

Vessel detections are defined by the following criterion (Figure 5):

1. SPL in the shipping band (40–315 Hz) is at least 3 dB above the 12 h mean for the shipping band for at least 5 min.
2. AND at least three shipping tonals (0.125 Hz bandwidth) are present for at least 1 min per 5 min window. Tonals are difficult to detect during turns and near the closest points of approach (CPA) due to Lloyds' mirror and Doppler effects.
3. AND SPL in the shipping band is within 12 dB of the system weighted SPL.

The duration where these constraints are valid is identified as a period with shipping present. A 10 min shoulder period before and after the detection period is also included in the shipping period. The shipping period is searched for the highest 1 min SPL in the vessel detection band, which is then identified as the closest point of approach (CPA) time. This algorithm is designed to find detectable shipping, meaning situations where the vessel noise can be distinguished from the background. It does not identify cases of two vessels moving together or cases of continuous noise from stationary platforms, such as oil and gas drilling and dynamic positioning operations. Those situations are easily identified from tools such as the daily SEL and long-term spectral average figures.

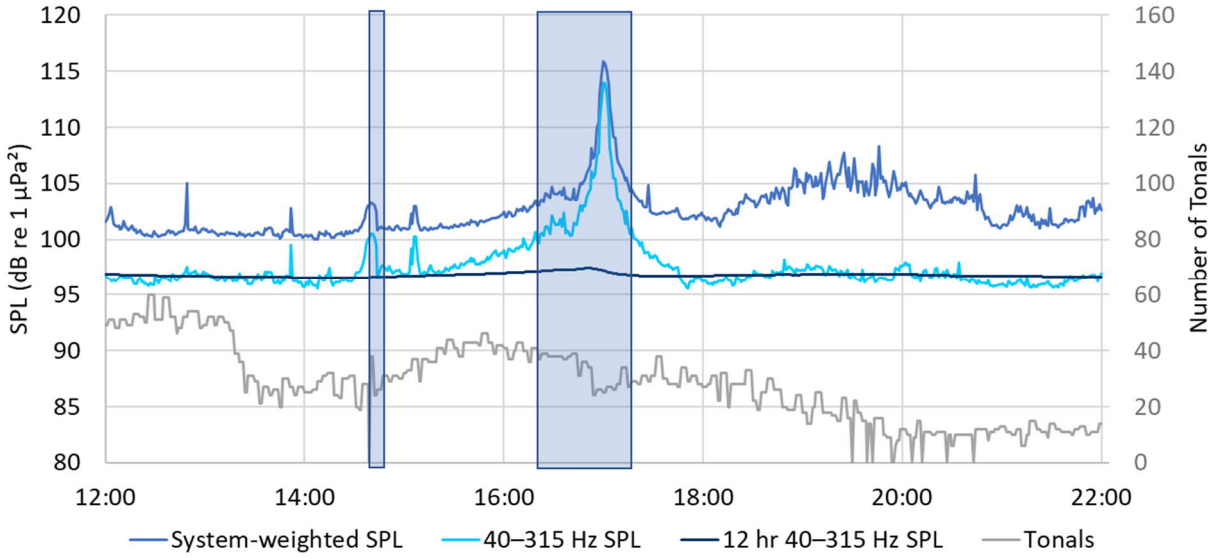


Figure 5. Example of broadband and 40–315 Hz band sound pressure level (SPL), as well as the number of tonals detected per minute as a vessel approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the vessel's closest point of approach (CPA) at 17:00 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies.

3. Results and Discussion

3.1. Soundscape Characterisation

3.1.1. Spectrograms and Statistical Analysis

The band-level plots, spectrograms (Long-term Spectral Averages), decidecade box-and-whisker plots, spectral density level percentiles and decade band box-and-whiskers plots (Figures 6 and 8) provide an overview of the sound variability in time and frequency, which demonstrates the presence and level of contribution from different sources. The values for the statistics shown in Figures 8 are provided in Table 2. Short-term events appear as vertical stripes on the spectrograms and spikes on the band level plots. Long-term events affect (increasing or decreasing accordingly) the band level over the event period and appear in the spectrograms as horizontal bands of colour.

The most substantial contribution to the soundscape is from vessel noise occupying bands below approximately 1000 Hz, as shown in both the spectrogram of Figure 6, the percentiles in Figure 7 and the lower two decade bands of Figure 8. In the spectrogram (Figure 6), both the horizontal bands of long-term trends (particularly in the approximate 30-100 Hz range), as well as the vertical events can be attributed to vessel noise. Due to the shallow deployment depth, and therefore closer range to passing vessels, many distinct tones related to vessel propulsion can be observed in the 30-200 Hz ranges of both spectrogram and percentiles. Figure 11 shows a short-term spectrum including both consistent tones associated with vessels, as well as elevated broader-band sounds of a passing vessel. Figure 12 shows the results of the automated vessel detector by hour, including both detections of large vessels and that of smaller boats. It is possible that very small recreational boats may not be detected either due to masking from larger vessels or distance from recorder.

The median SPL by hour of day (Figure 9) and day of week (Figure 10) demonstrate reasonable consistency of sound levels with respect to time. There are a few subtle trends, however the overall conclusion is that vessel related noise is mostly present. Figure 9 shows a slight increase in low frequency levels between approximately 06:00 to 16:00 local time (20:00 – 04:00 UTC), indicating a slightly higher vessel presence during daytime hours. On a weekly basis (Figure 10), sound levels in the 100-1000 Hz band demonstrate a slight decrease after Friday, which would indicate a slightly lower vessel presence on weekends.

There is an interesting trend in both the daily and weekly figures for the highest decade band, which is the slight peak just after 18:00 and 06:00 (08:00 and 20:00 UTC) which is likely a dusk and dawn invertebrate chorus, with the local morning peak being greater than the evening. The predominant contributor is likely to be snapping shrimp (Erbe et al. 2016, McPherson et al. 2016), whose impulsive signals can be seen above approximately 1 kHz in Figure 11.

The tidal range in this area is less than 1 m, generally approximately 0.5 m. As such, flow noise does not offer a strong contribution to the soundscape, as supported by low sound levels below 30 Hz, where vessel noise begins. On 20 Sep 2021 there are slightly elevated broadband sound levels up to approximately 10 kHz, which may be because of a severe storm in the region which included wind speeds of up to 100 km/h, heavy rain, and thunder. Due to the shallow deployment, the wind, rain, thunder, and waves induced have a high likelihood of causing increased sound levels across many frequency bands. However, vessels may not have been operating during this storm time, and so the storm noise may be replacing the vessel noise, rather than adding to it.

The monitoring results demonstrate that Corio Bay is typically louder and exhibits less variation in the soundscape than Fremantle Inner Harbour (Salgado Kent et al. 2012). Five months of monitoring in Fremantle Inner Harbour determined this location has broadband noise levels typically between 110

and 140 dB re 1 µPa, and an approximately 10 dB diurnal variation, compared to a broadband median and 124.6 and a maximum of 153.3 dB re 1 µPa less than 5 dB average diurnal variation for Corio Bay.

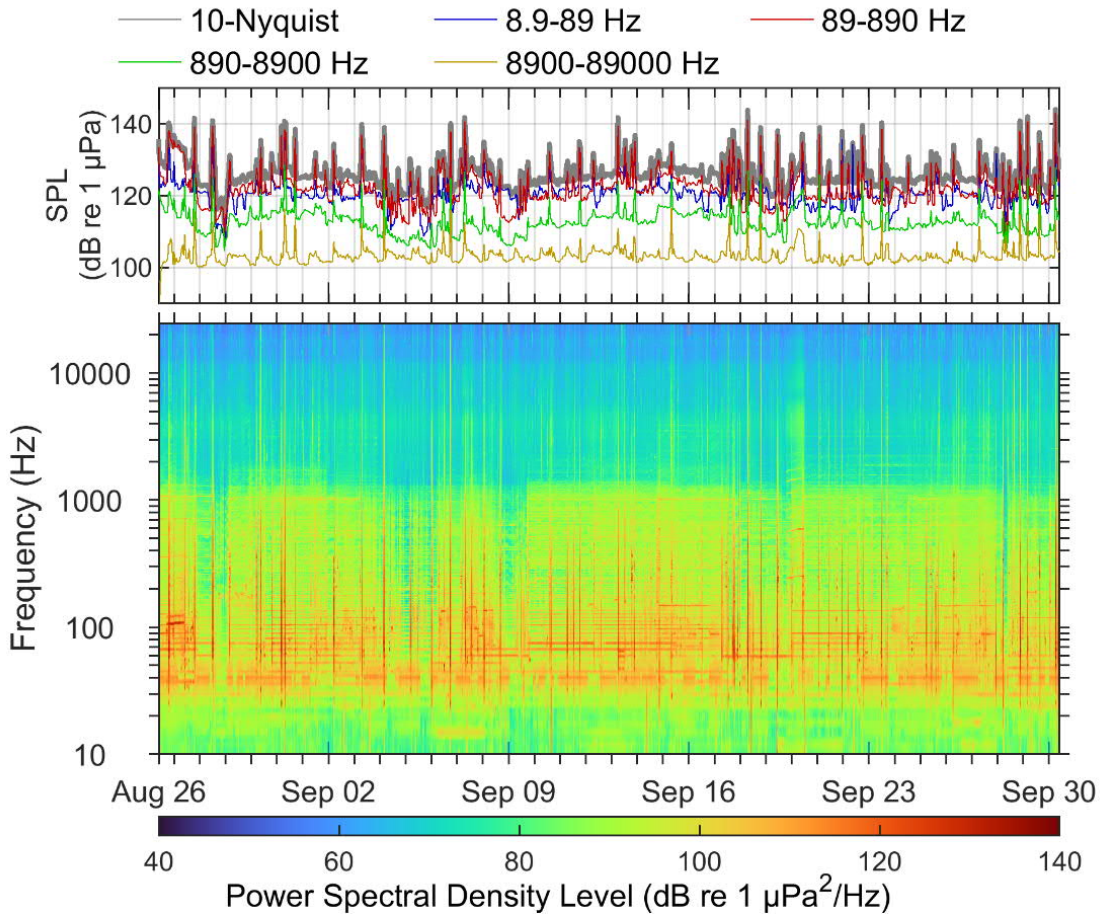


Figure 6. (Top) In-band sound pressure level (SPL) by decade band and (bottom) long-term spectral average (LTSA) of underwater sound (UTC+10).

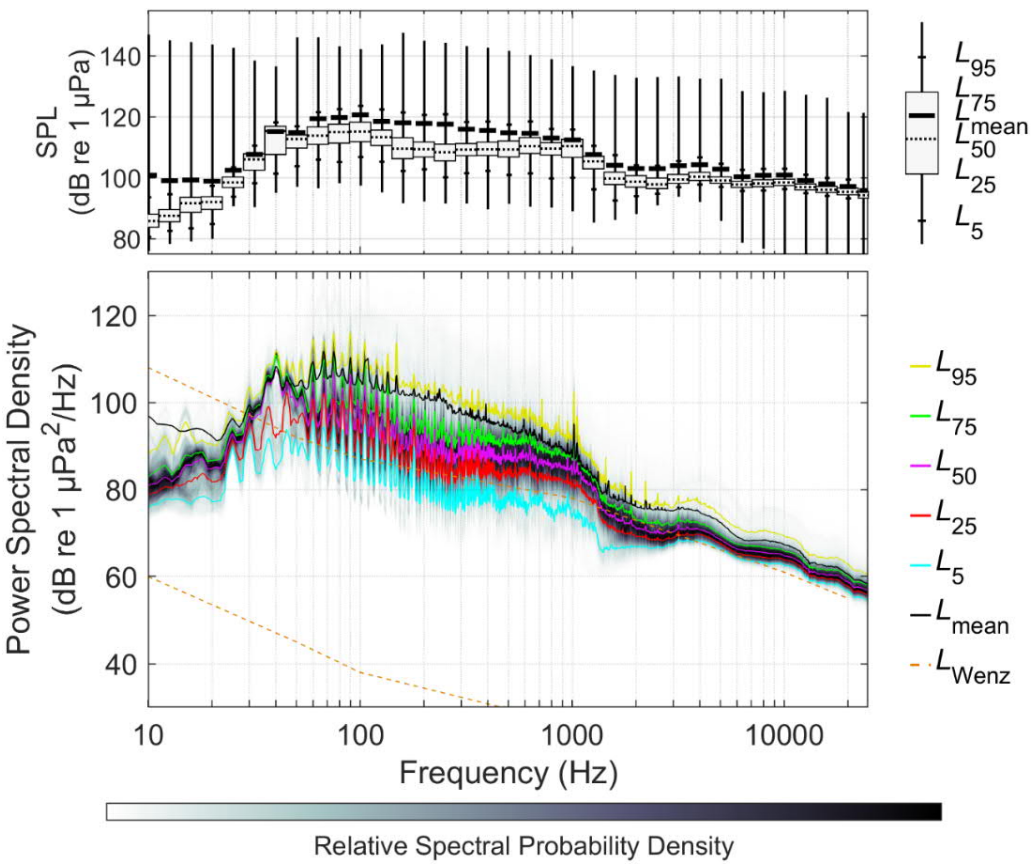


Figure 7. (Top) percentiles and mean of decidecade sound pressure level (SPL) and (bottom) percentiles and probability density (grayscale) of 1-min power spectral density levels, by station compared to the Wenz curve limits (coloured lines) of prevailing noise (Wenz 1962).

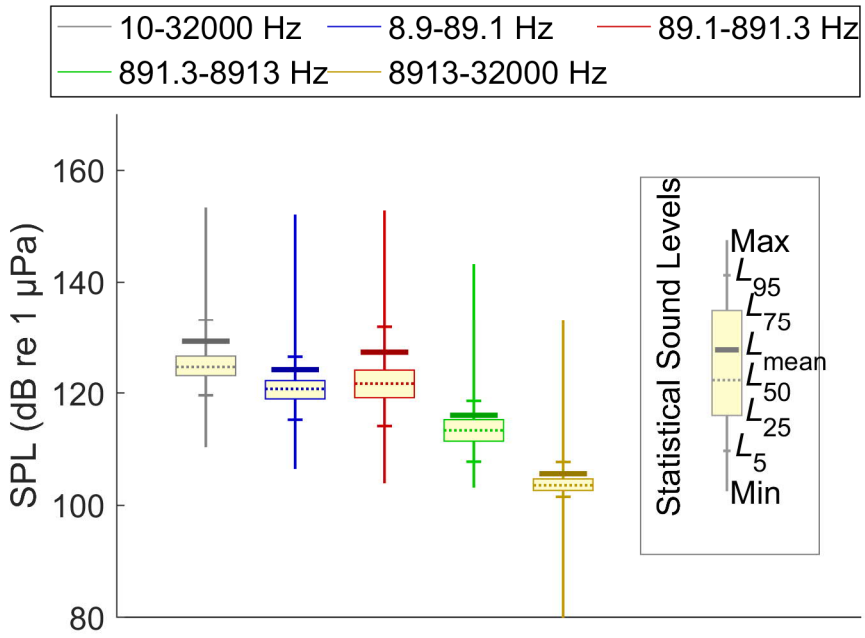


Figure 8. SPL by decade band, showing mean levels and percentiles over entire recording duration.

Table 2. Statistical analysis of sound levels for full recording period. SPL units: dB re 1 µPa.

Sound level statistic	Sound level				
	10-Nyquist	8.9-89 Hz	89-890 Hz	890-8900 Hz	8900-Nyquist Hz
Minimum	110.3	106.5	103.9	103.2	78.7
L_5	119.6	115.2	114.1	107.8	101.5
L_{25}	123.1	118.9	119.2	111.4	102.6
L_{50}	124.6	120.7	121.7	113.4	103.6
L_{75}	126.6	122.2	124.1	115.3	104.7
L_{95}	133.1	126.5	131.8	118.6	107.7
Maximum	153.3	152.1	152.8	143.2	133
Mean	129.2	124.2	127.3	116	105.6

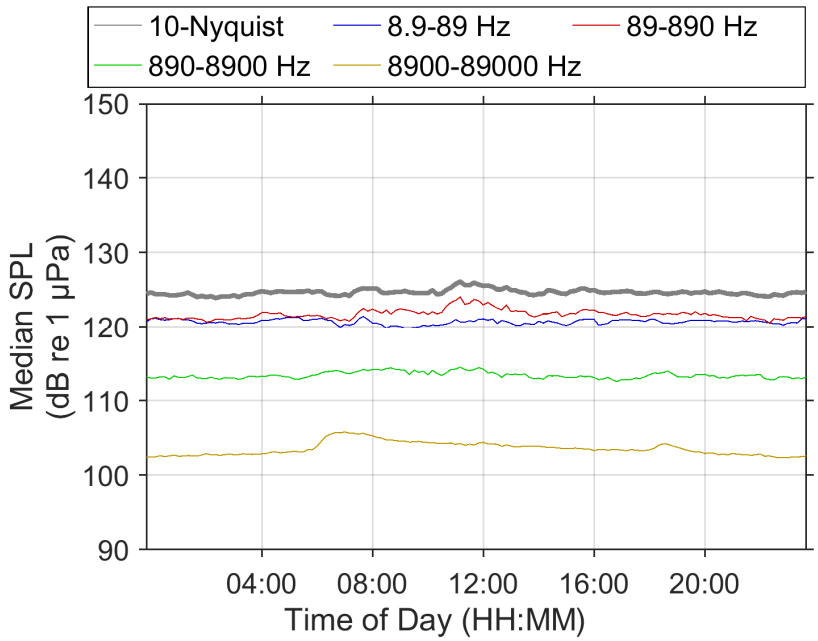


Figure 9. Median SPL by time of day for entire recording duration. Recording occurred during Australian Eastern Standard Time, UTC+10.

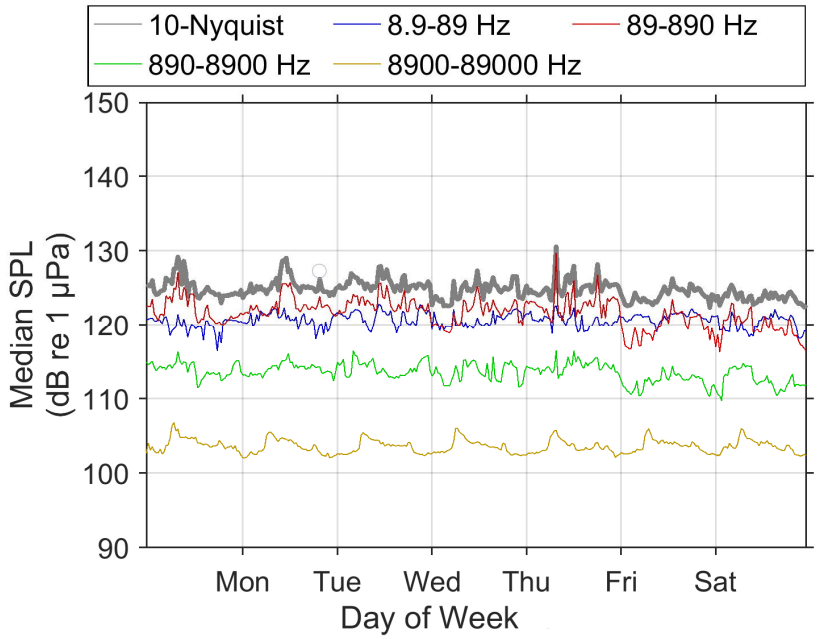


Figure 10. Median SPLs by day of week for entire recording duration. Recording occurred during Australian Eastern Standard Time, UTC+10.

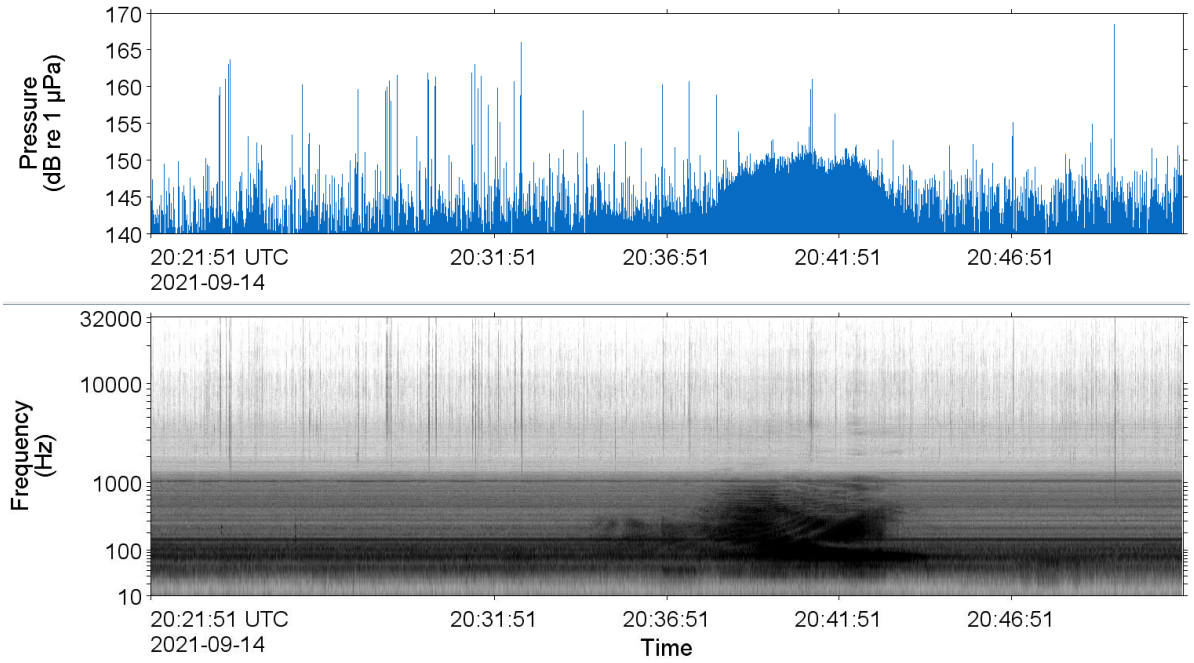


Figure 11. Spectrum of sound levels on 14 Sep 2021 (UTC). Demonstrates sound level contributions from consistent vessel tones and passing vessel.

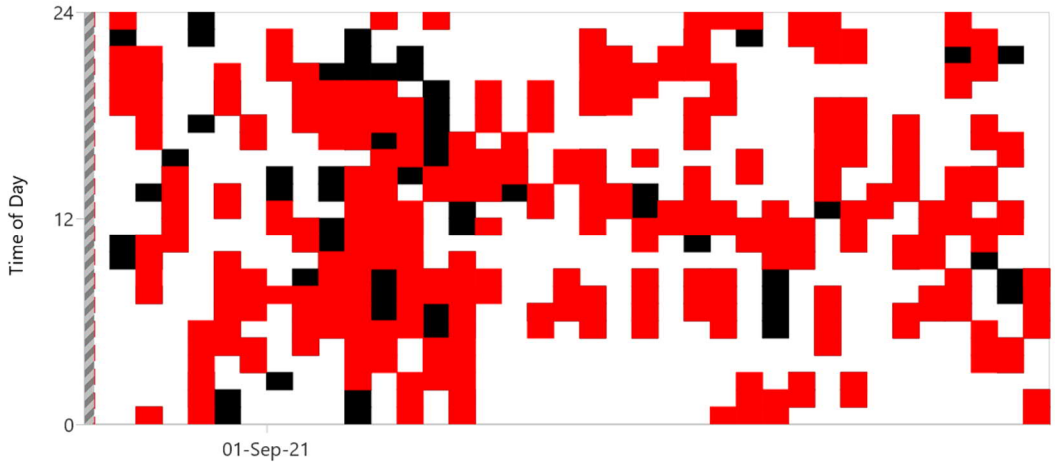


Figure 12. Vessel detections by hour. Red indicates a large vessel detection, and black indicates a smaller boat.

3.1.2. Frequency Weighted Sound Exposure Levels

The perception of underwater sound depends on the hearing sensitivity of the receiving animal in the frequency bands of the sound. Hearing sensitivity in animals, however, varies over the frequency band of their hearing (the hearing curve (audiogram) usually resembling a U-shaped form). The frequency range of hearing and hearing sensitivity differ between species, resulting in the fact that different species will perceive underwater sound differently. Auditory (frequency) weighting functions (Appendix D) are applied to account for this difference as they reflect an animal's ability to hear a sound, emphasising the frequency band of best sensitivity over frequencies animals do not hear well. Figure 13 shows the difference between perceived ambient noise by cetaceans and seals. The hearing groups of relevance to the Viva Energy Gas Terminal project are mid-frequency cetaceans (referred to as high-frequency cetaceans in Southall et al. (2019)) and otariid seals, statistics for these species are provided in Table 3.

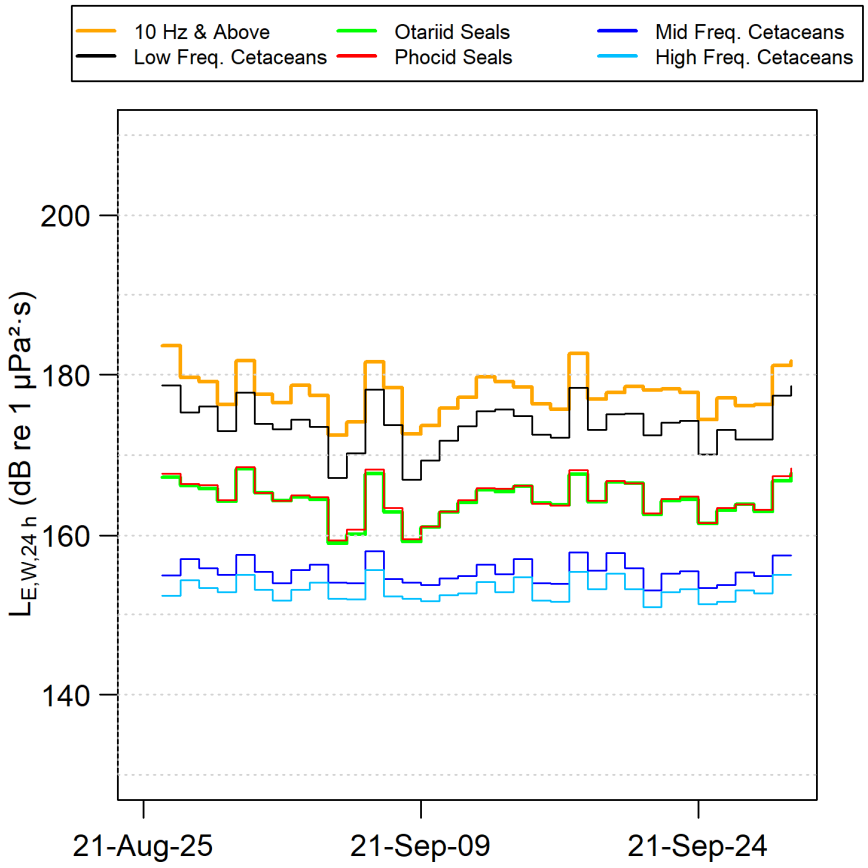


Figure 13. Auditory frequency weighted ambient noise (10 Hz and above) over the measurement period shown as daily sound exposure levels (SEL) (NMFS 2018).

Table 3. Daily sound exposure level (SEL, dB re 1 µPa²s) statistics for the hearing groups (NMFS 2018) relevant to the assessment over the entire measurement period.

Sound level statistic	Unweighted	Mid-Frequency Cetacean	Otariid Seals
Minimum	172.5	153.0	159.0
Median	177.8	155.1	164.3
Maximum	183.6	158.0	168.3

The data presented in this report will be used to inform an assessment of potential underwater noise impacts for the Viva Energy Gas Terminal project.

Acknowledgements

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Glossary

1/3-octave

One third of an octave. *Note*: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec).

1/3-octave-band

Frequency band whose bandwidth is one one-third octave. *Note*: The bandwidth of a one-third octave-band increases with increasing centre frequency.

90%-energy time window

The time interval over which the cumulative energy rises from 5 to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% sound pressure level (90% SPL)

The sound pressure level calculated over the 90%-energy time window of a pulse.

absorption

The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

acoustic noise

Sound that interferes with an acoustic process.

acoustic self-noise

Sound at a receiver caused by the deployment, operation, or recovery of a specified receiver, and its associated platform.

ambient sound

Sound that would be present in the absence of a specified activity, usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

audiogram

A graph or table of hearing threshold as a function of frequency that describes the hearing sensitivity of an animal over its hearing range.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

automated detection

The output of an **automated detector**.

automated detector

An algorithm that includes both the **automated detection** of a sound of interest based on how it stands out from the background and its automated classification based on similarities to templates in a library of reference signals.

background noise

Combination of ambient sound, acoustic self-noise, and sonar reverberation. Ambient sound detected, measured, or recorded with a signal is part of the background noise.

bandwidth

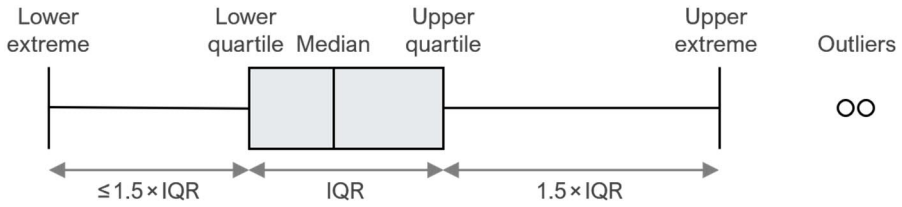
The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI S1.13-2005 (R2010)).

bar

Unit of pressure equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 10^5 Pa or 10^{11} µPa.

box-and-whisker plot

A plot that illustrates the centre, spread, and overall range of data from a visual 5-number summary. The box is the interquartile range (IQR), which shows the middle 50% of the data—from the lower quartile (25th percentile) to the upper quartile (75th percentiles). The line inside the box is the median (50th percentile). The whiskers show the lower and upper extremes excluding outliers, which are data points that fall more than 1.5 × IQR beyond the upper and lower quartiles.



boxcar averaging

A signal smoothing technique that returns the averages of consecutive segments of a specified width.

broadband level

The total level measured over a specified frequency range.

cavitation

A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of noise.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

conductivity-temperature-depth (CTD)

Measurement data of the ocean's conductivity, temperature, and depth; used to compute sound speed and salinity.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period . A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade. *Note*: An alternative name for decidecade (symbol ddec) is “one-tenth decade”. A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a “one-third octave”.

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

delphinid

Family of oceanic dolphins, or Delphinidae, composed of approximately thirty extant species, including dolphins, porpoises, and killer whales.

duty cycle

The time when sound is periodically recorded by an acoustic recording system.

energy source level

A property of a sound source obtained by adding to the sound exposure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^2m^2s.

energy spectral density

Ratio of energy (time-integrated square of a specified field variable) to bandwidth in a specified frequency band f_1 to f_2. In equation form, the energy spectral density E_f is given by:

$$E_f = \frac{2\int_{f_1}^{f_2} |X(f)|^2 \, \mathrm{d}f}{f_2 - f_1},$$

where $X(f)$ is the Fourier transform of the field variable $x(t)$

$$X(f) = \int_{-\infty}^{+\infty} x(t) \exp(-2\pi \mathrm{i} f t) \, \mathrm{d}t \, .$$

The field variable $x(t)$ is a scalar quantity, such as sound pressure. It can also be the magnitude or a specified component of a vector quantity such as sound particle displacement, sound particle velocity,

or sound particle acceleration. The unit of energy spectral density depends on the nature of *x*, as follows:

- If *x* = sound pressure: Pa^2 s/Hz
- If *x* = sound particle displacement: m^2 s/Hz
- If *x* = sound particle velocity: $(m/s)^2$ s/Hz
- If *x* = sound particle acceleration: $(m/s^2)^2$ s/Hz

The factor of two on the right-hand side of the equation for E_f is needed to express a spectrum that is symmetric about $f = 0$, in terms of positive frequencies only. See entry 3.1.3.9 of ISO 18405 (2017a).

energy spectral density level

The level ($L_{E,f}$) of the **energy spectral density** (E_f). Unit: decibel (dB).

$$L_{E,f} := 10 \log_{10}\left(E_f / E_{f,0}\right) \text{ dB}\,.$$

The frequency band and integration time should be specified.

As with **energy spectral density**, energy spectral density level can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement). The reference value ($E_{f,0}$) for energy spectral density level depends on the nature of field variable.

energy spectral density source level

A property of a sound source obtained by adding to the energy spectral density level of the sound pressure measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 $\mu Pa^2m^2s/Hz$.

ensonified

Exposed to sound.

Fourier transform (or Fourier synthesis)

A mathematical technique which, although it has varied applications, is referenced in the context of this report as a method used in the process of deriving a spectrum estimate from time-series data (or the reverse process, termed the inverse Fourier transform). A computationally efficient numerical algorithm for computing the Fourier transform is known as fast Fourier transform (FFT).

flat weighting

Term indicating that no frequency weighting function is applied. Synonymous with unweighted.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

geoacoustic

Relating to the acoustic properties of the seabed.

Global Positioning System (GPS)

A satellite based navigation system providing accurate worldwide location and time information.

harmonic

A sinusoidal sound component that has a frequency that is an integer multiple of the frequency of a sound to which it is related. For example, the second harmonic of a sound has a frequency that is double the fundamental frequency of the sound.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hearing threshold

The sound pressure level for any frequency of the hearing group that is barely audible for a given individual for specified background noise during a specific percentage of experimental trials.

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See **hearing group**.

hydrophone

An underwater sound pressure transducer. A passive electronic device for recording or listening to underwater sound.

intermittent sound

A sound whose level abruptly drops below the background noise level several times during an observation period.

impulsive sound

Qualitative term meaning sounds that are typically transient, brief (less than 1 second), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile drivers.

knot

One nautical mile per hour. Symbol: kn.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

masking

Obscuring of sounds of interest by sounds at similar frequencies.

median

The 50th percentile of a statistical distribution.

mid-frequency (MF) cetacean

See **hearing group**.

monopole source level (MSL)

A source level that has been calculated using an acoustic model that accounts for the effect of the sea-surface and seabed on sound propagation, assuming a point-like (monopole) sound source. Also see **radiated noise level**.

Monte Carlo simulation

The method of investigating the distribution of a non-linear multi-variate function by random sampling of all of its input variable distributions.

multiple linear regression

A statistical method that seeks to explain the response of a dependent variable using multiple explanatory variables.

mysticete

A suborder of cetaceans that use baleen plates to filter food from water. Members of this group include rorquals (Balaenopteridae), right whales (Balaenidae), and grey whales (*Eschrichtius robustus*).

N percent exceedance level

The sound level exceeded *N*% of the time during a specified time interval. Also see **percentile level**.

non-impulsive sound

Sound that is not an impulsive sound. A non-impulsive sound is not necessarily a continuous sound.

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

odontocete

The presence of teeth, rather than baleen, characterizes these whales. Members of the Odontoceti are a suborder of cetaceans, a group comprised of whales, dolphins, and porpoises. The skulls of toothed whales are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises.

otariid

A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups are phocids and walrus.

otariid pinnipeds in water (OPW)

See **hearing group**.

other marine carnivores in air (OCA)

See **hearing group**.

other marine carnivores in water (OCW)

See **hearing group**.

peak sound pressure level (zero-to-peak sound pressure level)

The level ($L_{p,pk}$ or L_{pk}) of the squared maximum magnitude of the sound pressure (p^2_{pk}).
Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 µPa^2.

$$L_{p,\mathrm{pk}}: = 10\log_{10}\left(p^2_{\mathrm{pk}}/p_0^2\right)\ \mathrm{dB}\ = 20\log_{10}\left(p_{\mathrm{pk}}/p_0\right)\ \mathrm{dB}$$

The frequency band and time window should be specified. Abbreviation: PK or Lpk.

peak-to-peak sound pressure

The difference between the maximum and minimum sound pressure over a specified frequency band and time window. Unit: pascal (Pa).

percentile level

The sound level not exceeded *N*% of the time during a specified time interval. The *N*th percentile level is equal to the (100−*N*)% exceedance level. Also see ***N* percent exceedance level**.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

phocid

A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

phocid pinnipeds in water (PPW)

See **hearing group**.

pinniped

A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

point source

A source that radiates sound as if from a single point.

power spectral density

Generic term, formally defined as power in a unit frequency band. Unit: watt per hertz (W/Hz). The term is sometimes loosely used to refer to the spectral density of other parameters such as squared sound pressure. ratio of **energy spectral density**, E_f, to time duration, Δt, in a specified temporal observation window. In equation form, the power spectral density P_f is given by:

$$P_f = \frac{E_f}{\Delta t}.$$

Power spectral density can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement).

power spectral density level

The level ($L_{P,f}$) of the **power spectral density** (P_f). Unit: decibel (dB).

$$L_{P,f} := 10 \log_{10}\left(P_f / P_{f,0}\right) \text{ dB}.$$

The frequency band and integration time should be specified.

As with **power spectral density**, power spectral density level can be expressed in terms of various field variables (e.g., sound pressure, sound particle displacement). The reference value ($P_{f,0}$) for power spectral density level depends on the nature of field variable.

power spectral density source level

A property of a sound source obtained by adding to the power spectral density level of the sound pressure measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 $\mu Pa^2 m^2/Hz$.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure. Unit: pascal (Pa).

pressure, hydrostatic

The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

propagation loss (PL)

Difference between a source level (SL) and the level at a specified location, PL(x) = SL − L(x). Also see **transmission loss**.

radiated noise level (RNL)

A source level that has been calculated assuming sound pressure decays geometrically with distance from the source, with no influence of the sea-surface and seabed. Also see **monopole source level**.

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound **levels**, e.g., the reference value for expressing sound pressure level in decibels is 1 µPa.

Quantity	Reference value
Sound pressure	1 µPa
Sound exposure	1 µPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 µm/s^2

rms

abbreviation for root-mean-square.

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 µPa^2 s.

$$L_E := 10 \log_{10}(E/E_0)\ \text{dB} = 20 \log_{10}\left(E^{1/2}/E_0^{1/2}\right)\ \text{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound exposure spectral density

Distribution as a function of frequency of the time-integrated squared sound pressure per unit bandwidth of a sound having a continuous spectrum. Unit: Pa^2 s/Hz.

sound field

Region containing sound waves.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level (rms sound pressure level)

The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p^2_{rms}). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_{p,\mathrm{rms}} := 10 \log_{10}(p^2_{\mathrm{rms}}/p_0^2)\ \mathrm{dB} = 20 \log_{10}(p_{\mathrm{rms}}/p_0)\ \mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

soundscape

The characterization of the ambient sound in terms of its spatial, temporal, and frequency attributes, and the types of sources contributing to the sound field.

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^2.

spectrogram

A visual representation of acoustic amplitude compared with time and frequency.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

surface duct

The upper portion of a water column within which the sound speed profile gradient causes sound to refract upward and therefore reflect off the surface resulting in relatively long-range sound propagation with little loss.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

transmission loss (TL)

The difference between a specified level at one location and that at a different location, TL(x1,x2) = L(x1) − L(x2). Also see **propagation loss**.

unweighted

Term indicating that no frequency weighting function is applied. Synonymous with flat weighting.

wavelength

Distance over which a wave completes one cycle of oscillation. Unit: metre (m). Symbol: λ.

Literature Cited

[ANSI] American National Standards Institute and [ASA] Acoustical Society of America. S1.1-2013. *American National Standard: Acoustical Terminology*. NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS12013.

[ANSI] American National Standards Institute and [ASA] Acoustical Society of America. S1.13-2005 (R2010). *American National Standard: Measurement of Sound Pressure Levels in Air*. NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS1132005R2010.

[ISO] International Organization for Standardization. 2006. *ISO 80000-3:2006 Quantities and units – Part 3: Space and time*. https://www.iso.org/standard/31888.html.

[ISO] International Organization for Standardization. 2017a. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[ISO] International Organization for Standardization. 2017b. *ISO 18406:2017(E). Underwater acoustics – Measurement of radiated underwater sound from percussive pile driving*. Geneva. https://www.iso.org/obp/ui/#iso:std:iso:18406:ed-1:v1:en.

[NMFS] National Marine Fisheries Service (US). 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*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 p.

[NMFS] National Marine Fisheries Service (US). 2018. *2018 Revision 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*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 p. https://www.fisheries.noaa.gov/webdam/download/75962998.

[NOAA] National Oceanic and Atmospheric Administration (US). 2019. *ESA Section 7 Consultation Tools for Marine Mammals on the West Coast* (webpage), 27 Sep 2019. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west. (Accessed 10 Mar 2020).

[NRC] National Research Council (US). 2003. *Ocean Noise and Marine Mammals*. National Research Council (US), Ocean Studies Board, Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. The National Academies Press, Washington, DC, USA. https://doi.org/10.17226/10564.

Ainslie, M.A., J.L. Miksis-Olds, S.B. Martin, K.D. Heaney, C.A.F. de Jong, A.M. von Benda-Beckmann, and A.P. Lyons. 2018. *ADEON Underwater Soundscape and Modeling Metadata Standard*. Version 1.0. Technical report by JASCO Applied Sciences for ADEON Prime Contract No. M16PC00003. https://doi.org/10.6084/m9.figshare.6792359.v2.

Andrew, R.K., B.M. Howe, and J.A. Mercer. 2011. Long-time trends in ship traffic noise for four sites off the North American West Coast. *Journal of the Acoustical Society of America* 129(2): 642-651. https://doi.org/10.1121/1.3518770.

Bailey, H., G. Clay, E.A. Coates, D. Lusseau, B. Senior, and P.M. Thompson. 2010. Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20(2): 150-158. https://doi.org/10.1002/aqc.1060.

Bom, N. 1969. Effect of rain on underwater noise level. *Journal of the Acoustical Society of America* 45(1): 150-156. https://doi.org/10.1121/1.1911351.

Cato, D.H. 1997. Ambient sea noise in Australian waters. *5th International Congress on Sound and Vibration*. Volume 5, 15-18 Dec 1997, Adelaide, Australia. pp. 2813-2818.

Delarue, J.J.-Y., K.A. Kowarski, E.E. Maxner, J.T. MacDonnell, and S.B. Martin. 2018. *Acoustic Monitoring Along Canada's East Coast: August 2015 to July 2017*. Document Number 01279, Environmental Studies

Research Funds Report Number 215, Version 1.0. Technical report by JASCO Applied Sciences for Environmental Studies Research Fund, Dartmouth, NS, Canada. 120 pp + appendices.

Erbe, C., R.D. McCauley, A. Gavrilov, S. Madhusudhana, and A. Verma. 2016. The underwater soundscape around Australia. *ACOUSTICS 2016*. 9-11 Nov 2016, Brisbane, Australia.

Erbe, C., R. Dunlop, K.C.S. Jenner, M.-N.M. Jenner, R.D. McCauley, I. Parnum, M. Parsons, T. Rogers, and C. Salgado-Kent. 2017. Review of underwater and in-air sounds emitted by Australian and Antarctic marine mammals. *Acoustics Australia*. https://doi.org/10.1007/s40857-017-0101-z.

Finneran, J.J. and A.K. Jenkins. 2012. *Criteria and thresholds for U.S. Navy acoustic and explosive effects analysis*. SPAWAR Systems Center Pacific, San Diego, CA, USA. 64 p.

Finneran, J.J. 2015. *Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores*. Technical report by SSC Pacific, San Diego, CA, USA.

Finneran, J.J. 2016. *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Technical Report for Space and Naval Warfare Systems Center Pacific, San Diego, CA, USA. 49 p. https://apps.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf.

Green, M.C., M. Wood, and C. McPherson. 2021. *Viva Energy Gas Terminal: Underwater Acoustic Modelling*. Technical report by JASCO Applied Sciences for AECOM. Document Number 02534, Version 1.0.

Hannay, D.E., J.J.-Y. Delarue, X. Mouy, S.B. Martin, D. Leary, J.N. Oswald, and J. Vallarta. 2013. Marine mammal acoustic detections in the northeastern Chukchi Sea, September 2007–July 2011. *Continental Shelf Research* 67: 127-146. https://doi.org/10.1016/j.csr.2013.07.009.

Heindsmann, T.E., R.H. Smith, and A.D. Arneson. 1955. Effect of rain upon underwater noise levels [Letter to the editor]. *Journal of the Acoustical Society of America* 27(2): 378-379. https://doi.org/10.1121/1.1907897.

Houser, D.S., W. Yost, R. Burkard, J.J. Finneran, C. Reichmuth, and J. Mulsow. 2017. A review of the history, development and application of auditory weighting functions in humans and marine mammals. *Journal of the Acoustical Society of America* 141(3): 1371-1413. https://doi.org/10.1121/1.4976086.

Knudsen, V.O., R.S. Alford, and J.W. Emling. 1948. Underwater ambient noise. *Journal of Marine Research* 7: 410-429.

Krause, B. 2008. Anatomy of the Soundscape: Evolving Perspectives. *Journal of the Audio Engineering Society* 56(1/2): 73-80. http://www.aes.org/e-lib/browse.cfm?elib=14377.

Lucke, K. and C. McPherson. 2021. *Appendix [X]: Underwater Noise Impact Assessment: Viva Energy Gas Terminal Project Environment Effects Statement*. Document Number 02558, Version 1.0 DRAFT. Technical report by JASCO Applied Sciences for AECOM.

Martin, B. 2013. Computing cumulative sound exposure levels from anthropogenic sources in large data sets. *Proceedings of Meetings on Acoustics* 19(1): 9. https://doi.org/10.1121/1.4800967.

Martin, S.B., C. Morris, K. Bröker, and C. O'Neill. 2019. Sound exposure level as a metric for analyzing and managing underwater soundscapes. *Journal of the Acoustical Society of America* 146(1): 135-149. https://doi.org/10.1121/1.5113578.

Martin, S.B., B.J. Gaudet, H. Klinck, P.J. Dugan, J.L. Miksis-Olds, D.K. Mellinger, D.A. Mann, O. Boebel, C.C. Wilson, et al. 2021. Hybrid millidecade spectra: A practical format for exchange of long-term ambient sound data. *JASA Express Letters* 1(1). https://doi.org/10.1121/10.0003324.

Matsumoto, H., D.R. Bohnenstiehl, J. Tournadre, R.P. Dziak, J.H. Haxel, T.K.A. Lau, M. Fowler, and S.A. Salo. 2014. Antarctic icebergs: A significant natural ocean sound source in the Southern Hemisphere. *Geochemistry, Geophysics, Geosystems* 15(8): 3448-3458. https://doi.org/10.1002/2014GC005454.

McPherson, C.R., B. Martin, J.T. MacDonnell, and C.J. Whitt. 2016. Examining the value of the acoustic variability Index in the characterisation of Australian marine soundscapes. *ACOUSTICS 2016*. 9-11 Nov 2016,

Brisbane, Australia. p. 13. https://www.acoustics.asn.au/conference_proceedings/AASNZ2016/papers/p19.pdf.

Miksis-Olds, J.L. and S.M. Nichols. 2016. Is low frequency ocean sound increasing globally? *Journal of the Acoustical Society of America* 139(1): 501-511. https://doi.org/10.1121/1.4938237.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

Nedwell, J.R., A.W. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, J.A.L. Spinks, and D. Howell. 2007. *A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise*. Document Number 534R1231 Report prepared by Subacoustech Ltd. for Chevron Ltd, TotalFinaElf Exploration UK PLC, Department of Business, Enterprise and Regulatory Reform, Shell UK Exploration and Production Ltd, The Industry Technology Facilitator, Joint Nature Conservation Committee, and The UK Ministry of Defence. 74 p. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-et-al-2007.pdf.

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. *Journal of the Acoustical Society of America* 115(4): 1832-1843. https://doi.org/10.1121/1.1675816.

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

Ross, D. 1976. *Mechanics of Underwater Noise*. Pergamon Press, NY, USA.

Salgado Kent, C.P., R.D. McCauley, I.M. Parnum, and A.N. Gavrilov. 2012. Underwater noise sources in Fremantle inner harbour: Dolphins, pile driving and traffic. *Acoustics 2012*. 21-23 Nov 2012, Fremantle, Australia.

Scrimger, J.A., D.J. Evans, G.A. McBean, D.M. Farmer, and B.R. Kerman. 1987. Underwater noise due to rain, hail, and snow. *Journal of the Acoustical Society of America* 81(1): 79-86. https://doi.org/10.1121/1.394936.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521. https://doi.org/10.1578/AM.33.4.2007.411.

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

Strasberg, M. 1979. Nonacoustic noise interference in measurements of infrasonic ambient noise. *Journal of the Acoustical Society of America* 66(5): 1487-1493. https://doi.org/10.1121/1.383543.

Urick, R.J. 1974. Sea-bed motion as a source of the ambient noise background of the sea. *Journal of the Acoustical Society of America* 56(3): 1010-1011. https://doi.org/10.1121/1.1903363.

Urick, R.J. 1983. *Principles of Underwater Sound*. 3rd edition. McGraw-Hill, New York, London. 423 p.

van Opzeeland, I. and O. Boebel. 2018. Marine soundscape planning: Seeking acoustic niches for anthropogenic sound. *Journal of Ecoacoustics* 2(5GSNT). https://doi.org/10.22261/JEA.5GSNT8.

Wenz, G.M. 1962. Acoustic Ambient Noise in the Ocean: Spectra and Sources. *Journal of the Acoustical Society of America* 34(12): 1936-1956. https://doi.org/10.1121/1.1909155.

Appendix A. Underwater Acoustics

A.1. Acoustic Metrics Mathematical Definitions

Sound levels with individual metrics defined below, are presented as:

- Broadband and approximate-decade-band SPL over time for these frequency bands for the 64 kHz sample rate: 8.9 Hz–32 kHz, 8.9–89 Hz, 89 Hz to 891 Hz, 891 Hz–8.91 kHz, and 8.91 kHz–32 kHz.
- Spectrograms: Ambient noise at each station was analysed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 min average spectra.
- Statistical distribution of SPL in each decidecade. The boxes of the statistical distributions indicate the first (L_5), second (L_{50}), and third (L_{75}) quartiles. The whiskers indicate the maximum and minimum range of the data. The solid line indicates the sound pressure level (SPL) or L_{eq} in each decidecade.
- Spectral level percentiles: Histograms of each frequency bin per 1 min of data. The L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles are plotted. The L_5 percentile curve is the frequency-dependent level exceeded by 95% of the 1 min averages. Equivalently, 5% of the 1 min spectral levels are above the 95th percentile curve.
- Daily cumulative sound exposure levels (SEL (24 h)): computed for the total received sound energy. The SEL (24 h) is the linear sum of the 1 min sound exposure levels (SEL). These SEL values were weighted to mimic different functional hearing groups according to the marine mammal frequency-weighted curves described in Appendix D.

Sound is most commonly described using the sound pressure level (SPL) metric. Underwater sound amplitude levels are commonly measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 µPa.

SPL (dB re 1 µPa) is the decibel level of the rms pressure in a stated frequency band over a time window (*T; s*) containing the acoustic event:

$$\text{SPL} = 10 \log_{10} \left(\frac{1}{T} \int_T p^2(t)\, dt \Big/ p_0^2 \right) \quad \text{(A-1)}$$

The SPL is a measure of the effective pressure level over the duration of an acoustic event, such as the emission of one acoustic pulse or sweep. Because the window length, *T*, is the divisor, events more spread out in time have a lower SPL even though they may have similar total acoustic energy density.

Power spectral density (PSD) level is a description of how the acoustic power is distributed over different frequencies within a spectrum. It is expressed in dB re 1 µPa^2/Hz.

The sound exposure level (SEL, dB re 1 µPa^2·s) is a measure of the total acoustic energy contained in one or more acoustic events. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100}):

$$\text{SEL} = 10 \log_{10} \left(\int_{T_{100}} p^2(t)\, dt \Big/ T_0 p_0^2 \right) \quad \text{(A-2)}$$

where T_0 is a reference time interval of 1 s. The SEL represents the total acoustic energy received at a location during an acoustic event; it measures the total sound energy an organism at that location would be exposed to.

Because the SPL and SEL are both computed from the integral of square pressure, these metrics are related by the following expression, which depends only on the duration of the energy time window T:

$$\mathrm{SPL} = \mathrm{SEL} - 10\log_{10}(T) \quad \text{(A-3)}$$

Sound level statistics, namely percentiles, were used to quantify the distribution of recorded sound levels. The *n*th percentile level (L_n) is the level (i.e., PSD level, SPL, or SEL) *n*% of the data are below this level. L_{eq} is the linear arithmetic mean of the sound power, which can be substantially different from the median sound level L_{50}. SPL can also be referred to as L_{eq}, which stands for 'equivalent level'. The two terms are used interchangeably throughout. L_{95}, the level exceeded by only 5% of the data, represents the highest typical sound levels measured. Sound levels between L_5 and L_{99} are generally from very close passes of vessels, very intense weather events, and other infrequent conditions. L_5 represents the quietest typical conditions.

Appendix B. Acoustic Data Analysis Methods

The data sampled at 64 and 128 kHz was processed for ambient sound analysis, vessel noise detection, and detection of all marine mammal vocalisations. This section describes the ambient, vessel, and marine mammal detection algorithms employed (Figure B-1).

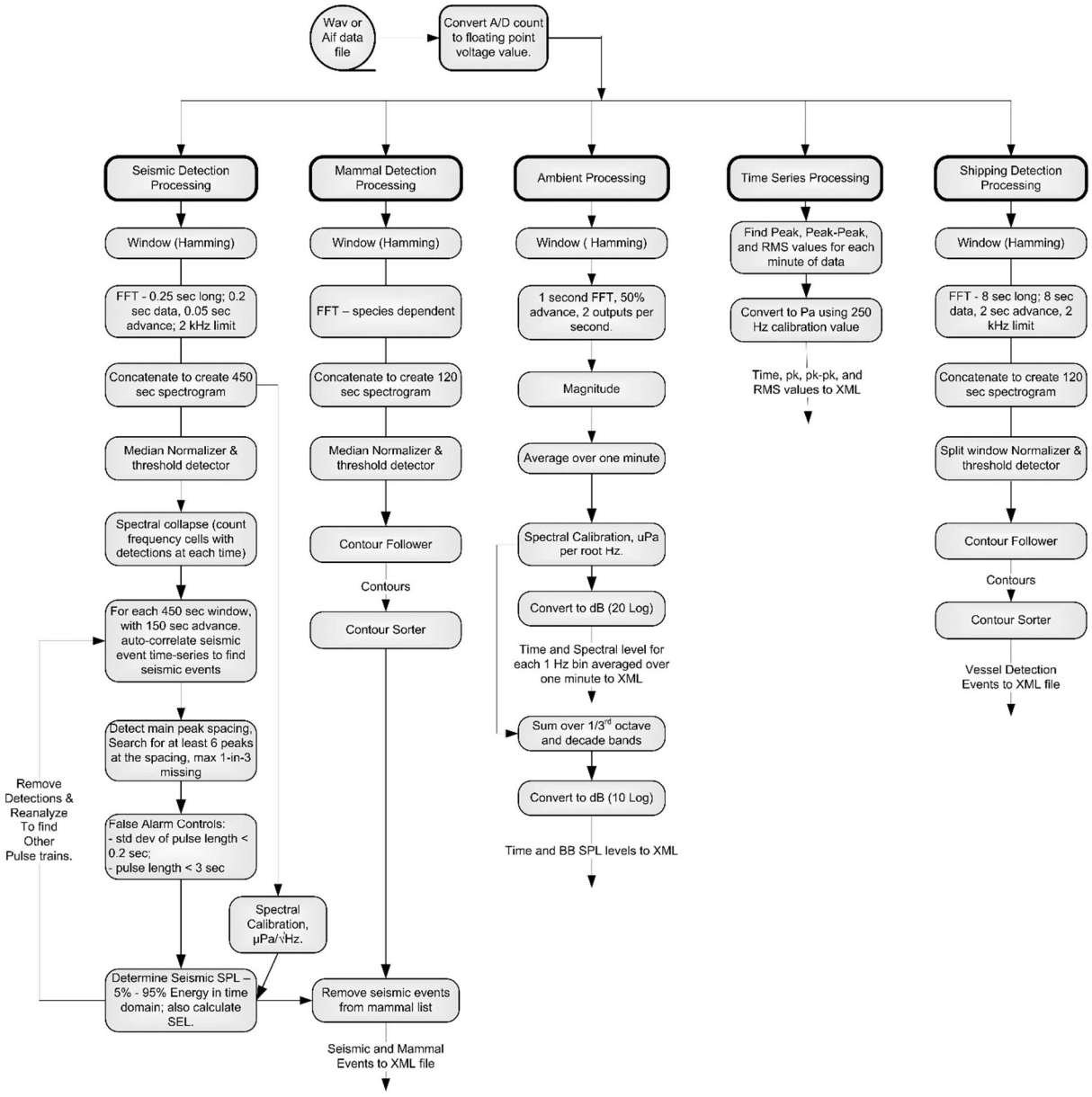


Figure B-1. Major stages of the automated acoustic analysis process performed with JASCO's custom software suite.

B.1. Total Ambient Sound Levels

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 µPa. Because the perceived loudness of sound, especially impulsive noise such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on marine life. We provide specific definitions of relevant metrics used in this report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The zero-to-peak pressure level, or peak pressure level (PK or $L_{p,pk}$; dB re 1 µPa), is the decibel level of the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$\text{PK} = L_{p,\text{pk}} = 10 \log_{10} \frac{\max|p^2(t)|}{p_0^2} \tag{B-1}$$

PK is often included as criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a noise event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or L_p; dB re 1 µPa) is the decibel level of the root-mean-square (rms) pressure in a stated frequency band over a specified time window (T; s) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$\text{SPL} = L_p = 10 \log_{10} \left[\frac{1}{T} \int_T p^2(t)\, dt \Big/ p_0^2 \right] \tag{B-2}$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalisation, the passage of a vessel, or over a fixed duration. Because the window length, T, is the divisor, events with similar sound exposure level (SEL), but more spread out in time have a lower SPL.

The sound exposure level (SEL or L_E, dB re 1 µPa^2·s) is a measure related to the acoustic energy contained in one or more acoustic events (N). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T):

$$\text{SEL} = L_E = 10 \log_{10} \left[\int_T p^2(t)\, dt \Big/ T_0 p_0^2 \right] \tag{B-3}$$

where T_0 is a reference time interval of 1 s. The SEL continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over periods with multiple events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10 \log_{10} \sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \tag{B-4}$$

To compute the SPL(T_{90}) and SEL of acoustic events in the presence of high levels of background noise, equations B-1 and B-2 are modified to subtract the background noise contribution:

$$\text{SPL}(T_{90}) = L_{p90} = 10\log_{10}\left[\frac{1}{T_{90}}\int_{T_{90}}\left(p^2(t) - \overline{n^2}\right)dt \Big/ p_0^2\right] \quad \text{(B-5)}$$

$$L_E = 10\log_{10}\left[\int_{T}\left(p^2(t) - \overline{n^2}\right)dt \Big/ T_0 p_0^2\right] \quad \text{(B-6)}$$

where $\overline{n^2}$ is the mean square pressure of the background noise, generally computed by averaging the squared pressure of a temporally-proximal segment of the acoustic recording during which acoustic events are absent (e.g., between pulses).

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \quad \text{(B-7)}$$

$$L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458 \quad \text{(B-8)}$$

where the 0.458 dB factor accounts for the 10% of SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same period of time, T:

$$L_{\text{eq}} = 10\log_{10}\left[\frac{1}{T}\int_{T} p^2(t)\,dt \Big/ p_0^2\right] \quad \text{(B–9)}$$

The equations for SPL and the energy-equivalent SPL are numerically identical; conceptually, the difference between the two metrics is that the former is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over times typically of one minute to several hours.

B.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. These values directly compare to the Wenz curves, which represent typical deep ocean sound levels (Figure 2) (Wenz 1962). This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analysing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3-octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}}\ \text{kHz} \quad \text{(B-1)}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decade band are defined as:

$$f_{\text{lo},i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{\text{hi},i} = 10^{\frac{1}{20}} f_c(i) \tag{B-2}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure B-2).

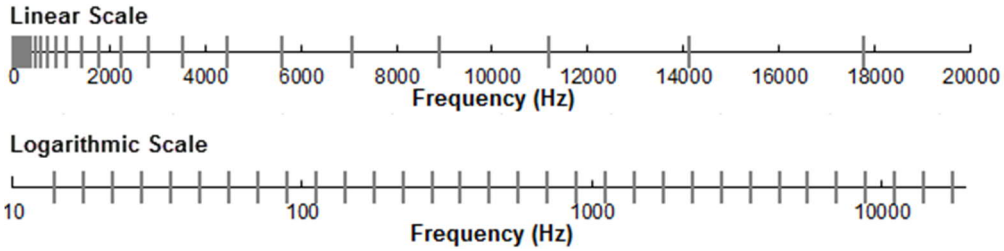


Figure B-2. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{\text{lo},i}$ and $f_{\text{hi},i}$:

$$L_{p,i} = 10 \log_{10} \int_{f_{\text{lo},i}}^{f_{\text{hi},i}} S(f)\, df \tag{B-3}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \tag{B-4}$$

Figure B-3 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient noise signal. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the spectral levels at higher frequencies. Decidecade band analysis is applied to continuous and impulsive noise sources. For impulsive sources, the decidecade band SEL is typically reported.

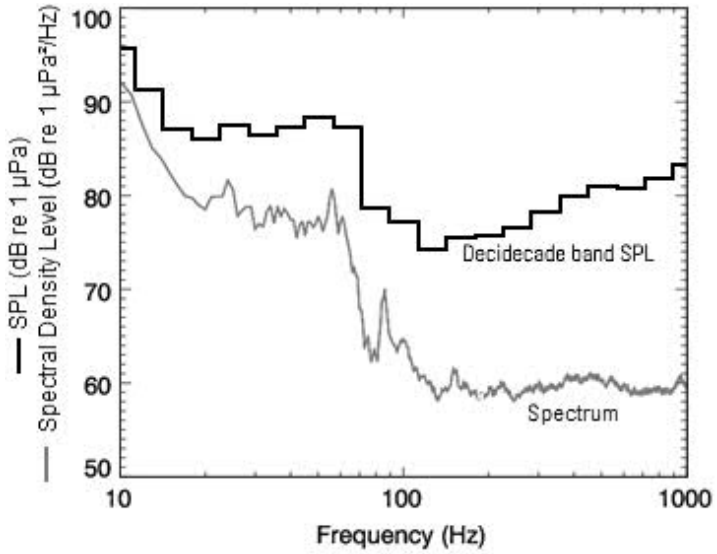


Figure B-3. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

Table B-1. Decidecade band frequencies (Hz)

Band	Lower frequency	Nominal centre frequency	Upper frequency
10	8.9	10.0	11.2
11	11.2	12.6	14.1
12	14.1	15.8	17.8
13	17.8	20.0	22.4
14	22.4	25.1	28.2
15	28.2	31.6	35.5
16	35.5	39.8	44.7
17	44.7	50.1	56.2
18	56.2	63.1	70.8
19	70.8	79.4	89.1
20	89.1	100.0	112.2
21	112	126	141
22	141	158	178
23	178	200	224
24	224	251	282
25	282	316	355
26	355	398	447
27	447	501	562
28	562	631	708
29	708	794	891
30	891	1000	1122
31	1122	1259	1413
32	1413	1585	1778
33	1778	1995	2239
34	2239	2512	2818
35	2818	3162	3548
36	3548	3981	4467
37	4467	5012	5623
38	5623	6310	7079
39	7079	7943	8913
40	8913	10000	11220
41	11220	12589	14125
42	14260	16000	17952
43	17825	20000	22440
44	22281	25000	28050
45	28074	31500	35344

Table B-2. Decade-band frequencies (Hz)

Decade band	Lower frequency	Nominal centre frequency	Upper frequency
A	8.9	50	89.1
B	89.1	500	891
C	891	5000	8910
D	8910	50000	89100 (Here limited to 64000)

B.3. Millidecade Band Analysis

JASCO Applied Sciences has adopted a hybrid millidecade spectrum system to store and exchange passive acoustic spectral data to optimise data resolution while minimising data size, described in Martin et al. (2021).

Millidecades are logarithmically spaced frequency bands but have a bandwidth equal to 1/1000th of a decade. This frequency resolution is high enough to support many types of analysis, including analysing different types of soundscapes, computing weighted sound exposure levels, and summing the millidecades to find decidecades, 1/3-octave, and other desired frequency bands. The size of the millidecade files greatly compresses the acoustic data compared to 1 Hz resolution, such that data from long-term, multiple-station, high-sampling frequency projects can easily be stored at a single location. For example, there are 1,000 millidecades in each frequency decade, where a decade is an increase in the frequency by a factor of 10. A pure millidecade presentation of a spectrum from 1–100,000 Hz has 5,000 bands rather than 100,000 1 Hz bands, which results in a 20:1 decrease in the amount of data required for storage or exchange. For a 256 kHz spectrum, which is becoming a common size for recorders sampling at 512 kHz, there are 3,206 hybrid millidecades resulting in a compression ratio of 80:1.

The format uses 1-Hz resolution up to 455 Hz and millidecades frequency bands above 455 Hz. The lowest millidecades over-resolve (bin sizes <1 Hz) the space between 1–435 Hz for nearly all soundscape applications. To address this, a hybrid solution was applied that uses 1 Hz bands up to 455 Hz, where the millidecades are 1 Hz wide.

Similar to decidecades, the centre frequency for the i^{th} millidecade (f_{c_i}) is defined as

$$f_{c_i} = 10^{i/1{,}000} \text{ (Hz)} \tag{10}$$

and the lower (f_{lo_i}) and upper (f_{hi_i}) bounds for each millidecade are

$$f_{lo_i} = f_{c_i} \cdot 10^{-1/2{,}000} \text{ (Hz)} \tag{11}$$

$$f_{hi_i} = f_{c_i} \cdot 10^{1/2{,}000} \text{ (Hz)} . \tag{12}$$

Appendix C. Recorder Calibration

The AMAR was calibrated before deployment with a pistonphone type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S; Figure C-1). Due to the unforeseen delay of the retrieval the battery life was exhausted which prevented a calibration after retrieval. The pistonphone calibrator produces a constant tone at 250 Hz at a fixed distance from the hydrophone sensor in an airtight space with known volume. The recorded level of the reference tone on the AMAR yields the system gain for the AMAR and hydrophone. To determine absolute sound pressure levels, this gain was applied during data analysis. Typical calibration variance using this method is less than 0.7 dB absolute pressure.

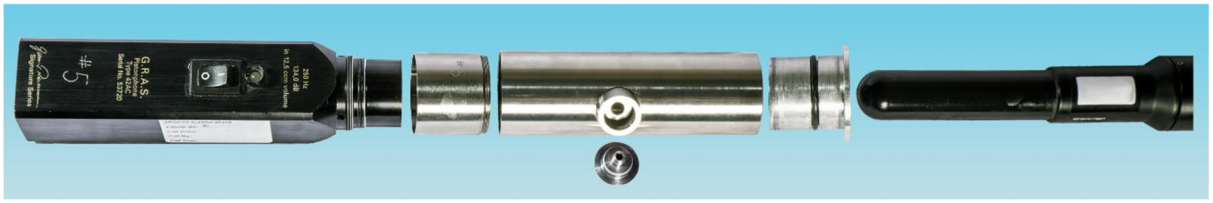


Figure C-1. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M36 hydrophone.

Appendix D. Noise Effect Criteria

D.1. Noise Effect Criteria

To assess the potential effects of a sound-producing activity, it is first necessary to establish exposure criteria (thresholds) for which sound levels may be expected to have a negative effect on animals. Whether acoustic exposure levels might injure or disturb marine fauna is an active research topic. Since 2007, several expert groups have developed sound exposure level (SEL) based assessment approaches for evaluating auditory injury, with key works including Southall et al. (2007), Finneran and Jenkins (2012), Popper et al. (2014), United States National Marine Fisheries Service (NMFS 2018) and Southall et al. (2019). The number of studies that investigate the level of behavioural disturbance to marine fauna by anthropogenic sound has also increased substantially.

Two sound level metrics, sound pressure level (SPL), and SEL (Appendix A), are commonly used to evaluate non-impulsive noise and its effects on marine life. In this report, the duration of the SEL accumulation is defined as integrated over a 24 h time period. Appropriate subscripts indicate any applied frequency weighting applied. The acoustic metrics in this report reflect the amended ANSI and ISO standards for acoustic terminology, ANSI S1.1 (S1.1-2013), and ISO 18405:2017 (2017a).

The following thresholds were chosen because they represent the best available science:

1. Frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from the US National Oceanic and Atmospheric Administration (NOAA) Technical Guidance (NMFS 2018) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals for non-impulsive sources.
2. Marine mammal behavioural threshold based on the current interim U.S. National Oceanic and Atmospheric Administration (NOAA) (2019) criterion for marine mammals of 120 dB re 1 µPa (SPL; L_p) for non-impulsive sound sources.

The criteria applied in this study to assess possible effects of vessel noise on marine mammals are summarised in Table D-1, with frequency weighting explained in Appendix D.2.

Table D-1. Criteria for effects of continuous noise exposure, including vessel noise, for marine mammals: Unweighted sound pressure level (SPL) and 24 h sound exposure level (SEL_{24h}) thresholds.

Hearing group	NOAA (2019)	NMFS (2018)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa2 s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa2 s)
Low-frequency (LF) cetaceans	120	199	179
High-frequency (HF) cetaceans		198	178
Very high-frequency (VHF) cetaceans		173	153
Phocid seals		201	181
Otariid seals		219	199

L_p denotes sound pressure level period and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 $\mu Pa^2 s$.

D.2. Auditory Frequency Weighting Functions

The potential for anthropogenic sounds to impact marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well, unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound (Nedwell and Turnpenny 1998, Nedwell et al. 2007). Houser et al (2017) provide an example illustrating the effect of applying a weighting function to a (hypothetical) sound (Figure D-1).

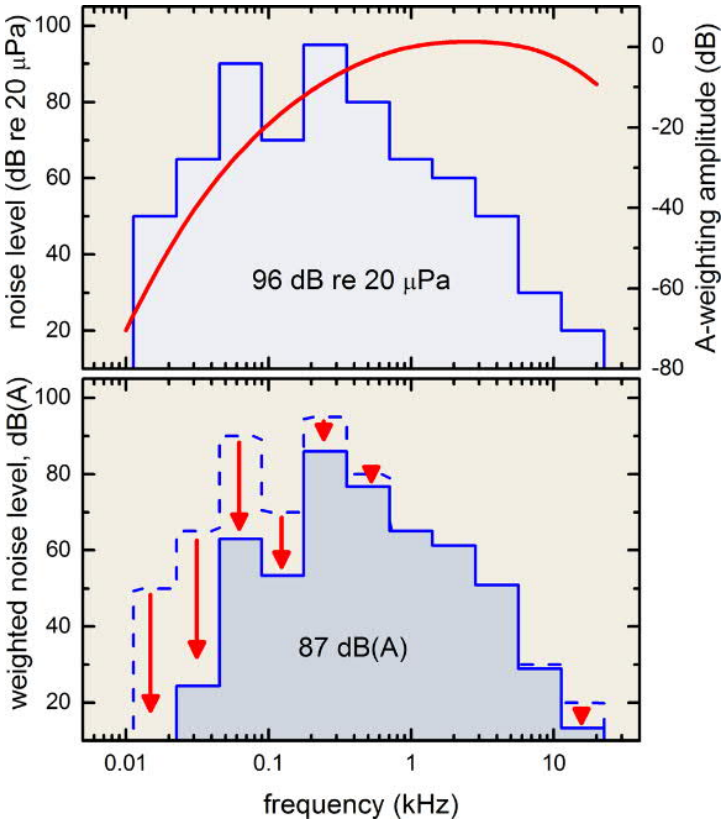


Figure D-1. Application of an auditory weighting function. Blue line shows a hypothetical, octave-band sound pressure spectrum in air, with a total sound pressure level (integrated over all octave-bands) of 96 dB re 20 µPa (This example uses in air-noise levels; therefore, a different reference pressure (20 µPa) applies. The principle is identical to underwater sound where a reference pressure of 1 µPa applies). (Top) Red line shows the human A-weighting function amplitude (A-weighting applies only to human hearing). (Bottom) To determine the weighted exposure level, the A-weighting amplitude at each frequency is added to the sound pressure level at each frequency (red arrows). The weighted spectrum has lower amplitude at the frequencies where the A-weighting function amplitudes are negative. The values from 1–4 kHz do not change substantially, because the weighting function is flat (i.e., the weights are near zero). The weighted SPL is calculated by integrating the weighted spectrum across all octave-bands; the result is 87 dBA, meaning a sound pressure level of 87 dB re 20 µPa after applying the human A-weighting function (Source: Houser et al. 2017).

To better reflect the auditory similarities between phylogenetically closely related species, but also significant differences between species groups among the marine mammals, the extant marine mammal species are assigned to functional hearing groups based on their hearing capabilities and sound production (NMFS 2018) (Table D-2). This division into broad categories is intended to provide a realistic number of categories for which individual noise exposure criteria were developed and the categorisation as such has proven to be a scientifically justified and useful approach in developing auditory frequency weighting functions and deriving noise exposure criteria for marine mammals.

Table D-2. Marine mammal hearing groups (NMFS 2018).

Hearing group	*Generalised hearing range**
Low-frequency (LF) cetaceans (mysticetes or baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (odontocetes: delphinids, beaked whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (other odontocetes)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater)	60 Hz to 39 kHz

* The generalised hearing range for all species within a group. Individual hearing will vary.

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

In 2015, a U.S. Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left[\left(\frac{(f/f_{lo})^{2a}}{\left[1+(f/f_{lo})^{2}\right]^{a}\left[1+(f/f_{hi})^{2}\right]^{b}}\right)\right] \quad \text{(D-1)}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2016, NMFS 2018). Table D-3 lists the frequency-weighting parameters for each hearing group; Figure D-2 shows the resulting frequency-weighting curves.

Table D-3. Parameters for the auditory weighting functions used in this project as recommended by NMFS (2018).

Hearing group	*a*	*b*	f_{lo} (Hz)	f_{hi} (kHz)	*K* (dB)
Low-frequency cetaceans (baleen whales)	1.0	2	200	19,000	0.13
Mid-frequency cetaceans (dolphins, plus toothed, beaked, and bottlenose whales)	1.6	2	8,800	110,000	1.20
High-frequency cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	1.8	2	12,000	140,000	1.36
Phocid seals in water	1.0	2	1,900	30,000	0.75
Otariid seals in water	2.0	2	940	25,000	0.64

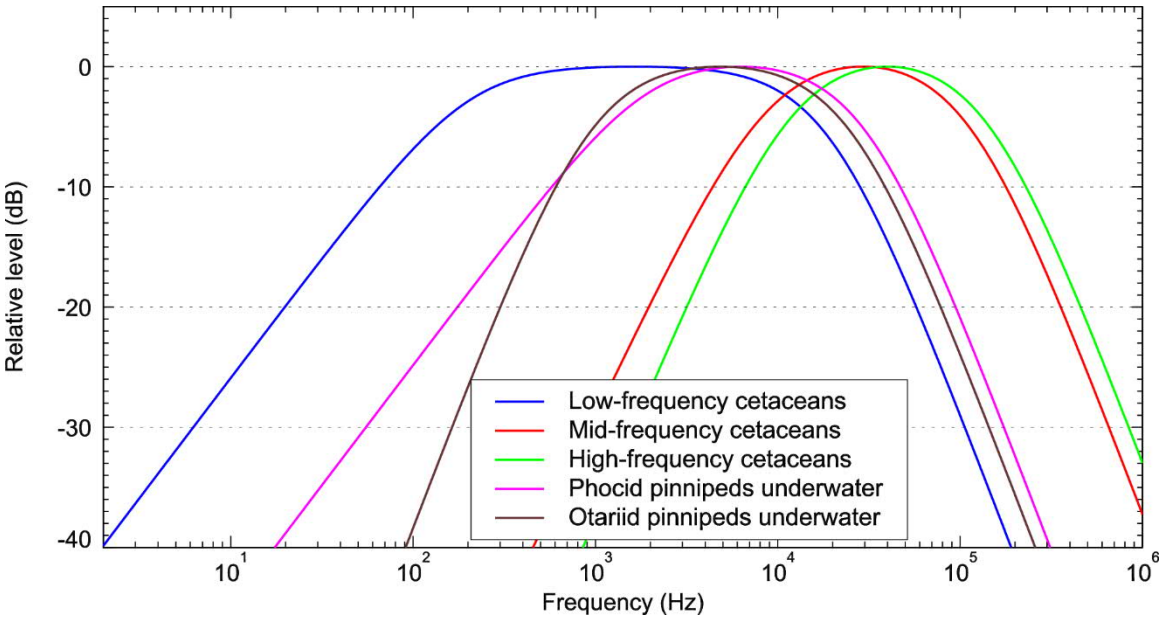


Figure D-2. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018).

Appendix E. Mooring Design

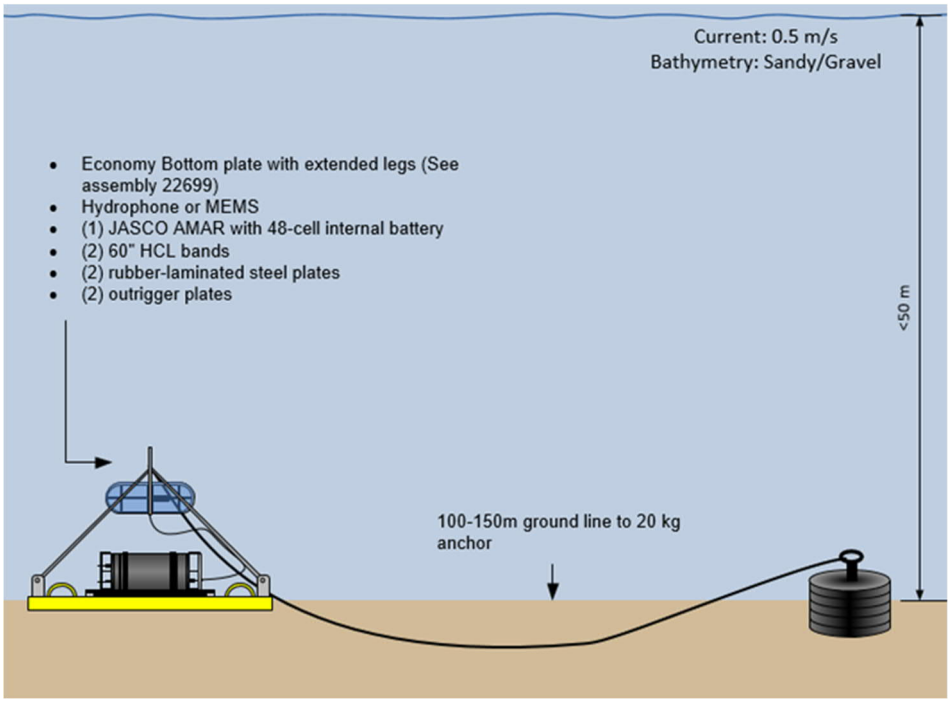


Figure E-1. Mooring design for acoustic environment recordings.

Appendix A-2: Underwater Noise Modelling

Viva Energy Gas Terminal Project Environment Effects Statement

JASCO Applied Sciences (Australia) Pty Ltd

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The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

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Executive Summary

This technical report provides the results of underwater acoustic modelling conducted to support an underwater noise impact assessment which forms part of the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

This underwater acoustic modelling study presents the outputs from models of underwater noise resulting from the construction phase and future operations of the Viva Gas Energy Terminal in Corio Bay. Acoustic models were used to simulate four main scenarios, each with a number of sub-scenarios, as follows:

1. Pile driving:
    a. Dolphin pile, part of the construction of the pier extension for the gas terminal.
    b. Mooring piles at Lascelles Wharf.
2. Dredging:
    a. Localised dredging at Refinery Pier to enable the FSRU and LNG carriers to berth at the pier extension.
    b. Installation of seawater transfer piping.
3. Future operations:
    a. FSRU berthed
    b. FSRU berthed and LNG carrier offloading
4. Future berthing:
    a. LNG carrier approaching (4 knots)
    b. LNG carrier approaching (2 knots)
    c. LNG carrier berthing (0.5 knots)

The study results are required for assessing the potential effects of noise exposure on marine mammals, fish (including eggs and larvae), and diving birds in the vicinity of the project. Due to the variety of species considered, there are several different thresholds for evaluating effects, including those associated with mortality, injury, temporary reduction in hearing sensitivity, and behavioural disturbance.

The modelling methodology considered scenario specific source levels and range-dependent environmental properties. Estimated underwater acoustic levels for non-impulsive (continuous) noise sources are presented as sound pressure levels (SPL, L_p), and as accumulated sound exposure levels (SEL, L_E). Estimated underwater acoustic levels for impulsive noise sources (piling) are presented as sound pressure levels, zero-to-peak pressure levels (PK, L_{pk}), and either single-impulse (i.e., per-pulse) or accumulated sound exposure levels as appropriate for different noise effect criteria. In this report, the duration of the SEL accumulation is defined as being integrated over a 24-hour period, which includes multiple piles being installed per day. SEL_{24h} is a cumulative metric that reflects the dosimetric impact of noise levels over 24 hours, based on the assumption that an animal is consistently exposed to such noise levels whilst remaining static for the period.

The modelling results predict very little sound transmission beyond Corio Bay and the Port of Geelong due to the local bathymetry.

Pile Driving

For impulsive sources, the SEL accumulates with each strike. Conservative estimates of SEL_{24h} for pile driving were calculated based on the assumption that a maximum of three piles could be driven per day for the dolphin pile at the pier extension, and four piles per day for the smaller mooring piles. Accumulated levels are based on the modelled sound emissions of a single mid-sequence strike at each location.

Marine Mammals:

The results for marine mammal injury used the criteria from Southall et al. (2019), which requires two metrics (PK and SEL_{24h}) to be considered when assessing marine mammal Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS). The longest distance associated with either metric should be applied.

Table 1 summarises the results from the modelling in terms of R_{max}, which represents the largest distances from the sound source to the indicated sound level thresholds. It includes the distances to the NOAA (2019) marine mammal behavioural response criterion of 160 dB re 1 µPa (SPL), and temporary threshold shift (TTS) based on the Southall et al. (2019) criteria. No criterion associated with permanent threshold shift (PTS) or peak pressure was exceeded within the resolution of the models.

Table 1. Summary of maximum (R_{max}) horizontal distances (in km) from piling modelled sites to behavioural response thresholds, temporary threshold shift (TTS) and permanent threshold shift (PTS) for marine mammals. Where dual criteria are used, the metric applied is that which is associated with the longer distance.

Hearing group	Modelled distance to effect threshold (R_{max})		
	Behavioural response[a]	Impairment: TTS[b]	Impairment: PTS[b]
1a) Dolphin pile			
High-frequency (HF) cetaceans	0.80	0.07	—
Otariid pinnipeds (OCW)		0.10	—
1b) Mooring pile			
High-frequency (HF) cetaceans	0.26	—	—
Otariid pinnipeds (OCW)		—	—

Noise exposure criteria: [a] NOAA (2019) and [b] Southall et al. (2019).
A dash indicates the threshold was not reached within the limits of the modelling resolution.

Fish, fish eggs, and fish larvae:

This modelling study assessed the ranges for quantitative criteria based on Popper et al. (2014) and considered both PK and SEL_{24h} metrics associated with mortality, potential mortal injury, and impairment in the following groups:

- Fish without a swim bladder (also appropriate for sharks in the absence of other information),
- Fish with a swim bladder that do not use it for hearing,
- Fish that use their swim bladders for hearing,
- Fish eggs and fish larvae.

Table 2 summarises distances to effect criteria for fish, fish eggs, and fish larvae along with the metric associated with the longest distance.

Table 2. Summary of maximum fish, fish eggs, and larvae injury and temporary threshold shift (TTS) onset distances for single impulse and 24-hour sound exposure level (SEL_{24h}) modelled scenarios. Where dual criteria are used, the metric applied is that which is associated with the longer distance.

Hearing group	1a – Dolphin pile		1b – Mooring pile	
	Metric	R_{max} (km)	Metric	R_{max} (km)
Injury/recoverable injury[a]				
Fish: No swim bladder	n/a	—	n/a	—
Fish: Swim bladder not involved in hearing and Swim bladder involved in hearing	SEL_{24h}	0.02	n/a	—
Fish eggs, and larvae	SEL_{24h}	0.02	n/a	—
TTS*				
Fish: No swim bladder Swim bladder not involved in hearing and Swim bladder involved in hearing	SEL_{24h}	0.87	SEL_{24h}	0.11

Noise exposure criteria: [a] Popper et al. (2014).
A dash indicates the threshold was not reached within the limits of the modelling resolution.

Diving birds:

There are no regulatory thresholds or criteria established to assess potential behavioural responses by diving birds to underwater noise. To assess possible impacts, a frequency-weighted onset criterion for behavioural responses of diving birds of 120 dB re 1 µPa (SPL) for impulsive sources was chosen based on information from Sørensen et al. (2020). Table 3 shows results determined to assist with assessing the potential effects on diving birds.

Table 3. Summary of maximum (R_{max}) horizontal distances (in km) from piling modelled sites to behavioural response threshold, temporary threshold shift (TTS) and permanent threshold shift (PTS) for diving birds.

Hearing group	Effect	1a – Dolphin pile		1b – Mooring pile	
		Metric	R_{max} (km)	Metric	R_{max} (km)
Diving birds	PTS[a]	n/a	—	n/a	—
	TTS[a]	SEL_{24h}	0.10	n/a	—
	Behavioural response[b]	SPL	4.90	SPL	3.62

Noise exposure criteria: [a] Southall et al. (2019) (Otariid pinnipeds (OCW) as a proxy), and [b] Sørensen et al. (2020)
A dash indicates the threshold was not reached within the limits of the modelling resolution.

Vessels

For continuous sources, the SEL accumulates over the duration the source is active. To calculate SEL_{24h} for the dredging and the FSRU operations, each were considered to be in continuous operation over 24 hours.

Marine Mammals:

The study investigated sound level thresholds associated with auditory impairment in high-frequency cetaceans and otariid pinnipeds. No relevant PTS levels were exceeded in these scenarios, therefore the table presents the longest distances to recommended threshold levels for TTS onset (Southall et al. 2019) and relevant behavioural thresholds (NOAA 2019) are shown in Table 4.

Table 4. Summary of temporary threshold shift (TTS) and behavioural response distances for marine mammals in the continuous sound scenarios (Scenarios 2 and 3).

Hearing group	Metric	2a – Dredging berth and swing basin	2b – Dredging seawater piping	3a – FSRU	3b – FSRU + LNG Carrier
		R_{max} (km)	R_{max} (km)	R_{max} (km)	R_{max} (km)
PTS[a]					
High-frequency cetaceans	SEL_{24h}	—	—	—	—
Otariid pinnipeds	SEL_{24h}	—	—	—	—
TTS[a]					
High-frequency cetaceans	SEL_{24h}	0.01	0.01	0.01	0.04
Otariid pinnipeds	SEL_{24h}	<0.01	0.01	—	0.03
Behavioural response[b]					
Marine mammals	SPL	1.55	1.84	1.10	1.46

Noise exposure criteria: [a] Southall et al. (2019), and [b] NOAA (2019).
A dash indicates the threshold was not reached within the limits of the modelling resolution.

Fish:

The maximum distances to recommended sound level thresholds for fish (Popper et al. 2014) are shown in Table 5. For continuous sounds, sound level thresholds are only provided for fish with a swim bladder involved in hearing. In terms of recoverable injury onset levels, the maximum distance is less than 10 m from the acoustic centre of the source in Scenario 2a only (48-hour exposure). The maximum distance to the TTS onset threshold level is 30 m in Scenario 3b (12-hour exposure). Additional investigations were carried out for demersal fish for which the modelling predicts that neither the recoverable injury or TTS onset thresholds will be reached at the seafloor.

Table 5. Maximum distances to recommended sound level thresholds by Popper et al. (2014) for fish with a swim bladder involved in hearing exposed to vessel noise (Scenarios 2 and 3).

Hearing group	Effect	2a) Dredging – berth & swing basin	2b) Dredging – seawater piping	3a) FSRU	3b) FSRU + LNG carrier
		R_{max} (km)	R_{max} (km)	R_{max} (km)	R_{max} (km)
Fish: Swim bladder involved in hearing	Recoverable injury	<0.01	—	—	—
	TTS	0.01	0.01	<0.01	0.03

A dash indicates the threshold was not reached within the limits of the modelling resolution.

Berthing

For the berthing scenario, the SEL accumulates over the equivalent length of time the sources are present at each point on a defined approach path.

Marine Mammals:

In this scenario, no relevant PTS or TTS levels were exceeded, therefore Table 6 presents relevant behavioural thresholds only.

Table 6. Summary behavioural response distances for marine mammals in Scenario 4.

Hearing group	Metric	4a – 4 knots	4b – 2 knots	4c – 0.5 knots
		R_{max} (km)	R_{max} (km)	R_{max} (km)
Marine mammals	SPL	3.84	3.84	4.27

Noise exposure criteria: NOAA (2019).

Fish:

The maximum distances to recommended sound level thresholds for fish (Popper et al. 2014) are shown in Table 7. Again, as these sounds are non-impulsive, thresholds are only provided for fish with a swim bladder involved in hearing.

Table 7. Maximum distances to recommended sound level thresholds by Popper et al. (2014) for fish with a swim bladder involved in hearing exposed to vessel noise (Scenario 4).

Hearing group	Effect	4a – 4 knots	4b – 2 knots	4c – 0.5 knots
		R_{max} (km)	R_{max} (km)	R_{max} (km)
Fish: Swim bladder involved in hearing	Recoverable injury	<0.01	<0.01	0.04
	TTS	0.02	0.02	0.04

The maximum distance to both recoverable injury and TTS onset levels is 40 m from the acoustic centre of the sources in Scenario 4c, however, since these metrics are for 48-hour and 12-hour exposures, respectively, these will not be exceeded in the time taken to complete the berthing operation.

1. Introduction

1.1. Project Overview

This technical report provides the results of underwater acoustic modelling conducted to support an underwater noise impact assessment (Lucke and McPherson 2021) which forms part of the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a gas terminal using a ship known as a floating storage and regasification unit (FSRU), which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas for the south-east Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU) and would convert LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification) as required to meet industrial, commercial, and residential customer demand. A 7 km gas transmission pipeline would transfer the gas from the FSRU to the Victorian Transmission System (VTS) at Lara.

The project would be situated adjacent to, and on, Viva Energy's Geelong Refinery, within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. Co-locating the project with the existing Geelong Refinery and within the Port of Geelong offers significant opportunity to minimise potential environmental effects and utilise several attributes that come with the port and industrial setting.

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the *Environment Effects Act 1978* (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic, and transport as well as visual amenity.

In January 2021, the project was also determined to require assessment and approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) due to the potential for the project to have a significant impact on wetlands of international importance, listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

1.2. Study Specific Introduction

The scope of this study covers sound emissions caused both by the construction of new facilities and those caused by the operation of the moored FSRU and associated LNG carrier during berthed operational activities. This report describes the underwater acoustic modelling approaches and presents the predicted underwater sound levels over the area surrounding the proposed activities at the Geelong Refinery. Estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_p), zero-to-peak pressure levels (PK, L_{pk}), and accumulated sound exposure levels (SEL, L_E), as appropriate for noise effect criteria for continuous and impulsive noise sources.

Acoustic modelling was performed to estimate the propagation of sound into nearby waters using JASCO's Marine Operations Noise Model (MONM), and full waveform range-dependent model (FWRAM), across the entire relevant frequency spectrum. Maps and metrics were produced

describing distances at which sound levels could cause fish, diving birds, and marine mammal disturbance or injury.

1.3. Modelling Scenario Details

Four main scenarios associated with the construction and use of new facilities were considered for this study. These are detailed in Table 8. Modelled source locations for Scenarios 1 to 3 are mapped with context in Figure 1, with a map of Scenario 4 shown in Figure 2. Monopole source locations for the FSRU and LNG carriers were based on approximate acoustic centres of the vessels, both of which were assumed to be 300 metres long and 45 metres wide.

Table 8. Scenarios modelled in this study and associated source locations.

Scenario		Description	Latitude (S)	Longitude (E)	MGA Zone 55		Water depth (m)
					Easting (m)	Northing (m)	
1	a	Impact piling (dolphin)	38° 5.318’	144° 23.600’	271 397.5	5 781 142.2	8.3
	b	Impact piling (Lascelles Wharf)	38° 5.452’	144° 22.995’	270 521.1	5 780 869.2	4.6
2	a	Dredging (new berth & swing basin)	38° 5.535’	144° 23.585’	271 386.9	5 780 740.5	9.4
	b	Dredging (seawater piping)	38° 5.097’	144° 23.253’	270 881.0	5 781 536.1	5.4
3	a	FSRU	38° 5.275’	144° 23.493’	271 240.2	5 781 217.9	10.4
	b	FSRU + LNG carrier offloading	38° 5.293’	144° 23.468’	271 204.9	5 781 183.5	12.3
4	a	LNG carrier berthing (4 knots)	38° 5.738′	144° 23.178′	270 803.2	5 780 348.4	12.0
	b	LNG carrier berthing (2 knots)	38° 5.494′	144° 23.499′	271 259.5	5 780 811.5	12.0
	c	LNG carrier berthing (0.5 knots)	38° 5.356′	144° 23.533′	271 302.7	5 781 068.3	12.0

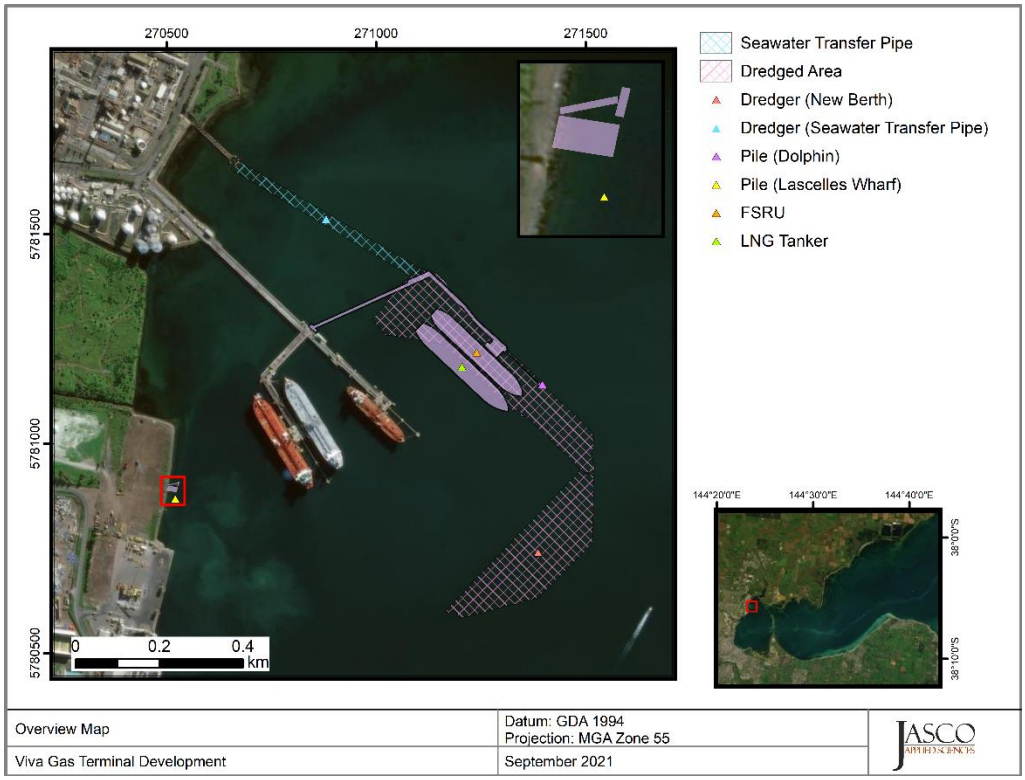


Figure 1. Map of the study area indicating modelled sound source locations for Scenarios 1 to 3.

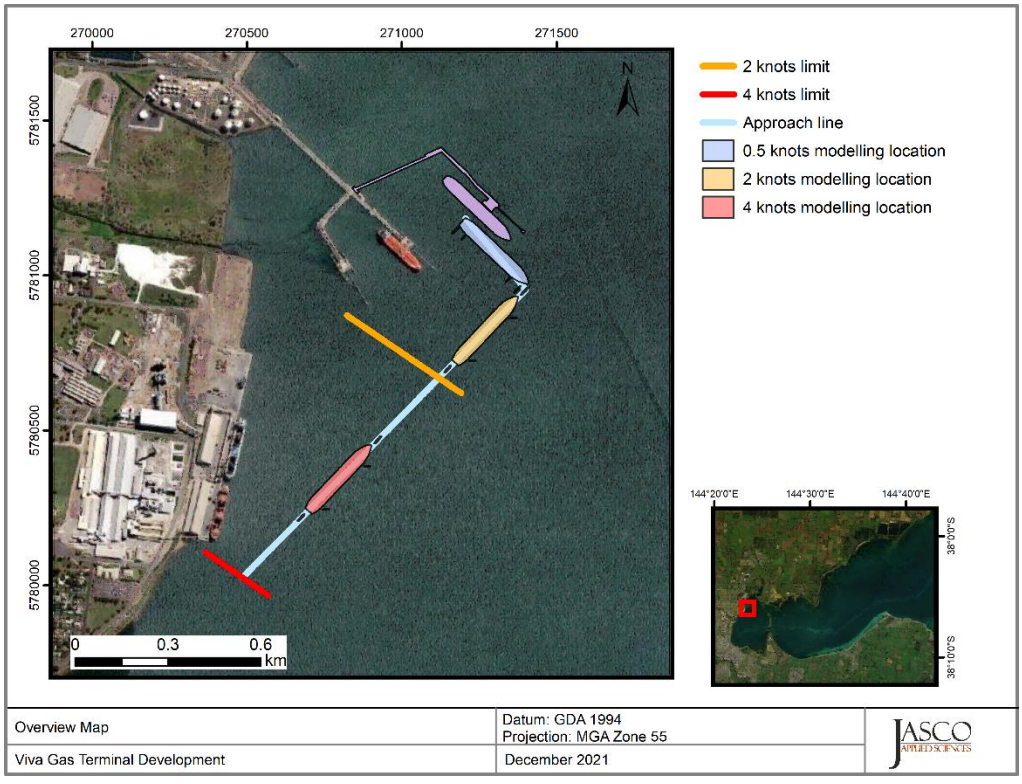


Figure 2. Map of the Scenario 4 indicating modelled source positions and line of approach.

2. Noise Effect Criteria

To assess the potential effects of a sound-producing activity, it is necessary to first establish exposure criteria (thresholds) for which sound levels may be expected to have a negative effect on animals. Whether acoustic exposure levels might injure or disturb marine fauna is an active research topic. Since 2007, several expert groups have developed SEL-based assessment approaches for evaluating auditory injury, with key works including Southall et al. (2007), Finneran and Jenkins (2012), Popper et al. (2014), United States National Marine Fisheries Service (NMFS 2018) and Southall et al. (2019). The number of studies that investigate the level of behavioural disturbance to marine fauna by anthropogenic sound has also increased substantially.

Two sound level metrics, SPL, and SEL, are commonly used to evaluate non-impulsive noise and its effects on marine life. In this report, the duration of the SEL accumulation is defined as integrated over a 24-hour time period. Appropriate subscripts indicate any frequency weighting applied (Appendix B.3). The acoustic metrics in this report reflect the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (2013) and ISO 18405:2017 (2017).

The following thresholds and guidelines for this study were chosen because they represent the best available science and sound levels presented in literature for fauna with no defined thresholds:

1. Peak pressure levels (PK; L_{pk}) and frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from Southall et al. (2019) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals, including high-frequency (HF) cetaceans and otariid pinnipeds (as a proxy for diving birds – see Section 2.3).
2. Marine mammal behavioural threshold based on the current interim U.S. National Oceanic and Atmospheric Administration (NOAA 2019) criterion for marine mammals of 120 dB re 1 µPa (SPL; L_p) and 160 dB re 1 µPa (SPL; L_p) for non-impulsive and impulsive sound sources, respectively.
3. Sound exposure guidelines for fish, fish eggs, and larvae from Popper et al. (2014).
4. Behavioural response to impulsive sound of 120 dB re 1 µPa (SPL; L_p) for diving birds based on information from Sørensen et al. (2020).

The following sections (Sections 2.1 and 2.2, along with Appendix B.3), expand on the thresholds, guidelines and sound levels for marine mammals, fish, fish eggs, fish larvae, and diving birds.

2.1. Marine Mammals

The criteria applied in this study to assess possible effects of non-impulsive and impulsive noise sources on marine mammals are summarised in Tables 9 and 10. High-frequency cetaceans and otariid seals were identified as the only mammalian hearing groups requiring assessment. Details on thresholds related to auditory threshold shifts or hearing loss and behavioural response are provided in Appendix B.3, with frequency weighting explained in detail in Appendix B.4. Note, that whilst the latest publication by Southall et al. (2021) provides recommendations and discusses the nuances of assessing behavioural response, the authors do not recommend new numerical thresholds for the onset of behavioural responses for marine mammals.

Table 9. Criteria for effects of non-impulsive noise exposure including vessel noise, for marine mammals considered in this study: Unweighted SPL and SEL_{24h} thresholds.

Hearing group	NOAA (2019)	Southall et al. (2019)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)
High-frequency (HF) cetaceans	120	198	178
Otariid seals		219	199

L_p denotes sound pressure level period and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24-hour period and has a reference value of 1 µPa²s.

Table 10. Acoustic effects of impulsive noise on marine mammals considered in this study: Unweighted SPL, SEL_{24h}, and PK thresholds.

Hearing group	NOAA (2019)	Southall et al. (2019)			
	Behaviour	PTS onset thresholds [a] (received level)		TTS onset thresholds [a] (received level)	
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)	PK (L_{pk}; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)	PK (L_{pk}; dB re 1 µPa)
High-frequency (HF) cetaceans	160	185	230	170	224
Otariid seals		203	232	188	226

[a] Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.
L_p denotes sound pressure level period.
$L_{pk,flat}$ denotes peak sound pressure is flat weighted or unweighted.
L_E denotes cumulative sound exposure over a 24-hour period.

2.2. Fish, Fish Eggs, and Fish Larvae

In 2006, the Working Group on the Effects of Sound on Fish and Sea Turtles was formed to continue developing noise exposure criteria for fish and sea turtles, following work began by a NOAA panel two years earlier. The group developed guidelines with specific thresholds for different levels of effects for several species groups (Popper et al. 2014), and define quantitative thresholds for three types of immediate effects:

- Mortality, including injury leading to death.
- Recoverable injury, including injuries unlikely to result in mortality, such as hair cell damage and minor haematoma.
- Temporary threshold shift.

Masking and behavioural effects can be assessed qualitatively by assessing relative risk rather than by specific sound level thresholds. However, as these depend upon activity-based subjective ranges, these effects are not addressed in this report, and are included in Tables 11 and 12 for completeness only. Because the presence or absence of a swim bladder has a role in hearing, fish susceptibility to injury from noise exposure depends on the species as well as the presence and role of a swim bladder in hearing. Thus, different thresholds were proposed for fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information), fish with a swim bladder not used for hearing, and fish that use their swim bladders for hearing. Fish eggs, and fish larvae are considered separately.

Impulsive noise from pile driving is assessed in this study based on the relevant effect thresholds from Popper et al. (2014), listed in Table 11. In general, whether an impulsive sound adversely affects fish behaviour depends on the species and the state of the fish exposed, amongst other factors.

The SEL metric integrates sound energy over a specified period of exposure. Because the period of integration for regulatory assessments is not well defined for very long-lasting exposures or sounds that do not have a clear start or end time, an exposure evaluation time must be defined. NMFS (2018) defines the exposure evaluation time as the lesser of 24 hours or the duration of the activity. Popper et al. (2014) recommend a standard period of the duration of the activity, but also include caveats regarding consideration of the actual exposure times if fish move. In this study, integration times for piling have been applied over both the time taken to drive a single pile, and the total number of piles expected to be driven per day.

Table 11. Criteria for pile driving noise exposure for fish, adapted from 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)	> 219 dB SEL_{24h} or > 213 dB PK	> 216 dB SEL_{24h} or > 213 dB PK	>> 186 dB SEL_{24h}	(N) Moderate (I, F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	210 dB SEL_{24h} or > 207 dB PK	203 dB SEL_{24h} or > 207 dB PK	>> 186 dB SEL_{24h}	(N) Moderate (I, F) Low	(N) High (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{24h} or > 207 dB PK	203 dB SEL_{24h} or > 207 dB PK	186 dB SEL_{24h}	(N, I) High (F) Moderate	(N, I) High (F) Moderate
Fish eggs and fish larvae	> 210 dB SEL_{24h} or > 207 dB PK	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I, F) Low	(N) Moderate (I, F) Low

Peak sound pressure level dB re 1 µPa; SEL_{24h} dB re 1µPa^2s.
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 12 lists the relevant effects thresholds from Popper et al. (2014) for vessel noise. Some studies suggest that fish sensitive to acoustic pressure show a recoverable loss in hearing sensitivity or injury when exposed to high levels of noise (Scholik and Yan 2002, Amoser and Ladich 2003, Smith et al. 2006). This is reflected in the SPL thresholds for fish with a swim bladder involved in hearing.

Table 12. Criteria for non-impulsive (vessel) noise exposure for fish, adapted from 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 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 SPL for 48 h	158 dB SPL for 12 h	(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

Sound pressure level dB re 1 µPa.
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).

2.3. Diving Birds

There are no regulatory thresholds or criteria established to assess potential behavioural responses by diving birds (penguins, flying seabirds, swans) to underwater noise. This section provides a short overview of the proposed noise exposure criteria which are applied to model potential impact ranges in this report; Lucke and McPherson (2021) present more comprehensive background information and discuss the rationale for the chosen noise exposure criteria.

In a controlled exposure experiment, Sørensen et al. (2020) exposed captive gentoo penguins (*Pygoscelis papua*) to impulsive signals, and the majority of animals showed strong aversive reactions at received levels above 120 dB re 1 µPa (SPL). In a study on free-ranging African penguins (*Spheniscus demersus*) Pichegru et al. (2017) investigated their behavioural response to seismic surveys within 100 km of their colony in South Africa. The authors documented strong avoidance by penguins over long distances, thereby corroborating the relatively low threshold for onset of behavioural responses measured by Sørensen et al. in principle.

To apply this onset criterion to project-related noise emission, it must be frequency-weighted to reflect the difference of bird hearing over the frequency band of their hearing. In the absence of frequency weighting functions for birds, the function for other carnivores in water (OCW) from Southall et al. (2019) is used as a proxy.

There is also insufficient information available to determine the onset thresholds of behavioural responses of diving birds from non-impulsive noise such as vessel or dredger noise; therefore, this assessment has not considered potential effects from non-impulsive noise on behaviour of diving birds.

There are also no regulatory thresholds for the onset of hearing impairment for penguins or any other bird, or any phylogenetically or anatomically related species. To allow for assessing the noise-induced impact risk of the pile driving on penguins, other carnivores in water (OCW), from Southall et al. (2019), is once again recommended as a proxy due to the similarity in hearing sensitivity in the frequency band of underwater hearing for the two species groups. This is a conservative approach as otariids are considered more sensitive to underwater sound at higher frequencies than penguins.

3. Methods

3.1. Environmental Parameters

Bathymetry for the project was taken mainly from high-resolution survey data provided by the client, combined with depth soundings from Australian Hydrographic Office (AHO) survey AU439144. Many additional sources were required to fill in missing details, and these are covered in Appendix A.1.

A single sound speed profile for the month of May was used in all scenarios. This profile is largely flat, varying between 1505.7 m/s and 1506.0 m/s for all depths of interest, see expanded details in Appendix A.2.

Geoacoustics were derived from a geotechnical report provided by the client (Coffey Services Australia Pty Ltd 2021). Based on this, a two-layer system was used as the geoacoustic profile in this study with material properties taken from Hamilton (1980), and is outlined in Table 13. Whittaker et al. (2013) indicates that the bedrock at the modelled location is at a depth of 2.5 km, which is distant enough to disregard as part of the acoustic models in this study.

Table 13. Geoacoustic profile based on Port of Geelong geotechnical data. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave. The shear wave is the secondary wave.

Depth below seafloor (m)	Material	Compressional wave		Shear wave	
		Speed (m/s)	Attenuation (dB/ λ)	Speed (m/s)	Attenuation (dB/ λ)
0–16.5	Sand-silt-clay	1555–1584	0.23–0.37	283	1.36
16.5–200	Silty Sand	1648–1876	1.23–0.86		

3.2. Acoustic Source Parameters

3.2.1. Scenario 1 - Impact Pile Driving

JASCO's pile driving source model (PDSM, MacGillivray 2014) was used in conjunction with the GRLWEAP 2010 wave equation model (Pile Dynamics 2010) to predict source levels associated with impact pile driving activities. Further detail on PDSM is included in Appendix C.1.2. GRLWEAP, which includes a database of commercial impact hammers, was used to model a forcing function at the top of the pile. This model accounts for several parameters that describe the pile and hammer, along with the penetration depth. Based on information provided by the client, these parameters were set as shown in Tables 14 and 15. The resultant hammer forcing functions are shown in Figure 3.

Table 14. Parameters for the pile geometry used in the impact piling modelling scenarios.

Scenario	Pile type	Diameter (m)	Wall thickness (m)	Length (m)	Modelled penetration depth (m)
1a	Cylindrical steel	1.400	0.0250	56.0	15.0
1b		1.063	0.0254	21.0	4.0

Table 15. Parameters for the hammer used in the impact piling modelling scenarios.

Hammer model	Maximum energy (kJ)	Stroke (m)	Helmet weight (kN)	Helmet stiffness (kN/mm)
S-150	150	2.02	22.46	963

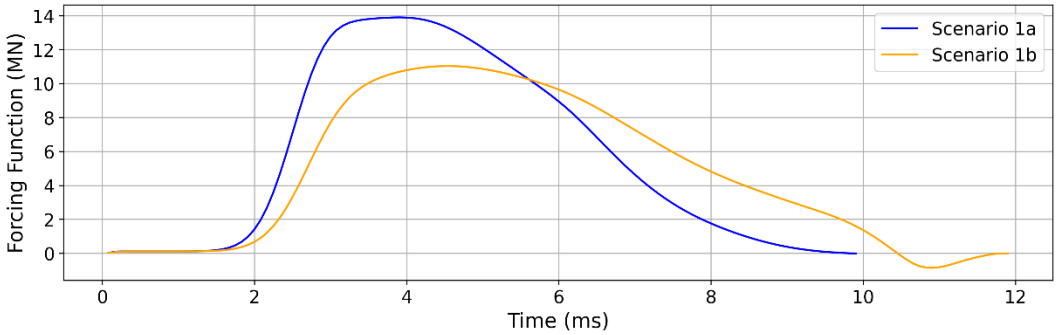


Figure 3. Forcing functions at the top of the pile for the pile-driving scenarios.

Another key factor affecting the source model and eventual calculation of cumulative sound exposure metrics is the pile penetration rate, which is the distance the pile embeds into the sediment as a result of a single hammer impact. Based on specifications and sediment data provided, this was estimated at 25 mm per strike. For Scenario 1a, a stress wave reflection coefficient of 0.3 was used in order to match this vertical pile displacement estimate, whilst the coefiicient for Scenario 1b was 0.17; the resultant displacement estimates as a function of time after impact are shown in Figures 4 and 5.

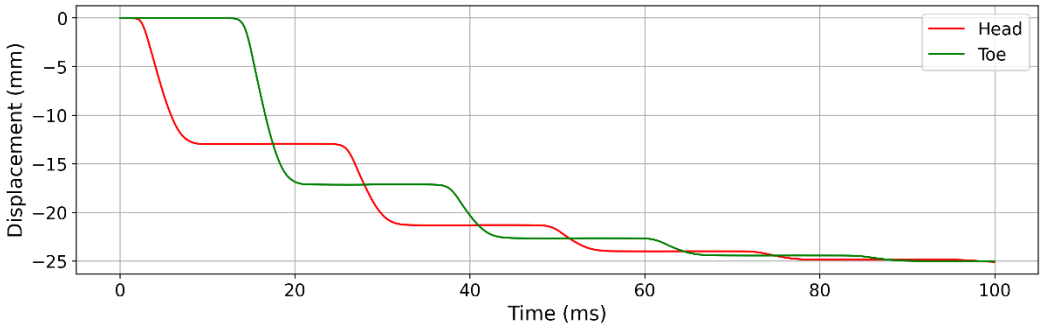


Figure 4. Modelled vertical displacement of the head and toe of the pile in Scenario 1a at 15m penetration.

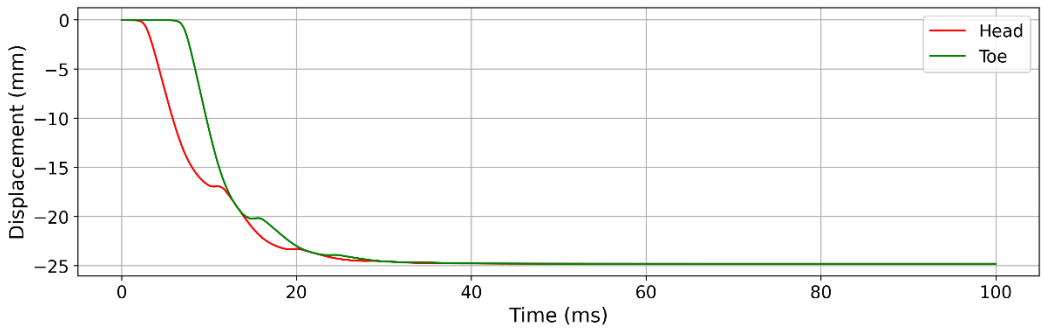


Figure 5. Modelled vertical displacement of the head and toe of the pile in Scenario 1b at 4m penetration.

Given that piles are distributed and directional sources (Appendix C.1), they cannot be accurately approximated by a point source. The sound radiating from the piles was therefore simulated using vertical arrays of discrete point sources, as described in Appendix C.1.2.

For the purposes of comparison, it is possible to inspect the levels received a short distance from the modelled source. Figure 6 shows the maximum-over-depth decidecade band received levels for a single strike in the two pile-driving scenarios, at a horizontal range of 10 m from the centre of the pile. The levels above 1 kHz were extrapolated using a 20 dB/decade decay rate to match acoustic measurements of impact pile driving of similarly sized piles (Illingworth & Rodkin 2007, Matuschek and Betke 2009).

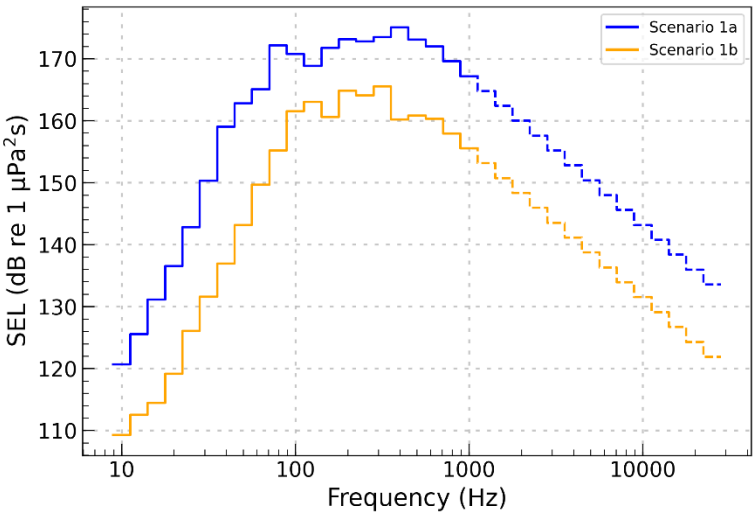


Figure 6. Maximum-over-depth decidecade band SELs at a receiver 10 m horizontally from the modelled pile driving sources. Dashed line indicates extrapolated portions of the spectra.

3.2.2. Scenario 2 – Dredging

Specifications for multiple backhoe dredging vessels were supplied as representative of the type of vessel to be used on this project. The vessel with the largest specified excavator engine power (3356 kW), *Magnor*, was chosen as the source to be modelled. Since there are no measured source levels (SLs) available for this particular dredger, levels reported by Reine et al. (2014) for the backhoe dredger *New York* were used as a proxy. Since *New York* has an excavator power of 2565 kW, the following equation was used to calculate a source level offset Δ_{Lp} to account for the difference in power:

$$\Delta_{L_p} = 10 \log\left(\frac{P}{P_{ref}}\right) \quad (1)$$

where P_{ref} and P are the power of the proxy vessel and the target vessel respectively. In this case, an offset of 1.17 dB was calculated and applied to the proxy source levels, giving a broadband level of 176.3 dB re 1 µPa²m²s. Source levels were linearly extrapolated to cover the modelled frequency range. Figure 7 shows the resultant source level in decidecade bands from 10 Hz to 25 kHz, alongside source levels for the FSRU and LNG Carrier (see Section 3.2.3).

A modelled source depth of 2.37 m was used based on 0.7 × ship draft (3.39 m for *Magnor*), as specified in ISO 17208-1 (2016).

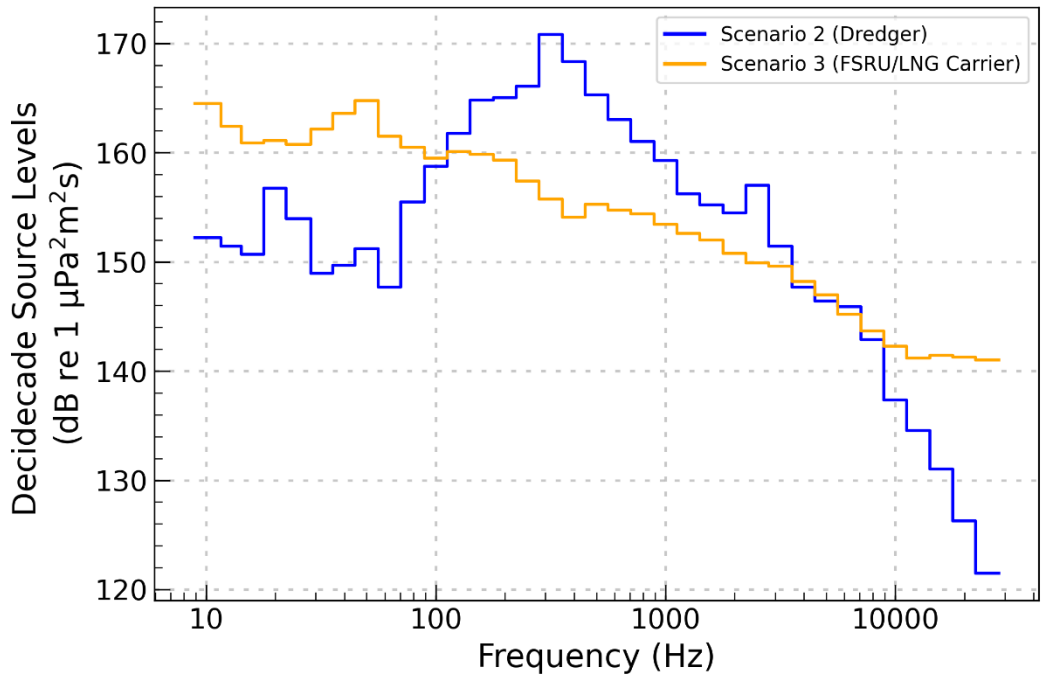


Figure 7. Decidecade band monopole source levels for vessel sources. *Magnor* derived from the backhoe dredger *New York* (Reine et al. 2014), and FSRU and LNG carrier derived by averaging the *Nganhurra* and *Ngujima Yin* (Erbe et al. 2013).

Scenario 3 – FSRU and LNG Carrier Operations

Scenario 3 investigates radiated sound from the FSRU and LNG carrier. As the FSRU would be continuously moored and the LNG carrier would be berthed alongside, noise from the considered operational scenarios is likely to be associated with pumps, generators, and other machinery within the vessels, rather than the propeller cavitation typically associated with vessels underway. There is at present no literature describing measured SLs for either FSRUs or berthed LNG carriers. Erbe et al. (2013), however, includes measured SLs from two Floating Production Storage and Offload (FPSO) facilities, the *Nganhurra* and the *Ngujima Yin*. Given the similarity in vessel sizes and operations, an average of these two measured SLs, with a broadband level of 173.9 dB re 1 µPa^{2}m^{2}s, was used as a proxy for both the FSRU and LNG carrier in this study. Figure 7 shows the source level in decidecade bands from 10 Hz to 25 kHz, alongside levels for the dredger (see Section 3.2.1).

A source depth of 6 m for both vessels was chosen to approximate an average of hull-radiated noise from the submerged hull of each vessel. As the depth of the newly dredged channel will be just over 12 m, this corresponds to the middle of the water column, a location expected to give optimal noise propagation and therefore a reasonable estimate for the maximum likely threshold distances.

3.2.4. Scenario 4 – LNG Carrier Berthing

Scenario 4 consists of an LNG carrier approaching the proposed new berth, accompanied by two escort tug boats and two berthing tug boats. The final part of the berthing sequence was modelled, as the carrier and tugs move through defined zones at 4 knots, 2 knots, and finally 0.5 knots for the berthing. Single points in the middle of these three areas were modelled to calculate SPL-based metrics, and these three points were translated to ‘footprint’ locations at 50 m increments along a defined line of approach in order to calculate accumulated SEL metrics. Figure 2 shows an overview of the scenario, showing modelled SPL locations and the approach line along which the 50 m SEL footprints were distributed.

The SEL sound field at any given point p along the approach line is dependent upon the duration of exposure, which with a fixed footprint spacing Δ_p depends upon the modelled speed of the vessel at

each point. The SPL modelling results at each point for each vessel were therefore converted to SEL according to the following equation:

$$L_{E,p} = L_E + 10\log_{10}\left(\frac{\Delta_p}{c}\right) \quad (2)$$

where c represents the vessel speed. This equated to an addition of 13.86 dB at points in the 4 knots zone, 16.87 dB at points in the 2 knots zone, and 22.89 dB at points in the 0.5 knots final berthing zone.

The escort and berthing tug models in this scenario were based on the Damen ASD Tug 3212 (6865 hp) and Damen ASD Tug 2312 (5172 hp), respectively, following information provided by the client. These two types of tugs were both modelled using recorded source levels from the *Britoil 51*, an anchor handling tug of similar size and power, travelling at half speed (6.5 knots). Since *Britoil 51* has a power of 6600 hp, Equation 1 was used to calculate source level offsets to account for the differences in power for the two types of modelled vessels. Offsets of 0.17 dB and -1.06 dB were calculated and applied to the source levels for the escort and berthing tugs, respectively. As the 6.5 knot speed of *Britoil 51* for these recorded SLs is slightly higher than the highest speed modelled in this scenario, these SLs should be considered a conservative estimate.

The SLs for *Britoil 51* do not include information above 10 kHz, so levels at frequencies above this were linearly extrapolated from the level reduction between the 8 kHz and 10 kHz bands. The decidecade energy source level (ESL) spectra for the *Britoil 51* is shown in Figure 8, with the extrapolated portion shown as a dashed line. The broadband ESL (5 Hz to 25 kHz) is 190.8 dB re 1 μPa^2m^2s.

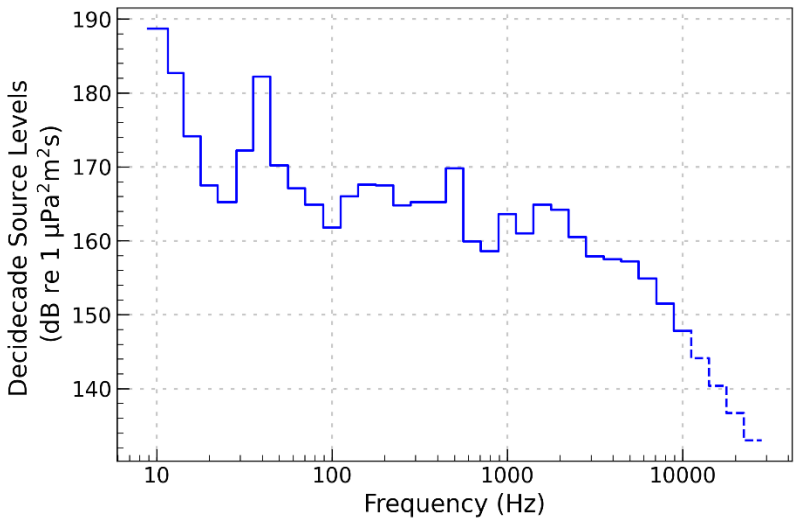


Figure 8. Estimated decidecade energy source level (ESL) spectra of the *Britoil 51*, used for both escort and berthing tugs. Dashed line indicates extrapolated portion of spectrum.

Due to uncertainty in terms of how much the LNG carrier's propulsion system would be contributing at such slow speeds relative to the tugs, no propulsion has been modelled for the carrier, and instead the measured SLs from FPSOs *Nganhurra* and *Ngujima Yin* were once again used for this vessel.

A source depth of 6 m was again used for the carrier, whilst a depth of 3.85 m (0.7 × ship draft) was used for the tugs, as both tug models have a draft of 5.5 m.

3.3. Modelling Sound Propagation

3.3.1. Impulsive Sources

For the impulsive impact pile driving sources, JASCO's full waveform range-dependent model (FWRAM - see Appendix C.3) was used to model sound propagating away from the driven pile along radial planes at 1° separation. The maximum modelled distance was 12 km for Scenario 1a, and 25 km for Scenario 1b, with a 10 m range step increasing with distance from the source. Receiver depths spanned the entire water column over the modelled areas.

Given respective final pile penetration depths of 30 m and 8 m, it can be estimated that the complete driving of a single pile in Scenario 1a will take 1200 strikes, and a single pile in Scenario 1b will take 320 strikes. For the purposes of this study, the SEL over the operation is calculated based on a single mid-sequence strike, rather than separate models for various penetration depths. The SELs over the complete sequence were therefore calculated using the following equation:

$$L_{E,\text{cumulative}} = L_E + 10\log_{10}(N) \quad (3)$$

where L_E is the per-strike energy source level and N is the number of strikes. Values of N = 1200 and N = 320 were used for single-pile estimates, and N = 3600 and N = 1280 for estimates assuming the maximum number of piles driven per day. In this study, all piling is modelled at a single location for each scenario.

3.3.2. Non-impulsive Sources

For the non-impulsive vessel sources in Scenarios 2 and 3, JASCO's combined Marine Operations Noise Model (MONM) and gaussian beam acoustic ray-trace model (BELLHOP) were used to predict the acoustic field at frequencies from 10 Hz to 25 kHz; details on these models are included in Appendix C.2. The SEL over 24 hours was calculated using the following equation:

$$L_{E,24h} = L_E + 10\log_{10}(T) \quad (4)$$

where L_E is the per-second energy source level and T is the total number of operational seconds in a 24-hour period. Assuming constant operation over 24 hours, this amounts to an offset of 49.3 dB.

4. Results

This section contains the results from the models of the scenarios described in the previous section. These are presented as tables of distances, and contour maps showing the directivity and range to maximum-over-depth sound levels, with isopleths showing various relevant noise effect thresholds for marine mammals, diving birds, and fish. Vertical slice plots showing per-strike sound propagation are also included for the pile driving sources.

The monitoring report, Wilson and McPherson (2021), determined that the soundscape was primarily defined by anthropogenic contributors, with shipping being the dominant factor. The sound level statistics used in this report are the median broadband sound level (L_p = 124.6 dB re 1 µPa), the 5th percentile (L_p = 119.6 dB re 1 µPa) and median measured unweighted ambient level (L_E = 178 dB re 1 µPa²s).

4.1. Scenario 1 - Pile Driving

This section presents the sound fields for the two pile driving operations in terms of maximum-over-depth PK, SPL, and SEL. Metrics are presented as follows:

- PK metrics within the water column, relevant to thresholds and guidelines for marine mammals, fish, fish eggs and larvae (as well as plankton) (see Sections 2.1 and 2.2).
- SPL sound fields, used to determine the distances to marine mammal and penguin behavioural thresholds (see Sections 2.1 and 2.3).
- SEL sound fields (per-pile and 24 h), relevant to thresholds and guidelines for marine mammals, fish, fish eggs and larvae, and penguins (Section 2).

Maximum distances to PK thresholds were calculated for both piles, with maximum-over-depth results presented in Table 16. The maximum and 95% distances for SEL and SPL metrics (calculated as detailed in Appendix A.3) are presented in Tables 17 and 18.

The SEL and SPL sound fields and distances to relevant isopleths, are visualised on the contour maps presented in Figures 9 to 14. SEL maps show contours down to the median measured unweighted ambient level (L_E = 178 dB re 1 µPa²s), whilst SPL maps show contours including median (L_p = 124.6 dB re 1µPa) and 5th percentile (L_p = 119.6 dB re 1µPa) ambient levels, averaged from decidecade band levels. The SPL sound fields are also presented as vertical slices for both piles with the sound field on either side of the pile shown (Figures 14–18). Note that the measured ambient SPL in the area is higher than the diving bird behavioural threshold, therefore the diving bird behavioural threshold distances are included for completeness.

4.1.1. Tables

Table 16. *Piling, PTS and TTS PK thresholds*: Maximum (R_{max}) horizontal distances (km) from the dolphin pile (Scenario 1a) and mooring pile (dolphin pile (Scenario 1b) to modelled maximum-over-depth peak pressure level (PK) PTS and TTS thresholds for marine mammals (Southall et al. 2019) and fish (Popper et al. 2014).

Hearing group	PK threshold (L_{pk}; dB re 1 µPa)	Distance R_{max} (km)	
		1a – Dolphin pile	1b – Mooring pile
PTS			
High-frequency cetaceans	230	—	—
Otariid pinnipeds in water	232	—	—
TTS			
High-frequency cetaceans	224	—	—
Otariid pinnipeds in water	226	—	—
Mortal Injury			
Fish: No swim bladder	213	—	—
Fish: Swim bladder not involved in hearing; swim bladder involved in hearing; and fish eggs, and larvae	207	—	—

A dash indicates the threshold was not reached within the limits of the modelling resolution.

Table 17. *Piling, SPL*: Maximum (R_{max}) horizontal distances (km) from the dolphin pile (Scenario 1a) and mooring pile (Scenario 1b) to maximum-over-depth per-strike SPL isopleths.

SPL (L_p; dB re 1 µPa)	1a – Dolphin pile		1b – Mooring pile	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
180	0.03	0.03	–	–
170	0.26	0.24	0.05	0.05
160[a]	**0.80**	**0.71**	**0.26**	**0.23**
150	2.00	1.48	1.05	0.93
140	4.04	2.69	2.20	1.91
130	5.12	4.23	3.70	3.23
124.6[b]	6.04	5.10	4.58	3.92
120	6.60	5.65	5.42	4.58
119.6[c]	6.64	5.68	5.46	4.62
120[d]	**5.76**	**4.90**	**4.30**	**3.62**

[a] Marine mammal behavioural threshold for impulsive sound sources (NOAA 2019).
[b] Median ambient level
[c] 5th percentile ambient level
[d] Diving bird behavioural response threshold (OCW weighted) for impulsive noise (Sørensen et al. 2020).
A dash indicates the threshold was not reached within the limits of the modelling resolution.

Table 18. *Piling, PTS and TTS SEL thresholds*: Maximum (R_{max}) horizontal distances (m) from the dolphin pile (Scenario 1a) and mooring pile (Scenario 1b) to maximum-over-depth weighted SEL isopleths for marine mammals and diving birds (Southall et al. 2019).

Hearing group	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	1a – Dolphin pile				1b – Mooring pile			
		Single pile		3 piles		Single pile		4 piles	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
PTS									
HF cetaceans	185	—	—	—	—	—	—	—	—
Otariid pinnipeds and diving birds	203	—	—	—	—	—	—	—	—
TTS									
HF cetaceans	170	0.03	0.03	0.07	0.07	—	—	—	—
Otariid pinnipeds and diving birds	188	0.04	0.04	0.10	0.09	—	—	—	—

A dash indicates the threshold was not reached within the limits of the modelling resolution.

Table 19. *Piling, thresholds for effects on fish*: maximum and 95% distances to maximum-over-depth unweighted SEL isopleths for fish (Popper et al. 2014).

Hearing group	SEL_{24h} threshold (L_E; dB re 1 µPa²s)	1a – Dolphin pile				1b – Mooring pile			
		Single pile		3 piles		Single pile		4 piles	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Mortal Injury									
Fish: No swim bladder	219	—	—	—	—	—	—	—	—
Fish: Swim bladder not involved in hearing; and eggs and larvae	210	—	—	0.02	0.02	—	—	—	—
Fish: Swim bladder involved in hearing	207	0.02	0.02	0.03	0.03	—	—	—	—
Recoverable Injury									
Fish: No swim bladder	216	—	—	—	—	—	—	—	—
Fish: Swim bladder not involved in hearing; and swim bladder involved in hearing	203	0.03	0.03	0.06	0.06	—	—	—	—
TTS									
Fish: No swim bladder; swim bladder not involved in hearing; and swim bladder involved in hearing	186	0.52	0.48	0.87	0.77	0.05	0.05	0.11	0.10

A dash indicates the threshold was not reached within the limits of the modelling resolution.

4.1.2. Sound Field Maps

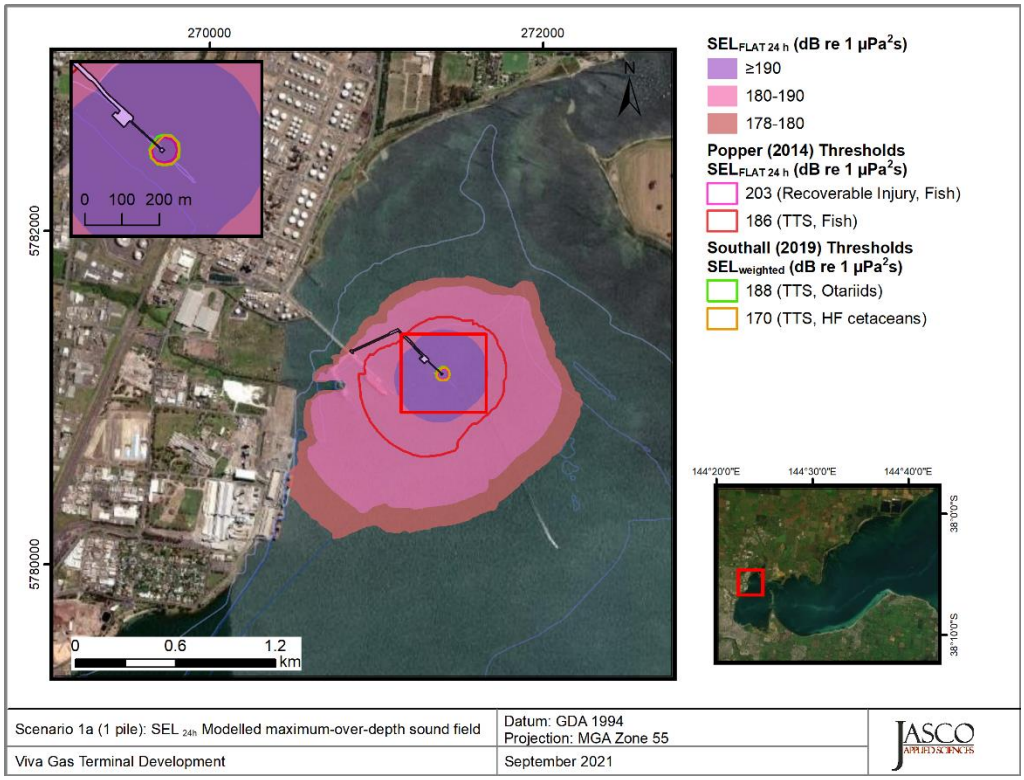


Figure 9. Unweighted maximum-over-depth SEL for the complete driving of a single pile in Scenario 1a. Isopleths show distances to temporary threshold shift onset levels for high-frequency cetaceans and otariids, based on weighted levels for impulsive sources, and unweighted levels relevant to fish.

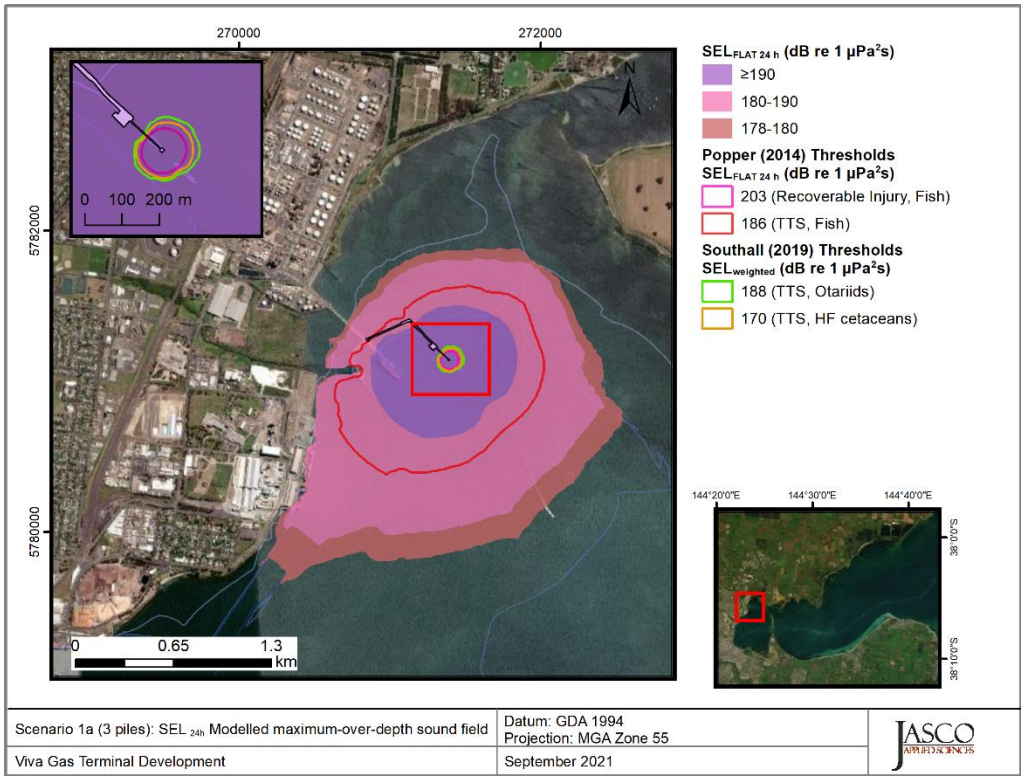


Figure 10. Unweighted maximum-over-depth SEL for the complete driving of three piles in Scenario 1a. Isopleths show distances to temporary threshold shift onset levels for high-frequency cetaceans and otariids, based on weighted levels for impulsive sources, and unweighted levels relevant to fish.

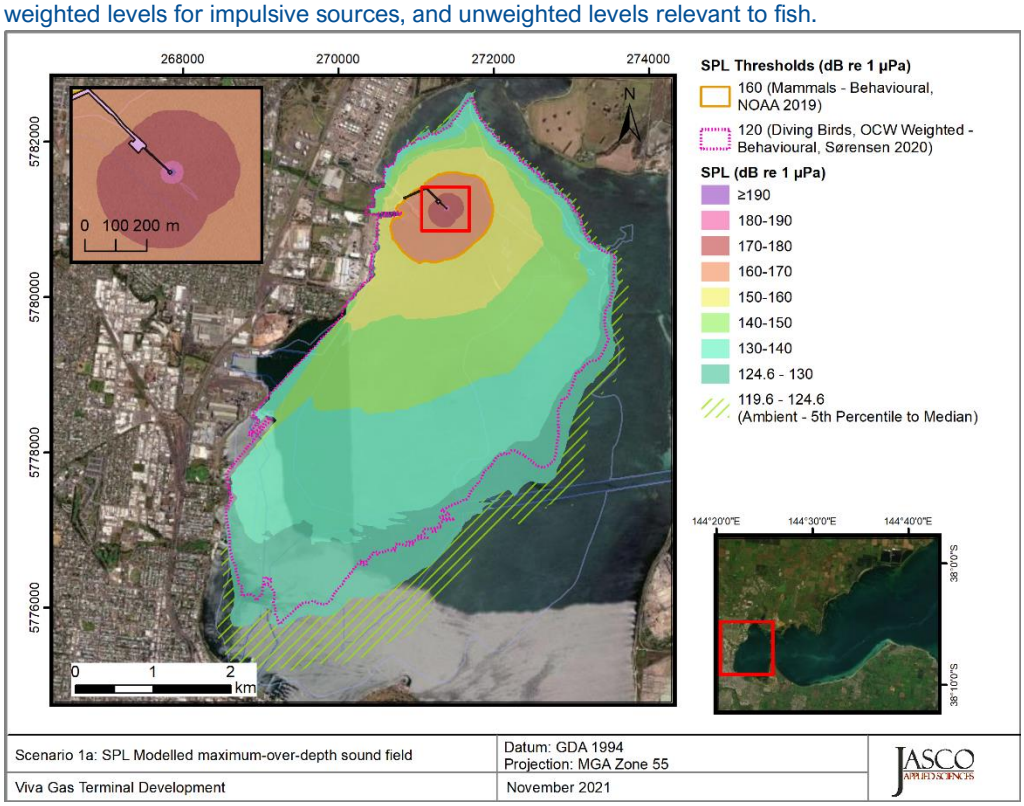


Figure 11. Maximum-over-depth SPL levels in Scenario 1a. Isopleths show distances to behavioural effect onset levels in marine mammals and diving birds.

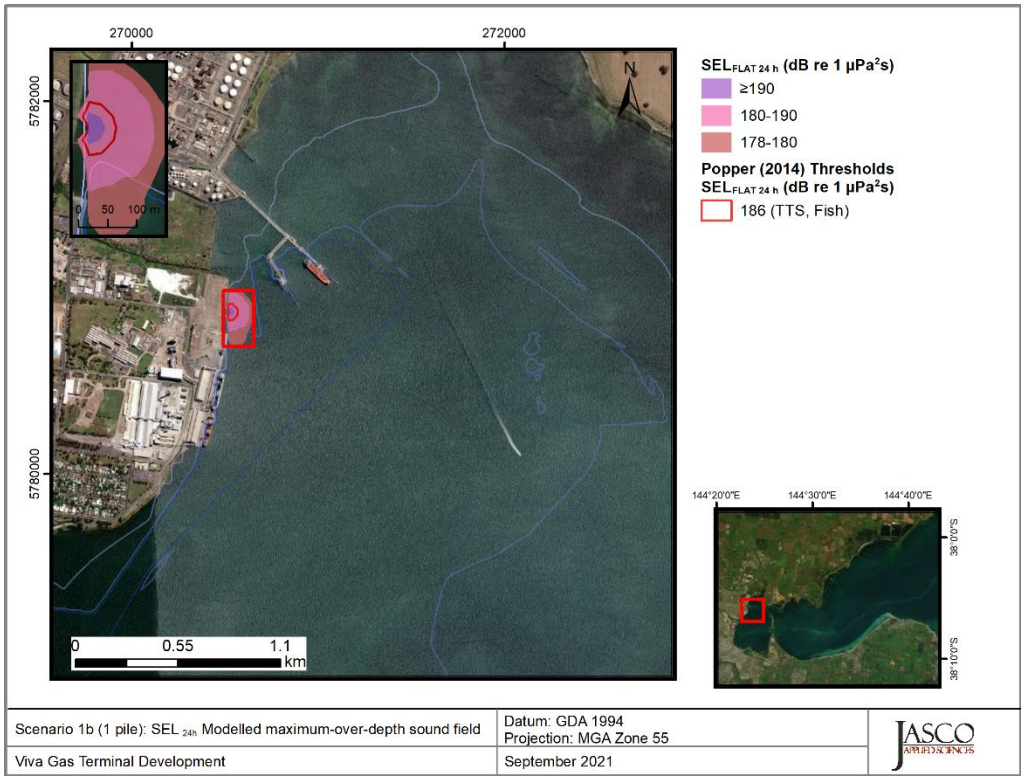


Figure 12. Unweighted maximum-over-depth SEL levels for the complete driving of a single pile in Scenario 1b. Isopleths shows distance to temporary threshold shift onset level for fish based on unweighted levels.

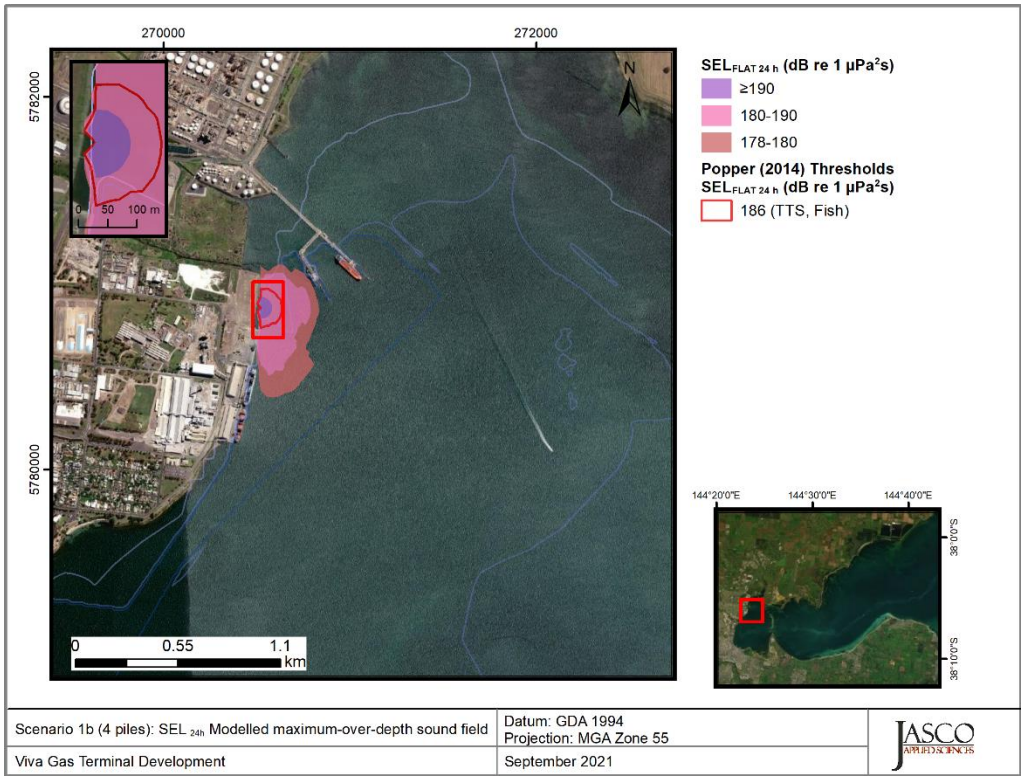


Figure 13. Unweighted maximum-over-depth SEL levels for the complete driving of four piles in Scenario 1b. Isopleths shows distance to temporary threshold shift onset level for fish based on unweighted levels.

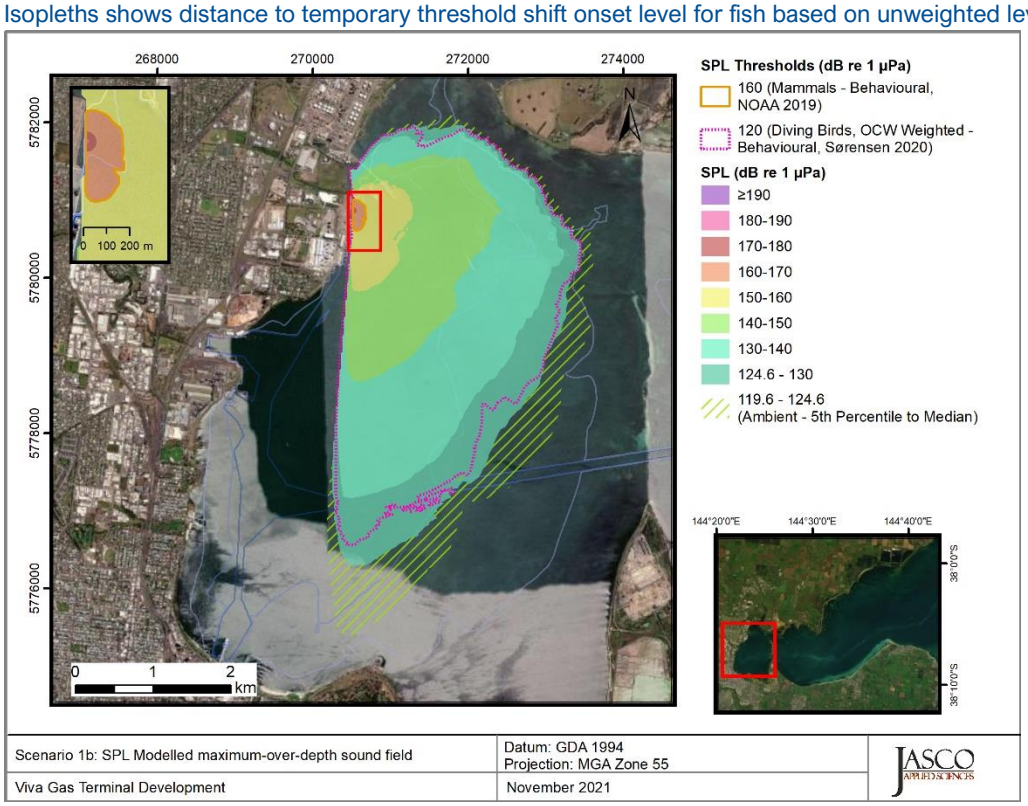


Figure 14. Maximum-over-depth per-strike SPL levels in Scenario 1b. Isopleths show distances to behavioural effect onset levels in marine mammals and diving birds.

4.1.3. Vertical Slice Plots

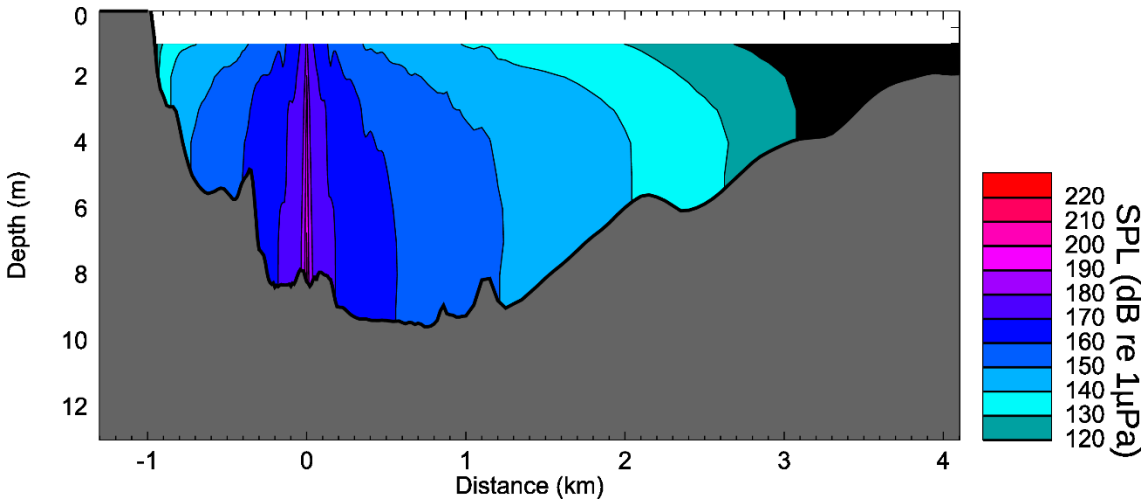


Figure 15. *SPL, dolphin pile*: Vertical slice of the predicted SPL sound field for a single impact strike along azimuths 135° and 315° for Scenario 1a.

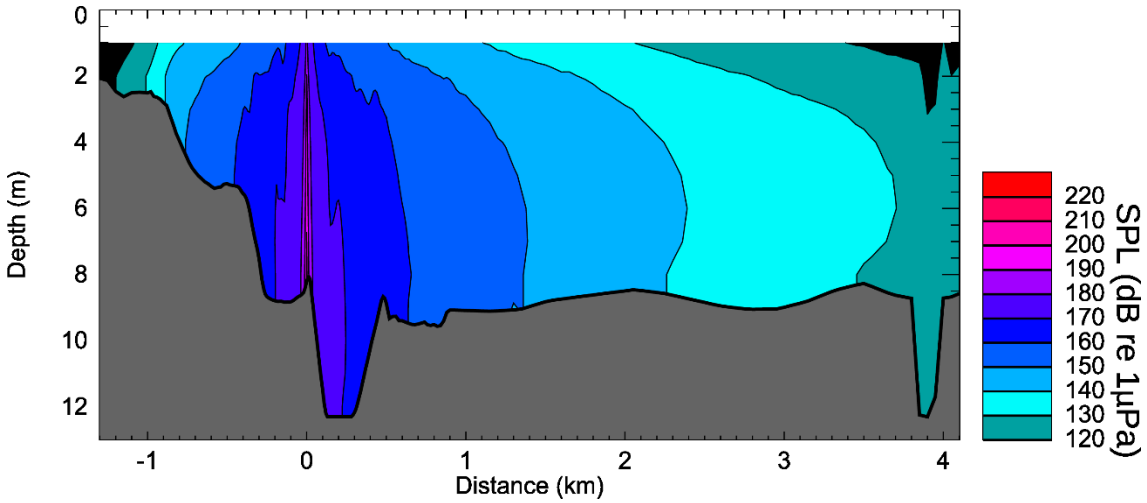


Figure 16. *SPL, dolphin pile*: Vertical slice of the predicted SPL sound field for a single impact strike along azimuths 0° and 180° for Scenario 1a.

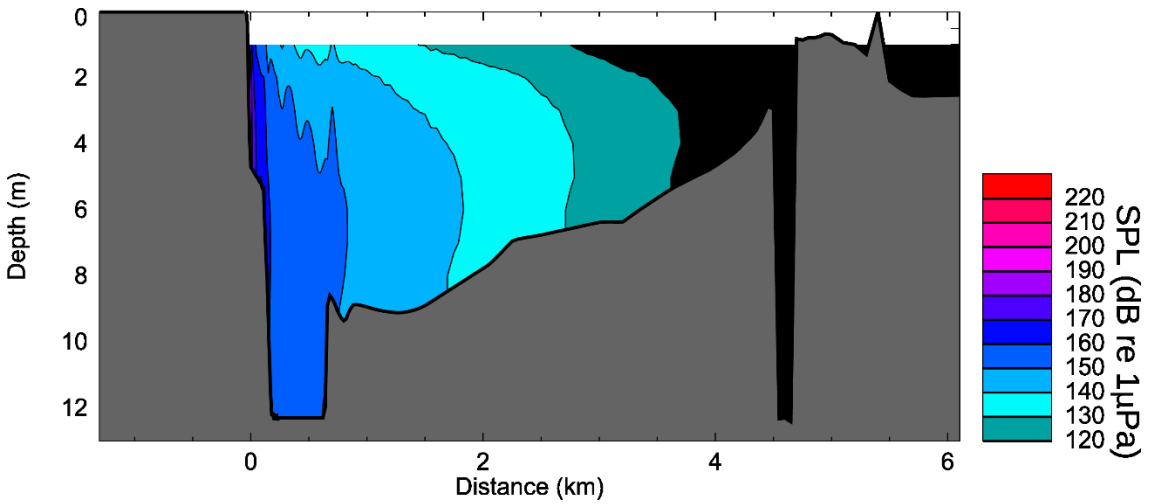


Figure 17. *SPL, Lascelles Wharf pile*: Vertical slice of the predicted SPL sound field for a single impact strike along azimuths 135° and 315° for Scenario 1b.

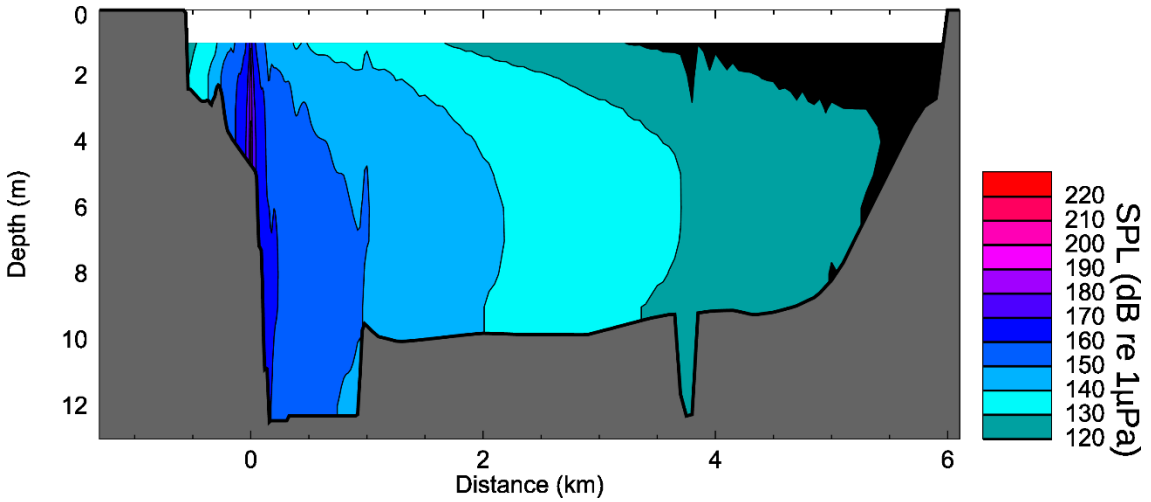


Figure 18. *SPL, Lascelles Wharf pile*: Vertical slice of the predicted SPL sound field for a single impact strike along azimuths 0° and 180° for Scenario 1b.

4.2. Scenarios 2 and 3 – Vessels

This section presents the sound fields for the dredging and FSRU and LNG carrier scenarios in terms of maximum-over-depth SPL and SEL. Metrics are presented as follows:

- SPL sound fields, used to determine the distances to marine mammal behavioural thresholds (Section 2.1).
- SEL sound fields (24 h), relevant to thresholds and guidelines for marine mammals, fish, fish eggs and larvae (Section 2.1).

The maximum and 95% distances (calculated as detailed in Appendix A.3) for SEL and SPL metrics are presented in Tables 20 and 21. The SEL and SPL sound fields and distances to relevant isopleths are visualised on the contour maps presented in Figures 19 to 26. SEL maps show contours down to the median measured unweighted ambient level (L_E = 178 dB re 1 µPa²s), whilst SPL maps show contours including median (L_p = 124.6 dB re 1µPa) and 5th percentile (L_p = 119.6 dB re 1µPa) ambient levels, averaged from decidecade band levels. Note that the measured ambient SPL in the area is higher than the marine mammal behavioural threshold, at 120 dB re 1µPa.

4.2.1. Tables

Table 20. Vessels, SPL: Maximum (R_{max}) horizontal distances (km) from dredging (Scenario 2) and FSRU (Scenario 3) scenarios to maximum-over-depth SPL isopleths.

SPL (L_p; dB re 1 µPa)	2a – Berth & swing basin dredging		2b – Seawater pipe dredging		3a – FSRU		3b – FSRU + LNG carrier	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	**<0.01**	**<0.01**	—	—	—	—	—	—
160	0.01	0.01	0.01	0.01	<0.01	<0.01	0.03	0.03
158[b]	**0.01**	**0.01**	**0.01**	**0.01**	**<0.01**	**<0.01**	**0.03**	**0.03**
150	0.04	0.04	0.03	0.03	0.02	0.02	0.04	0.04
140	0.12	0.11	0.15	0.14	0.06	0.05	0.09	0.08
130	0.80	0.64	0.51	0.47	0.31	0.27	0.44	0.38
124.6[c]	1.11	1.01	1.16	1.00	0.65	0.57	0.90	0.76
119.6[d]	1.60	1.47	1.90	1.66	1.14	1.03	1.52	1.30
120[e]	**1.55**	**1.43**	**1.84**	**1.60**	**1.10**	**0.98**	**1.46**	**1.26**

[a] Recoverable injury threshold for fish, 48 hours exposure (Popper et al. 2014).
[b] Temporary threshold shift in fish, 12 hours exposure (Popper et al. 2014).
[c] Median ambient level.
[d] 5th percentile ambient level.
[e] Marine mammal (NOAA 2019) behavioural threshold (non-impulsive sources).
A dash indicates the threshold was not reached within the limits of the modelling resolution.

Table 21. *Vessels, TTS SEL thresholds*: Maximum (R_{max}) horizontal distances (m) from the dredging (Scenario 2) and FSRU (Scenario 3) scenarios to maximum-over-depth weighted SEL isopleths for marine mammals (Southall et al. 2019). PTS thresholds were not exceeded.

Hearing group	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	2a – Berth & swing basin dredging		2b – Seawater pipe dredging		3a – FSRU		3b – FSRU + LNG carrier	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
HF cetaceans	178	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.04
Otariid pinnipeds	199	<0.01	<0.01	0.01	0.01	—	—	0.03	0.03

A dash indicates the threshold was not reached within the limits of the modelling resolution (20 m).

4.2.2. Sound Field Maps

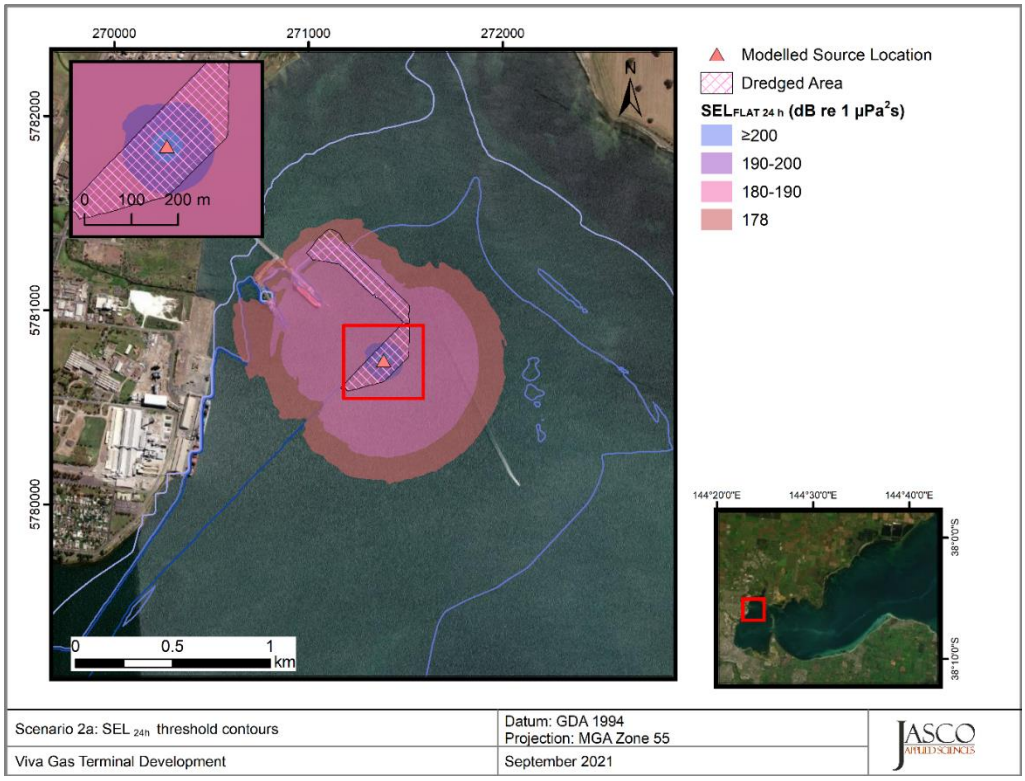


Figure 19. Unweighted maximum-over-depth SEL levels for Scenario 2a. No relevant thresholds were exceeded within the modelling resolution.

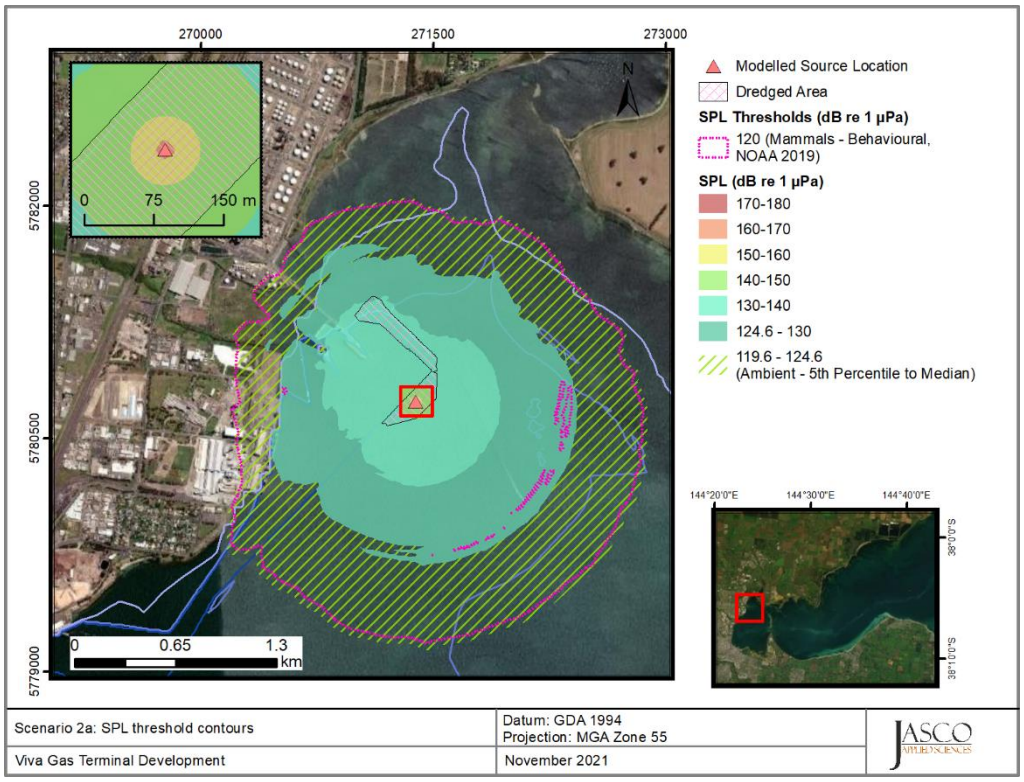


Figure 20. Maximum-over-depth SPL levels for Scenario 2a. Isopleth shows distance to behavioural effect onset level for marine mammals.

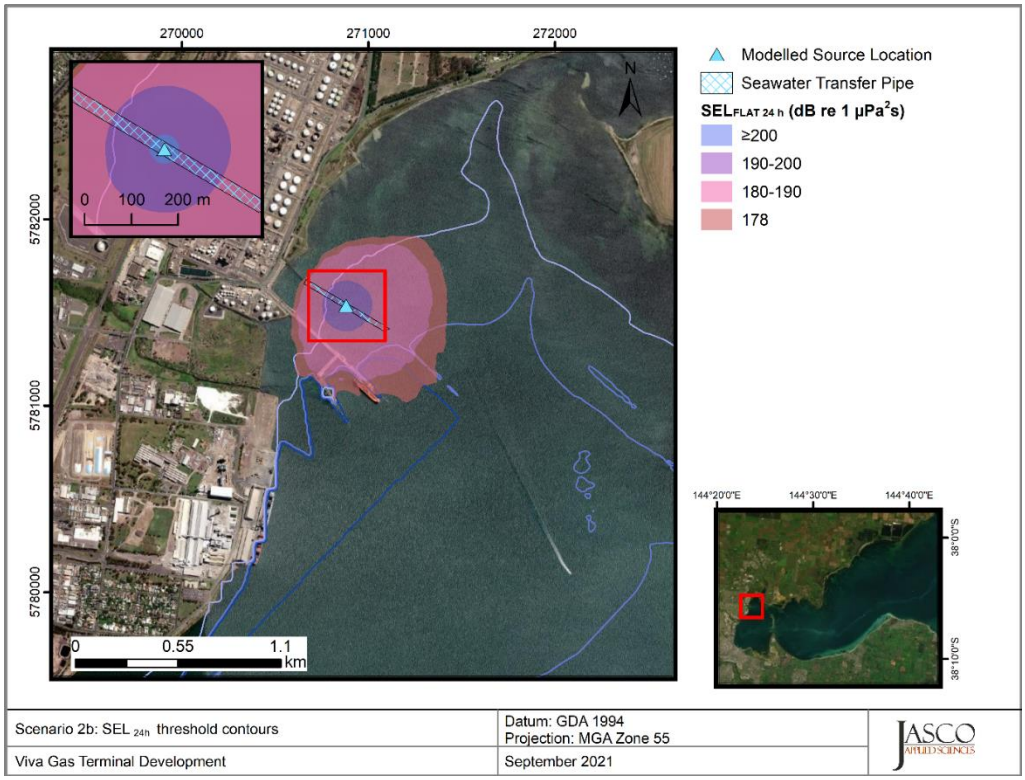


Figure 21. Unweighted maximum-over-depth SEL levels for Scenario 2b. No relevant thresholds were exceeded within the modelling resolution.

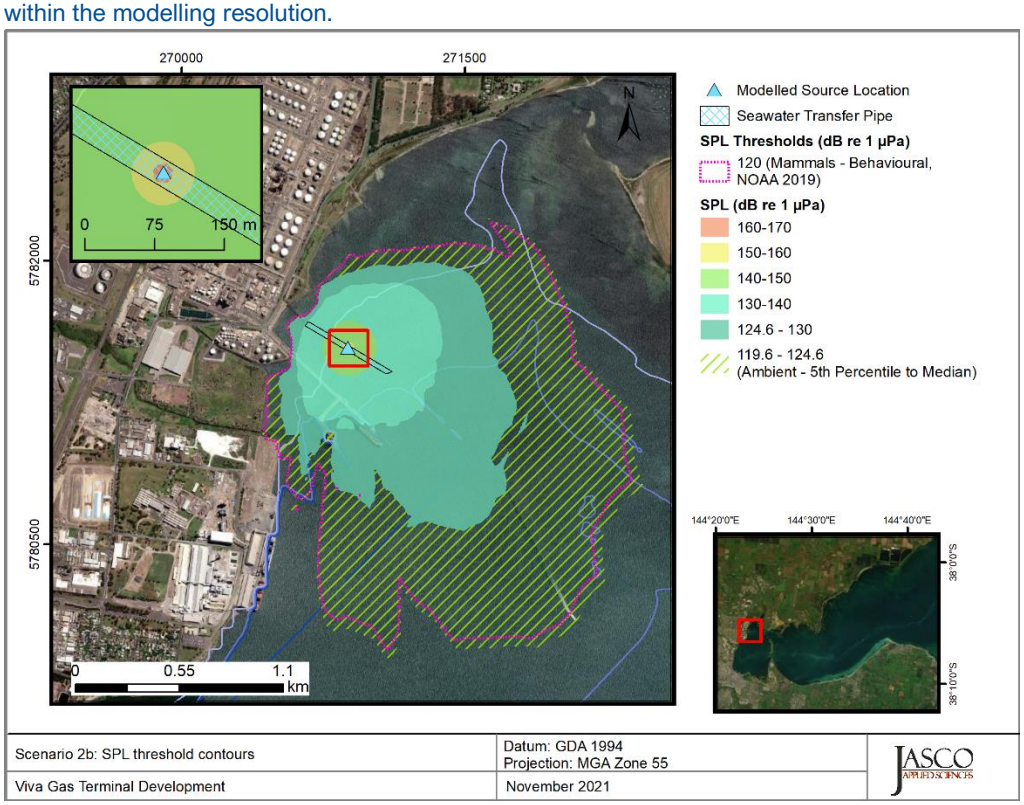


Figure 22. Maximum-over-depth SPL levels for Scenario 2b. Isopleth shows distance to behavioural effect onset level for marine mammals.

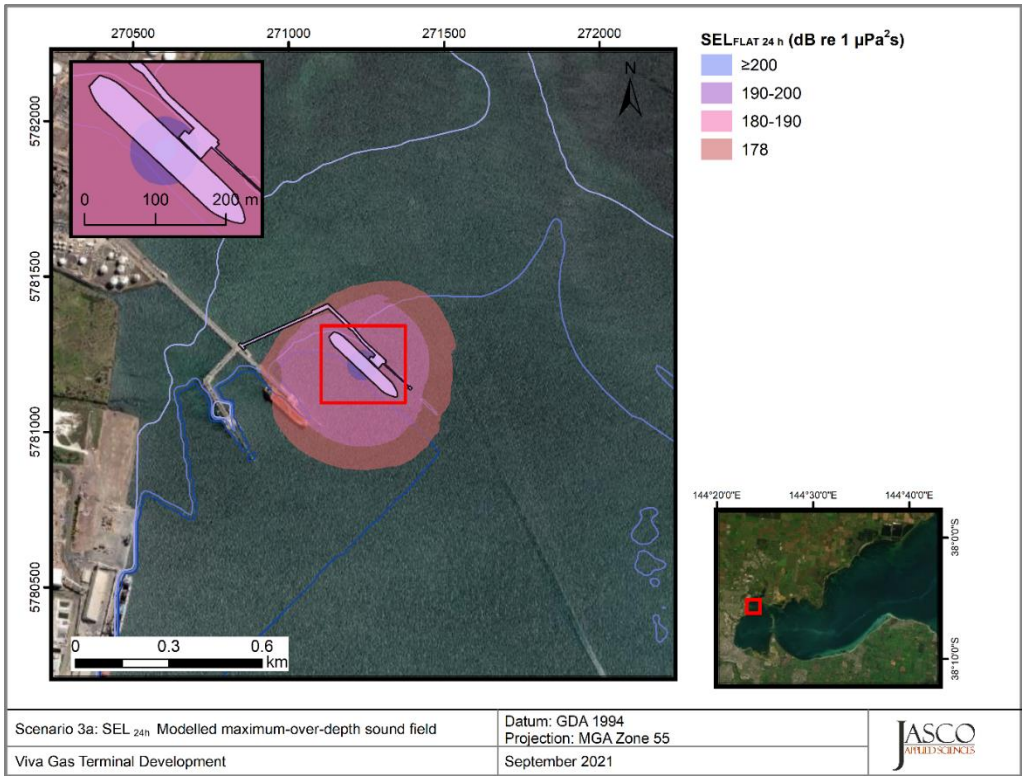


Figure 23. Unweighted maximum-over-depth SEL levels for Scenario 3a. No relevant thresholds were exceeded within the modelling resolution.

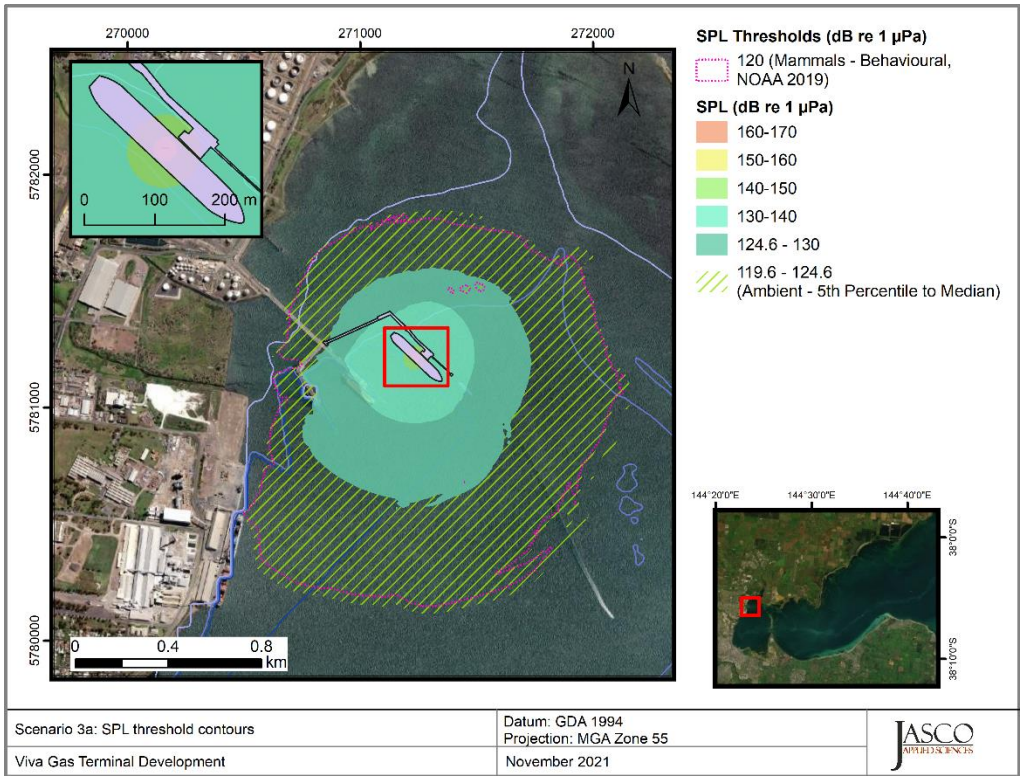


Figure 24. Maximum-over-depth SPL levels for Scenario 3a. Isopleth shows distance to behavioural effect onset level for marine mammals.

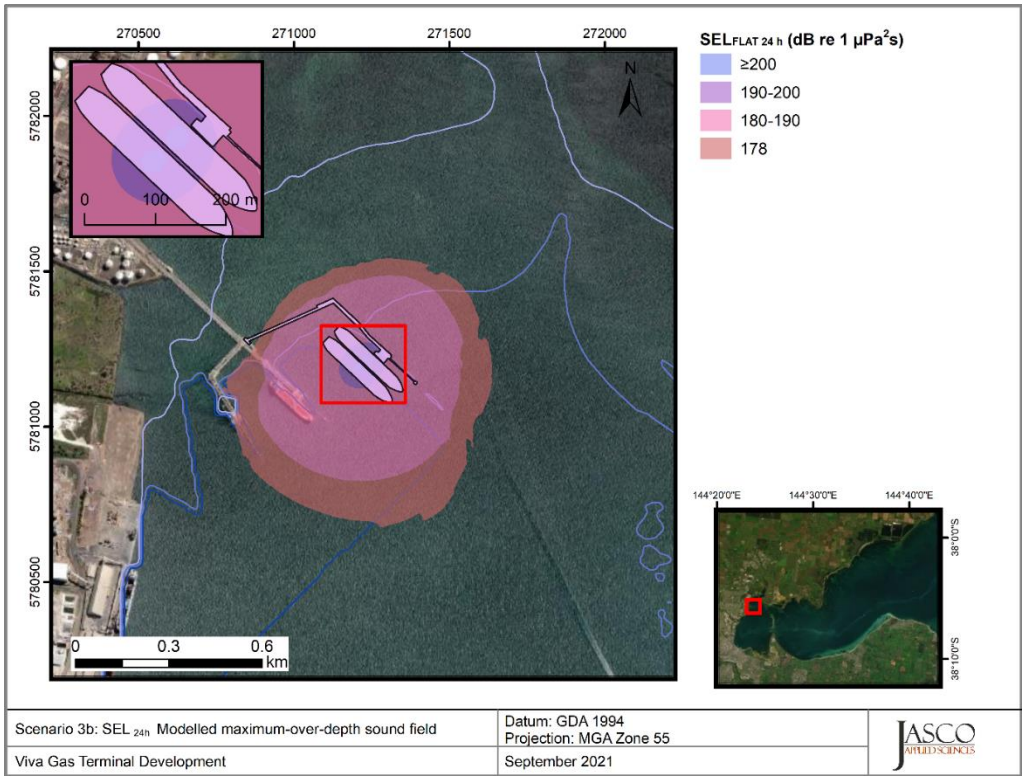


Figure 25. Unweighted maximum-over-depth SEL levels for Scenario 3b. No relevant thresholds were exceeded within the modelling resolution.

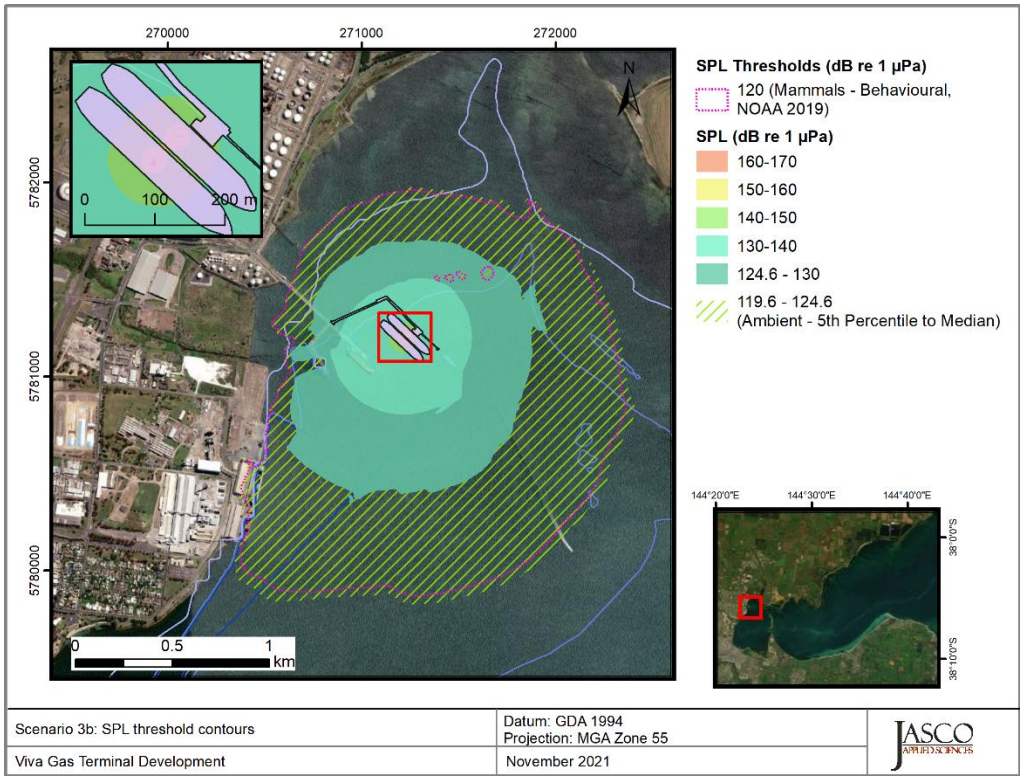


Figure 26. Maximum-over-depth SPL levels for Scenario 3b. Isopleth shows distance to behavioural effect onset level for marine mammals.

4.3. Scenario 4 – Berthing

This section presents the sound fields for LNG carrier berthing scenario in terms of maximum-over-depth SPL and SEL. Metrics presented are to those in Section 4.2.

4.3.1. Tables

Table 22. Berthing Scenario, SPL: Maximum (R_{max}) horizontal distances (km) from three modelled locations representing an LNG carrier berthing operation to maximum-over-depth SPL isopleths.

SPL (L_p; dB re 1 µPa)	4a – 4 knots		4b – 2 knots		4c – 0.5 knots	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.04**	**<0.01**
160	0.02	0.02	0.02	0.02	0.04	0.02
158[b]	**0.02**	**0.02**	**0.02**	**0.02**	**0.04**	**0.02**
150	0.06	0.05	0.06	0.05	0.07	0.06
140	0.45	0.33	0.43	0.36	0.47	0.36
130	1.43	1.22	1.45	1.14	1.59	1.27
124.6[c]	2.49	2.23	2.61	2.02	2.75	2.21
119.6[d]	3.99	3.30	3.99	3.21	4.33	3.58
120[e]	**3.84**	**3.23**	**3.84**	**3.11**	**4.27**	**3.47**

[a] Recoverable injury threshold for fish, 48 hours exposure (Popper et al. 2014).
[b] Temporary threshold shift in fish, 12 hours exposure (Popper et al. 2014).
[c] Median ambient level.
[d] 5th percentile ambient level.
[e] Marine mammal (NOAA 2019) behavioural threshold (non-impulsive sources).

Table 23. Berthing Scenario, TTS SEL Thresholds: Maximum (R_{max}) horizontal distances (m) from the berthing scenario line to maximum-over-depth weighted SEL isopleths for marine mammals (Southall et al. 2019). PTS thresholds were also not exceeded.

Hearing group	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	R_{max} (km)	$R_{95\%}$ (km)
HF cetaceans	178	—	—
Otariid pinnipeds	199	—	—

A dash indicates the threshold was not reached within the limits of the modelling resolution (20 m).

4.3.2. Sound Field Maps

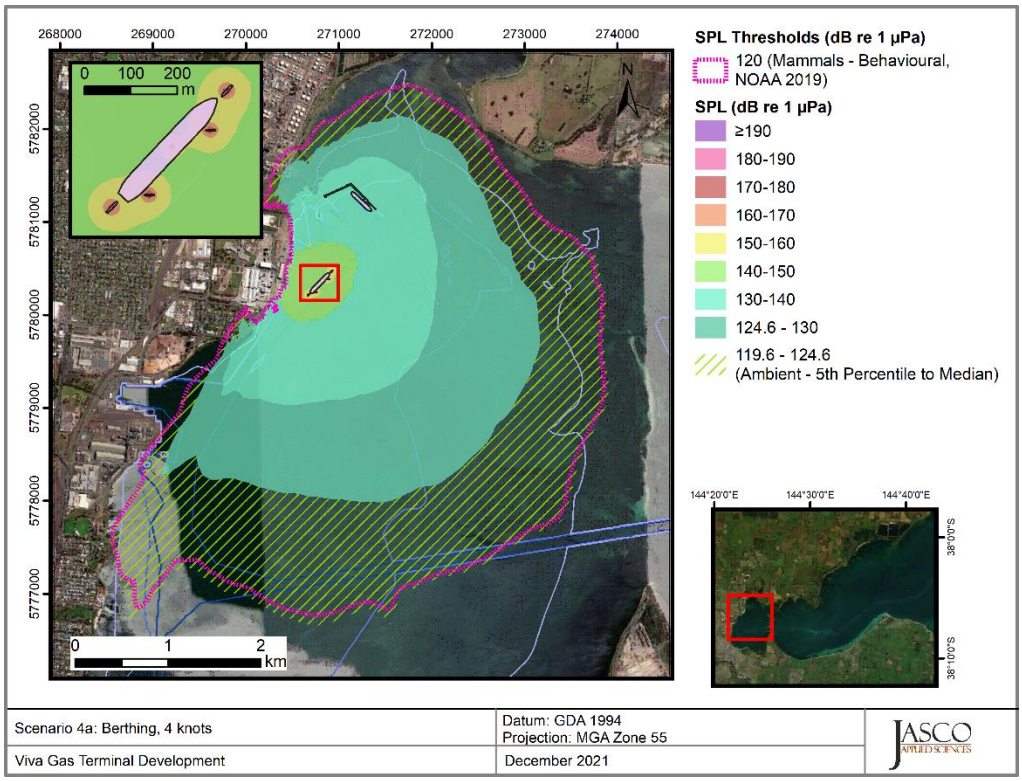


Figure 27. Maximum-over-depth SPL levels for Scenario 4a. Isopleth shows distance to behavioural effect onset level for marine mammals.

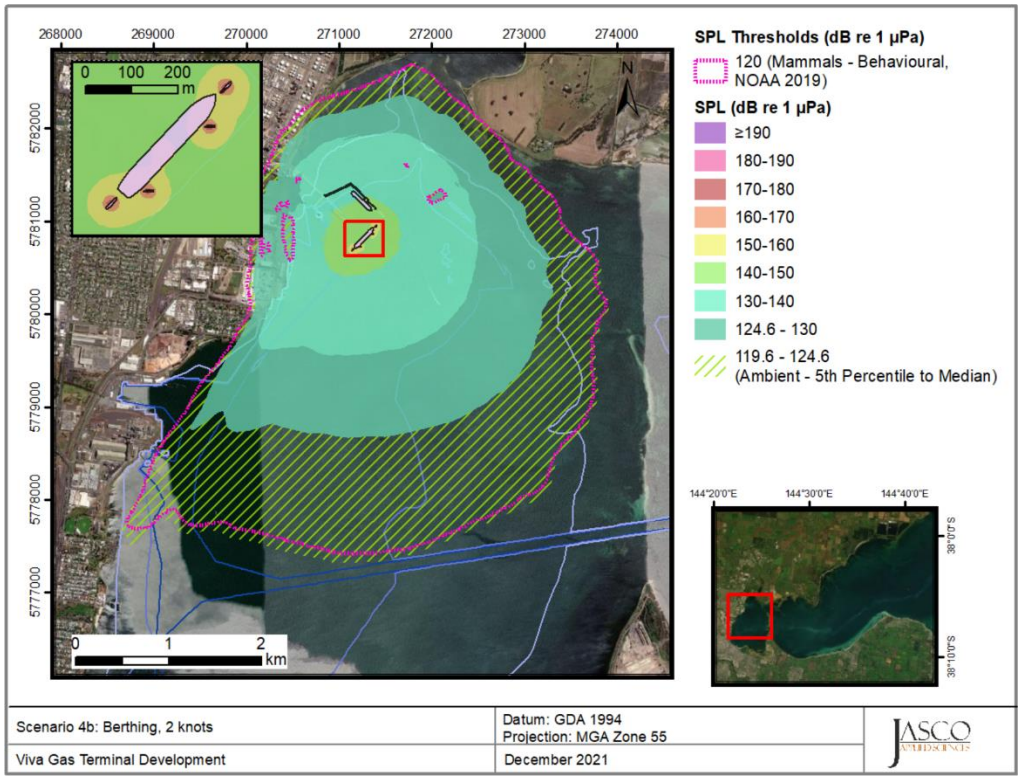


Figure 28. Maximum-over-depth SPL levels for Scenario 4b. Isopleth shows distance to behavioural effect onset level for marine mammals.

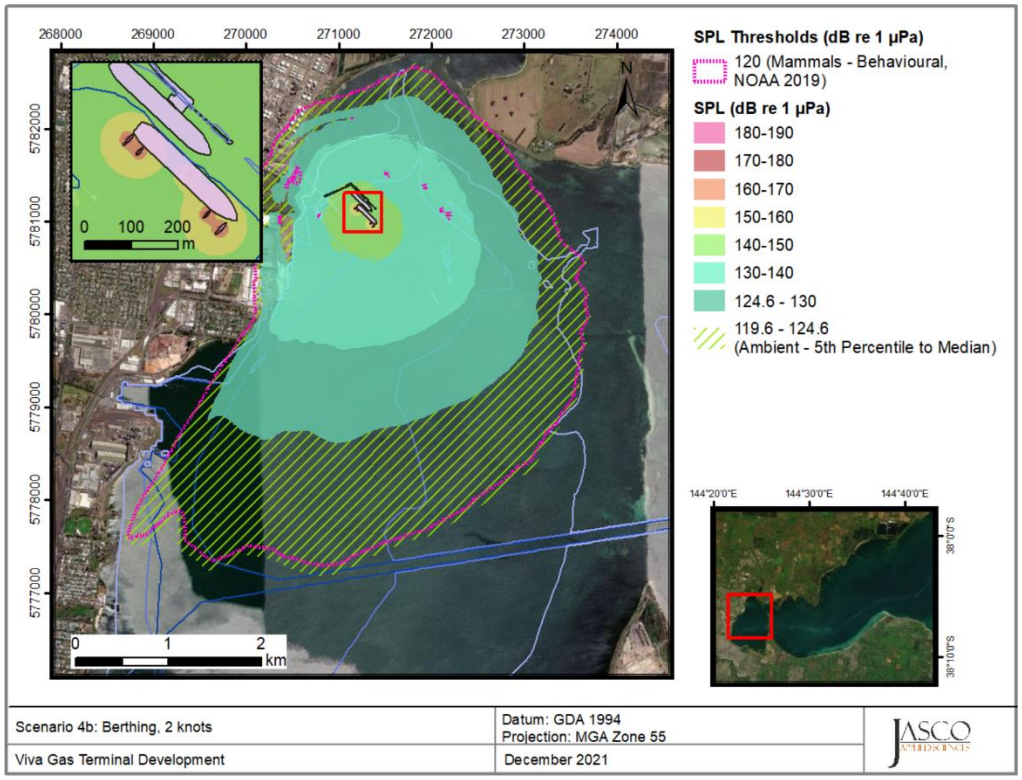


Figure 29. Maximum-over-depth SPL levels for Scenario 4c. Isopleth shows distance to behavioural effect onset level for marine mammals.

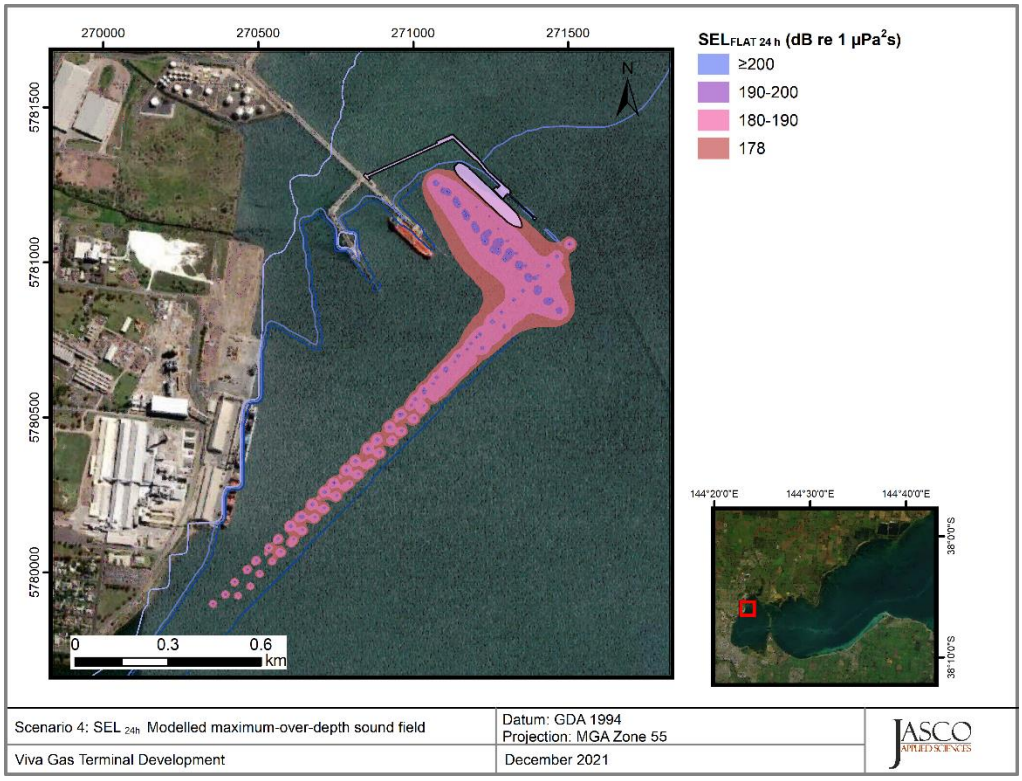


Figure 30. Unweighted maximum-over-depth SEL levels for Scenario 4. No relevant thresholds were exceeded within the modelling resolution.

5. Discussion

The modelling in this report shows sound field predictions from activities associated with construction and operational activities at the Viva Energy Gas Terminal. Scenario 1 considers impulsive radiated sound from two impact piling operations, while Scenarios 2 and 3 consider the continuous radiated sound propagation from dredging operations and FSRU operations, respectively.

5.1. Scenario 1

Scenario 1 describes the modelling of two pile driving operations: a dolphin pile to be driven as part of the construction of the pier extension for the gas terminal (Scenario 1a), and a smaller mooring pile driven at Lascelles Wharf (Scenario 1b) for the temporary loadout facility. The received spectra at 10 m from the pile central axes (Figure 6) show that the pile driven in Scenario 1a generates higher sound levels close to the source than that in Scenario 1b. This is likely to be due to the dolphin pile having a larger radiating (pile wall) area in the water column due to the larger water depth at its location (8.2 m) than the Lascelles Wharf pile (4.6 m).

The resulting sound fields for Scenarios 1a and 1b are shown in Figures 9 to 11 and Figures 12 to 14 respectively. Given the identical geoacoustic and sound speed properties between the modelled locations, the dominant influence on the variation in sound propagation between these sites is the bathymetry. The presence of the land blocks sound propagation to the north and west, and the shallow water depth (maximum of 12 m in inlet) serves to attenuate sound energy rapidly, especially at lower frequencies.

Across the sources studied in this report, the pile driving generates the highest source levels. Despite this, because of the shallow bathymetry, there is little sound propagation beyond the immediate vicinity of Geelong Inner Harbour. The influence of the bathymetry can be seen in the sound propagation results for Scenario 1a, visualised in Figures 9 and 10, which show slightly increased propagation in the south-westerly direction, likely due to the presence of the Geelong shipping channel. Conversely, south-westerly propagation for Scenario 1b is entirely blocked due to the proximity of the source to the shoreline (see Figure 17).

With regards to the recommended impact thresholds, none were exceeded when considering the PK levels (Table 16). The distances to SPL thresholds, shown in Table 17, indicate the maximum distance to the behavioural response onset level in marine mammals (NOAA 2019) is 0.80 km for Scenario 1a and 0.26 km in Scenario 1b. The largest distances at which the behavioural response onset threshold in diving birds was exceeded was 4.90 km in Scenario 1a, and 3.62 km in Scenario 1b.

The cumulative assessments consider radiated sound energy over the course of a single piling operation, and for all piling over a 24-hour period. For marine mammals and diving birds (Table 18), no PTS onset threshold level was reached for the studied auditory groups. Sound levels exceeding TTS onset levels were reached only for the dolphin pile (Scenario 1a), with a maximum distance of 0.10 km (otariid pinnipeds and diving birds) for piling operations over 24 hours.

Results for cumulative levels for fish are shown in Table 19. Sound levels associated with injury in fish with a swim bladder are exceeded up to 0.06 km from the pile in Scenario 1a, and not at all in Scenario 1b. Maximum distances to TTS onset levels are 0.87 and 0.11 km for piling operations over 24 hours for Scenarios 1a and 1b respectively.

5.2. Scenarios 2 and 3

Scenarios 2 and 3 describe the modelling of continuous noise from vessel sources. Scenario 2 comprises dredging activities as part of construction of the new berth (Scenario 2a) and for the

seawater transfer pipe (Scenario 2b). Scenario 3 comprises activities associated with the FSRU alone (Scenario 3a), and in conjunction with an offloading LNG carrier (Scenario 3b).

Results shown in Tables 20 and 21, and Figures 19 to 26, indicate that the two dredging operations in Scenario 2 generally result in slightly larger ensonified areas than the FSRU operations in Scenario 3, despite the fact that Scenario 3b features two simultaneous vessel sources. This is due to the source level of the dredger being higher than that of the FSRU and LNG carrier at frequencies that will be attenuated less rapidly given the shallow bathymetry (see Figure 7). The source spectrum used for the dredger has a peak in level between 100 and 1000 Hz, whereas the FSRU and LNG carrier sources peak below 100 Hz; this is reflected in the fact that in Scenario 3 the vessels are berthed, so there will be no high-frequency cavitation noise from propellers. Shallow waters act as a high-pass filter. The low-frequency cut-off f_c can be estimated as:

$$f_c \approx \frac{c_w}{4D\sqrt{1-(c_w/c_b)^2}} \quad (5)$$

where D is depth, c_w is a single-value estimate for the speed of sound in the water column, and c_b is a single-value estimate for the speed of sound in the sediment (Jensen et al. 2011). Using figures from the environmental parameters specified in Section 3.1, and D = 12 m, it can be estimated that for the area of concern in this study, the cut-off frequency is approximately 125 Hz. Thus, the majority of the low frequency sound, which is to say the most prevalent portion of the spectrum emanating from the FSRU and LNG carrier sources, is rapidly absorbed into the sediment, and the ensonified area is small.

Table 20 shows that marine mammal behavioural thresholds are exceeded up to a range of 1.84 km in Scenario 2b, and between 1.1 km and 1.6 km for other vessel scenarios. It should be noted, however, that the median ambient level exceeds the behavioural threshold. It can be seen from Table 21 that weighted TTS levels are only exceeded at very short distances from any of the vessel sources, with PTS levels not exceeded at all within the 20 m resolution of the models used in this study. As shown in Figures 21 to 26, there is no propagation further than the vicinity of Geelong Inner Harbour.

5.3. Scenario 4

Scenario 4 describes the final part of an approach and berthing of an LNG carrier at the proposed new berth. This involves the approach of the LNG carrier accompanied by two escort tugs and two berthing tugs.

Results presented in Table 22 and Figures 27 to 29 show that this berthing operation results in significantly larger ensonified areas than any of the other vessel scenarios due to the high source levels of the four tugs. Maximum distances to marine mammal behavioural response thresholds are between 3.8 km and 4.3 km. Since the berthing operation takes place over a shorter time scale than the other modelled vessel operations, however, marine mammals that may be present will not experience these elevated levels for as long as in other scenarios. It should also be noted that, for this reason, although the TTS and recoverable injury thresholds for fish are exceeded at very short distances, since these measures are for 12-hour and 48-hour exposures, respectively, these are effectively not exceeded in practise.

This short operational duration is also reflected in the SEL results. As seen in Figure 30, exposure levels are only elevated over the ambient noise over relatively short distances, and no relevant injury thresholds are exceeded.

Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017).

absorption

The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

ambient sound

Sound that would be present in the absence of a specified activity, usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

attenuation

The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

bandwidth

The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI R2010).

broadband level

The total level measured over a specified frequency range.

cavitation

A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of noise.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

compressional wave

A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called primary wave or P-wave.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period. A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade. *Note*: An alternative name for decidecade (symbol ddec) is "one-tenth decade". A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a "one-third octave".

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

energy source level

A property of a sound source obtained by adding to the sound exposure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^2m^2s.

ensonified

Exposed to sound.

far field

The zone where, to an observer, sound originating from an array of sources (or a spatially distributed source) appears to radiate from a single point.

Fourier transform (or Fourier synthesis)

A mathematical technique which, although it has varied applications, is referenced in the context of this report as a method used in the process of deriving a spectrum estimate from time-series data (or the reverse process, termed the inverse Fourier transform). A computationally efficient numerical algorithm for computing the Fourier transform is known as fast Fourier transform (FFT).

flat weighting

Term indicating that no frequency weighting function is applied. Synonymous with unweighted.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See **hearing group**.

impulsive sound

Qualitative term meaning sounds that are typically transient, brief (less than 1 second), broadband, with rapid rise time and rapid decay. They can occur in repetition or as a single event. Examples of impulsive sound sources include explosives, seismic airguns, and impact pile drivers.

isopleth

A line drawn on a map through all points having the same value of some quantity.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

monopole source level (MSL)

A source level that has been calculated using an acoustic model that accounts for the effect of the sea-surface and seabed on sound propagation, assuming a point-like (monopole) sound source. Also see radiated noise level.

M-weighting

See **auditory frequency weighting function** (as proposed by Southall et al. 2007).

non-impulsive sound

Sound that is not an impulsive sound. A non-impulsive sound is not necessarily a continuous sound.

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

otariid

A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups are phocids and walrus.

other marine carnivores in water (OCW)

See **hearing group**.

parabolic equation method

A computationally efficient solution to the acoustic wave equation that is used to model propagation loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of propagation loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

peak sound pressure level (zero-to-peak sound pressure level)

The level ($L_{p,pk}$ or L_{pk}) of the squared maximum magnitude of the sound pressure (p_{pk}^2).
Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 µPa^2.

$$L_{p,\mathrm{pk}} := 10\log_{10}\left(p_{\mathrm{pk}}^2/p_0^2\right)\mathrm{dB} = 20\log_{10}\left(p_{\mathrm{pk}}/p_0\right)\mathrm{dB}$$

The frequency band and time window should be specified. Abbreviation: PK or L_{pk}.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

phocid

A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus.

pinniped

A common term used to describe all three groups that form the superfamily Pinnipedia: phocids (true seals or earless seals), otariids (eared seals or fur seals and sea lions), and walrus.

point source

A source that radiates sound as if from a single point.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure. Unit: pascal (Pa).

radiated noise level (RNL)

A source level that has been calculated assuming sound pressure decays geometrically with distance from the source, with no influence of the sea-surface and seabed. Also see **monopole source level**.

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

rms

root-mean-square.

shear wave

A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called a secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s.

$$L_E := 10 \log_{10}(E/E_0)\,\text{dB} = 20 \log_{10}\left(E^{1/2}/E_0^{1/2}\right)\,\text{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound field

Region containing sound waves.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level (rms sound pressure level)

The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p^2_{rms}). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_{p,\mathrm{rms}} := 10\log_{10}(p^2_{\mathrm{rms}}/p_0^2)\ \mathrm{dB} = 20\log_{10}(p_{\mathrm{rms}}/p_0)\ \mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^2.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

unweighted

Term indicating that no frequency weighting function is applied. Synonymous with flat weighting.

Literature Cited

[AHO] Australian Hydrographic Office. 2021. *AU439144* (webpage), 27 Sep 2021. https://www.hydro.gov.au/webapps/jsp/charts/encDetails.jsp?chart=AU439144.

[HESS] High Energy Seismic Survey. 1999. *High Energy Seismic Survey Review Process and Interim Operational Guidelines for Marine Surveys Offshore Southern California*. Prepared for the California State Lands Commission and the United States Minerals Management Service Pacific Outer Continental Shelf Region by the High Energy Seismic Survey Team, Camarillo, CA, USA. 98 p. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2001100103.xhtml.

[ISO] International Organization for Standardization. 2006. *ISO 80000-3:2006. Quantities and Units – Part 3: Space and time*. https://www.iso.org/standard/31888.html.

[ISO] International Organization for Standardization. 2016. *ISO 17208-1:2016. Underwater acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: Requirements for precision measurements in deep water used for comparison purposes*. https://www.iso.org/standard/62408.html.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[NAVO] Naval Oceanography Office (US). 2003. *Database description for the Generalized Digital Environmental Model (GDEM-V) (U)*. Document Number MS 39522-5003. Oceanographic Data Bases Division, Stennis Space Center.

[NMFS] National Marine Fisheries Service (US). 1998. *Acoustic Criteria Workshop*. Dr. Roger Gentry and Dr. Jeanette Thomas Co-Chairs.

[NMFS] National Marine Fisheries Service (US). 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*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 p.

[NMFS] National Marine Fisheries Service (US). 2018. *2018 Revision 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*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 p. https://www.fisheries.noaa.gov/webdam/download/75962998.

[NOAA] National Oceanic and Atmospheric Administration (US). 2013. *Draft guidance for assessing the effects of anthropogenic sound on marine mammals: Acoustic threshold levels for onset of permanent and temporary threshold shifts*. National Oceanic and Atmospheric Administration, U. Department of Commerce, and NMFS Office of Protected Resources, Silver Spring, MD, USA. 76 p.

[NOAA] National Oceanic and Atmospheric Administration (US). 2015. *Draft guidance for assessing the effects of anthropogenic sound on marine mammal hearing: Underwater acoustic threshold levels for onset of permanent and temporary threshold shifts*. NMFS Office of Protected Resources, Silver Spring, MD, USA. 180 p.

[NOAA] National Oceanic and Atmospheric Administration (US). 2016. *Document Containing Proposed Changes to the NOAA Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Threshold Levels for Onset of Permanent and Temporary Threshold Shifts*. National Oceanic and Atmospheric Administration and US Department of Commerce. 24 p.

[NOAA] National Oceanic and Atmospheric Administration (US). 2018. Takes of Marine Mammals Incidental to Specified Activities; Taking Marine Mammals Incidental to Marine Site Characterization Surveys off of Delaware. *Federal Register* 83(65): 14417-14443. https://www.federalregister.gov/d/2018-12225.

[NOAA] National Oceanic and Atmospheric Administration (US). 2019. *ESA Section 7 Consultation Tools for Marine Mammals on the West Coast* (webpage), 27 Sep 2019. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west. (Accessed 10 Mar 2020).

[ONR] Office of Naval Research. 1998. *ONR Workshop on the Effect of Anthropogenic Noise in the Marine Environment*. Dr. R. Gisiner Chair.

[VRCA] Victoria Regional Channels Authority. 2020. *Vic Tides*. https://vrca.vic.gov.au/wp-content/uploads/2020/02/Tides-Tables-2020-web.pdf.

Aerts, L.A.M., M. Blees, S.B. Blackwell, C.R. Greene, Jr., K.H. Kim, D.E. Hannay, and M.E. Austin. 2008. *Marine mammal monitoring and mitigation during BP Liberty OBC seismic survey in Foggy Island Bay, Beaufort Sea, July-August 2008: 90-day report*. Document Number P1011-1. Report by LGL Alaska Research Associates Inc., LGL Ltd., Greeneridge Sciences Inc., and JASCO Applied Sciences for BP Exploration Alaska. 199 p. ftp://ftp.library.noaa.gov/noaa_documents.lib/NMFS/Auke%20Bay/AukeBayScans/Removable%20Disk/P1011-1.pdf.

Amoser, S. and F. Ladich. 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes. *Journal of the Acoustical Society of America* 113(4): 2170-2179. https://doi.org/10.1121/1.1557212.

ANSI S1.1-2013. 2013. *American National Standard Acoustical Terminology*. American National Standards Institute, NY, USA.

ANSI/ASA S1.13-2005. R2010. *American National Standard Measurement of Sound Pressure Levels in Air*. American National Standards Institute and Acoustical Society of America, NY, USA.

Buehler, D., R. Oestman, J.A. Reyff, K. Pommerenck, and B. Mitchell. 2015. *Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*. Report Number CTHWANP-RT-15-306.01.01. California Department of Transportation (CALTRANS), Division of Environmental Analysis. 532 p. http://www.dot.ca.gov/hq/env/bio/files/bio_tech_guidance_hydroacoustic_effects_110215.pdf.

Carnes, M.R. 2009. *Description and Evaluation of GDEM-V 3.0*. US Naval Research Laboratory, Stennis Space Center, MS. NRL Memorandum Report 7330-09-9165. 21 p. https://apps.dtic.mil/dtic/tr/fulltext/u2/a494306.pdf.

Christopherson, A. and J. Lundberg. 2013. *Underwater Sound Attenuation in Construction Projects: Applying Science to Pile Driving Permits*. Deep Foundations Institute. Article #1629. OneMine.org. 6 p.

Coffey Services Australia Pty Ltd. 2021. *Geelong LNG Regasification Terminal Project*. Technical report by Coffey Services Australia Pty Ltd for Viva Energy Australia Pty Ltd. Geotechnical Factual Report 754-MELGE271165AD_Rev2.

Collins, M.D. 1993. A split-step Padé solution for the parabolic equation method. *Journal of the Acoustical Society of America* 93(4): 1736-1742. https://doi.org/10.1121/1.406739.

Collins, M.D., R.J. Cederberg, D.B. King, and S. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. *Journal of the Acoustical Society of America* 100(1): 178-182. https://doi.org/10.1121/1.415921.

Coppens, A.B. 1981. Simple equations for the speed of sound in Neptunian waters. *Journal of the Acoustical Society of America* 69(3): 862-863. https://doi.org/10.1121/1.382038.

Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. *Journal of Experimental Biology* 220(16): 2878-2886. https://jeb.biologists.org/content/220/16/2878.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2018. A behavioural dose-response model for migrating humpback whales and seismic air gun noise. *Marine Pollution Bulletin* 133: 506-516. https://doi.org/10.1016/j.marpolbul.2018.06.009.

Ellison, W.T. and P.J. Stein. 1999. *SURTASS LFA High Frequency Marine Mammal Monitoring (HF/M3) Sonar: Sustem Description and Test & Evaluation*. Under U.S. Navy Contract N66604-98-D-5725. http://www.surtass-lfa-eis.com/wp-content/uploads/2018/02/HF-M3-Ellison-Report-2-4a.pdf.

Ellison, W.T. and A.S. Frankel. 2012. A common sense approach to source metrics. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Springer, New York. pp. 433-438.

Erbe, C., R. McCauley, C.R. McPherson, and A. Gavrilov. 2013. Underwater noise from offshore oil production vessels. *Journal of the Acoustical Society of America* 133(6): EL465-EL470. https://doi.org/10.1121/1.4802183.

Finneran, J.J. and C.E. Schlundt. 2010. Frequency-dependent and longitudinal changes in noise-induced hearing loss in a bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 128(2): 567-570. https://doi.org/10.1121/1.3458814.

Finneran, J.J. and A.K. Jenkins. 2012. *Criteria and thresholds for U.S. Navy acoustic and explosive effects analysis*. SPAWAR Systems Center Pacific, San Diego, CA, USA. 64 p.

Finneran, J.J. 2015. *Auditory weighting functions and TTS/PTS exposure functions for cetaceans and marine carnivores*. Technical report by SSC Pacific, San Diego, CA, USA.

Finneran, J.J. 2016. *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Technical Report for Space and Naval Warfare Systems Center Pacific, San Diego, CA, USA. 49 p. http://www.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf.

Fisher, F.H. and V.P. Simmons. 1977. Absorption of sound in sea water. *Journal of the Acoustical Society of America* 62(S13): 558-564. https://doi.org/10.1121/1.2015423.

Funk, D., D.E. Hannay, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2008. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–November 2007: 90-day report*. LGL Report P969-1. Prepared by LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for Shell Offshore Inc., National Marine Fisheries Service (U.S.), and U.S. Fish and Wildlife Service. 218 p.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. *Journal of the Acoustical Society of America* 68(5): 1313-1340. https://doi.org/10.1121/1.385100.

Hannay, D.E. and R.G. Racca. 2005. *Acoustic Model Validation*. Document Number 0000-S-90-04-T-7006-00-E, Revision 02. Technical report by JASCO Research Ltd. for Sakhalin Energy Investment Company Ltd. 34 p.

Illingworth & Rodkin, Inc. 2007. Appendix I. Compendium of pile driving sound data. *In Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish*.

Illingworth & Rodkin, Inc. for the California Department of Transportation, Sacramento, CA, Sacramento, CA. p. 129. www.dot.ca.gov/hq/env/bio/files/pile_driving_snd_comp9_27_07.pdf.

Ireland, D.S., R. Rodrigues, D. Funk, W.R. Koski, and D.E. Hannay. 2009. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–October 2008: 90-Day Report*. Document Number P1049-1. 277 p.

Jensen, F.B., W.A. Kuperman, M.B. Porter, and H. Schmidt. 2011. *Computational Ocean Acoustics*. 2nd edition. AIP Series in Modern Acourics and Signal Processing. AIP Press - Springer, New York. 794 p.

Lucke, K., U. Siebert, P. Lepper, A., and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. *Journal of the Acoustical Society of America* 125(6): 4060-4070. https://doi.org/10.1121/1.3117443.

Lucke, K. and C. McPherson. 2021. *Appendix [X]: Underwater Noise Impact Assessment: Viva Energy Gas Terminal Project Environment Effects Statement*. Document Number 02558, Version 1.0 DRAFT. Technical report by JASCO Applied Sciences for AECOM.

MacGillivray, A.O. and N.R. Chapman. 2012. Modeling underwater sound propagation from an airgun array using the parabolic equation method. *Canadian Acoustics* 40(1): 19-25. https://jcaa.caa-aca.ca/index.php/jcaa/article/view/2502/2251.

MacGillivray, A.O. 2014. A model for underwater sound levels generated by marine impact pile driving. *Proceedings of Meetings on Acoustics* 20(1). https://doi.org/10.1121/2.0000030

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyak, and J.E. Bird. 1983. *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior*. Report Number 5366. http://www.boem.gov/BOEM-Newsroom/Library/Publications/1983/rpt5366.aspx.

Malme, C.I., P.R. Miles, C.W. Clark, P.L. Tyack, and J.E. Bird. 1984. *Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Phase II: January 1984 migration*. Report Number 5586. Report prepared by Bolt, Beranek and Newman Inc. for the US Department of the Interior, Minerals Management Service, Cambridge, MA, USA. 357 p. https://www.boem.gov/BOEM-Newsroom/Library/Publications/1983/rpt5586.aspx.

Malme, C.I., B. Würsig, J.E. Bird, and P.L. Tyack. 1986. *Behavioral responses of gray whales to industrial noise: Feeding observations and predictive modeling*. Document Number 56. Final Reports of Principal Investigators. 393-600 p.

Martin, B., K. Bröker, M.-N.R. Matthews, J.T. MacDonnell, and L. Bailey. 2015. Comparison of measured and modeled air-gun array sound levels in Baffin Bay, West Greenland. *OceanNoise 2015*. 11-15 May 2015, Barcelona, Spain.

Matuschek, R. and K. Betke. 2009. Measurements of construction noise during pile driving of offshore research platforms and wind farms. *NAG-DAGA 2009 International Conference on Acoustics*. Rotterdam, Netherlands. pp. 262-265.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

Nedwell, J.R., A.W. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, J.A.L. Spinks, and D. Howell. 2007. *A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise*. Document Number 534R1231 Report prepared by Subacoustech Ltd. for the UK Department of Business, Enterprise and Regulatory Reform under Project No.

RDCZ/011/0004. 74 p. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-et-al-2007.pdf.

O'Neill, C., G. Warner, and D.E. Hannay. 2010. Verification of a Bubble Curtain Model Using an Impulse Response Function for a Towed Source. *Canadian Acoustics* 38(3): 68-69. https://jcaa.caa-aca.ca/index.php/jcaa/article/view/2248/1996.

Payne, R. and D. Webb. 1971. Orientation by means of long range acoustic signaling in baleen whales. *Annals of the New York Academy of Sciences* 188: 110-142. https://doi.org/10.1111/j.1749-6632.1971.tb13093.x.

Pichegru, L., R. Nyengera, A.M. McInnes, and P. Pistorius. 2017. Avoidance of seismic survey activities by penguins. *Scientific Reports* 7: 16305. https://doi.org/10.1038/s41598-017-16569-x.

Pile Dynamics, Inc. 2010. GRLWEAP.

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

Porter, M.B. and Y.-C. Liu. 1994. Finite-element ray tracing. *In*: Lee, D. and M.H. Schultz (eds.). *International Conference on Theoretical and Computational Acoustics*. Volume 2. World Scientific Publishing Co. pp. 947-956.

Racca, R.G., A.N. Rutenko, K. Bröker, and M.E. Austin. 2012a. A line in the water - design and enactment of a closed loop, model based sound level boundary estimation strategy for mitigation of behavioural impacts from a seismic survey. *11th European Conference on Underwater Acoustics*. Volume 34(3), Edinburgh, UK.

Racca, R.G., A.N. Rutenko, K. Bröker, and G. Gailey. 2012b. Model based sound level estimation and in-field adjustment for real-time mitigation of behavioural impacts from a seismic survey and post-event evaluation of sound exposure for individual whales. *In*: McMinn, T. (ed.). *Acoustics 2012 Fremantle: Acoustics, Development and the Environment. Proceedings of the Annual Conference of the Australian Acoustical Society*. Fremantle, Australia. http://www.acoustics.asn.au/conference_proceedings/AAS2012/papers/p92.pdf.

Reine, K.J., D. Clarke, and C. Dickerson. 2014. Characterization of underwater sounds produced by hydraulic and mechanical dredging operations. *Journal of the Acoustical Society of America* 135(6): 3280-3294. https://doi.org/10.1121/1.4875712.

Scholik, A.R. and H.Y. Yan. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. *Environmental Biology of Fishes* 63(2): 203-209. https://doi.org/10.1023/A:1014266531390.

Smith, M.E., A.B. Coffin, D.L. Miller, and A.N. Popper. 2006. Anatomical and functional recovery of the goldfish (*Carassius auratus*) ear following noise exposure. *Journal of Experimental Biology* 209(21): 4193-4202. http://jeb.biologists.org/content/209/21/4193.abstract.

Sørensen, K., C. Neumann, M. Dähne, K.A. Hansen, and M. Wahlberg. 2020. Gentoo penguins (Pygoscelis papua) react to underwater sounds. *Royal Society Open Science* 7(2): 191988.

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

Southall, B.L., D.P. Nowaceck, P.J.O. Miller, and P.L. Tyack. 2016. Experimental field studies to measure behavioral responses of cetaceans to sonar. *Endangered Species Research* 31: 293-315. https://doi.org/10.3354/esr00764.

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

Southall, B.L., D.P. Nowacek, A.E. Bowles, V. Senigaglia, L. Bejder, and P.L. Tyack. 2021. Marine Mammal Noise Exposure Criteria: Assessing the Severity of Marine Mammal Behavioral Responses to Human Noise. *Aquatic Mammals* 47(5): 421-464.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. *Journal of Geophysical Research* 95(C5): 7167-7183. https://doi.org/10.1029/JC095iC05p07167.

Warner, G.A., C. Erbe, and D.E. Hannay. 2010. Underwater Sound Measurements. (Chapter 3) *In* Reiser, C.M., D. Funk, R. Rodrigues, and D.E. Hannay (eds.). *Marine Mammal Monitoring and Mitigation during Open Water Shallow Hazards and Site Clearance Surveys by Shell Offshore Inc. in the Alaskan Chukchi Sea, July-October 2009: 90-Day Report*. LGL Report P1112-1. Report by LGL Alaska Research Associates Inc. and JASCO Applied Sciences for Shell Offshore Inc., National Marine Fisheries Service (US), and Fish and Wildlife Service (US). pp. 1-54.

Whittaker, J.M., A. Goncharov, S.E. Williams, R.D. Müller, and G. Leitchenkov. 2013. Global sediment thickness data set updated for the Australian-Antarctic Southern Ocean. *Geochemistry, Geophysics, Geosystems* 14(8): 3297-3305. https://doi.org/10.1002/ggge.20181.

Wilson, C.C. and C. McPherson. 2021. *Viva Energy Gas Terminal Project: Baseline Monitoring of Ambient Environment*. Document Number 02580, Version 1.0 DRAFT. Technical report by JASCO Applied Sciences for AECOM.

Wood, J., B.L. Southall, and D.J. Tollit. 2012. *PG&E offshore 3-D Seismic Survey Project Environmental Impact Report–Marine Mammal Technical Draft Report*. SMRU Ltd. 121 p. https://www.coastal.ca.gov/energy/seismic/mm-technical-report-EIR.pdf.

Zhang, Z.Y. and C.T. Tindle. 1995. Improved equivalent fluid approximations for a low shear speed ocean bottom. *Journal of the Acoustical Society of America* 98(6): 3391-3396. https://doi.org/10.1121/1.413789.

Appendix A. Additional Methods and Parameters

A.1. Bathymetry

Water depths for the modelled area were extracted from a number of sources:

- Survey data for distances from the source location on the order of 1-2 km, supplied by the client. This data has ~1 m resolution in the area immediately around the proposed FSRU mooring, reducing to ~25 m, then ~50 m resolution as the distance from this area increases.
- Depth soundings from Australian Hydrographic Office (AHO) survey AU439144, which have a resolution of ~250 m.
- Lower resolution (on the order of kilometres) depth contours provided by the client.
- Shapefile for Geelong shipping channel from an Australian government source.
- Post-dredge depths of the area to be dredged as part of this project in Scenario 2a, provided by the client.

The main source of bathymetry for the majority of the modelled area was the AU439144 survey (AHO 2021). This data was, however, missing the northeast corner of Port Philip, so the low-resolution depth contours were used to fill in this area, with a 250 m buffer to smooth the transition between the two datasets. The area around the modelled source locations was replaced by the high-resolution survey data, with a 20 m buffer to smooth between this and the AU439144 data.

All of these datasets are referenced to chart datum, which is -0.58 m offset from Australian height datum (AHD). Mean higher high water (MHHW) for the port is reported as AHD + 0.42 m (VRCA 2020). The combined bathymetry was therefore adjusted to MHHW by adding 1 m. The Geelong shipping channel was then added to the bathymetry by manually creating a zone at a depth of 12.3 m (the channel depth at MHHW according to the AU439144 metadata) in areas based on the channel shapefile. The final composite bathymetry data was re-gridded onto a Map Grid of Australia (MGA) coordinate projection (Zone 55 south) with a regular grid spacing of 10 m. Figure A.1 shows a simplified overview of the composite bathymetry, highlighting the different data sources.

Scenario 2a was modelled using bathymetry as described above, as it was reasoned that a pre-dredged bathymetry would be more representative for this dredging operation. For all other scenarios, the post-dredged depths were also added to the composite bathymetry.

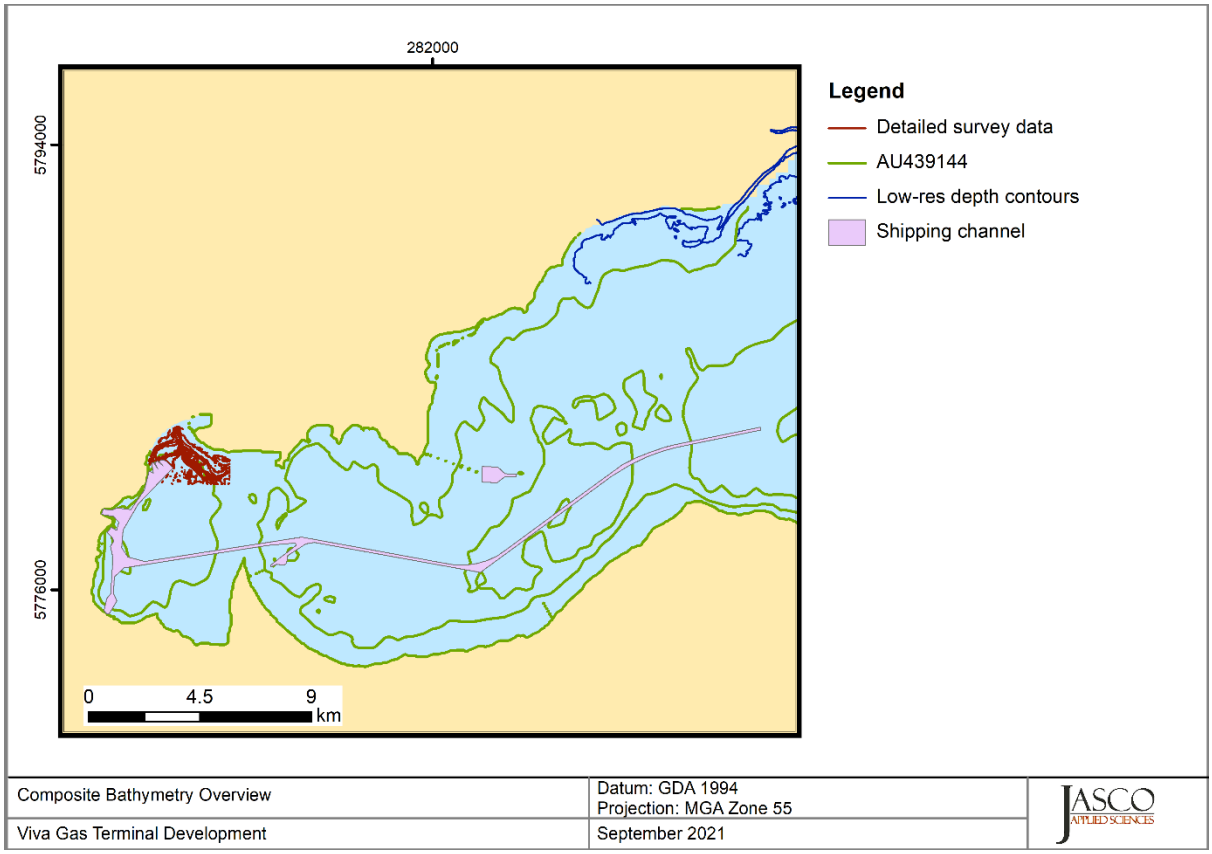


Figure A.1. Simplified overview of composite bathymetry data.

A.2. Sound Speed Profile

The sound speed profile (SSP) for the modelled site was derived from temperature and salinity data from the US Naval Oceanographic Office's *Generalized Digital Environmental Model V 3.0* (Teague et al. 1990, NAVO 2003, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the US Navy's Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m (where the ocean is that deep). The GDEM temperature-salinity data were converted to sound speed profiles according to Coppens (1981).

The SSP used in this study was generated using extracted temperature and salinity data for May from 38°S, 144.5°E, up to a depth of 4 m. This was combined with data from 38.25°S, 144.5°E to extend the profile to 45 m. Ultimately, no modelled scenarios resulted in sound propagating beyond the immediate vicinity of the sources, so sound speed data for depths greater than this was not required. The resultant SSP is largely flat, varying between 1505.7 m/s and 1506.0 m/s for all depths of interest in this study, as shown in Figure A.2

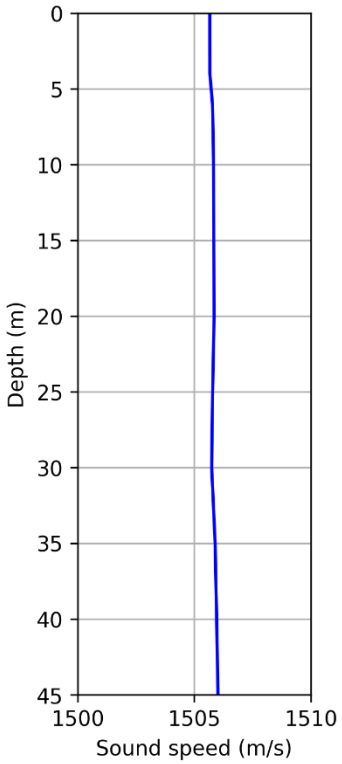


Figure A.2 Sound speed profile used in this study.

A.3. Estimating Ranges to Threshold Levels

Sound level contours were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the seafloor for each location in the modelled region. The predicted distances to specific levels were computed from these contours. Two distances relative to the source are reported for each sound level: R_{max}, the maximum range to the given sound level over all azimuths, and $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure A.3).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in Figure A.3a. In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In contrast, in strongly radially asymmetric cases such as shown in Figure A.3b, $R_{95\%}$ neglects to account for substantial protrusions in the footprint. In such cases, R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features that affect propagation. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

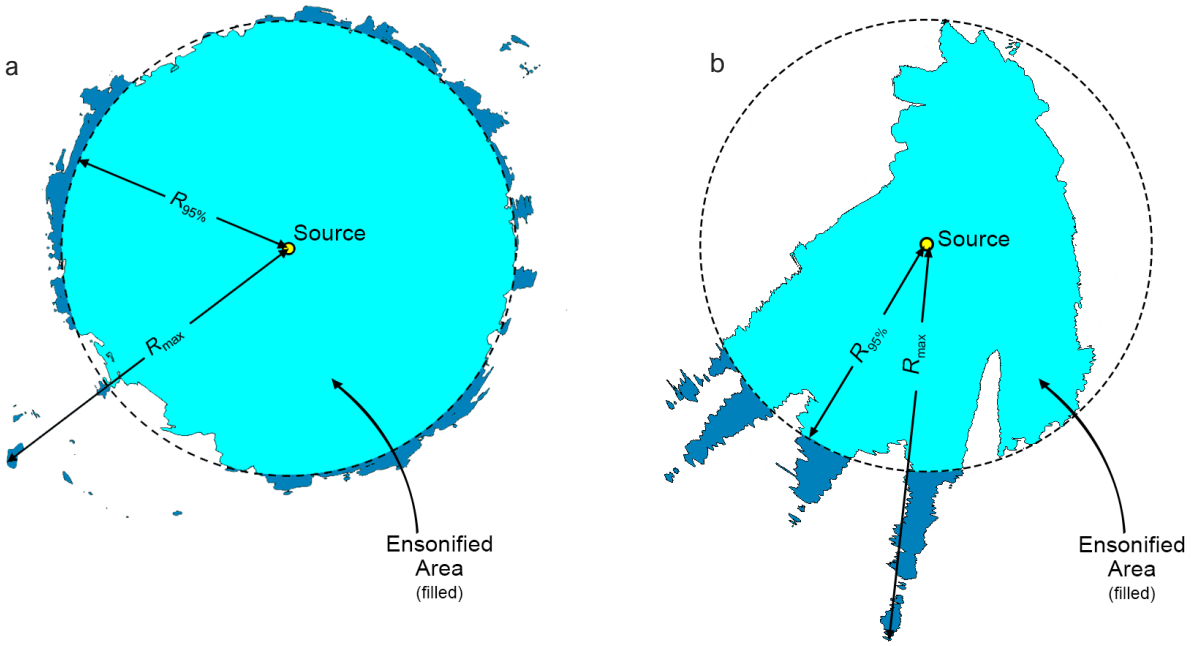


Figure A.3. R_{max} and $R_{95\%}$ ranges shown for two contrasting scenarios. Cyan indicates the ensonified areas bounded by $R_{95\%}$, whilst dark blue indicates the ensonified areas beyond $R_{95\%}$ that determine R_{max}.

Appendix B. Underwater Acoustic Metrics

B.1. Level Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 µPa. Because the perceived loudness of sound, especially pulsed sound such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (ANSI 2013, e.g., ISO 2017).

The zero-to-peak sound pressure, or peak sound pressure (PK or $L_{p,pk}$; dB re 1 µPa), is the decibel level of the maximum instantaneous acoustic pressure in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{p,\mathrm{pk}} = 10\log_{10}\frac{\max|p^2(t)|}{p_0^2} = 20\log_{10}\frac{\max|p(t)|}{p_0} \qquad \text{(B-1)}$$

PK is often included as a criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of an acoustic event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or L_p; dB re 1 µPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt \Big/ p_0^2\right)\ \mathrm{dB} \qquad \text{(B-2)}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,boxcar\ 125ms}$. Another approach, historically used to evaluate SPL of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (SEL or L_E; dB re 1 µPa^2 s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10 \log_{10} \left(\int_T p^2(t)\, dt \Big/ T_0 p_0^2 \right) \text{ dB} \tag{B-3}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10 \log_{10} \left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \right) \text{ dB} \tag{B-4}$$

Energy equivalent SPL (L_{eq}; dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same time period, T:

$$L_{\text{eq}} = 10 \log_{10} \left(\frac{1}{T} \int_T p^2(t)\, dt \Big/ p_0^2 \right) \tag{B-5}$$

The equations for SPL and the energy-equivalent SPL are numerically identical. Conceptually, the difference between the two metrics is that the SPL is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the L_{eq} reflects the average SPL of an acoustic signal over time periods typically of 1 min to several hours.

B.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analysing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3 octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_{\text{c}}(i)$, is defined as:

$$f_{\text{c}}(i) = 10^{\frac{i}{10}} \text{ kHz} \tag{B-6}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decade band are defined as:

$$f_{\text{lo},i} = 10^{\frac{-1}{20}} f_{\text{c}}(i) \quad \text{and} \quad f_{\text{hi},i} = 10^{\frac{1}{20}} f_{\text{c}}(i) \tag{B-7}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure B.1). The acoustic modelling spans from $f_c(1) = 10$ Hz to $f_c(35) = 25119$ Hz.

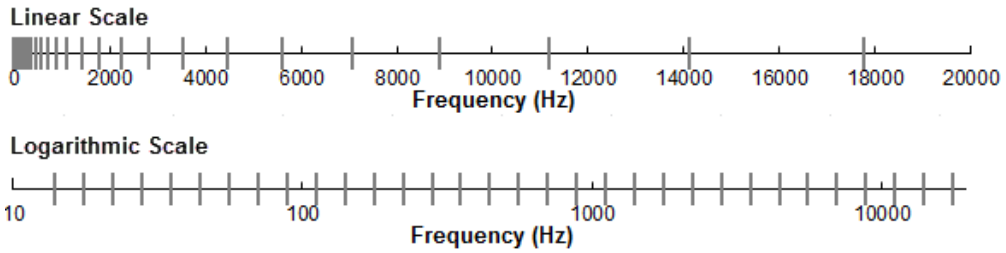


Figure B.1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{\mathrm{lo},i}$ and $f_{\mathrm{hi},i}$:

$$L_{p,i} = 10 \log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\, \mathrm{d}f \ \ \mathrm{dB} \tag{B-8}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \ \ \mathrm{dB} \tag{B-9}$$

Figure B.2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the decidecade bands are wider than 1 Hz, the decidecade band SPL is higher than the spectral levels at higher frequencies. Acoustic modelling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

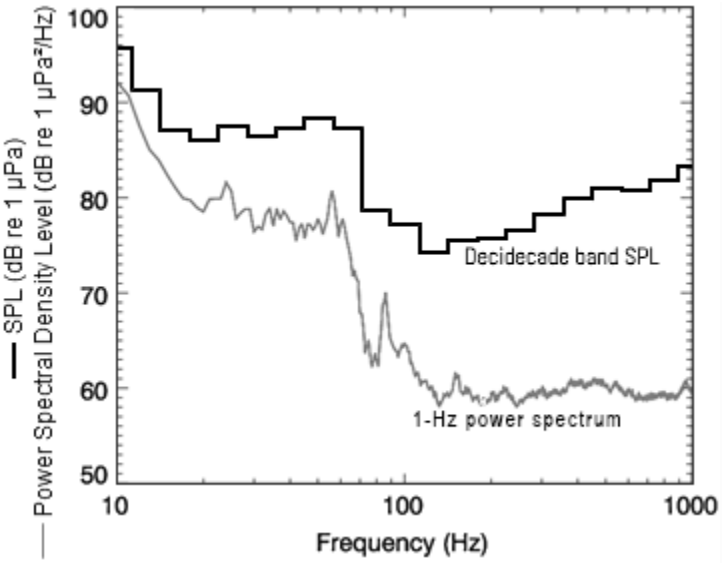


Figure B.2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale.Because the decidecade bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

B.3. Marine Mammal Noise Effect Criteria

It has been long recognised that marine mammals can be adversely affected by underwater anthropogenic noise. For example, Payne and Webb (1971) suggest that communication distances of fin whales are reduced by shipping sounds. Subsequently, similar concerns arose regarding effects of other underwater noise sources and the possibility that impulsive sources—primarily airguns used in seismic surveys—could cause auditory injury. This led to a series of workshops held in the late 1990s, conducted to address acoustic mitigation requirements for seismic surveys and other underwater noise sources (NMFS 1998, ONR 1998, Nedwell and Turnpenny 1998, HESS 1999, Ellison and Stein 1999). In the years since these early workshops, a variety of thresholds have been proposed for auditory injury, impairment, and disturbance. The following sections summarise the recent development of thresholds; however, this field remains an active research topic.

B.3.1. Injury and Hearing Sensitivity Changes

In recognition of shortcomings of the SPL-only based auditory injury criteria, in 2005 NMFS sponsored the Noise Criteria Group to review literature on marine mammal hearing to propose new noise exposure criteria. Some members of this expert group published a landmark paper (Southall et al. 2007) that suggested assessment methods similar to those applied for humans. The resulting recommendations introduced dual auditory injury criteria for impulsive sounds that included peak pressure level thresholds and SEL_{24h} thresholds, where the subscripted 24h refers to the accumulation period for calculating SEL. The peak pressure level criterion is not frequency weighted whereas SEL_{24h} is frequency weighted according to one of four marine mammal species hearing groups: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively) and Pinnipeds in Water (PINN). These weighting functions are referred to as M-weighting filters (analogous to the A-weighting filter for humans; see Appendix B.3). The SEL_{24h} thresholds were obtained by extrapolating measurements of onset levels of Temporary Threshold Shift (TTS) in belugas by the amount of TTS required to produce Permanent Threshold Shift (PTS) in chinchillas. The Southall et al. (2007) recommendations do not specify an exchange rate, which suggests that the thresholds are the same regardless of the duration of exposure (i.e., it implies a 3 dB exchange rate).

Wood et al. (2012) refined Southall et al.'s (2007) thresholds, suggesting lower PTS and TTS values for LF and HF cetaceans while retaining the filter shapes. Their revised thresholds were based on TTS-onset levels in harbour porpoises from Lucke et al. (2009), which led to a revised impulsive sound PTS threshold for HF cetaceans of 179 dB re 1 $\mu Pa^2 \cdot s$. Because there were no data available for baleen whales, Wood et al. (2012) based their recommendations for LF cetaceans on results obtained from MF cetacean studies. In particular they referenced the Finneran and Schlundt (2010) research, which found mid-frequency cetaceans are more sensitive to non-impulsive sound exposure than Southall et al. (2007) assumed. Wood et al. (2012) thus recommended a more conservative TTS-onset level for LF cetaceans of 192 dB re 1 $\mu Pa^2 \cdot s$.

As of 2017, a definitive approach is still not apparent. There is consensus in the research community that an SEL-based method is preferable, either separately or in addition to an SPL-based approach to assess the potential for injuries. In August 2016, after substantial public and expert input into three draft versions and based largely on the above-mentioned literature (NOAA 2013, 2015, 2016), NMFS finalised technical guidance for assessing the effect of anthropogenic sound on marine mammal hearing (NMFS 2016). The guidance describes auditory injury criteria with new thresholds and frequency weighting functions for the five hearing groups described by Finneran and Jenkins (2012). The latest revision to this work was published in 2018 (NMFS 2018). Southall et al. (2019) revisited the interim criteria published in 2007. All noise exposure criteria in NMFS (2018) and Southall et al. (2019) are identical (for impulsive and non-impulsive sounds); however, the mid-frequency cetaceans from NMFS (2018) are classified as high-frequency cetaceans in Southall et al. (2019), and high-frequency cetaceans from NMFS (2018) are classified as very-high-frequency cetaceans in Southall et al. (2019).

B.3.2. Behavioural Response

Numerous studies on marine mammal behavioural responses to sound exposure have not resulted in consensus in the scientific community regarding the appropriate metric for assessing behavioural reactions. However, it is recognised that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison and Frankel 2012, Southall et al. 2016, Southall et al. 2021).

B.3.2.1. Non-Impulsive Noise

NMFS currently uses step function (all-or-none) threshold of 120 dB re 1 µPa SPL (unweighted) for non-impulsive sounds to assess and regulate noise-induced behavioural impacts on marine mammals (NOAA 2019). The 120 dB re 1 µPa threshold is associated with continuous sources and was derived based on studies examining behavioural responses to drilling and dredging, referring to Malme et al. (1983), Malme et al. (1984), and Malme et al. (1986), which were considered in Southall et al. (2007). Malme et al. (1986) found that playback of drillship noise did not produce clear evidence of disturbance or avoidance for levels below 110 dB re 1 µPa (SPL), possible avoidance occurred for exposure levels approaching 119 dB re 1 µPa. Malme et al. (1984) determined that measurable reactions usually consisted of rather subtle short-term changes in speed and/or heading of the whale(s) under observation. It has been shown that both received level and proximity of the sound source is a contributing factor in eliciting behavioural reactions in humpback whales (Dunlop et al. 2017, Dunlop et al. 2018).

B.3.2.2. Impulsive Noise

For impulsive noise, NMFS currently uses step function thresholds of 160 dB re 1 µPa SPL (unweighted) to assess and regulate noise-induced behavioural impacts for marine mammals (NOAA 2018, NOAA 2019). The threshold for impulsive sound is derived from the High-Energy Seismic Survey (HESS) panel (HESS 1999) report that, in turn, is based on the responses of migrating mysticete whales to airgun sounds (Malme et al. 1984). The HESS team recognised that behavioural responses to sound may occur at lower levels, but significant responses were only likely to occur above a SPL of 140 dB re 1 µPa. Southall et al. (2007) found varying responses for most marine mammals between a SPL of 140 and 180 dB re 1 µPa, consistent with the HESS (1999) report, but lack of convergence in the data prevented them from suggesting explicit step functions.

B.4. Marine mammal frequency weighting

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left(\frac{\left(\frac{f}{f_{lo}}\right)^{2a}}{\left(1+\left(\frac{f}{f_{lo}}\right)^{2}\right)^{a}\left(1+\left(\frac{f}{f_{hi}}\right)^{2}\right)^{b}}\right) \quad \text{(B-10)}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2016, NMFS 2018). A further update to these weighting functions is presented in Southall (2019), whereby mid- and high- frequency cetaceans are now known as high- and very-high-frequency cetaceans.

Table B-1 lists the frequency-weighting parameters for each hearing group, and Figure B.3 shows the resulting frequency-weighting curves.

Table B-1. Parameters for the auditory weighting functions used in this project (Southall et al. 2019).

Hearing group	a	b	f_{lo} (Hz)	f_{hi} (kHz)	K (dB)
High-frequency cetaceans	1.6	2.0	8,800	110,000	1.2
Otariid seals in water	2.0	2.0	940	25,000	0.64

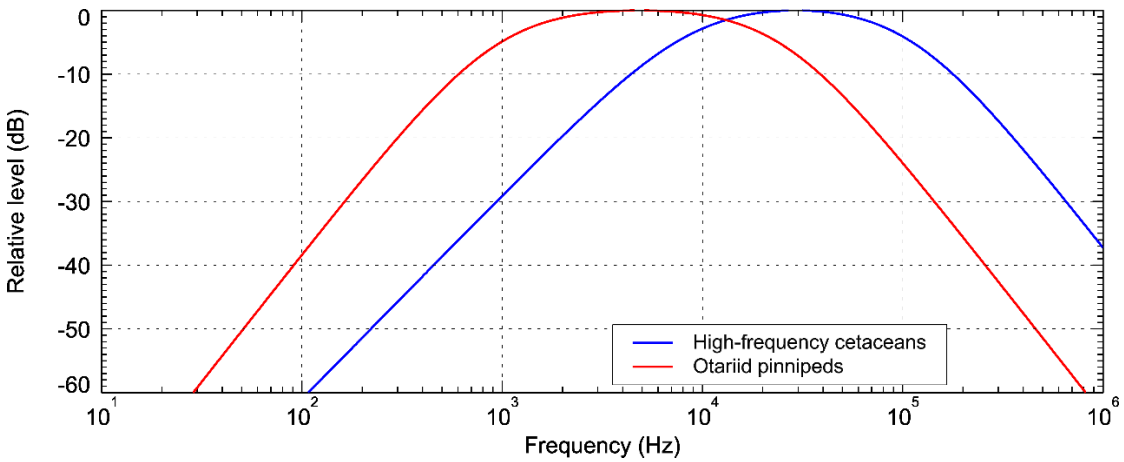


Figure B.3. Auditory weighting functions for functional marine mammal hearing groups used in this project.

Appendix C. Sound Source and Propagation Models

C.1. Pile Driving

C.1.1. Source Properties

For most projects involving pile driving in shallow-water environments, there is potential for direct transmission from the sound source to biological receivers, and there are reflected sound paths from the water's surface and bottom that may be perceived by marine fauna (megafauna and fish), and people. Normally, ground-radiated sound is dominated by low frequencies that cannot propagate efficiently through shallow water. When pile driving is the sound source, there is the potential for substrate-borne sound caused by the hammer's action on the pile to be re-radiated back into the water where it may reach a biological receiver. For pile driving, energy transmission through water depends on the following factors (Christopherson and Lundberg 2013):

1. Direct contact between the pile and the water,
2. The depth of the water column,
3. The size of the pile,
4. The type of hammer,
5. The hammer energy, and
6. The addition of re-radiation of substrate-borne sound.

The way sound propagates in water is affected by obstructions (barges, breakwater walls, other piles, etc.) and the bathymetric characteristics (Buehler et al. 2015). Figure C.1 illustrates these basic propagation concepts.

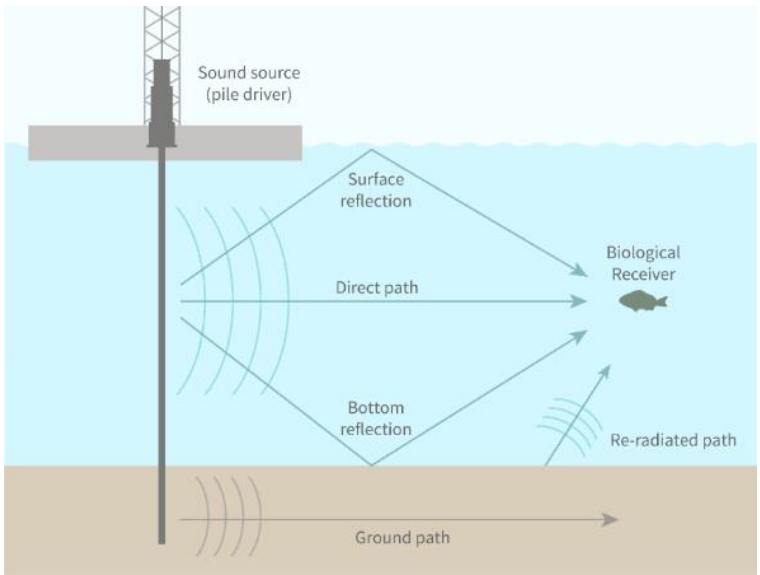


Figure C.1 Underwater sound propagation paths associated with pile driving (Buehler et al. 2015).

C.1.2. Source Model

A physical model of pile vibration and near-field sound radiation is used to calculate source levels of piles. The physical model employed in this study computes the underwater vibration and sound

radiation of a pile by solving the theoretical equations of motion for axial and radial vibrations of a cylindrical shell. These equations of motion are solved subject to boundary conditions, which describe the forcing function of the hammer at the top of the pile and the soil resistance at the base of the pile, as shown in Figure C.2. Damping of the pile vibration due to radiation loading is computed for Mach waves emanating from the pile wall. The equations of motion are discretised using the finite difference (FD) method and are solved on a discrete time and depth mesh.

To model the sound emissions from the piles, the force of the pile driving hammers also had to be modelled. The force at the top of each pile was computed using the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010), which includes a large database of simulated hammers—both impact and vibratory—based on the manufacturer's specifications. The forcing functions from GRLWEAP were used as inputs to the FD model to compute the resulting pile vibrations.

The sound radiating from the pile itself is simulated using a vertical array of discrete point sources. The point sources are centred on the pile axis. Their amplitudes are derived using an inverse technique, such that their collective particle velocity, calculated using a near-field wave-number integration model, matches the particle velocity in the water at the pile wall. The sound field propagating away from the vertical source array is then calculated using a time-domain acoustic propagation model (see Appendix C.3). MacGillivray (2014) describes the theory behind the physical model in more detail.

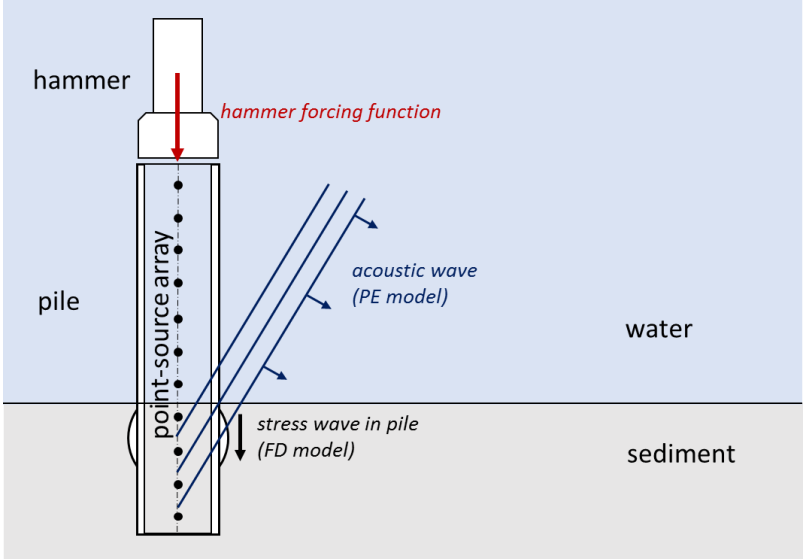


Figure C.2. Physical model geometry for impact driving of a cylindrical pile(vertical cross-section). The hammer forcing function is used with the finite difference (FD) model to compute the stress wave vibration in the pile. A vertical array of point sources is used with the parabolic equation (PE) model to compute the acoustic waves that the pile wall radiates.

C.2. Marine Operations Noise Model

Underwater sound propagation (i.e., transmission loss) at frequencies of 10 Hz to 2 kHz was predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes received per-pulse SEL for directional impulsive sources, and SEL over 1 s for non-impulsive sources, at a specified source depth. Sound propagation at frequencies greater than 2.5 kHz was computed via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994).

MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the US Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996).

MONM accounts for the additional reflection loss at the seabed, which results from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modelled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor. Additionally, BELLHOP accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water (Fisher and Simmons 1977). This type of sound attenuation is important for frequencies higher than 5 kHz and cannot be neglected without noticeably affecting the model results.

MONM computes acoustic fields in three dimensions by modelling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as $N \times$2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ number of planes (see Figure C.3).

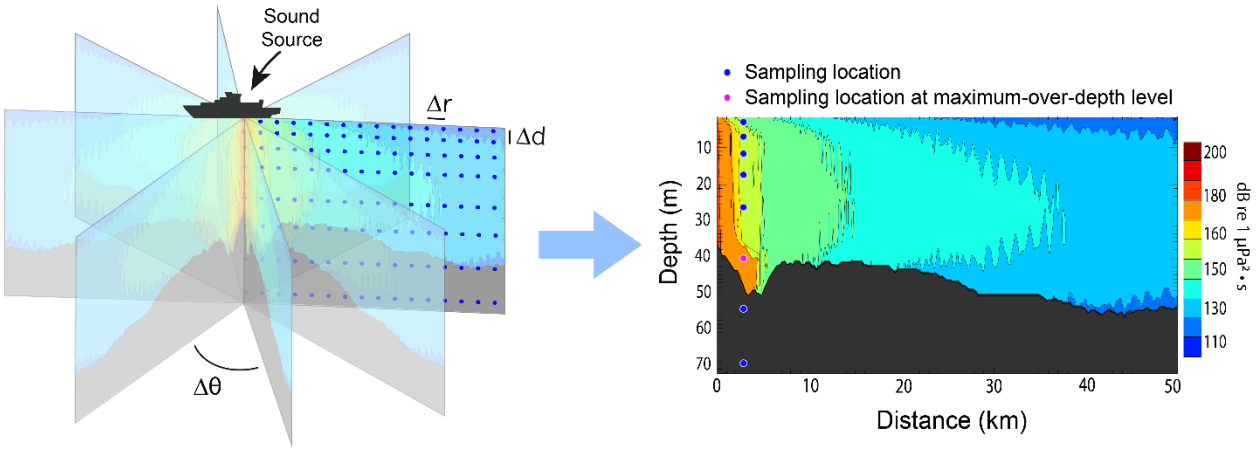


Figure C.3. The $N \times$2-D and maximum-over-depth modelling approach used by MONM.

MONM treats frequency dependence by computing acoustic transmission loss at the centre frequencies of decidecade bands. Sufficiently many decidecade frequency, starting at 10 Hz, are modelled to include most of the acoustic energy emitted by the source. At each centre frequency, the transmission loss is modelled within each of the N vertical planes as a function of depth and range from the source. The decidecade received per-pulse SEL are computed by subtracting the band propagation loss values from the directional source level in that frequency band. Composite broadband received per-pulse SEL are then computed by summing the received decidecade levels.

The received per-pulse SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size (Δr in Figure C.3). At each sampling range along the surface, the sound field is sampled at various depths (Δd in Figure C.3) with the step size between samples increasing with depth below the surface. The step sizes are chosen to provide increased coverage near the depth of the source and at depths of interest for the sound speed profile. For areas with deep water, sampling is not performed at depths beyond those reachable by marine mammals. The received per-pulse SEL at a surface sampling location is taken as the maximum value that occurs over all samples within the water column, i.e., the maximum-over-depth received per-pulse SEL. These maximum-over-depth per-pulse SEL are presented as colour contours around the source.

MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs conducted by JASCO (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b, Martin et al. 2015).

C.3. Full Waveform Range-dependent Model

For impulsive sounds from impact pile driving, time-domain representations of the pressure waves generated in the water are required for calculating SPL and peak pressure level. Furthermore, the pile must be represented as a distributed source to accurately characterise vertical directivity effects in the near-field zone.

FWRAM is a time-domain acoustic model based on the same wide-angle parabolic equation (PE) algorithm as MONM. FWRAM computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments, and it takes the same environmental inputs as MONM (bathymetry, water sound speed profile, and seabed geoacoustic profile). Unlike MONM, FWRAM computes pressure waveforms via Fourier synthesis of the modelled acoustic transfer function in closely spaced frequency bands.

FWRAM employs the array starter method to accurately model sound propagation from a spatially distributed source (MacGillivray and Chapman 2012). Synthetic pressure waveforms are modelled over the frequency range 10 Hz to 1123 Hz inside a one-second time window. An example of these waveforms at increasing distance from the source is shown in Figure C.4. The synthetic pressure waveforms are post-processed, after applying a travel time correction, to calculate standard SPL and SEL metrics versus range and depth from the source.

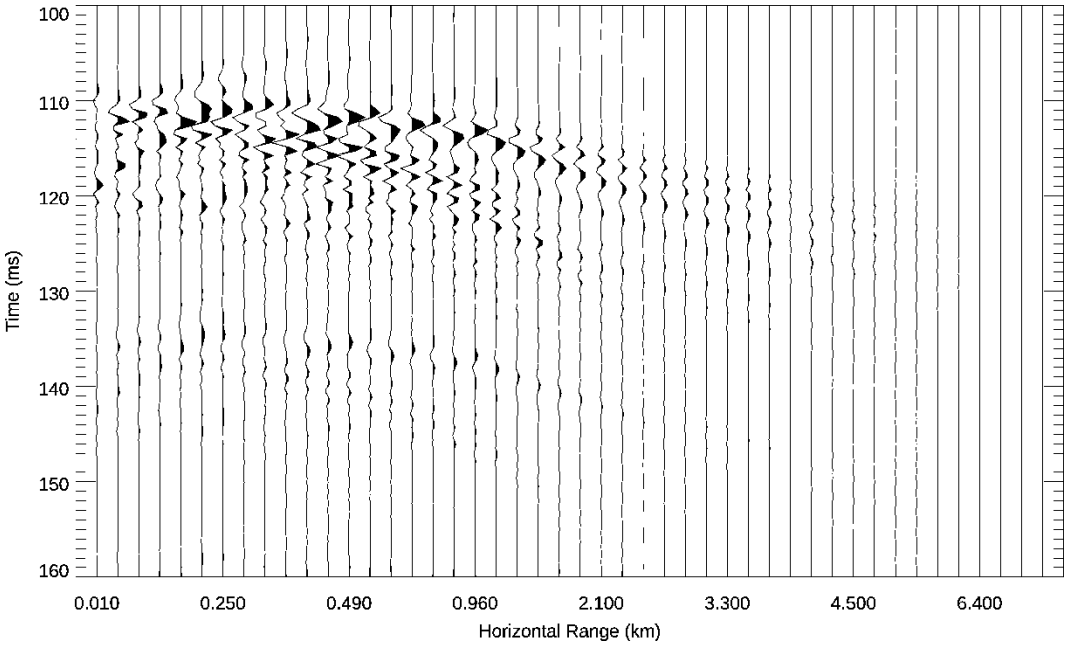


Figure C.4. Example of synthetic pressure waveforms computed for this project by FWRAM at multiple ranges.

Appendix A-3: Underwater Noise Impact Assessment

Viva Energy Gas Terminal Project Environment Effects Statement

JASCO Applied Sciences (Australia) Pty Ltd

26 November 2021

Submitted to:
AECOM
Contract Dated 21 July 2021

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JASCO APPLIED SCIENCES

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

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Executive Summary

This technical report provides an underwater noise impact assessment conducted to support the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the Environment Effects Act 1978 (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic, and transport as well as visual amenity.

In January 2021, the project was also determined to require assessment and approval under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) due to the potential for the project to have a significant impact on wetlands of international importance, listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

Overview

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a gas terminal using a ship known as a floating storage and regasification unit (FSRU), which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas for the south-east Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU), and regasify the LNG as required to meet industrial, commercial, and residential customer demand. A 7 km gas transmission pipeline would transfer the gas from the FSRU to the Victorian Transmission System (VTS) at Lara.

The gas terminal would be located adjacent to, and on, Viva Energy's Geelong Refinery in a heavily industrialised setting and would benefit from Viva Energy's experience and capability as an existing Major Hazard Facility (MHF) operator and potential synergies between the two facilities such as reuse of the FSRU seawater discharge within the refinery operations.

Existing conditions

Underwater acoustic monitoring was conducted in Corio Bay for a period of 37 days (Wilson and McPherson 2021) to characterise the ambient acoustic environment. Data were collected continuously over the frequency band of 10–32000 Hz, and thus captured the majority of anthropogenic contributions to the underwater sound field in the area, along with natural and biological contributors. These data document the baseline underwater sound conditions in Corio Bay and allow examination of temporal variations, and to correlate with external factors that change sound levels such as weather and other human activities.

The most substantial contribution to the soundscape in Corio Bay is from vessel noise occupying frequency bands below approximately 1000 Hz, with many distinct tones related to vessel propulsion observed in the 30-200 Hz range; these signals are present for a significant amount of time per day for the entire monitoring period.

The soundscape also includes a faint dusk and dawn invertebrate chorus, with the primary contributor likely being snapping shrimp.

The monitoring results demonstrate that when compared to long term recordings of other Australian harbours, such as Fremantle Inner Harbour (Salgado Kent et al. 2012), Corio Bay has higher median sound levels, and has a soundscape primarily defined by anthropogenic contributors, with shipping being the dominant factor.

Methodology

The marine fauna that could be exposed to underwater noise from project-related activities in Corio Bay comprises all taxonomic groups, from invertebrates to marine mammals and also includes birds. Several species permanently or potentially occurring in the project area are listed under the EPBC Act or the Flora and Fauna Guarantee Act 1988 (FFG Act), however, the study found that these species would not be significantly impacted as a result of the project. Potential noise-induced effects on marine fauna can range from increased stress, behavioural responses, and acoustic masking to hearing impairment or non-auditory injuries and therefore it is important to understand the predicted underwater noise emissions from the project to determine potential effects. There are substantial differences in sensitivity to underwater sound and ecological relevance of the potential impacts between species groups. The potential impacts are assessed in this report based on the already existing (ambient) noise as well as the modelled noise environment created by the project activities. In general, there is a widespread lack of quantitative information on noise-induced impacts on marine fauna. Where possible, relevant noise exposure criteria are used to determine the exceedance of these criteria by the construction activities and future operation of the FSRU and to quantify the impact ranges for each species group.

Impact of construction activities and future operations

Noise monitoring conducted as part of this study indicates that the existing ambient noise level in the project area is high and adding another noise source such as project related activities including dredging, pile driving and operation of the FSRU, would lead to a localised increase in levels in the vicinity of the project area and for the duration of these activities.

In an unmitigated ‘worst-case’ scenario, the most significant impacts to be expected are temporary behavioural responses over a range of several hundred meters for most species (fish and marine mammals) and for diving birds (when submerged) up to several kilometres from the project area. The impact ranges presented in this assessment indicate the onset of behavioural responses which are likely of little or no ecological relevance at their lowest level of severity and only become more severe and relevant the closer the animals are to the sound source(s). It can be expected that at received levels above the threshold, animals would react by subtly altering their behaviour. At higher received levels, i.e., closer to the sound source, where noise levels are generally higher, it is likely that animals would abandon current behaviour. Ultimately, at the highest received levels animals would avoid the area for the duration of the sound-producing activity. The potential avoidance zones are comparatively small relative to the overall habitat of the marine mammals, birds and fishes and being excluded from these areas is not likely to have any ecologically significant consequences for the animals. It is likely that the animals would gradually return into the area after the noise emissions have ceased or abated.

Pile driving during construction represents the most significant anthropogenic change to the existing soundscape in Corio Bay due to the impulsiveness of the signals, as compared to the ambient noise which is dominated by continuous noise. Dolphins and fur seals are expected to respond behaviourally to pile driving noise over a range of up to 800 m and diving birds (when submerged) over more than five kilometres for the duration of the activity. Pile driving noise is expected to exceed the noise exposure thresholds for recoverable injury for fishes at a distance of up to 60 m and the threshold for onset of Temporary Threshold Shift (TTS) at a distance of up to 870 m from the sound source. While temporary behavioural responses for most fish species are likely in the range of 10–100 m, there is a moderate likelihood that Australian anchovy, the only fish species in the project area with high sensitivity to underwater sound, would show responses at ranges exceeding 1 km.

Dredging, and vessel movement, during construction generates continuous sounds similar in their acoustic characteristics to the already existing ambient sound field. The noise generated by these activities is likely to temporarily exceed the onset threshold for behavioural responses of dolphins and fur seals at ranges of up to 1.84 km. There is a moderate likelihood that fish species in the project area would be temporarily exposed to noise levels generated by these activities exceeding their threshold for onset of behavioural responses at ranges up to 100 m.

Operating the FSRU would also generate continuous sound similar in its acoustic characteristic to the existing ambient soundscape. The noise generated by this activity is likely to exceed the onset threshold for behavioural responses of dolphins and fur seals at ranges within 1.1 km. There is a moderate likelihood that fish species in the project area would be temporarily exposed to noise levels generated by these activities exceeding their threshold for onset of behavioural responses at ranges up to 100 m.

More severe effects are not likely to occur. Stress and acoustic masking, while not quantifiable per se, can be assumed to occur at the same ranges as (ecologically relevant) behavioural responses. Applying recommended mitigation measures has the potential to avoid, minimise and manage potential impacts related to underwater noise and this is discussed below.

Residual impacts

Applying mitigation measures has the potential of reducing the noise levels emitted by the construction activities and future operation and lead to reducing the severity and range of the noise-induced impacts. The level of noise reduction is specific to each measure but not every measure can or should be applied to every activity; rather a differentiated approach is necessary, accounting for the proportionality principle. The potential noise-induced impacts for marine fauna arising from the planned project activities are not considered severe. However, a well-designed mitigation concept, such as reducing noise at the source, deterring animals from the construction area and noise awareness training, would reduce or even eliminate the risk of behavioural responses with the exception of the immediate vicinity of the activities. Due to the high existing acoustic conditions in the area, it is very likely that the animals are already accustomed (habituated) to living in a noisy environment and those individuals more sensitive to noise have long left the area.

The most efficient methods to mitigate the noise exposure for marine mammals and diving birds is implementing and enforcing a safety zone around sound sources and constant visual monitoring of the surrounding area during noise-critical activities. Moreover, a soft start of the pile driving activities and the spatially and temporally limited use of acoustic deterrent devices prior to commencing the pile driving would reduce the likelihood of strong behavioural responses of listed species such as dolphins or penguins.

With a reasonable (proportional) set of mitigation measures implemented, the underwater noise emissions generated by the construction and operation of the FSRU are not expected to have unacceptable impacts on the marine fauna in Corio Bay.

Decommissioning

It is anticipated that the FSRU would leave Corio Bay after the end of the project and that the infrastructure would be retained. While decommissioning activities may be subject to change and subject to legislative requirements at the time, it is assumed that no additional underwater noise would be emitted during the decommissioning phase and underwater noise would return to levels similar to those measured prior to its construction once the decommissioning phase is completed.

Population level effects

There is no information available about abundance or densities of marine organisms in the project area as compared to Port Phillip Bay which makes it difficult to assess the potential population effects. Based on the relatively small acoustic and impact footprint of the activities it is justifiable to assume that, especially in a mitigated scenario, the ecological effects would be restricted to individuals and would not affect populations negatively.

1. Introduction

This technical report provides an underwater noise impact assessment conducted to support the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a gas terminal using a ship known as a floating storage and regasification unit (FSRU), which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas for the south-east Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU) and would convert LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification) as required to meet industrial, commercial, and residential customer demand. A 7 km gas transmission pipeline would transfer the gas from the FSRU to the Victorian Transmission System (VTS) at Lara.

The project would be situated adjacent to, and on, Viva Energy's Geelong Refinery, within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. Co-locating the project with the existing Geelong Refinery and within the Port of Geelong offers significant opportunity to minimise potential environmental effects and utilise several attributes that come with the port and industrial setting.

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the *Environment Effects Act 1978* (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic, and transport as well as visual amenity.

In January 2021, the project was also determined to require assessment and approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) due to the potential for the project to have a significant impact on wetlands of international importance, listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

1.1. Purpose

This underwater noise impact assessment identifies, assesses, and characterises potential environmental impacts on underwater noise associated with the construction, operation, and eventual decommissioning of the project to inform the preparation of the EES required for the project.
The report identifies and recommends mitigation measures to avoid, minimise and manage potential impacts which will inform the development of an Environmental Management Framework (EMF) for the project. The mitigation measures listed in the EMF would be implemented in the approvals and management plans for the project.

1.2. Why Understanding Underwater Noise is Important

Underwater noise has the potential to affect a wide range of marine fauna receptors. Potential noise-induced effects on marine fauna can range from increased stress, behavioural responses, and acoustic masking to hearing impairment or non-auditory injuries and therefore it is important to understand the predicted underwater noise emissions from the project to determine potential effects

Marine fauna uses sound for important life functions such as communication, locating prey and navigation. The hearing systems of some taxa such as cetaceans and pinnipeds are highly adapted and sensitive to perceiving underwater sound but also very susceptible to noise-induced impacts.

While increased airborne noise from existing shore based or nearshore boating activities (not related to the project) has already been identified as risk to waterbirds in the Ramsar site (DELWP 2020), underwater noise has not been considered so far for any marine fauna species. The potential for underwater noise to impact an animal (the 'receiver') depends on the occurrence of the receiver in the project area, the temporal and spectral characteristics of the emitted sound, the distance and sound propagation environment between the source and the receiver, and the sensitivity of the receiver to sound.

An introduction to the specific terminology used in describing underwater sound (underwater 'noise' being the unwanted part of underwater 'sound') is provided in Section 4.2 and Supplement A information. This provides important background information for non-experts to understand the technical terms and specific considerations related to measuring and assessing underwater noise and its impacts. Moreover, a definition of many acoustic terms can be found in the Glossary and the acoustic metrics are explained in greater detail in Section 3.2.1.

1.3. Project Area

The project would be located at, and adjacent to, the Geelong Refinery and Refinery Pier in the City of Greater Geelong, 75 kilometres (km) south-west of Melbourne. The project area is within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. The Geelong central business district is located approximately 7 km south of the project.

Corio Bay is the largest bay in the south-west corner of Port Phillip Bay and is a sheltered, shallow basin at the western end of the Geelong Arm, with an area of 44 square kilometres (km^2). The Point Wilson/Limeburners Bay section of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site is located along the northern shoreline of Corio Bay, approximately one kilometre to the north-east of the project.

The Port of Geelong has been in operation for over 150 years and is the largest industrial bulk cargo port in Victoria, attracting over 600 ship visits and handling more than 14 million tonnes of product annually. Geelong's shipping channels extend 18 nautical miles through Corio Bay from Point Richards through to Refinery Pier. Ports Victoria (formerly the Victoria Regional Channels Authority (VRCA)) manages commercial navigation in the port waters in and around Geelong and is responsible for the safe and efficient movement of shipping, and for maintaining shipping channels and navigation aids. The channels are man-made having been deepened and widened through periodic dredging to support port trade development.

Refinery Pier is the primary location within the Port of Geelong for movement of bulk liquids. Vessels up to 265 metres in length currently utilise the four berths at Refinery Pier which service Viva Energy refinery operations. Most ship visits to the port are to Refinery Pier, with Viva Energy accounting for over half of the trade through the Port of Geelong.

The Geelong Refinery has been operating since 1954 with both the refinery and the co-located Lyondell Bassell plant being licensed Major Hazard Facilities (MHFs). A range of industrial activities are situated in the Port environs including wood fibre processing and chemical, fertiliser and cement manufacturing.

To the north of the Geelong Refinery, along the proposed underground pipeline corridor, the area is predominantly rural. There are several other existing Viva Energy-owned underground pipelines running between the refinery and the connection point to the South West Pipeline (SWP) at Lara. The proposed pipeline route follows already disturbed pipeline corridors, where possible, through a mix of land uses.

The project area is shown in Figure 1.

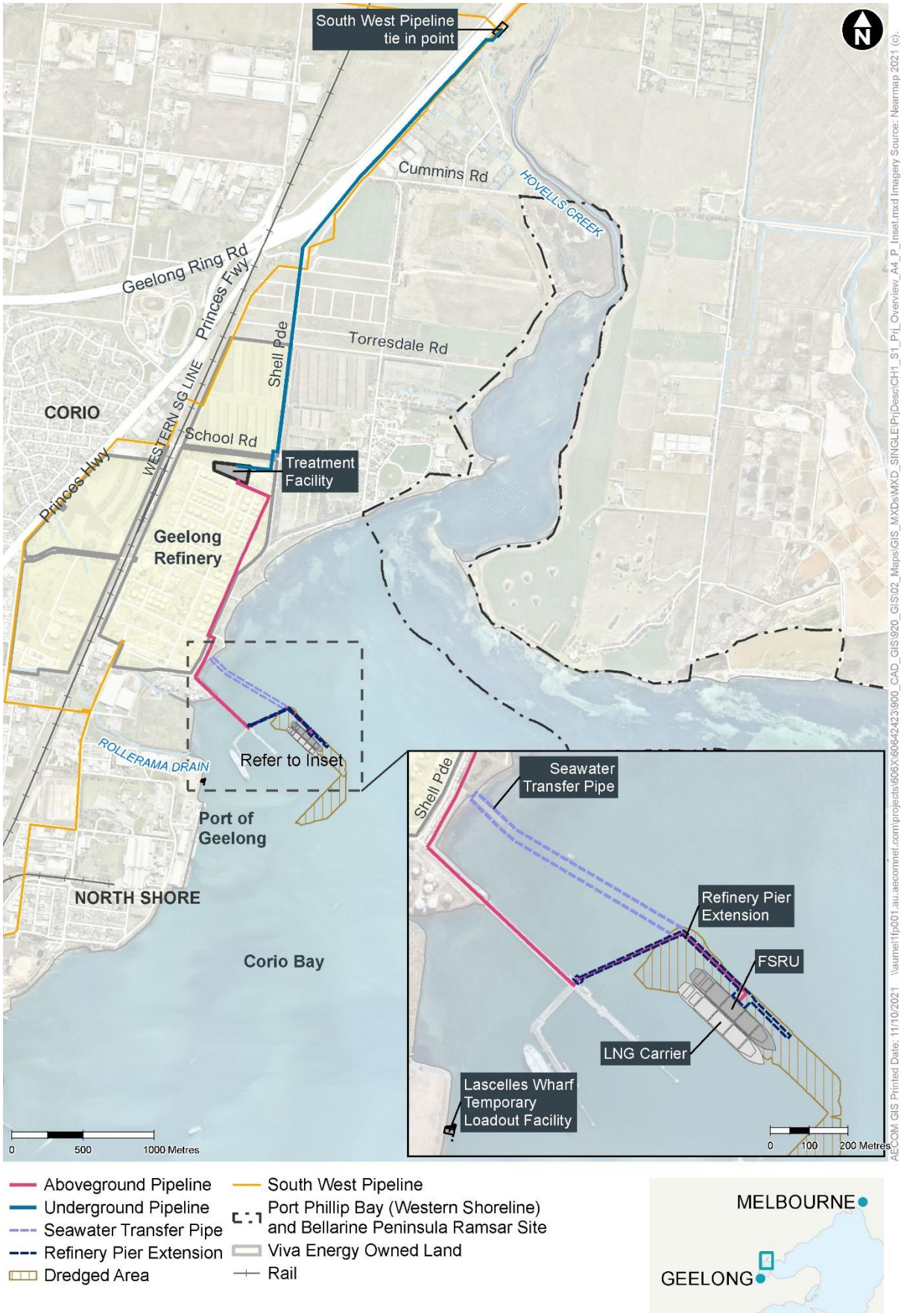


Figure 1. Project overview.

1.4. Project Description

This section summarises the project as described in Chapter 4 *Project description*. Key components of the project include:

- Extension of the existing Refinery Pier with an approximately 570 metre (m) long angled pier arm, new berth and ancillary pier infrastructure including high pressure gas marine loading arms (MLAs) and transfer lines connecting the seawater discharge points on the FSRU to the refinery seawater intake
- Continuous mooring of an FSRU at the new Refinery Pier berth to store and convert LNG into natural gas. LNG carriers would moor alongside the FSRU and unload the LNG
- Construction and operation of approximately 3 km of aboveground gas pipeline on the pier and within the refinery site connecting the FSRU to the new treatment facility
- Construction and operation of a treatment facility on refinery premises including injection of nitrogen and odorant (if required)
- Construction and operation of an underground gas transmission pipeline, approximately 4 km in length, connecting to the SWP at Lara.

The Refinery Pier extension would be located to the north-east of Refinery Pier No. 1. The new pier arm would be positioned to allow for sufficient clearance between an LNG carrier berthed alongside the FSRU and a vessel berthed at the existing Refinery Pier berth No. 1. Dredging of approximately 490,000 cubic metres of seabed sediment would be required to allow for the new berth pocket and swing basin.

The FSRU vessel would be up to 300 m in length and 50 m in breadth, with the capacity to store approximately 170,000 cubic metres (m^3) of LNG. The FSRU would receive LNG from visiting LNG carriers and store it onboard in cryogenic storage tanks at about -160 °C.

The FSRU would receive up to 140 PJ per annum (approximately 45 LNG carriers) depending on demand. The number of LNG carriers would also depend on their storage capacity, which could vary from 140,000 to 170,000 m^3.

When gas is needed, the FSRU would convert the LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification). The natural gas would then be transferred through the aboveground pipeline from the FSRU to the treatment facility where odorant and nitrogen would be added, where required, to meet Victorian Transmission System (VTS) gas quality specifications. Nitrogen injection would occur when any given gas cargo needs to be adjusted (diluted) to meet local specifications. Odorant is added as a safety requirement so that the normally odourless gas can be smelt when in use. From the treatment facility, the underground section of the pipeline would transfer the natural gas to the tie-in point to the SWP at Lara.

1.4.1. Key Construction Activities

Construction of the project would occur over a period of 18 to 24 months. The key construction activities relate to:

- Localised dredging of seabed sediments to enable the FSRU and LNG carriers to berth at Refinery Pier and excavation of a shallow trench for the seawater transfer pipe.
- Construction of the new pier arm and berthing infrastructure, and aboveground pipeline along Refinery Pier and through the refinery.
- Construction of the treatment facility on a laydown area at the northern boundary of the refinery site.

- Construction of the buried pipeline.
- Construction at the tie-in point to the SWP at Lara.

There are no construction activities required for the FSRU component of the project. The vessel would be built, commissioned and all production and safety systems verified prior to being brought to site.

An estimated 490,000 cubic metres (m^3) of dredging would be required over an area of approximately 12 hectares (ha) adjacent to the existing shipping channel to provide sufficient water depth at the new berth and within the swing basin for visiting LNG carriers to turn. Dredging within the new berth would be undertaken to a depth of 13.1 metres and the swing basin would be dredged to a depth of 12.7 metres. The dredging footprint is shown in Figure 1. It is planned to deposit the dredged material within Ports Victoria's existing dredged material ground (DMG) in Port Phillip Bay to the east of Point Wilson, approximately 26 km from Refinery Pier.

Construction of the pier arm would be carried out once dredging was complete, primarily from the water using barge-mounted cranes. Steel piles would be driven into the seabed by cranes mounted on floating barges and pre-cast concrete and prefabricated steel components would be transported to site by barge and lifted into position. The installation of pier infrastructure such as the marine loading arms (MLAs), piping from the FSRU to the existing refinery seawater intake (SWI) and aboveground pipeline would also be undertaken from the water using barge-mounted cranes and construction support boats.

Installation of the 3 km above ground pipeline along the pier and through the refinery is anticipated to take 3.5 months to complete. The above ground pipeline would run along the pier to the existing pipe track east of Shell Parade within the pier foreshore compound. It would then pass through a road under-crossing to the existing refinery pipe track. The pipeline would then run north along the existing refinery pipe track to an existing laydown area where the treatment facility would be located.

The treatment facility would be located within an existing laydown area in the refinery site and cover an area of approximately 80m x 120m. Construction of the treatment facility would take approximately 6 months and would be undertaken by specialist crews across distinct phases of work. These would include initial earthworks and civil construction, mechanical installation and electrical and instrumentation works.

The 4 km underground pipeline would be installed in stages over an approximate four-month period within a corridor which has been selected to avoid the need for trenchless construction beneath watercourses or other environmental sensitivities. Firstly, a construction right of way (ROW) would be established, clearly identified, and fenced off where required. Typically, this would be between 15 and 20m wide, and minimised where possible to reduce disturbance. Once the construction ROW is established, vegetation would be removed, and a trench excavated to a maximum depth of 2m and a maximum width of 1m for the pipeline to be placed. Following the placement of the pipeline, the construction ROW would be rehabilitated to its pre-existing condition as far as practicable.

Trenchless construction (including thrust boring or horizontal directional drilling (HDD)) would be used to install the underground pipeline in areas that are not suited to open trenching techniques, such as at intersections with major roads. Trenchless construction would involve boring or drilling a hole beneath the ground surface at a shallow angle and then pushing or pulling a welded length of pipe through the hole without disturbing the surface. It is anticipated that the maximum depth of the trenchless section would be 25 m.

Construction at the tie-in point to the SWP at Lara would be undertaken by specialist crews across the distinct phases of works, as with the treatment facility.

1.4.2. Key Operation Activities

The project is expected to be in operation for 20 years. Key activities relating to project operation include:

- Receipt of up to 45 LNG carriers each year at Refinery Pier – the number and frequency of LNG carriers arriving each year would depend on their storage capacity and gas demand.
- Regasification of LNG onboard the FSRU using seawater as a heat source, which would then be reused within the refinery as cooling water.
- Injection of nitrogen and odorant into the gas prior to distribution via the VTS.
- Monitoring and maintenance of the pipeline easement.

1.4.3. Key Decommissioning Activities

The FSRU, which continues to be an ocean-going vessel throughout the operation of the project, would leave Corio Bay on completion of the project life to be used elsewhere.

It is anticipated that the Refinery Pier berth and facilities would be retained for other port related uses. The underground pipeline would likely remain in situ subject to landholder agreements and either decommissioned completely or placed into care and maintenance arrangements.

Decommissioning activities may be subject to change, subject to legislative requirements at the time and potential repurposing of the infrastructure at the end of the project.

1.4.4. Project Activities Relevant to the Assessment

The following construction and operational activities are relevant to the underwater noise impact assessment:

- localised dredging of seabed sediments to enable the FSRU and LNG carriers to berth at Refinery Pier and excavation of seabed sediments for installation of the seawater transfer pipe
- construction of a temporary loadout facility at Lascelles Wharf to enable construction overwater to occur and construction of the new pier arm and berthing infrastructure

The operation activities relevant to the underwater noise impact assessment relate to the continuous mooring of the FSRU and receipt of up to 45 LNG carriers each year at the pier.

The decommissioning activities relevant to the underwater noise impact assessment include the departure (i.e., removal) of the FSRU.

2. Scoping Requirements

The scoping requirements for the EES set out the specific environmental matters to be investigated in the EES. The scoping requirements include a set of draft evaluation objectives. These objectives identify the desired outcomes to be achieved in managing the potential impacts of constructing and operating the project.

The following evaluation objective is relevant to the underwater noise impact assessment:

- **Water and catchment values** – To minimise adverse effects on water (in particular wetland, estuarine, intertidal, and marine) quality and movement, and to the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.

The scoping requirements of relevance to this underwater noise impact assessment and where they are addressed in the report are shown in Table 1.

Table 1. Scoping requirements relevant to underwater noise.

Aspect	Scoping requirement	Section addressed
Key issues	Noise-induced effects on marine fauna and birds	3.2
Existing environment	Industrial and recreational activities in the project area producing an already disturbed soundscape	5
Likely effects	Adverse effects on relevant behaviours, life functions and health or marine fauna and exclusion from important habitats	6 and 7
Mitigation measures	Various noise abatement measures that can be implemented to reduce or avoid underwater noise and mitigate its effects	9
Performance objectives	Reduction of underwater noise generated by the project activities to acceptable levels	**Error! Reference source not found.**

3. Legislation, Policy, and Guidelines

3.1. Key Environmental Legislation

Table 2 summarises the key environmental legislation and policy that apply to the project in the context of this underwater noise impact assessment, as well as the implications for the project and the required approvals (if any). Additional guidelines and technical criteria relevant to underwater noise are described in Section 3.2.

Table 2. Primary environmental legislation and associated information

Legislation/policy	Description	Implications for the project	Approval required
Commonwealth			
Legislation			
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	The EPBC Act identifies Matters of National Environmental Significance (MNES) that need to be protected.	EES process conducted to assess potential impacts on MNES listed under EPBC Act	Decision by Commonwealth Minister or delegate
Victoria			
Legislation			
Victorian Fauna and Flora Guarantee Act 1988 / Flora and Fauna Guarantee Amendment Act 2019	This Act identifies threatened species and communities and processes that require management to minimise threats to those species and communities.	EES process conducted to assess potential impacts	
Policy			
Department of Environment, Land, Water and Planning 2018 Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan	Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site is a wetland of international importance and is identified as a MNES under the EPBC Act. The site management plan identifies priority threats to be addressed.	EES process conducted to assess potential impacts	

3.2. Noise Impacts and Exposure Thresholds

The most extensive research on the effects of noise has been conducted on humans where noise has been shown to have cardiovascular, endocrinological, neurological and auditory effects (Basner et al. 2014). Among marine fauna, marine mammals have received most scientific attention regarding potential auditory effects of underwater noise, while studies on other noise effects (stress, acoustic masking) and for marine taxa or birds are scarce. In general, underwater noise can impact marine fauna in six principal ways:

- Inducing stress, which can be acute or chronic and affect health and behaviour.
- Masking or interfering with other biologically important sounds (including vocal communication, echolocation, signals, and sounds produced by predators or prey).
- Causing disturbance that leads to behavioural changes or displacement of fauna. The occurrence and intensity of disturbance is highly variable and depends on a range of factors relating to the animal and situation.

- Causing injury to hearing or other organs. Hearing loss may manifest as temporary threshold shift (TTS) or permanent threshold shift (PTS).
- Causing mortality and mortal injury, that is, immediate or delayed death either due to injury or substantially reduced fitness.
- Causing cumulative or chronic effects, whereby repeated or long-term exposure to noise leads to additive severity of noise-induced impacts.

The disparity that exists in empirical information on noise-induced effects for different taxa and in the understanding of different source-effect relationships is also reflected in the availability and level of detail provided in regulatory guidance on exposure of marine fauna to underwater noise.
Ideally, noise exposure criteria should consider the auditory susceptibility of the receiving animals to different types of noise in terms of physiological, behavioural, and physical impacts. Detailed noise exposure criteria, including thresholds and frequency weighting functions, aimed at reducing the risk of hearing impairment have been promulgated for marine mammals and, to some extent, for fishes. None exist for marine invertebrates or birds.

3.2.1. Acoustic Metrics

The publication of ISO 18405 Underwater Acoustics – Terminology (ISO 2017) provides a dictionary of underwater bioacoustics terms that builds and expands on previous standards (IEC 1994, ANSI/ASA S1.1-2013).The present document follows the definitions and conventions of ISO (2017), unless directly referring to definitions of metrics used in published literature.

The US National Marine Fisheries Service (NMFS) issued a Technical Guidance document providing regulatory criteria for noise exposure of marine mammals (NMFS 2018). The Technical Guidance uses a slightly different notation for the acoustic metrics (Table 3) with a dual criterion for assessing injurious exposures, including a peak (unweighted/flat) sound pressure level metric PK (L_{pk}) and a cumulative sound exposure level SEL_{cum} metric with frequency weighting. The acoustic metric terminology used in Southall et al. (2019) is equivalent to this guidance. Following the ISO standard, the L_{pk} as used by NMFS and Southall et al. (2019) is denoted as PK in impact assessment. The SEL_{cum} metric as used by NMFS and Southall et al. (2019) describes the sound energy received by a receptor over 24 h. Following the ISO (2017) standard, this is denoted as SEL_{24h} in this impact assessment.

Table 3. Acoustic metrics used in this impact assessment as compared to other publications.

Metric	NMFS (2018) and Southall et al. (2019)	Impact assessment (as per ISO 2017)		Unit
		Abbreviation in main text	Symbol in equations/tables	
Sound pressure level	Not applicable	SPL	L_p	decibel (dB) re 1 micropascal (µPa)
Peak sound pressure level	PK	PK	L_{pk}	dB re 1 µPa
Sound exposure level (per pulse)	Not applicable	Per-pulse SEL	L_E	dB re 1 $\mu Pa^2 \cdot s$
Sound exposure level (accumulated over time), SEL time-period	SELcum	SEL24h	$L_{E,24h}$	dB re 1 $\mu Pa^2 \cdot s$
Source level	SL	SL	$L_{S,pk}$ $L_{S,p}$ $L_{S,E}$	dB re 1 µPa·m (peak source pressure level, SPL source level) or dB 1 $\mu Pa^2 m^2 s$ (per-pulse source SEL)

3.2.2. Marine Mammals

Stress and Acoustic Masking

To date, there are no exposure criteria for the onset of stress or acoustic masking in marine mammals. Due to the limited information about acoustically induced stress responses in marine fauna, a precautionary approach would be to assume that any physical effect (e.g., hearing loss, hearing impairment) or significant behavioural response is also associated with a stress response.

Behavioural responses

Because of the complexity and variability of marine mammal behavioural responses to acoustic exposure, few countries have developed and implemented thresholds for the noise-induced onset of behavioural reactions. The Australian regulation of underwater noise exposure to marine fauna is non-prescriptive and, accordingly, no behavioural thresholds are promulgated. Instead, the current US National Marine Fisheries Service (NMFS) noise criteria for impulsive and non-impulsive sounds (NOAA 2019) were selected for this assessment because they represent the most commonly applied behavioural response criteria by regulators for impulsive sound sources (such as impact pile driving) and non-impulsive sound sources (such as vessels). The distances at which behavioural responses could occur were therefore determined from the areas ensonified above an unweighted SPL of 120 dB re 1 µPa for non-impulsive sounds and 160 dB re 1 µPa for impulsive sounds (NOAA 2019).

These behavioural criteria, however, are conservative estimates. Moreover, they vary between functional hearing groups and species due to differences in hearing sensitivity and they will vary with the behavioural context (see details in Section 4.4.2).

There are data for marine mammals that indicate the received sound levels at which TTS occurs, so the onset of PTS is extrapolated from the TTS onset level and an assumed growth function (Southall et al. 2007, NMFS 2018, Southall et al. 2019). US NMFS issued a Technical Guidance document that provides acoustic thresholds for the onset of TTS and PTS in marine mammal hearings for all sound sources (NMFS 2018). NMFS also provided guidance on the use of weighting functions when applying hearing impairment criteria (see Section 3.2). The NMFS Guidance recommends applying a dual criterion for assessing injurious exposures, including an unweighted (flat) peak sound pressure level metric peak sound pressure (PK; L_{pk}) levels and a sound exposure level SELcum ($L_{E,24h}$) metric with frequency weighting. Both acoustic criteria and weighting function application are different for the marine mammal functional hearing groups and types of noise. Southall et al. (2019) published an updated set of criteria for onset of TTS and PTS in marine mammals. While the proposed thresholds and weighting functions for exposure to underwater sound do not differ in effect from those promulgated by NMFS (2018), the authors propose a new nomenclature and classification for the marine mammal functional hearing groups[1] based on the most recent information about hearing sensitivity in marine mammal species. As this represents the most up-to-date information, this impact assessment follows the criteria and nomenclature proposed by Southall et al. (2019). These criteria incorporate also the best available science to estimate PTS onset in marine mammals from either sound energy accumulated over 24 h (SEL), or very loud, instantaneous PK levels. These dual threshold criteria of SEL and PK are used to calculate marine mammal exposures (Table 4).

[1] The new nomenclature for functional marine mammals hearing groups proposed by Southall et al. (2019) has not yet been adopted by NMFS.

Table 4. Summary of relevant permanent threshold shift (PTS) and temporary threshold shift (TTS) onset acoustic thresholds (Southall et al. 2019).

Hearing group	PTS onset thresholds[1] (received level)		TTS onset thresholds[1] (received level)	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
Low-frequency (LF) cetaceans	$L_{pk,\,flat}$: 219 dB $L_{E,\,LF,\,24h}$: 183 dB	$L_{E,\,LF,\,24h}$: 199 dB	L_{pk}: 213 dB $L_{E,\,LF}$: 168 dB	$L_{E,\,LF}$: 179 dB
High-frequency (HF) cetaceans	$L_{pk,\,flat}$: 230 dB $L_{E,\,HF}$, 24h: 185 dB	$L_{E,\,HF,\,24h}$: 198 dB	L_{pk}: 224 dB L_{E}, HF: 170 dB	$L_{E,\,HF}$: 178 dB
Very High-frequency (VHF) cetaceans	$L_{pk,\,flat}$: 202 dB $L_{E,\,VHF,\,24h}$: 155 dB	$L_{E,\,VHF,\,24h}$: 173 dB	L_{pk}: 196 dB $L_{E,\,VHF}$: 140 dB	$L_{E,\,VHF}$: 153 dB
Phocid Marine Carnivores (water) (PCW)	$L_{pk,\,flat}$: 218 dB $L_{E,PCW,\,24h}$: 185 dB	$L_{E,\,PCW,\,24h}$: 201 dB	L_{pk}: 212 dB $L_{E,\,PCW}$: 170 dB	$L_{E,\,PCW}$: 181 dB
Other Marine Carnivores (water) (OCW)	$L_{pk,\,flat}$: 232 dB $L_{E,\,OCW,\,24h}$: 203 dB	$L_{E,\,OCW,\,24h}$: 219 dB	L_{pk}: 226 dB $L_{E,\,OCW}$: 188 dB	$L_{E,\,OCW}$: 199 dB

[1] Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.

L_{pk}, flat denotes peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa.

L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^2·s. The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting.

3.2.3. Fishes

The US Working Group on the Effects of Sound on Fish and Turtles developed guidelines with specific thresholds for different levels of effects for several species groups (Popper et al. 2014). The guidelines define quantitative thresholds for three types of immediate effects:

- Mortality, including injury leading to death;
- Recoverable injury, including injuries unlikely to result in mortality, such as auditory hair cell damage and minor haematoma; and
- Temporary threshold shift (TTS).

Tables 5 and 6 lists the relevant effects thresholds from Popper et al. (2014) for pile driving and vessel noise. Some evidence suggests that fish species sensitive to acoustic pressure show a recoverable loss in hearing sensitivity or injury when exposed to high levels of noise (Scholik and Yan 2002, Amoser and Ladich 2003, Smith et al. 2006). This is reflected in the SPL thresholds for fishes with a swim bladder involved in hearing.

The noise impact criteria for marine mammals (Section 3.2.2) and the criteria proposed by Popper et al. (2014) are, in fact, the only sets of criteria regulating the potential of underwater noise to cause hearing impairment (TTS or PTS) for any marine faunal group.

Table 5. Noise exposure criteria for pile driving noise exposure for fishes, fish eggs and larvae, adapted from Popper et al. (2014).

Category and type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
I. Fish: No swim bladder[1] (particle motion detection)	> 219 dB SEL_{24h} or > 213 dB PK	> 216 dB SEL_{24h} or > 213 dB PK	>> 186 dB SEL_{24h}	Pile driving: (N) Moderate (I, F) Low	(N) High (I) Moderate (F) Low
II. Fish: Swim bladder not involved in hearing (particle motion detection)	210 dB SEL_{24h} or > 207 dB PK	203 dB SEL_{24h} or > 207 dB PK	>> 186 dB SEL_{24h}	Pile driving: (N) Moderate (I, F) Low	(N) High (I) Moderate (F) Low
III. Fish: Swim bladder involved in hearing[2] (primarily pressure detection)	207 dB SEL_{24h} or > 207 dB PK	203 dB SEL_{24h} or > 207 dB PK	186 dB SEL_{24h}	Pile driving: (N, I) High (F) Moderate	(N, I) High (F) Moderate
Fish eggs and fish larvae	> 210 dB SEL_{24h} or > 207 dB PK	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	Pile driving: (N) Moderate (I, F) Low	(N) Moderate (I, F) Low

SPL, Sound pressure level dB re 1 µPa.
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). The near, intermediate, and far relative distances may be considered respectively as, tens of meters, hundreds of meters, and thousands of meters away from the source.
[1] The swim bladder is missing in some bottom-dwelling and deep-sea bony fishes (teleosts) and in all cartilaginous fishes (sharks, skates, and rays).
[2] The group includes some of the squirrelfish (Holocentridae), drums and croakers (Sciaenidae), herrings (Clupeidae), and the large group of Otophysan fishes (a non-taxonomic) group consisting of four distinct orders: Cypriniformes (minnows), Characiformes (characins), Siluriformes (catfish) and Gymnotiformes (knifefish).

Table 6. Noise exposure criteria for vessel noise exposure for fishes, fish eggs and larvae, adapted from Popper et al. (2014).

Category and type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
I. Fish: No swim bladder[1] (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
II. 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) Moderate (I) Moderate (F) Low
III. Fish: Swim bladder involved in hearing[2] (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB SPL for 48 h	158 dB SPL for 12 h	(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, Sound pressure level dB re 1 µPa.
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). The near, intermediate, and far relative distances may be considered respectively as, tens of meters, hundreds of meters, and thousands of meters away from the source.
[1] The swim bladder is missing in some bottom-dwelling and deep-sea bony fishes (teleosts) and in all cartilaginous fishes (sharks, skates, and rays).
[2] Group includes some of the squirrelfish (Holocentridae), drums and croakers (Sciaenidae), herrings (Clupeidae), and the large group of Otophysan fishes (a non-taxonomic) group consisting of four distinct orders: Cypriniformes (minnows), Characiformes (characins), Siluriformes (catfish) and Gymnotiformes (knifefish).

3.2.4. Invertebrates

There is no regulatory guidance with respect to setting criteria for particle motion impact. Few particle motion measurements have been collected in conditions typically encountered in monitoring situations. This is due in part to limitations in the available instrumentation and a general lack of experience in recording this quantity.

3.2.5. Avifauna

There are no regulatory thresholds or criteria established in Australia or anywhere else in the world to assess potential behavioural responses by diving birds (penguins, flying seabirds, swans) to underwater noise. While the main bird species of concern in the EES are migratory waders and other waterbirds, particularly in the Ramsar wetland which is approximately 1.3 km from the FSRU and construction activity, these species are not expected to be impacted by underwater noise. Noise impacts can only occur if an animal's body is fully submerged in the water or, if at least partially immersed in the water, impacts are only possible if the body parts contain pressure sensitive organs such as ears or lungs; the waders' beaks or legs which are immersed in the water are not known to be sensitive to underwater sound. Moreover, sound propagation is substantially reduced in shallow water and near the surface and sound generated by the FSRU and construction activities is not expected to be transmitted into near-shore very shallow areas at relevant levels; accordingly, the focus in the study being on diving birds.

In a controlled exposure experiment, Sørensen et al. (2020) exposed gentoo penguins (*Pygoscelis papua*) to underwater noise bursts (impulsive signals), and the animals showed a graded reaction depending on received sound levels. The researchers conducted this study on captive animals, and results may not be a true representation of the behavioural responses in free-ranging animals. Pichegru et al. (2017) investigated the behavioural response of African penguins (*Spheniscus demersus*) to seismic surveys within 100 km of their colony in South Africa. Penguins showed a strong avoidance of their preferred foraging areas during seismic activities; foraging took place significantly farther from the survey vessel when in operation, increasing the overall foraging effort and energy expenditure. The birds reverted to normal behaviour when the operation ceased. While Pichegru et al. (2017) did not provide quantitative information on the noise levels corresponding to the observed behavioural responses, their study on wild animals corroborates the finding by Sørensen et al. (2020) which indicates a high susceptibility of penguins to noise-induced behavioural responses. Therefore, to enable assessing the potential for noise impacts, an onset criterion for behavioural responses of penguins and flying seabirds of 120 dB re 1 µPa (SPL) for impulsive sources was chosen based on information from Sørensen et al. (2020).

There is also insufficient information available to determine the onset thresholds of behavioural responses of diving birds from non-impulsive noise. In the absence of relevant information, the behavioural noise exposure criterion for impulsive noise is applied.

To apply this onset criterion to any project-related noise emission, it must be frequency-weighted to reflect the variation of penguin auditory acuity over the frequency band of their hearing. However, there is limited information on hearing sensitivity and frequency band of hearing of diving birds (see Section 4.3 for more details). Although these results are still insufficient for generating a full audiogram for diving birds, the hearing sensitivity values in the frequency range tested are comparable to those of otariid seals over the equivalent frequency range. As relevant information on frequency-weighting is available only for marine mammals, the weighting function from Southall et al. (2019) for the least sensitive marine mammal hearing group, other carnivores in water (OCW), is recommended as a proxy. This hearing group has been selected due to similar hearing sensitivity in the frequency band of underwater hearing for diving birds and otariid pinnipeds, which are included in the group.

There are also no regulatory thresholds for the onset of hearing impairment for penguins or any other diving bird species, or any phylogenetically or anatomically related species. The only scientifically robust noise exposure thresholds in this context exist for marine mammals. To allow assessing the noise-induced impact risk of the pile driving on penguins, the criterion from Southall et al. (2019) for other carnivores in water (OCW) is recommended as a proxy due to the similarity in hearing sensitivity in the frequency band of underwater hearing for the two species groups. Since otariids are considered more sensitive to underwater sound at frequencies above the frequency range tested for diving birds, using the frequency weighted otariid thresholds likely overestimates the sensitivity of diving birds and can be considered a conservative approach.

4. Methodology

This section describes how the underwater noise assessment was conducted to understand the existing environment and potential impacts of the project on underwater noise. The following sections outline the study methodology, background information on underwater sound, and impacts of noise on marine fauna that are equally important to understand and follow the assessment.

4.1. Existing Conditions Assessment Method

4.1.1. Study Area

The core project area is the inner harbour area in Corio Bay, but the study area extends also into the adjacent outer harbour area. The exact delineation of the study area is defined by the results of the noise propagation modelling study (Green et al. 2021) as the study indicates the ranges over which marine fauna can be exposed to project-related noise levels above the relevant exposure threshold levels.



Figure 2. Overview map of the project and assessment area.

4.1.2. Existing Noise Conditions

As the project would be situated within a heavily developed port and industrial area, many currently operational water-based activities in Corio Bay will already cause emission of noise into the water as an unwanted by-product, e.g., noise from vessels and pumps. Land-based activities directly adjacent to the water could also contribute to the sound field in Corio Bay, though to a lesser extent.

Prior to this EES, there was no information available on the existing sound field with its temporal changes and spatial variations. To provide relevant baseline information, underwater noise was recorded in a sound monitoring study (Wilson and McPherson 2021). The results of this study are used to assess the existing acoustic exposure of marine fauna and birds to natural and anthropogenic noise before the project-related construction and operations begin.

The noise propagation modelling for the pile driving and dredging activities and operation of the FSRU predicts very limited sound transmission beyond Corio Bay and the Port of Geelong, mainly due to the local bathymetry (Green et al. 2021). The ambient noise in Corio Bay varies over a daily basis and also shows longer-term fluctuations, with a lowest (5th percentile) ambient noise SPL of 119.6 dB re 1 µPa and a median noise SPL of 124.6 dB re 1 µPa (Figure 3). The ambient noise levels thus even exceed some of the noise exposure criteria (Wilson and McPherson 2021).

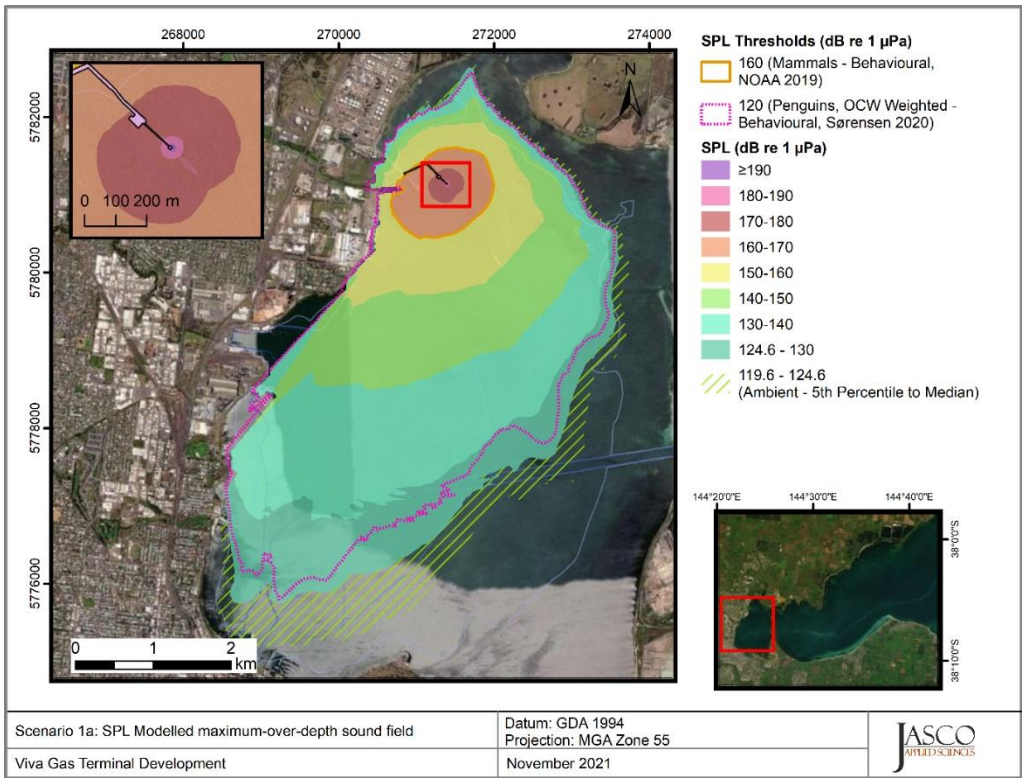


Figure 3. Maximum-over-depth SPL levels in Scenario 1a. and ambient noise levels. Isopleths show distances to behavioural effect onset levels in marine mammals and penguins (taken from Green et al. 2021).

4.2. Underwater Sound

Sound is always present in the underwater environment. It is naturally caused by biological sources such as marine fauna (e.g., snapping shrimp) and by meteorological and oceanographical sources (such as rain, wind driven waves, and currents). The existing sound in an environment is known as the ambient sound or soundscape. While the term ‘sound’ is objective, the term ‘noise’ can be defined subjectively as the ‘unwanted’ sound, i.e., sound that has an impact on a receptor. Anthropogenic sound is emitted by almost all activities at sea, either intentionally (e.g., operating an echosounder) or

as a by-product (e.g., shipping or pile driving). A sound wave can be detected underwater and classified by the pressure fluctuation (compression and rarefaction of the supporting medium). However, when pressure and density change, the particles that comprise the media also move (Nedelec et al. 2016). Pressure and particle motion, the two components of sound, serve as input to the sensory systems in marine animals.

Sounds types can be classified as impulsive and non-impulsive sounds and are primarily distinguished by their temporal pattern. Impulsive or 'pulsed' sounds can be described as discrete (single pulses) and sometimes repetitive sounds (multiple pulses) produced by sources such as pile driving. These sounds, sometimes also termed transients, are typically brief signals reaching high peak sound pressure with a rapid rise time and a rapid decay (NIOSH 1998).

Non-impulsive sounds, which can be intermittent or continuous, are produced by sound sources such as ships and pumps. Non-impulsive sounds have longer durations than impulsive ones and usually do not have the high peak sound pressure and rapid rise/decay time that impulsive sounds do (NIOSH 1998). However, especially in respect to their auditory effects, the term non-impulsive does not imply long duration signals. All vessel operations are considered non-impulsive sound sources.

Assessing the impact of anthropogenic underwater noise on marine receptors requires an understanding of the basic physical principles of the sound pressure and particle motion components of underwater sound, which are presented in detail in Supplement A.

4.3. Underwater Hearing Sensitivity of Marine Animals

Marine mammals use sound for important life functions such as communicating, locating prey, and navigating. The hearing system of cetaceans is highly adapted to perceiving underwater sound. Their hearing range and frequencies of best sensitivity are species-specific. Toothed whales (odontocetes) are usually quite sensitive to high frequency sounds while baleen whales are assumed to be sensitive to very low frequency sounds. All cetacean species can theoretically be affected by acute or chronic exposure to sound depending on their susceptibility to sound effects, and the temporal and acoustic characteristics of the sound.

The sounds that marine animals hear and generate vary in characteristics, such as dominant frequency, bandwidth, energy, temporal pattern, and directivity. Just as many terrestrial animals integrate multiple stimuli from their visual landscape, marine life must discriminate a signal (meaningful sound) among multiple stimuli in their marine soundscape. Anthropogenic sounds can interfere with auditory (i.e., hearing related) processes in various ways.

Different species (or taxa) developed sensors for either the pressure or the particle motion components of sound, and some are sensitive to both. Many fish species and all invertebrate species studied to date do not have hearing organs that detect pressure differences due to sound pressure waves. Instead, they use receptors that sense particle motion in the water column to detect sound. The relevant exposure metric for most fishes and all invertebrates is therefore particle motion.

Marine animals only respond to or are impacted by acoustic signals they can detect. The sensitivity of an individual's auditory (i.e., hearing) system is described as a function of sound frequency. The lowest intensity of a sound at a particular frequency that an individual can hear describes its hearing threshold. The graphical representation of these thresholds over the range of frequencies that are audible to the individual is called its hearing curve or audiogram. Only a few individuals in a small number of marine species have been tested for their hearing sensitivity in all taxonomic groups of marine animals.

4.3.1. Marine Mammals

Acoustic signals have evolved as the principal mode of information transmission for many marine species. It is well known that cetaceans (whales, dolphins, and porpoises) use sound passively when listening to the environment and actively when communicating and foraging.

Current data and predictions on hearing sensibility show that marine mammal species differ in their hearing capabilities, in absolute hearing sensitivity, as well as their frequency band of hearing (Richardson et al. 1995, Wartzok and Ketten 1999, Southall et al. 2007). While hearing measurements are available for a small number of species based on captive animal studies, no direct measurements exist for many odontocetes and any mysticetes. As a result, hearing ranges for many odontocetes are grouped with similar species, and predictions for mysticetes are based on other methods, such as anatomical studies and modelling (Houser et al. 2001, Parks et al. 2007, Tubelli et al. 2012, Cranford and Krysl 2015), vocalizations (see reviews in Richardson et al. 1995, Wartzok and Ketten 1999, Au and Hastings 2008b), taxonomy, and behavioural responses to sound (Dahlheim and Ljungblad 1990).

4.3.1.1. Marine Mammal Hearing Groups

Southall et al. (2007) assigned the extant marine mammal species to functional hearing groups based on their hearing capabilities and sound production to better reflect the auditory similarities between phylogenetically closely related species but also the significant differences between species groups among the marine mammals,. This division into broad categories was intended to provide a realistic number of categories for which individual noise exposure criteria were developed. These groups were revised by Southall et al. (2019) (Table 7), but the categorisation as such has proven to be a scientifically justified and useful approach in developing auditory weighting functions and deriving noise exposure criteria for marine mammals.

Table 7. Marine mammal hearing groups (Southall et al. 2019).

Hearing group	Generalized hearing range*
Low-frequency (LF) cetaceans (mysticetes or baleen whales)	7 Hz to 35 kHz
High-frequency (HF) cetaceans (odontocetes: delphinids, beaked whales)	150 Hz to 160 kHz
Very High-frequency (VHF) cetaceans (other odontocetes)	275 Hz to 160 kHz
Phocid Carnivores in Water (PCW)	50 Hz to 86 kHz
Other Carnivores in Water (OCW)	60 Hz to 39 kHz

* The generalized hearing range for all species within a group. Individual hearing will vary.

4.3.1.2. Marine Mammal Weighting Functions

The potential for anthropogenic sounds to impact marine mammals is largely dependent on whether the sound occurs at frequencies that an animal can hear well unless the sound pressure level is so high that it can cause physical tissue damage regardless of frequency. Auditory (frequency) weighting functions reflect an animal's ability to hear a sound (Nedwell and Turnpenny 1998, Nedwell et al. 2007). To better reflect the auditory similarities between phylogenetically closely related species, hearing ranges for cetaceans and pinnipeds are grouped with similar species via anatomical analyses and/or modelling studies. Southall et al. (2007, 2019) assigned the extant cetacean and pinniped species to functional hearing groups based on their hearing capabilities and sound production. Marine mammal auditory weighting functions published by Finneran (2016) are included in the NMFS (2018) Technical Guidance for use in conjunction with corresponding PTS (injury) onset acoustic criteria.

Figure 4 shows the resulting frequency-weighting curves proposed by Southall et al. (2007, 2019) which are identical to promulgated by NMFS (2018).

Applying marine mammal auditory weighting functions emphasizes the importance of making measurements and characterizing sound sources in terms of their overlap with biologically-important frequencies (e.g., frequencies of environmental signals, communication, or the detection of predators or prey), and not only the frequencies of dominant concern for the sound-producing activity such as a vessel (i.e., context of sound source; NMFS 2018).

Knowledge of the auditory capabilities of marine mammals is necessary for understanding their acoustic ecology, how they sense their environment, over what ranges they remain in acoustic contact, whether they can detect predators and prey, and how they receive ambient and anthropogenic noise.

While hearing measurements are available for a small number of species based on captive animal studies, direct measurements of many species do not exist. Current data and predictions on hearing sensitivity show that marine mammal species differ in their hearing capabilities, both in their absolute sensitivity to sound and in their frequency band of hearing (Wartzok and Ketten 1999, Southall et al. 2019).

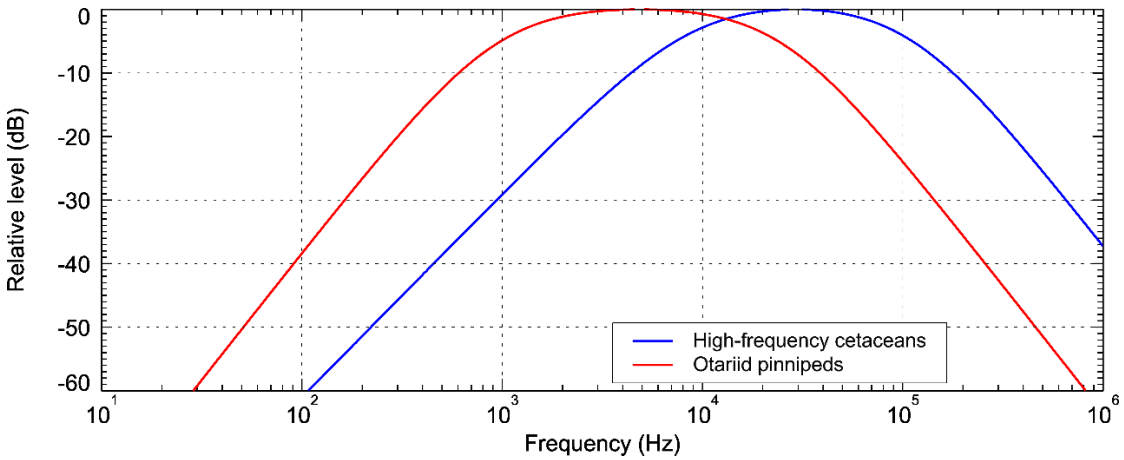


Figure 4. Auditory weighting functions for the functional marine mammal hearing groups assessed in this report (Southall et al. 2019).

4.3.2. Fishes

Although hearing ranges and sensitivities vary substantially between species (e.g., Ladich and Fay 2013), all fish species tested to date can hear (Dale et al. 2015). Fishes have developed two sensory mechanisms for detecting, localising, and interpreting underwater sounds and vibrations: the inner ear, which is tuned to sound detection, and the lateral line system, which allows them to detect vibration and water flow. Inter-specific variations in hearing range and sensitivity result from the different adaptations in these systems for perceiving sound pressure and particle motion information (Popper and Fay 2011).

The critical issue for understanding if an anthropogenic sound affects hearing is whether the sound is within the hearing (sound pressure) or detection (particle motion) frequency range of a fish and whether the sound is loud enough to be detected above the fish's hearing threshold.

Sensitivity to sound pressure seems to be functionally correlated in fishes to the presence and absence of gas-filled chambers in the sound transduction system. These chambers enable fishes to detect sound pressure and to extend their hearing abilities to lower sound levels and higher frequencies (Ladich and Popper 2004, Braun and Grande 2008).

Based on their morphology, the Popper et al. (2014) classifications into three categories can be assigned to the following families or species of fish, common in Australian waters (see Figure 5 for hearing curves ('audiograms') of representatives of each group):

I) Fishes with swim bladders or other gas volumes, whose hearing does not directly involve the swim bladder, e.g., snappers, emperors, groupers and rock cods (Lutjanids and Lethrinids such as *Pristipomoides* spp., *Lethrinus* spp., *Lutjanus* spp., and family Serranidae), and some species of tuna (*Thunnus sp*.) (Tavolga and Wodinsky 1963, Bertrand and Josse 2000, Ramcharitar et al. 2006, Braun and Grande 2008, Engineering-Environmental Management 2008, Song et al. 2008, Caiger et al. 2012);

II) Fishes whose hearing does directly involve a swim bladder or other gas volume, e.g., family Clupeidae (herrings, sardines, pilchards, and shads), family Gadidae (true cods such as whiting), and potentially some nearshore/reef species relevant to tropical Australia, including some Pomacentridae (damsel fish and clown fish), some Holocentridae (soldierfish and squirrelfish), and some Haemulidae (grunters and sweetlips) (Nedwell et al. 2004, Braun and Grande 2008, Popper et al. 2014); and

III) Fishes without a swim bladder (e.g., mackerel, *Scomberomorus spp*., some tuna species, *Thunnus spp*, and sharks, including whale sharks, *Rhincodon typus*) (Casper et al. 2012a, Popper et al. 2014, Carroll et al. 2017).

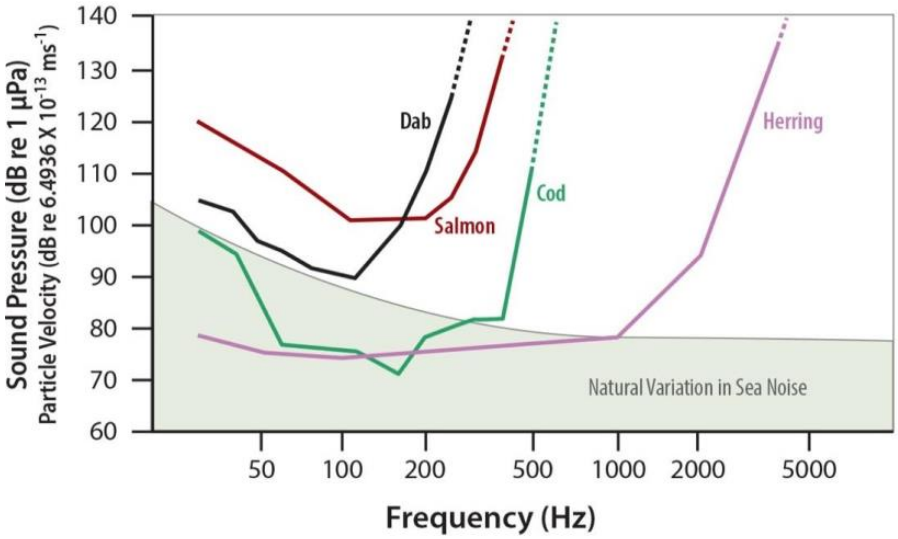


Figure 5. Fish audiograms obtained under open sea, free-field conditions; species representing different categories as classified by Popper et al. (2014) (source: Popper et al. 2019). Salmon (*Salmo salar*) have a swim bladder that does appear to play a role in hearing (category I), cod (*Gadus morhua*) and herring (*Clupea harengus*) have special structures mechanically linking the swim bladder to the ear (category II) and dab (*Limanda limanda*) are bottom-living fishes with no swim bladder (category III).

4.3.3. Invertebrates

Available literature suggests that particle motion, rather than sound pressure, is the most important factor for marine invertebrate hearing. At the seafloor interface, marine invertebrates are subject to particle motion stimuli from several acoustic or acoustically induced waves. These include the particle motion associated with an impinging sound pressure wave in the water column (the incident, reflected, and transmitted portions), substrate acoustic waves, and interface waves (such as Scholte waves, which are propagating at a water-sediment interface (Vinh 2013)). However, it is unclear which aspect(s) of these waves is/are most relevant to animals, either when the animals normally sense the environment or their physiological responses to loud sounds.

A few studies provide quantitative information on the sensitivity thresholds of marine invertebrates to sound. Electrophysiological studies measuring auditory evoked potentials (AEP) showed that cephalopods are capable of perceiving sound between 10 and 400 Hz (Packard et al. 1990, Parks et al. 2007, Hu et al. 2009, Mooney et al. 2010, Hughes et al. 2014). In a behavioural study, Mooney et al. (2016) showed that squid (*Doryteuthis pealeii*) can perceive sound pressure of signals as low as 80 Hz and have their optimal hearing range between 200–400 Hz. Lovell et al. (2005) measured AEP responses in prawns (*Palaemon serratus*) between 100 Hz to 3 kHz, and Pye and Watson (2004) tested lobster (*Homarus americanus*) up to 5 kHz using the AEP technique. However, as pointed out by several authors (Ladich 2013, Popper et al. 2014, Hawkins et al. 2015, Sisneros et al. 2016), studies employing the AEP technique may not reflect the true sensitivity to acoustic stimuli as the studies fail to incorporate natural soundscapes and processing at higher cortical levels.

Packard et al. (1990) used a classical conditioning approach to test low-frequency hearing in cephalopods (*Sepia sp.*, *Octopus sp*., and *Loligo sp*.) and found the best sensitivities at 10 Hz and below. Other studies obtained perception thresholds (using reflex movements of antennae or legs as proxy) for underwater sound in species such as the brown shrimp (*C. crangon*) (Heinisch and Wiese 1987, Berghahn et al. 1995), hermit crab (*Pagurus bernhardus*) (Roberts et al. 2016), common littoral crab (*Carcinus maenas*) (Barth 1980), and northern prawn (*Pandalus borealis*) (Klages et al. 2002). The studies revealed these species are sensitive to acoustic or vibratory stimuli at frequencies below 400–500 Hz.

Moreover, detection of substrate-borne low-frequency vibration (<200 Hz) has been demonstrated to induce behavioural responses in some crustacean and bivalve species (Roberts et al. 2015, Roberts and Elliott 2017).

Most studies on marine invertebrates do not differentiate between pressure and particle motion. If conducted in tanks, the resulting thresholds and high-frequency ranges (e.g., Pye and Watson 2004, Lovell et al. 2005) may be artefacts, possibly resulting from acoustic interferences in the confines of the test environment (Sisneros et al. 2016, Carroll et al. 2017). These experiment outcomes should be applied to impact assessments with caution, due to the aspects regarding study design and representation of true hearing sensitivity (see above).

Mooney et al. (2010) quantified the acoustic sensitivity of the longfin squid (*Loligo pealeii*) using near-field acoustic and shaker-generated acceleration stimuli. Sound field pressure and particle motion components were measured from 30 to 10,000 Hz. Acceleration stimuli were measured from 20 to 1000 Hz. Their results suggest that squid detect the acceleration and particle motion components of a sound field up to frequencies of ~500 Hz.

Jézéquel et al. (2021) corroborated the conclusion that crustaceans can sense particle motion but not sound pressure. In their study of sound detection in American lobster (*Homarus americanus*), they determined thresholds for particle acceleration levels (PAL_{rms}, in dB re. 1 m s^{-2}) ranging between −35 dB re 1 m·s^{-2} at 80 Hz and –30.2 dB re 1 m·s^{-2} at 220 Hz. The animals' best sensitivity ranged from 80–120 Hz and was limited to an upper frequency of 250 Hz.

Jézéquel et al. (2021) reported the important finding that statocysts, a long-proposed auditory structure in crustaceans, are not the sensory organs responsible for lobster sound detection. This raises doubt about studies investigating the noise-induced impact on statocysts in crustaceans and their conclusions regarding the ecological effects of the documented statocyst impairment or damage.

Irrespective of the sensory modality for sound perception, marine invertebrates produce, detect, and respond to sound as shown in a review by Edmonds et al. (2016), thus indicating that these species are susceptible to effects from underwater sound. While research in this area is limited, the sensitivity of invertebrates to water-borne particle motion and substrate vibration across a broad range of frequencies may potentially impact marine invertebrates through physical effects (Solé et al. 2017) and behaviour disruption (Solan et al. 2016).

However, due to the relative novelty in scientific understanding of invertebrate detection of and sensitivity to underwater sound, there are currently no established detection thresholds for this taxonomic group.

4.3.4. Avifauna

Hearing in birds has been tested predominantly in terrestrial species (Dooling 2010). There are only two studies providing information on the underwater hearing sensitivity of a (pursuit) diving bird species, the great cormorant (*Phalacrocorax carbo*) (Johansen et al. 2016, Anderson-Hansen et al. 2017). These studies show that the birds have underwater hearing sensitivity over the range of at least 1–4 kHz, with greatest sensitivity of 70 dB SPL found at 2 kHz. This suggests that their hearing capabilities in water are better than what would be expected for a purely in-air adapted bird's ear (Johansen et al. 2016). Mooney et al. (2019) found comparable results for two seabird species, the common murre (*Uria aalge*) and the Atlantic puffin (*Fratercula arctica*). A behavioural response conducted on Gentoo penguins (*Pygoscelis papua*) (Sørensen et al. 2020) similarly indicates that underwater hearing may be important for penguins and that their auditory system is adapted for the underwater environment.

Best hearing sensitivity for in-air sound was measured at 2 kHz for the puffin and 1 kHz for the murre. The overall hearing range was highest for the puffin including frequencies between 0.5 to 6 kHz. Wever et al. (1969) investigated the hearing of African (black-footed) penguins (*Pheniscus demersus*) and documented a similar hearing range for this species. Apart from this, there are limited data on the hearing range or sound-induced effects for birds underwater.

In the absence of data on auditory information for most seabird species, information sensitivity can be drawn from the animals' vocalisations. Of the penguin and flying seabird species, to date only the Macaroni penguin (*Eudyptes chrysolophus*) has been proven to produce sound underwater. Markov (1977) documented that their vocalisation frequencies range from 2.5 to 7 kHz, but the functionality of these sounds and therefore the role acoustic cues play for birds underwater remains unclear.

4.4. Impact of Underwater Noise on Marine Fauna

The audibility of a sound does not represent an impact per se but is the necessary condition for any direct effects to occur, i.e., sound becomes relevant in the context of this impact assessment only if it exceeds the threshold for any of the impacts listed in Section 3.2.

The potential for noise to impact marine fauna depends on the acoustic characteristics of the sound, the sound propagation characteristics of the physical environment, and biological factors such as hearing sensitivity and behavioural context (Southall et al. 2007, Ellison et al. 2012, Southall et al. 2016). Noise can have a variety of impacts on marine animals depending on its characteristics, including the sound intensity, temporal pattern, directivity, bandwidth, frequency range, and whether it is impulsive or not. Typically, the negative effects of noise are directly related to the type of noise and its level, which usually decreases with distance of the receptor from the noise source. A conceptual model describing the spatial extent of four theoretical zones of acoustic influence on marine life was proposed by Richardson et al. (1995) (Figure 6). With the highest levels of sound at the sound source at the centre of the model, the noise level and severity of noise-induced impacts decline with increasing distance from the source.

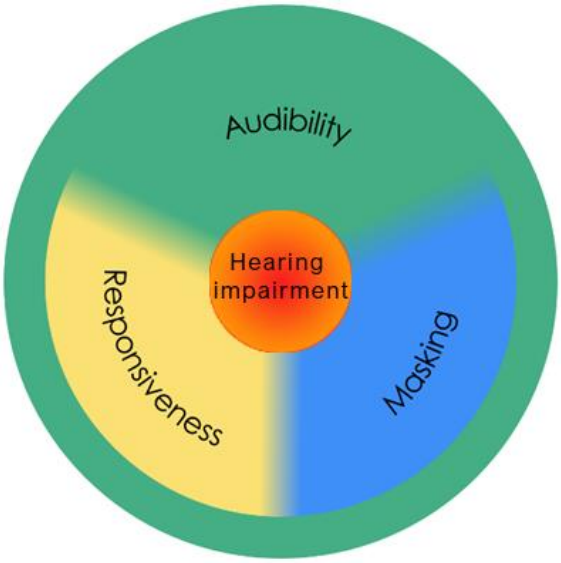


Figure 6. Conceptual relationship between the distances from a noise source and the overlapping effects on hearing and behaviour; (not to scale). Adapted from Richardson et al. (1995).

The four categories are described below in increasing severity of effect:

1. Audibility–Signal source levels decrease with range from a source due to propagation losses; their audibility is limited by the signal dropping either below the animal's hearing threshold or below ambient sound levels.
1. Responsiveness–The zone of behavioural response is generally smaller than the zone of audibility, as an animal is not likely to respond to a sound that is just detectable.
2. Masking–The zone overlaps with zone of responsiveness; masking occurs when a noise impedes the ability of the animal to perceive a biologically relevant signal.
3. Hearing impairment–Physical injury, temporary or permanent impairment of the auditory (hearing) system.

When the receptor is close to the noise source, all four categories of effects can occur simultaneously if the noise exposure is sufficiently intense. As the receptor moves away from the noise source, the effects become systematically less prominent. When the noise source is far enough away, only behavioural and/or physiological effects remain as possible responses to noise, as the very perception of a sound can cause a physiological stress response in the receiving animal. The direct impacts of anthropogenic noise on marine fauna are described in more detail below.

An effect of sound on certain marine species that is not defined in a zonal sense is the potential reduction in prey availability, for example, when prey responds to anthropogenic sound and is displaced from a particular feeding area. This is considered an indirect or secondary effect. The consequences of indirect effects, such as reduced food availability, on an individual or species are often difficult to determine. For most marine animals, the abundance of prey species near a source of impact (e.g., construction site) would, if reduced at all due to sound exposure, likely remain so only for a short duration (hours to days) past the end of the activity. Post noise exposure the area would likely be repopulated by the same animals or unaffected animals from adjacent waters. In some extreme cases, recovery of the habitat or prey resources could occur over a longer time frame (days to weeks). It is important to note that indirect impacts likely differ among species, as well as on spatial and temporal scales.

4.4.1. Physiological Stress

Stress is an integral and necessary part of the body's homeostasis, and certain stress levels are tolerable. At higher levels, if repeated too often or continued over long durations, stress can; however, become deleterious by creating an allostatic load to the body. This is expressed and can be measured as imbalances in the autonomic nervous system, central nervous system, neuroendocrine system, and immune system, and/or result in changes in growth rate, disruption of diurnal rhythms, and behavioural changes. Marine animals of all taxa may not show overt signs of responding to an increase in noise but may nonetheless show physiological changes (e.g., Slabbekoorn et al. 2010, Kight and Swaddle 2011, Slabbekoorn et al. 2019). Symptomatic stress responses include acute changes in respiration rate, oxygen consumption, excretion, and food consumption rates, or chronic effects such as immune suppression. The effects of increased stress levels (acute or chronic) can be expressed through various metabolic and/or physiological factors. The imbalance caused by stress in these factors can lead to immune suppression and/or result in altered growth rate, disrupted diurnal rhythms, and behavioural changes. This cascade of effects may reduce an individual's fitness through impacts on reproduction (e.g., Sierra-Flores et al. 2015) and, ultimately, survival (see review by Slabbekoorn et al. 2010).

While physiological responses such as increased heart rate or startle response can be difficult to measure in the field, they often accompany more easily measured reactions such as behavioural responses. A startle is a reflex characterized by rapidly increasing heart rate, shutting down nonessential functions, and mobilising glucose reserves. Habituation keeps animals from expending energy and wasting attention on harmless stimuli, but the physiological component might not habituate completely (Bowles 1995).

A strong and consistent physiological response does not necessarily indicate negative consequences to individuals or to populations (Larkin et al. 1996). Many reported physiological responses to in-air noise, e.g., are usually within the range of normal adaptive responses to external stimuli, such as predation. In many cases, individuals would return to homeostasis[2] or a stable equilibrium almost immediately after exposure. The individual's overall metabolism and energy budgets would not be affected if it had time to recover before being exposed again. If the individual does not have the opportunity to recover, however, physiological responses could be cumulative and lead to reduced fitness.

The difficulty of assessing noise-induced stress in marine animals is exemplified by a carefully controlled exposure experiment conducted by Houser et al. (2020) who exposed trained bottlenose dolphins (*Tursiops truncatus*) to 1-s tones at different SPL. Their results show that stress-related hormones were either below detection limits (aldosterone) or levels did not show a consistent relationship with received levels (cortisol nor epinephrine). Stress responses may be species- and context-specific and depend on previous exposures (sensitisation/habituation, see Section 4.4.2) and the (lack of) results in the study by Houser et al. (2020) may reflect the fact that these animals had been exposed to artificial underwater sound before. However, it also gives reason to question if marine mammals interpret high-level anthropogenic sound as stressful and whether behavioural responses to sound can be equated to a physiological (endocrine) response.

[2] The state of steady conditions of living organisms where they are optimally functioning.

4.4.2. Behavioural Responses

The intensity of behavioural responses of marine fauna to sound exposure does range from subtle responses, which may be difficult to observe and have little implication for the affected animal, to obvious responses, such as avoidance or panic reactions. Behavioural responses to hearing a sound include (in approximate order of increasing severity but decreasing likelihood):

1. Looking or increased alertness;
2. Minor behavioural responses;
3. Cessation of feeding or social interactions;
4. Temporary avoidance behaviour;
5. Modification of group structure or activity state;
6. Habitat abandonment; and
7. Injury or death from direct response.

The context in which the sound is received by an animal affects the nature and extent of responses to a stimulus. The threshold for elicitation of behavioural responses depends on received sound level, as well as multiple contextual factors such as the activity state of animals exposed to different sounds, the type of sound, spatial relations between a sound source and receiving animals, the gender, age, and reproductive status of the receiving animal and the and novelty of or previous exposure to the sound (Ellison et al. 2012). This means that individual animals will react differently depending on their previous experience, their life stage (e.g., mother-calf pairs versus solitary adult males), and the motivation to continue an ongoing activity such as feeding.

In general, noise exposure may result in alterations in the behaviour of marine fauna, particularly those individuals in closer proximity to the sound sources. The likely potential consequences for marine fauna are:

- Changes in species composition near the project site, with less noise-tolerant species moving farther away;
- Selection for more noise-tolerant individuals within the populations of species closer to the project site; and
- Habituation of some species and individuals to the noise impacts.

The differences in behavioural responsiveness that exist between individuals and species can furthermore change over time due to habituation or sensitisation to (repeated) exposure to the noise. Previous exposure to a sound can influence the severity of a behavioural response, leading to an increased or decreased tolerance to the sound. A novel acoustic stimulus may initially provoke a substantial anti-predator response (Voellmy et al. 2016). Behavioural habituation is the relative persistent waning of a response as a result of repeated stimulation to that novel stimulus (Thorpe 1963, Bejder et al. 2009). Habituation is a process involving a reduction in response over time as individuals learn that there are neither adverse nor beneficial consequences of the occurrence of the stimulus. Sensitisation refers to the opposite phenomenon, an increasing “behavioural responsiveness over time when animals learn that a repeated or ongoing stimulus has significant consequences for the animal” (Richardson et al. 1995). Individuals that are sensitised to acoustic stimuli (such as emitted by anthropogenic activities) will thus exhibit a progressive intensification of their response to these stimuli, e.g., by fleeing farther and faster when they encounter the stimulus or by responding at progressively lower stimulus intensities. Since habituation and sensitisation constitute learning processes that are ongoing, they reflect an individual’s cumulative experience with anthropogenic activities, including the number and outcome of its exposures to anthropogenic stimuli over the course

of its lifetime (Knight and Temple 1995). Tolerance describes the “intensity of disturbance that an individual […] tolerates without responding in a defined way” (Nisbet 2000 p. 315).

In fishes, noise exposure can lead to behavioural effects such as reduced foraging, shelter or nest maintenance, and predator avoidance (Engås et al. 1996, Popper et al. 2003, Picciulin et al. 2010, Bruintjes and Radford 2013, Hawkins et al. 2014, Simpson et al. 2015). Not all studies, however, report an impact. For example, Nedwell et al. (2003) reported no apparent behavioural impacts or injuries to caged brown trout (*Salmo trutta*), located 400 m from pile driving operations where they were exposed to estimated received levels of 134 dB re 1 µPa (PK). Likewise, Ruggerone et al. (2008) reported no injury or behavioural changes in caged coho salmon (*Oncorhynchus kisutch*) located up to 15 m from pile driving activity.

Small-scale avoidance of noise is unlikely to have any long-lasting effects on fitness. If noise was to occur in breeding or feeding grounds, then fishes might relocate to other areas. More research is required to assess this possibility. Other behavioural effects include increased motility (Buscaino et al. 2010), reduced feeding efficiency (Voellmy et al. 2014), and masking of communication signals (Codarin et al. 2009).

To date, there have been few studies regarding behavioural responses by seabirds to impulsive underwater sound sources. Stemp (1985; as cited in Golde and Houtman (2012)) conducted observations on the effects of impulsive sounds generated by a seismic exploration on seabirds and did not observe any negative effects. Lacroix et al. (2003) investigated the effect of near shore seismic surveys on moulting long-tailed ducks (*Clangula hyemalis*) in the Beaufort Sea, Alaska, and found no noticeable impacts on the movements or diving behaviour of ducks.

Pichegru et al. (2017) investigated the behavioural response of breeding endangered African penguins (*Spheniscus demersus*) to seismic surveys within 100 km of their colony in South Africa. Penguins showed a strong avoidance of their preferred foraging areas during seismic activities; foraging took place significantly farther from the survey vessel when in operation, while increasing their overall foraging effort and energy expenditure. The birds reverted to normal behaviour when the operation ceased.

In a controlled exposure experiment, Sørensen et al. (2020) exposed seven gentoo penguins (*Pygoscelis papua*) to underwater noise bursts (i.e., impulsive signals) and documented that the animals showed a graded reactions ranging from no reactions at 100 dB re 1 µPa SPL to strong reactions in more than 60% of the playbacks at 120 dB re 1 µPa SPL.

It can be expected that pursuit-diving birds react to underwater sound emissions depending on the received noise level and possibly respond differently to different types of noise; most likely a behavioural response to onset of noise emissions will manifest itself as altering or abandoning a foraging pursuit; it remains unclear if or at what received levels and under what contextual circumstances birds entering an already existing sound field, i.e., with ongoing construction or operational activities, will avoid the area. Penguins, however, seem more prone to respond to acoustic disturbance than the other bird species and can be assumed to avoid ensonified areas for the duration of a sound-producing activity before returning to their habitat. However, the limited scientific information on behavioural responses of seabirds (including penguins) to underwater sound indicates that the response are likely species- and context-specific

4.4.3. Acoustic Masking

Auditory masking is the process by which the threshold of hearing for one sound is raised by the presence of another (masking) sound (Erbe and Farmer 1998, Erbe 2008, Erbe et al. 2016). This describes the reduction in audibility for one sound (termed 'signal') caused by the simultaneous presence of another sound (termed 'noise'). For this to occur, the sound must be loud enough, have similar frequency content to the signal, and must happen at the same time.

Masking is a complex phenomenon, and the onset levels and severity are difficult to predict for any given combination of sender, environment, and receiver characteristics (Erbe et al. 2016b). Masking depends on the spectral and temporal characteristics of signal and noise and is reduced if the signal and noise (masker) are separated in time, frequency, or direction (space). It can occur if the noise happens shortly before or after the signal (forward and backward masking).

The severity and extent of auditory masking depends on the spectral and temporal characteristics of both the signal and the noise. The zone of auditory masking can maximally be as large as the zone of audibility, i.e., a faint noise might mask a faint signal. However, auditory masking ends immediately after the masking sound ceases.

Masking sound can interfere with the perception of communication between conspecifics and echolocation signals and the detection of environmental, predator and prey sounds. These acute masking effects can have cascading consequences for communities through altered species interactions (Francis et al. 2009). Auditory masking can lead to disruption of a behaviour, lack of appropriate behavioural reactions, increased vulnerability to predators, reduced access to prey, reduced communication or listening space (Clark et al. 2009, Pine et al. 2018a, Pine et al. 2018b), changes in vocal behaviour, disruption of spawning activities, and stress (Houser et al. 2020).

The masking effect can be reduced or remedied by various active or passive mechanisms for masking-release, such as spatial or temporal release from masking (for more information, see Erbe et al. 2016, Popov et al. 2020). The masking effect can be reduced if the signal and noise are separated in time, frequency, or direction (space).

The biological significance of acoustic masking is directly linked to the duration of the masking sound. Both anthropogenic and natural marine sound can affect hearing and partially or completely reduce an individual's ability to effectively communicate. Auditory masking is likely occurring for all marine fauna; however, masking is most frequently associated with marine mammals. Masking in fishes or other taxa has not been studied in detail.

Repeating a signal or lengthening it may reduce the amount of masking because whales seem most reactive when the sound level is increasing and at the onset of a sound. Although limited, data suggest that stationary industrial activities producing non-impulsive sounds (such as dredging, drilling, and oil-production-related activities) result in less dramatic vocal reactions by cetaceans than do moving sound sources, particularly ships (Richardson et al. 1995). Masking and the potential effects of masking on communication and listening space of marine mammals are not fully understood and remain an area of active research (Terhune et al. 1979, Cunningham and Mountain 2014, Tennessen and Parks 2016, Cholewiak et al. 2018, Dunlop 2018, Gabriele et al. 2018, Putland et al. 2018, Dunlop 2019).

4.4.4. Hearing Impairment

Exposure to sufficiently intense sound may lead to an increased hearing threshold in any living animal capable of perceiving acoustic stimuli (Finneran 2015). If this shift is reversed and the hearing threshold returns to normal, the effect is called a temporary threshold shift (TTS). The onset of TTS is often defined as threshold shift of 6 dB above the normal hearing threshold (Southall et al. 2019). If the threshold shift does not return to normal, the residual shift is called a permanent threshold shift (PTS). Both TTS and PTS are hearing impairments that are considered an injury (DAWE 2021).

Hearing loss occurs naturally in marine mammals and possibly also in other taxa, most likely explained by advancing age, diseases, or congenital defects (Ridgway and Carder 1997, Mulsow et al. 2011). Threshold shifts can also be caused by acoustic trauma from a very intense sound of short duration, as well as from exposure to lower level sounds over longer time periods (Houser et al. 2017). Injury to the hearing apparatus of a marine animal may result from a fatiguing stimulus measured in terms of sound exposure level (SEL), which considers the sound level and duration of the exposure signal. Intense sounds may also damage the hearing apparatus independent of duration, so an additional metric of peak pressure (PK) is needed to assess acoustic exposure injury risk. Noise-induced effects mediated by particle motion have not been studied to date, and it is unclear what the exposure thresholds for marine animals sensitive to particle motion are.

The severity of TTS is a function of recovery time and is expressed as the magnitude of the shift in hearing sensitivity relative to pre-exposure sensitivity and the duration of hearing impairment. TTS occurs at lower sound levels than PTS. Though the relationship between the onset levels of TTS and the onset levels of PTS is not fully understood for marine mammal species, PTS onset acoustic thresholds have been extrapolated from marine mammal TTS measurements using growth rates from terrestrial and marine mammal data (Finneran et al. 2017).

The most severe physiological or physical effects caused by exposure to intense sound described in published literature are TTS and PTS, respectively, which were investigated in several bird species (Saunders and Dooling 1974, Ryals et al. 1999, Saunders and Dooling 2018). These studies also show that birds can regenerate the sensory cells in their inner ears, providing them with a mechanism to restore their hearing sensitivity even after a sound exposure that initially impacted their hearing negatively. During this restorative process, however, sound induced impairment of their hearing can have ecological consequences for these taxa as their ability to detect biologically important sounds is reduced.

As in other animal groups, hearing impairment in fishes can result from mutations, treatment with ototoxic chemicals, and exposure to excessive levels of underwater noise. Hearing impairment has been demonstrated in several fish species after exposure to different types of sounds (Popper and Clarke 1976, Scholik and Yan 2001, Amoser et al. 2004, Smith et al. 2004, Popper et al. 2005, Popper et al. 2007). Multiple exposures to very intense sounds (SPL over 190 dB re 1 µPa) or long-term exposure to lower-level sounds were necessary to cause hearing threshold shifts. The onset thresholds for hearing impairment, however, varied between individuals and species (Popper et al. 2005, Popper et al. 2007, Hastings et al. 2008, Hastings and Miksis-Olds 2012). Not all experiments involving exposure to intense sound, however, caused a hearing threshold shift in the exposed fishes; some species exhibited no or minimal hearing threshold shifts following intense sound exposure (Smith and Monroe 2016).

The biological significance of hearing impairment in fishes is mediated by the fact that perception of underwater sound for communication purposes is linked to regulating social and reproductive behaviours of fishes; fishes listen to other fishes (both conspecific and heterospecific) and other aquatic sound-producing organisms such as their predators (Lagardère et al. 2005, Vasconcelos et al. 2011, McIver et al. 2014). With sound playing such a vital role in a variety of behaviours, fishes of all life stages face a higher risk of mortality and decreased fitness if their hearing is impaired.

Noise induced effects on anatomical structures (statocysts), which were purportedly responsible for sound detection by marine invertebrates, have been shown, but results from a recent study on American lobster (Jézéquel et al. 2021) indicate that external cuticular hairs, which cover much of lobster bodies are the sensory organs for detecting particle motion. This implies that previous studies investigated the wrong organ, and their conclusions may be irrelevant. Despite this recent paradigm shift in scientific understanding of functional morphology of marine invertebrates, sound plays an ecologically important role for marine invertebrates, and it is justifiable to assume that impairing their perception of acoustic stimuli may lead to, however undefined and not quantified, ecological consequences.

4.4.5. Mortality

Exposure to excessive levels of impulsive sound or events characterised by rapid overpressure in water can kill and injure marine fauna (Carlson et al. 2011). Impulsive sounds, with rapid changes in pressure, are more damaging to tissues than gradual changes (Popper et al. 2014).

Mortality is either a direct effect of the exposure (in case of severe injury) or indirect if an animal is moderately injured. Data on sound-induced mortality have been documented for fishes (Caltrans 2001), but are scarce for marine mammals (Ketten 1995, Landsberg 2000) and only hypothesised for other taxa (Guerra et al. 2004).

Exposure to intense underwater sound may not directly result in death or injury; however, it may be one of the indirect causative factors in death or injury to marine mammals. Marine mammal strandings of beaked whales (D'Amico et al. 2009) and common dolphin (Jepson et al. 2013) are thought to be a result of the animals' behavioural responses to acoustic exposure to military mid-frequency sonar.

Investigating the mass stranding of approximately 100 melon-headed whales in the Loza Lagoon system in Madagascar lead to the conclusion that the use of a 12 kHz multibeam echosounder (with SPL of 236 to 246 dB re 1 µPa and per pulse SEL of 218 to 224 dB re 1 $\mu Pa^2 \cdot s$) was "the most plausible and likely initial behavioural trigger of the stranding event, but that a variety of secondary factors contributed to or ultimately caused mortalities […]" (Southall et al. 2013).

Sound-induced mortality in birds and/or marine invertebrate species relevant for this assessment has not been documented. Fishes, however, have been shown to suffer non-acoustic traumata after exposure to intense impulsive sounds, e.g., near pile driving operations (Caltrans 2001). Popper et al. (2014) provide a review of existing information on non-acoustic injury to fishes and propose a comprehensive set of (qualitative and quantitative) noise exposure criteria.

4.5. Risk Screening Method

A risk-based screening approach has been used for the EES assessment in accordance with the requirements outlined in the 'Ministerial guidelines for assessment of Environmental Effects under the *Environment Effects Act 1978'* (page 14). The risk screening is undertaken to ensure that the level of investigation conducted in each technical study is adequate to inform an assessment of the significance and acceptability of the project's potential environmental impacts.

An environmental, social, and economic issues risk screening tool has been used to prioritise and focus the proposed investigations, assessments, and approaches to avoiding, minimising, or managing potential impacts. The issue screening process involved an evaluation of the potential environmental, social, and economic issues associated with the project based on the information collected through a series of initial assessments undertaken into the potential effects of the project.

A risk workshop convened by a qualified risk practitioner and comprising technical specialists from the proponent, project design team and EES team conducted the initial risk screening. The risk screening

process utilised knowledge of the project infrastructure and design, existing environment and land use setting to assess potential risks based on the specialised knowledge of the technical experts.

The purpose of the issues screening approach was to assist in identifying:

- Significant issues, uncertainties and/or potential impacts that require more detailed characterisation and/or assessment within the EES, and
- Matters or potential impacts considered to be already well understood or less significant.

A high, medium, or low screening value was assigned to potential issues to determine the level of assessment required to identify and investigate impacts.

Each potential issue was given a score (1, 2 or 3) against the categories of:

- Community and stakeholder interest,
- Significance of assets, values and uses, and
- Potential impact (spatial, temporal and severity).

The scores were added together, or the highest score across the three contributing categories was used, to give a 'screening value' of high, medium, or low, which gives an indication of the level of impact assessment that is required. Issues that were assigned a screening value of high or medium required detailed assessment in the EES at a level commensurate with them being considered primary level issues.

Issues that were assigned a screening value of low were proposed to be documented and managed with some investigation and assessment in the EES at a level commensurate with them being considered secondary level issues.

4.5.1. Criteria and Consequence Ratings

Risks, issues, and potential impact pathways were identified for both construction and operation of the project. Table 8 defines the criteria and consequence ratings for each of the three categories that have been used to inform the issues screening. The sum of the scores against each of the three categories or the highest rating across any of the three contributing categories gives the 'screening value'.

Table 8. Issues screening criteria and consequence ratings.

Rating	Community and stakeholder interest	Significance of assets, values and uses	Potential impact (spatial, temporal and severity)
1	Low interest and perceived impact	Locally significant asset, value, or use	Potential for localised, temporary impact
2	Some interest and targeted perceived impacts	Regionally significant asset, value, or use	Potential for significant temporary, or localised permanent impact
3	Broad community and stakeholder interest or impacts	State or nationally significant asset, value, or use	Potential for significant permanent impact

Table 9 shows the screening values are then used to determine the level of assessment required.

Table 9. Issue investigation categories.

Screening score	Screening value	Potential consequences	Complexity of mitigation	Level of assessment
7, 8, or 9 or the highest rating across any one of the three contributing categories is 3	High	Potential for elevated, longer-term impacts, significant assets or values may be affected with enduring changes. Considers both impacts and benefits, or Issue may not be well defined and insufficient information is available for the impact assessment, or High level of community interest.	Stringent management measures may be required	Detailed assessment required
4, 5, or 6 or the highest rating across any one of the three contributing categories is 2	Medium	Potential for moderate level impacts, significant assets or values may be affected over an extended time frame with some resultant changes. Considers both impacts and benefits, or Issue may be moderately understood, and some information is available, however more is required for the impact assessment, or Medium level of community interest.	Standard management measures are available that can be adopted with some modification	Moderate assessment required
3 or the highest rating across any one of the three contributing categories is 1	Low	Potential for short term and localised impact. Asset or values may be temporarily affected but recovery expected, or Issue is well understood and there is enough information available for the impact assessment, or Low level of community interest.	Standard management measures are available.	Some assessment required

Further information about the risk screening process is detailed in Chapter 7 *Assessment framework.*

Outcomes from the risk screening process are outlined in Section 4.5.2.

4.5.2. Risk Screening Results

Table 10 provides the key potential issues related to changes in underwater noise identified as part of the risk screening process for the project and presents the screening value for each issue.

Table 10. Underwater noise issues screening result.

Aspect	Issue	Community & stakeholder perceived impacts	Significance of assets, values & uses	Potential impact (spatial, temporal & severity)	Screening score	Screening value
Construction						
Marine ecology	Potential impacts on marine fauna from underwater noise generated from piling and dredging activities	1	2	2	5	Medium
Operation						
Marine ecology	Underwater noise generated by operation of the FSRU and visiting LNG carriers impacts marine fauna	2	2	1	5	Medium

4.6. Impact Assessment Method

Underwater noise effects of the construction activities and operation of the facility are given a medium screening score (5) indicating the requirement for a detailed assessment in the EES at a level commensurate with them being considered primary level issues. There is no information about combined effects of underwater noise with the other environmental effects assessed for the project and, accordingly, underwater noise is assessed as a single impacting factor.

The impact assessment method includes a review of existing background information on the sensitivity of marine fauna species occurring in the area to underwater noise. In combination with the outcome of the underwater noise modelling study Green et al. (2021) this will provide the basis for assessing the likely impact severity, impact ranges and, ultimately, the ecological relevance of the impacts.

4.7. Stakeholder and Community Engagement

Stakeholders and the community were consulted to support the preparation of the project's EES and to inform the development of the project and understanding of its potential impacts.

An extensive engagement and consultation program was undertaken to ensure that the community and interested stakeholders were informed, involved and able to actively contribute to the development of the project and preparation of the EES. No specific issues related to underwater noise were raised by stakeholders and the community, however, concerns were raised about the potential impacts on the marine environment within and around Corio Bay and the Ramsar site

In accordance with the scoping requirements, a Technical Reference Group (TRG) was convened and chaired by DELWP on behalf of the Minister for Planning. The TRG has provided input throughout the EES process. Chapter 6 *Community and stakeholder engagement* provides a summary of the project's key engagement activities.

4.8. Assumptions and Limitations

4.8.1. Assumptions

The following conservative approaches/assumptions were made:

- The impact ranges are based on the maximum impact range (R_{max}) values calculated by Green et al. (2021), i.e., including the farthest extent at which the impact thresholds are exceeded. This can include outliers that are not representative of the main (95%) extent of the sound fields (which would be represented by the $R_{95\%}$ values, see Green et al. 2021 for details). These outliers were not found to lie irrationally beyond the main extent of the 95% impact range, so their inclusion makes the ranges precautionary but not unrealistic.
- It is assumed that animals will remain within the TTS impact zone to stay in their preferred habitat, thereby enduring TTS noise levels.
- The impact assessment is based on a static receiver approach. The predicted SEL levels (relevant for TTS and PTS thresholds) are calculated over a 24 h period, and animals are assumed to remain stationary, thus receiving and accumulating noise exposure over this period. This scenario, however, is unrealistic because marine mammals and birds are highly mobile species and are likely using the entire area dynamically, i.e., moving in and out of the area surrounding the project site; this includes pinnipeds that display vocal behaviour at or just under the water surface over extended periods.

4.8.2. Limitations

This assessment was made with the following limitations:

- This assessment considers the sound fields around the construction activities and use of new facilities as modelled by Green et al. (2021) for the following six scenarios:
    1. Pile driving:
        a. Dolphin pile, part of the construction of the pier extension for the gas terminal.
        b. Mooring piles at Lascelles Wharf.
    2. Dredging:
        a. Localised dredging at Refinery Pier to enable the FSRU and LNG carriers to berth at the pier extension.
        b. Installation of seawater transfer piping.
    3. Future operations:
        a. FSRU berthed .
        b. FSRU berthed and LNG carrier offloading.

    The assessment of potential impact to the different receiver groups (Sections 6–8) is based on calculated propagation ranges to the impact thresholds and accounts for the available information on their (auditory) sensitivity to sound into account.

- There are no intrinsic mitigation and management measures planned yet as part of the construction and operations plan to reduce the potential noise-induced effects of the planned activities.
- Scientific information on the importance of sound, sensitivity to underwater sound, and susceptibility to sound-induced effects on many of the marina fauna species considered in this assessment is scarce or does not exist. This restricts or precludes assessing the impact of noise-induced behavioural responses or physical impacts/hearing impairment for these animals. In the absence of sufficient site-specific or species-specific information, where available, studies at other locations, other sound sources or on phylogenetically related taxa were applied for assessing potential impacts of the planned activities at the project site.
- Scientific information is available indicating that invertebrates and fishes are sensitive to particle motion. There is, however, no information available on the importance of particle motion, and susceptibility to effects from exposure to particle motion. There are currently no thresholds for exposure to particle motion for any taxonomic group.

4.8.3. Linkages to Other EES Technical Studies

The findings of this study were used as inputs into Technical Report A: *Marine ecology and water quality impact assessment*.

5. Existing Conditions

5.1. Areas of Wildlife Conservation Value in the Project Area

In 1982, Port Phillip Bay (Western Shoreline) and Bellarine Peninsula were designated as Ramsar Site 266 under the Ramsar Convention (1971) as a wetland of international importance. The area is also part of the Swan Bay and Port Phillip Bay Islands Important Bird Area (Dutson et al. 2009), as it supports at least 1% of the flyway population of several waterbird (wader) species.

The site was designated mainly because of its value as waterbird habitat, and it was recognised as being of international importance for waders. Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site is also significant for supporting breeding of at least 49 species of waterbird. (DEWLP 2018).

5.2. Marine Fauna occurring in the Project Area

Underwater noise can only affect receptor species that a) live permanently in the marine environment exposed to noise or enter it at least temporarily and b) are sensitive to sound or particle motion. Based on these considerations, species representing four major taxonomic groups were identified and are considered in this impact assessment (Table 11). No differentiation was made in the assessment regarding likelihood and duration of their occurrence in the project area.

The main bird species of concern in the EES are migratory waders and other waterbirds, particularly in the Ramsar wetland which is approximately 1.3 km from the FSRU and construction activity. However, these species are not considered in this assessment as they are not immersing their body partially or fully in/under the water and are therefore not likely to be impacted by underwater noise (their beaks or legs which are immersed in the water are not known to be sensitive to underwater sound); accordingly, the focus in the study being on diving birds.

Diving bird species expected to be present in the area include several pursuit diving species (penguins and cormorants), which spend a substantial amount of time underwater and dive to find food. Black swans (*Cygnus atratus*), while not a diving species per se, are equally dependent on finding food underwater, even though in the shallow inter-tidal areas where sound propagation is substantially reduced; moreover, they temporarily immerse only their head, neck, and potentially the upper part of their bodies.

Table 11. List of marine fauna species potentially occurring in the project area.

Taxonomic group	Common name	Scientific name	Status under EPBC Act/ FFG Act	Frequency range of vocalisations[1] and hearing	Sensitivity to underwater sound
Marine mammals					
Toothed whales	Bottlenose dolphin, subspecies: Burrunan dolphin[2]	*Tursiops aduncus australis*	Listed	Medium to high	High
	Short-beaked common dolphin	*Delphinus delphis*	Listed	Medium to high	High
Pinnipeds	Australian fur seal	*Arctocephalus pusillus dosiferus*	Listed	Low to medium	High
Fishes					
Finfish (Ray-finned fish, Teleost)	Australian anchovy	*Engraulis australis*	Not listed	Low	High
	Whiting	*Sillago spp.*	Not listed	Low	Moderate
	Silver sea bream	*Pagrus auratus*	Not listed	Low	Moderate
	Flathead	*Platycephalus spp.*	Not listed	Low	Moderate
	Australian grayling	*Prototroctes maraena*	Listed	Low	Moderate
Sharks, rays (Chondryich-tyes)	Stingrays	Myliobatiformes	Not listed	Low	Low
Invertebrates					
Crustaceans	Crabs	Brachyura	Not listed	Low[3]	Unknown
Snapping shrimps	Snapping shrimp	*Alpheidae spp.*	Not listed	Low[3]	Unknown
Shellfishes/ Molluscs	Bivalves	Bivavlia	Some listed	Unknown	Unknown
Cephalopods	Squid	*Coleoidea*	Not listed	Low[2]	Moderate[3]
Avifauna[4]					
Penguins	Little (Fairy) penguin	*Eudyptula minor*	Listed	Low to medium[5]	Moderate
Cormorants	Australian pied cormorant	*Phalacrocorax varius*	Not listed	Low to medium[5]	Moderate
	Little black cormorant	*Phalacrocorax sulcirostris*	Not listed	Low to medium[5]	Moderate
	Black cormorant	*Phalacrocorax carbo*	Not listed	Low to medium[5]	Moderate
	Black-faced cormorant	*Phalacrocorax fuscescens*	Not listed	Low to medium[5]	Moderate
Swans	Black swan	*Cygnus atratus*	Not listed	Low to medium[5]	Unknown

[1] Including echolocation signals.
[2] Burrunan dolphin is considered a subspecies of the bottlenose dolphin; however, there remains controversy about its taxonomic status.
[3] Based on sensitivity to particle motion.
[4] Migratory waders and other waterbirds inhabiting the Port Phillip Bay and Bellarine Peninsula Ramsar site are not considered as they are not likely to be impacted by underwater noise.
[5] Based on in-air vocalisations.

6. Construction Impacts

Impacts were assessed based on information available on the occurrence and habitat use of the species/taxa in Corio Bay, information on their sensitivity to underwater sound, and the predicted ranges for sound levels to exceed impact thresholds around the project operations (Green et al. 2021). The impacts are described in terms of their expected magnitude, extent, and duration. The situation is assessed for the pre-mitigation and residual impacts are assessed for a post-mitigation scenario where mitigation measures are implemented to avoid, minimise, or manage impacts.

Stress

Detectable anthropogenic noise can cause stress in marine animals (e.g., Richardson et al. 1995, Nowacek et al. 2007, Erbe et al. 2019). While auditory perception of a sound per se does not automatically lead to an increased stress response and onset of stress can be considered as a gradual increase with increasing received levels, it is still impossible to quantify this impact. Moreover, it remains unclear what aspects of the noise (unfamiliarity, acoustic characteristics, behavioural context) are relevant in this context, to what extent stress is caused by noise, and what consequences an audible noise exposure would have for an individual. A conservative approach, however, would be to assume that any physical effect (e.g., hearing loss, hearing impairment) or significant behavioural response in reaction to exposure to construction noise is also associated with a stress response.

Due to the limited information about acoustically induced stress responses by marine fauna, this type of impact is not assessed in more detail for any species or activity-specific context in this impact assessment.

Acoustic masking

There is no quantitative information on the acoustic masking effect of construction activities for any marine fauna species. Based on the temporal pattern of the project-related construction and operational activities, it is likely that perception of acoustic signals will be partially or fully masked but that animals can use anti-masking strategies to release from masking (see Section 4.4.3) to compensate for the effects. A few disparate masking studies on different marine taxa provide insights into the presence of such impacts and their extent. Wherever these studies are available, the relevant results will be provided in this assessment. In general, the extent of masking effects and their ecological impact for the marine fauna cannot be fully assessed and only general qualitative statements can be made.

As for assessing stress impacts, a justifiable approach would be to assume that any physical effect (e.g., hearing loss, hearing impairment) or ecologically relevant behavioural response in response to exposure to construction noise is also associated with ecologically relevant level of auditory masking.

6.1. Noise Emissions of Construction Related Activities

6.1.1. Pile driving

The sound from impact pile driving is transient, repetitive, and discontinuous (Reinhall and Dahl 2011, McPherson et al. 2017). Sound levels produced depend on several interdependent factors such as pile size, hammer strike energy, and seabed geology. Field measurements of pile driving show that most acoustic energy is generated at frequencies <1 kHz (Robinson et al. 2007, Tougaard et al. 2009) (Figure 7), although it can extend (at greatly decreased sound levels) to much higher frequencies (MacGillivray 2018), including at least 100 kHz (Tougaard et al. 2009). The repetition rate for impact pile driving is usually in the order of 30–60 strikes per minute, depending on pile diameter and hammer type.

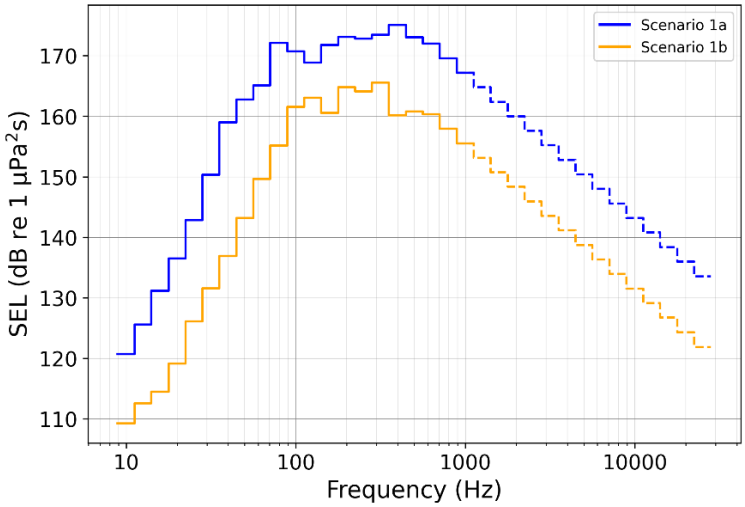


Figure 7. Maximum-over-depth decidecade band sound exposure level (SEL) at a receiver 10 m horizontally from the modelled pile driving sources. Dotted line indicates extrapolated portions of the spectra (taken from Green et al. 2021).

6.1.2. Dredging

Dredging generally produces continuous broadband sound with a peak level in the source spectrum between 100–1000 Hz (Thomsen et al. 2009, CEDA 2011, WODA 2013, Green et al. 2021) (Figure 8). Sound pressure levels can vary widely by dredger type and power, operational stage, and sediment type.

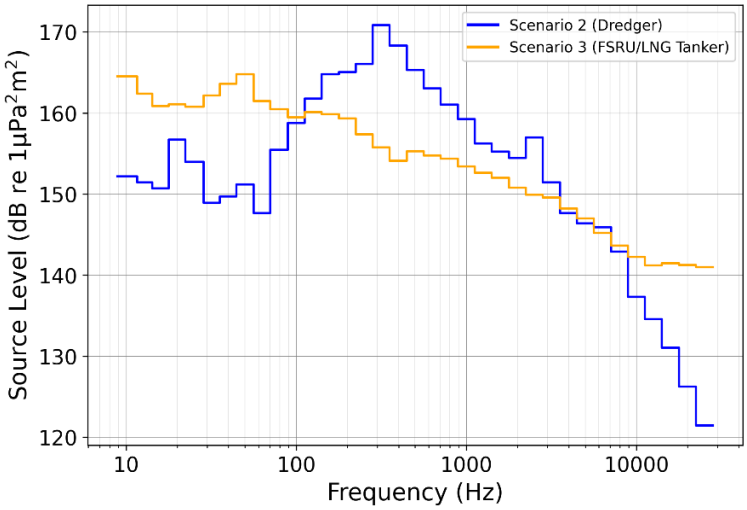


Figure 8. Decidecade band monopole source levels for dredging and vessel operations (FSRU/LNG carrier). Dredging noise spectrum derived from the backhoe dredger *New York* (Reine et al. 2014), and FSRU and LNG carrier noise spectrum derived by averaging the *Nganhurra* and *Ngujima Yin* (Erbe et al. 2013) (taken from Green et al. 2021).

6.2. Marine Mammals

6.2.1. Pile Driving

Behavioural Responses

Behavioural responses of the Burrunan dolphin and short-beaked common dolphin, which potentially occur in the project area, to impulsive noise such as emitted by impact pile driving have not been documented yet. A study on a closely related species, the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) in a busy harbour area, however, showed that impact pile driving reduced the number of animals detected in the study area (Paiva et al. 2015). Dähne et al. (2013) and Brandt et al. (2011) demonstrated avoidance of offshore pile driving activities by harbour porpoises (*Phocoena phocoena*), a smaller odontocete species over a distance of 20 km. While studies on captive animals are not necessarily representative of the behavioural responses of free-ranging animals, they provide useful information. Kastelein et al. (2013) conducted a study on a captive harbour porpoise and documented behavioural responses to playbacks of pile driving sounds. The results showed that above a received SPL of 136 dB re 1 µPa, the porpoise's respiration rate increased in response to pile driving sounds.

There is also evidence suggesting that harbour porpoises can habituate and/or adapt to impulsive anthropogenic sound in their environment (Cox et al. 2001).

Behavioural reactions of pinnipeds, such as the Australian fur seal, to pile driving impulses or comparable signals have not been investigated. A study on the effects of pile driving on ringed seals (*Phoca hispida*) at Northstar Island, Alaska, however, did not show dramatic reactions to underwater pile driving impulses with received SPL of at least 150 dB re 1 µPa (Blackwell et al. 2004). A study

conducted in the North Sea, in contrast, showed that offshore pile driving caused temporary localized displacement of harbour seals (*Phoca vitulina*) of up to 25 km from the centre of the pile driving site (Russell et al. 2016).

Hearing impairment

Sounds generated by impulsive sources such as pile driving have been tested directly and proven to cause noise-induced TTS[3] in marine mammals at high received levels. Finneran (2015) reviewed the current state of knowledge on TTS and PTS. TTS typically decreases in marine mammals relative to the logarithm of the increasing recovery time. There is, however, considerable individual difference in all TTS-related parameters between subjects and species tested to date.

Marine mammal TTS data from impulsive sources are limited to two studies with measured TTS of 6 dB or higher: Finneran et al. (2002) reported behaviourally-measured TTS of 6 and 7 dB in a beluga whale exposed to single impulses from a seismic water gun and Lucke et al. (2009) reported AEP-measured TTS of 7 to 20 dB in a harbour porpoise exposed to single impulses from a seismic airgun.

In addition to these data, Kastelein et al. (2015a) reported mean TTS of 4 dB at 8 kHz and 2 dB at 4 kHz after a harbour porpoise was exposed to a series of impulsive sounds produced by broadcasting underwater recordings of impact pile driving strikes through underwater sound projectors. The cumulative SEL was approximately 180 dB re 1 $\mu Pa^2 \cdot s$. The pressure waveforms for the simulated pile strikes exhibited significant "ringing" not present in the original recordings, and most of the energy in the broadcasts was between 500 and 800 Hz. As a result, some questions exist regarding whether the fatiguing signals were representative of underwater pressure signatures from impact pile driving.

Several impulsive noise exposure studies have also been conducted without measurable TTS. Finneran et al. (2000) exposed dolphins and beluga whales to single impulses from an "explosion simulator," and Finneran et al. (2015) exposed three dolphins to sequences of ten impulses from a seismic airgun (maximum cumulative SEL: 193 to 195 dB re 1 $\mu Pa^2 \cdot s$, PK: 196 to 210 dB re 1 µPa) without measurable TTS.

Pinnipeds seem to be more resilient to exposure to impulsive noise compared to cetaceans. Finneran et al. (2003) exposed two sea lions to single impulses from an arc-gap transducer with no measurable TTS (maximum unweighted SEL: 163 dB re 1 $\mu Pa^2 \cdot s$, PK: 183 dB re 1 µPa). Similarly, Reichmuth et al. (2016) exposed a spotted (*Phoca largha*) and a ringed (*Pusa hispida*) seal to seismic airgun impulses with received unweighted SEL from 165 to 181 dB re 1 μPa^2 s and peak-to-peak sound pressures from 190 to 207 dB re 1 µPa but did not measure any TTS.

Impact ranges

The impact ranges, i.e., the farthest extent at which the impact thresholds for marine mammals are exceeded by pile driving noise, were modelled by Green et al. (2021) and are reproduced in Table 12 for onset of behavioural responses and Table 13 for onset of hearing impairment (TTS and PTS).

The modelling results indicate that dolphin and pinniped behaviour is likely to be affected over a range of up to 800 m from the construction site during pile driving activities. TTS is only expected in the immediate vicinity of the construction site during these activities and PTS was not predicted within the limits of the modelling resolution (20 m).

[3] No PTS experiments have been performed on marine mammals.

Table 12. Behavioural impact ranges for pile driving; horizontal distances (m) from the dolphin pile (Scenario 1a) and mooring pile (dolphin pile (Scenario 1b) to maximum-over-depth per-strike SPL isopleths based on noise exposure criteria for non-impulsive sounds (NOAA 2019) (Green et al. 2021, Section 4.1.1).

SPL (L_p; dB re 1 µPa)	1a - Dolphin Pile		1b - Mooring Pile	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
180	0.03	0.03	–	–
170	0.26	0.24	0.05	0.05
160*	**0.80**	**0.71**	**0.26**	**0.23**
150	2.00	1.48	1.05	0.93

* Marine mammal behavioural threshold for impulsive sound sources (NOAA 2019)

Table 13. TTS ranges for marine mammals for pile driving noise based on noise exposure criteria for impulsive sounds (Southall et al. 2019); maximum (R_{max}) horizontal distances (m) from the dolphin pile (Scenario 1a) and mooring pile (dolphin pile, Scenario 1b) to maximum-over-depth weighted SEL isopleths for marine mammals (Southall et al. 2019) (Green et al. 2021, Section 4.1.1).

Hearing group	PTS					TTS				
	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	Single pile		3 piles		SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	Single pile		3 piles	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Dolphin pile										
HF cetaceans	185	–	–	–	–	170	0.03	0.03	0.07	0.07
Otariid pinnipeds (OCW)	203	–	–	–	–	188	0.04	0.04	0.10	0.09
Mooring pile										
HF cetaceans	185	–	–	–	–	170	–	–	–	–
Otariid pinnipeds (OCW)	203	–	–	–	–	188	–	–	–	–

A dash indicates the threshold was not reached within the limits of the modelling resolution (20 m).

Conclusions

With several piles installed per day, pile driving activity could potentially lead to a temporary and spatially limited exclusion of marine mammals from the surrounding area of the construction site. It must be noted that the behavioural threshold value for impulsive sound sources promulgated by NOAA (2019) is based on extrapolation from other species and other sound sources; moreover, the threshold assumes and regulates each sound source in isolation, i.e., it does not account for the presence of other sounds, such as from vessel or industrial activities in adjacent areas. While representing the currently most applied regulatory threshold for onset of behavioural responses in marine mammals, the NOAA thresholds are single value thresholds that do not incorporate the context specificity and complexity of animal behaviour and do not account for the severity and duration of behavioural responses. It is most likely that severity and duration of the behavioural responses increase with increasing received sound levels, i.e., ranging from subtle and short-lived responses at the outer limits of the predicted impact ranges to more severe and longer lasting responses close to the sound source. As indicated by the information published in the scientific literature, dolphins are more likely to avoid the area surrounding the construction site while pinnipeds may still venture into the area if, e.g., a good food resource can be found in the area. The potential exclusion zone is comparatively small relative to the overall habitat of the marine mammals and being excluded from the

area is not likely to have any ecologically significant consequences for the animals. It is likely that the animals would gradually return into the area after the noise emissions have ceased or abated.

As dolphins and seals are known to be highly mobile species, no marine mammal is likely to stay within the TTS range of 100 m around the construction site for the entire piling sequence of even a single pile; the likelihood of incurring TTS is therefore negligible.

6.2.2. Dredging

Unless an activity like dredging occurs in an otherwise acoustically undisturbed environment, it is difficult to assess distinct impacts of a on marine mammals specifically for this activity. As the soundscape in Corio Bay is dominated by continuous sounds such as vessel traffic (Wilson et al. 2021) dredging noise contributes to the cumulative sound field in the bay and its impact merges with the potential impact of other, existing sound sources. Nevertheless, potential impacts can be assessed based on the exceedance of noise exposure thresholds for marine mammals (Section 3.2.2).

Behavioural Responses

There are a few studies involving dredges, although these included very limited information about the sound levels during the exposures. Using fixed PAM (T-PODs, Chelonia Ltd., UK), Diederichs et al. (2010) found short-term avoidance in harbour porpoises at ranges of 600 m from a trailing suction hopper dredger operating to the west of Sylt (Germany, North Sea). Pirotta et al. (2013) also noted that presence of bottlenose dolphins in foraging areas in Aberdeen Harbour, Scotland, declined as dredging intensity increased. Aberdeen Harbour is subject to high shipping activity year-round, and thus dolphins are accustomed to high levels of vessel disturbance. In this case, it was possible for the authors to link avoidance to dredging activity noise and not vessel presence in general.

Hearing impairment

Noise-induced hearing impairment from exposure to non-impulsive sound such as vessel or dredging operations has not been directly observed or measured in free-ranging marine mammals. Many studies have been conducted on marine mammals in controlled conditions to investigate noise-induced threshold shift phenomena. The experiments have focused on measuring TTS exposed to intense tones and band-limited noise with various sound pressure levels, frequencies, durations, and temporal patterns. These studies have been performed with bottlenose dolphins and beluga whales (*Delphinapterus leucas*), and a harbour porpoise exposed to tones with durations ranging from 1 s to 1 h. Most of these studies employed non-impulsive exposures, though four studies used intermittent tones (Mooney et al. 2009, Finneran et al. 2010, Kastelein et al. 2014, Kastelein et al. 2015b). Tonal signals may be used to represent the effects of military sonars, fish finders, depth sounders, and other sources emitting narrowband signals but cannot be taken as proxy for exposure to vessel or dredging noise. The only generalisations that can be made from the results of these studies is that the temporal pattern of noise exposure affects the resulting threshold shift and for intermittent noise, the quiet periods between noise exposures allow some recovery of hearing thresholds compared to noise that is continuously present with the same total SEL (Ward 1997).

Impact ranges

The impact ranges, i.e., the farthest extent at which the impact thresholds for marine mammals are exceeded by dredging noise, were modelled by Green et al. (2021) and are reproduced in Table 14. for onset of behavioural responses and Table 15 for onset of hearing impairment (TTS and PTS). Dredging noise is classified as a continuous sound type and governed by substantially lower thresholds for onset of behavioural responses in marine mammals compared to impulsive noise. While the SPL levels are lower for dredging than for pile driving, the impact ranges are extending to a maximum of 1.84 km from the source.

Table 14. Behavioural impact ranges for marine mammals for dredging noise based on noise exposure criteria for non-impulsive sounds (NOAA 2019); horizontal distances (m) from the dredger (Scenario 2a Berth & swing basin dredging; Scenario 2b: Seawater pipe dredging) to maximum-over-depth per-strike SPL isopleths are given (Green et al. 2021, Section 4.2.1).

SPL (L_p; dB re 1 µPa)	2a – Berth & swing basin Dredging		2b – Seawater pipe Dredging	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
140	0.12	0.11	0.15	0.14
130	0.80	0.64	0.51	0.47
124.6[a]	1.11	1.01	1.16	1.00
119.6[b]	1.60	1.47	1.90	1.66
120[c]	**1.55**	**1.43**	**1.84**	**1.60**

[a] Median ambient level.
[b] 5th percentile ambient level
[c] Marine mammal behavioural threshold for non-impulsive sounds (NOAA 2019)

Table 15. TTS ranges for marine mammals for dredging noise based on noise exposure criteria for non-impulsive sounds (Southall et al. 2019); maximum horizontal distances (m) from the dredging scenarios (Scenarios 2a and b) to maximum-over-depth weighted SEL isopleths are given. PTS thresholds were not exceeded. (Green et al. 2021, Section 4.2.1).

Hearing group	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	2a – Berth & swing basin Dredging		2b – Seawater pipe Dredging	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
HF cetaceans	178	0.01	0.01	0.01	0.01
Otariid pinnipeds (OCW)	199	<0.01	<0.01	0.01	0.01

Conclusions

Dredging during construction could potentially lead to a temporary and spatially limited exclusion of marine mammals from the surrounding area of the construction site. As pointed out for impulsive (pile driving) noise, it must be noted that the behavioural threshold value for non-impulsive sound sources promulgated by NOAA (2019) is also based on extrapolation from other species and other sound sources; moreover, the threshold assumes and regulates each sound source in isolation, i.e., it does not take the presence of other sounds such as from vessel or industrial activities in adjacent areas into account. While representing the currently most applied regulatory threshold for onset of behavioural responses in marine mammals, the NOAA thresholds are single value thresholds that do not incorporate the context specificity and complexity of animal behaviour and do not account for the severity and duration of behavioural responses. It is most likely that severity and duration of the behavioural responses increase with increasing received sound levels, i.e., ranging from subtle and short-lived responses at the outer limits of the predicted impact ranges to more severe and longer lasting responses close to the sound source. As indicated by the information published in the scientific literature dolphins are more likely to avoid the area surrounding the construction site while pinnipeds may still venture into the area if, e.g., a good food resource can be found in the area. The potential exclusion zone is comparatively small relative to the overall habitat of the marine mammals and being excluded from the area is not likely to have any ecologically significant consequences for the animals. It is likely that the animals would gradually return into the area after the noise emissions have ceased or abated.

With TTS ranges of 10 m or less, this impact is not expected to occur in marine mammals from exposure to dredging noise as they are highly mobile species and are unlikely to stay close to the area during dredging.

6.3. Fishes

6.3.1. Pile Driving

Behavioural responses

The published information on behavioural responses of fishes to pile driving sound is relatively scarce. Ruggerone et al. (2008) conducted a behavioural response study in juvenile Coho salmon (*Oncorhynchus kisutch*) that were held in cages next to a pile driving operation in a harbour. No apparent change in behaviour during the pile driving was reported, as less than 10% of the fishes exhibited a startle response during the first or subsequent hammer strikes of each pile.

In controlled exposure experiment, Mueller-Blenkle et al. (2010) exposed Atlantic cod and sole (*Solea solea*) held in two large (40 m) net pens located in a quiet bay to playbacks of pile driving noise. They tracked their movements visually and quantified both the received sound pressure level and particle motion. Sole showed an increase in swimming speed at received peak sound pressure levels (PK) of 144–156 dB re 1µPa, and cod exhibited significant freezing response at onset and cessation of playback at received peak sound pressure levels of 140–161 dB re 1 µPa (particle motion was determined to be between 6.51 × 10^{-3} m/s^2 peak and 8.62 × 10^{-4} m/s^2 peak). The authors report a high variability in behavioural reactions across individuals and a decrease of response with multiple exposures.

In a sound playback experiment in an enclosed, quiet, coastal sea lough, Hawkins et al. (2014) exposed free-living pelagic fishes to sound playback of synthetic, low-frequency, impulsive sounds, mimicking some of the features of sounds produced by pile drivers and seismic airguns. Behavioural responses of fishes were observed with a sonar/echo sounder. The fishes they encountered were predominantly sprat and Atlantic mackerel (*Scomber scombrus*) and were not accustomed to heavy disturbance from shipping and other intense sound sources. Following a short latency, sprat schools reacted to sound exposure with lateral dispersal, taking them outside the sonar beam. The fishes often then reappeared at a greater depth recombined into a school. Mackerels responded by dispersing and/or a rapid depth change. The lowest received sound pressure level (PK-PK) eliciting a response in free-living sprat was 140 dB re 1 µPa, while mackerel responded to a received sound pressure level of 143 dB re 1 µPa. There was an increase in the proportion of sprat and mackerel schools responding to sound playback with increasing sound levels. The 50% response level for sprat was at a received sound pressure level (peak-to-peak, PK-PK) of 163.2 dB re 1 µPa, for mackerel schools the 50% level was reached at a peak-to-peak sound pressure level (PK-PK) of 163.3 dB re 1 µPa.

Acoustic masking

There are no studies investigating the effect of dredging noise on fish; instead, results from studies on effects of another non-impulsive sounds source, vessel operations, is used as a proxy here.

Scholik and Yan (2001), Vasconcelos et al. (2007), and Codarin et al. (2009) demonstrated masking effects due to vessel noise in several marine fish families. They measured decreased hearing sensitivities between 10 dB and more than 30 dB in the presence of vessel noise.

Codarin et al. (2009) investigated the effects of ambient and ship noise on representatives of three vocal fish families with different hearing abilities. In their laboratory study, they found that the noise

emanating from recreational shipping substantially masked the auditory perception in these fish species, with a pronounced effect on the frequencies used for communication.

Stanley et al. (2017) modelled the effective communication range in Atlantic cod and haddock at three spawning locations. These areas are characterised by elevated levels of anthropogenic underwater sound, particularly due to commercial shipping. They found near constant high levels of low-frequency sound and consequentially a reduction in the communication space during times of high vocalisation activity for these fish species.

TTS/PTS

Casper et al. (2013) used a specially designed wave tube to expose hybrid striped bass (white bass *Morone chrysops* and striped bass *Morone saxatilis*) and Mozambique tilapia (*Oreochromis mossambicus*) to pile driving sounds and investigated the effects on hair cells. Exposure to 960 pile driving strikes at SEL_{24h} levels of 210–216 dB re 1 $\mu Pa^2 \cdot s$ caused barotraumas in both species. Hair cells loss, in contrast, was only found at significant levels after exposure to the highest sound level in some striped bass and in a single tilapia.

Injury and Mortality

Casper et al. (2012b) showed that fishes can recover from less severe injuries under laboratory conditions, suggesting that minor injuries do not inevitably lead to mortality. Nevertheless, in open waters, minor injuries have the potential to reduce the animal's fitness to the extent that its ability to find food decreases and its risk of being predated increases (Halvorsen et al. 2011, 2012b).

Mortality is either a direct effect of barotrauma (in the case of severe injury) or indirect if an animal is moderately injured. Halvorsen et al. (2011, 2012a, 2012b) exposed different fish species in a well-controlled acoustic environment (using a wave tube) to signals replicated from actual pile driving operations and found that the extent of injury increased with sound exposure levels and number of pile driving strikes. Their results demonstrated that an appropriate metric for guidelines may be a combination of the single strike SEL (SEL_{ss}) and the number of strikes that are used to yield the SEL value, with the understanding that at the same SEL value, higher SEL_{ss} and fewer strikes can result in the same onset of effects as a lower SEL_{ss} and more strikes (Popper et al. 2014).

Data on sound-induced direct mortality in fishes are scarce and mainly related to underwater explosions (Popper and Hastings 2009). Observations conducted during pile driving activities showed that fishes within a few metres of driving a large pile were killed (Caltrans 2001, 2004), but no data from these studies document the sound levels to which the fishes were exposed or the extent of exposure before mortality occurred. At greater distances from pile driving activities, data from caged fishes show no mortality and no damage that can be clearly associated with pile driving activities (Abbott et al. 2005, Nedwell et al. 2006, Ruggerone et al. 2008, Caltrans 2010a, 2010b, Houghton et al. 2010).

Impact ranges

Pile driving noise is expected to exceed the noise exposure thresholds for recoverable injury at a distance of up to 60 m and the threshold for onset of TTS at a distance of up to 870 m from the sound source (Table 16).

Table 16. Impact ranges for fishes for pile driving noise; horizontal distances (m) from the pile driving site (Scenario 1a Dolphin pile; Scenario 1b: Mooring pile) to maximum-over-depth unweighted SEL isopleths for fish (Popper et al. 2014) (taken from Green et al. 2021, Section 4.1.1). A dash indicates the threshold was not reached within the limits of the modelling resolution.

Hearing group	SEL_{24h} threshold ($L_{E,}$; dB re 1 µPa²s)	1a – Dolphin pile				1b – Mooring pile			
		Single pile		3 piles		Single pile		4 piles	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Mortal Injury									
Fish: No swim bladder	219	—	—	—	—	—	—	—	—
Fish: Swim bladder not involved in hearing; and eggs and larvae	210	—	—	0.02	0.02	—	—	—	—
Fish: Swim bladder involved in hearing	207	0.02	0.02	0.03	0.03	—	—	—	—
Recoverable Injury									
Fish: No swim bladder	216	—	—	—	—	—	—	—	—
Fish: Swim bladder not involved in hearing; and swim bladder involved in hearing	203	0.03	0.03	0.06	0.06	—	—	—	—
TTS									
Fish: No swim bladder; swim bladder not involved in hearing; and swim bladder involved in hearing	186	0.52	0.48	0.87	0.77	0.05	0.05	0.11	0.10

Conclusions

Behavioural effects in fishes caused by exposure to pile driving are likely limited to changes in their vertical position in the water column, their aggregation behaviour and spatial avoidance of the ensonified area. Based on the qualitative criteria developed by Popper et al. (2014), there is a moderate likelihood that Australian anchovy, the only fishes species in the project area with high sensitivity to underwater sound, would be exposed to noise levels exceeding their threshold for onset of behavioural responses at ranges exceeding 1 km; behavioural impact ranges for all other fish species are likely limited to ranges closer to the sound sources, i.e., more likely in the range of 10–100 m. It is likely that that the animals would gradually return into the area after the noise emissions have ceased or abated.

The ranges to recoverable injury and onset of TTS for all fish species range between are 60 m and 870 m, respectively for pile driving noise. However, given that the duration required to accumulate the acoustic energy to reach the threshold is 12 and 48 hours, respectively, it is unlikely that any fish species would experience such impacts.

6.3.2. Dredging

As specific information on impact of dredging noise on fishes is not available, knowledge about impact of another continuous noise source, vessel noise, must be used as a proxy.

Behavioural responses

Fishes can respond to approaching vessels by diving towards the seafloor or by moving horizontally out of the vessel's path, with reactions often initiated well before the vessel reaches the fishes (Ona et al. 2007, Berthe and Lecchini 2016). The avoidance of vessels by fishes has been linked to the high levels of infrasonic and low-frequency noise (>10 to 1000 Hz) emitted by the ships. Accordingly, it was suggested that silent ships have a higher chance of encountering more fishes than noisier ones (De Robertis et al. 2010). This assumption was initially contradicted when two research vessels were compared with regard to their effect on schooling herring (Ona et al. 2007). The authors found that the reaction initiated by the silent vessel was stronger and more prolonged than the one initiated by the conventional vessel. In a comment to this publication, Sand et al. (2008) pointed out that fishes are highly sensitive to particle acceleration and that the cue, in this case, may have been low-frequency particle acceleration caused by displacement of water by the moving hull in the near field of the vessel. This fact would explain the stronger response to the larger noise-reduced vessel in the study by Ona et al. (2007), which would have displaced more water as it approached.

Nedelec et al. (2016) investigated the response of reef-associated fishes by exposing them in their natural environment to playback of motorboat noise. They found that juvenile fishes increased hiding and ventilation rate after a short-term boat noise playback, but responses diminished after long-term playback thus indicating habituation to sound exposure over longer durations. These results were corroborated by Holmes et al. (2017) who also observed short-term behavioural changes in juvenile reef fishes after exposure to boat noise as well as desensitisation over longer exposure periods.

Hearing impairment

A single study reported temporary threshold shift caused by exposure to vessel noise: Scholik and Yan (2001) exposed fathead minnows (*Pimephales promelas*) for 2 h to sound playback recorded from small boats at a level of 142 dB re 1 µPa. They measured noise-induced threshold shift (NITS) of 7.8–13.5 dB at frequencies between 1–2 kHz, the most sensitive hearing range of this species.

Impact ranges

Dredging noise is expected to exceed the noise exposure thresholds for recoverable injury and TTS at a distance of 10 m from the sound source (Table 17).

Table 17. Impact ranges for fishes for dredging noise; horizontal distances (m) from the dredger (Scenario 2a Berth & swing basin dredging; Scenario 2b: Seawater pipe dredging) to maximum-over-depth per-strike SPL isopleths based on noise exposure criteria for vessel noise (Green et al. 2021, Section 4.2.1). A dash indicates the threshold was not reached within the limits of the modelling resolution.

SPL (L_p; dB re 1 µPa)	2a – Berth & Swing basin Dredging		2b – Seawater pipe Dredging	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170*	**<0.01**	**<0.01**	**–**	**–**
160	0.01	0.01	0.01	0.01
158+	**0.01**	**0.01**	**0.01**	**0.01**
150	0.04	0.04	0.03	0.03

* Temporary threshold shift in fishes, 12 hours exposure (Popper et al. 2014)

[+] Recoverable injury threshold for fishes, 48 hours exposure (Popper et al. 2014).

Conclusions

Behavioural effects in fishes caused by exposure to dredging noise are likely limited to changes in their vertical position in the water column, their aggregation behaviour and spatial avoidance of the ensonified area. Based on the qualitative criteria developed by Popper et al. (2014), there is a moderate likelihood that fish species in the project area would be exposed to noise levels exceeding their threshold for onset of behavioural responses at ranges up to 100 m. It is likely that the animals would gradually return into the area after the noise emissions have ceased or abated.

The ranges to onset of TTS and recoverable injury for fishes are 10 m or less for dredging noise; given that the duration required to accumulate the acoustic energy to reach the threshold is 12 and 48 hours, respectively, it is unlikely that any fishes would experience such impacts.

6.4. Invertebrates

It remains unclear what physical parameters of underwater sound marine invertebrates are sensing (see Section 4.3.3) and what role and ecological relevance sound has for these species. Accordingly, studies conducted on impacts of noise focus on different effects for these species as compared to marine mammals and fishes, i.e., morphological, and physiological studies and investigations of abundance and mortality replace studies of behavioural responses and auditory impairment. There are no noise exposure criteria for invertebrates and, accordingly, impact ranges were not calculated.

6.4.1. Pile Driving

Specific information about effects of sound from offshore pile driving activities on invertebrates is not available. Instead, information on effects of another impulsive sound source, marine seismic airguns, is used as proxy for assessing the potential effects of pile driving. It must be noted though that sound levels emitted by the two sources and other acoustic signal characteristics differ between the two signal types, and therefore results from seismic airguns can only be taken as indicative of potential effects of pile driving.

Moreover, pile driving impulses introduce a substantial amount of energy into the sediment which may be detected by bottom-living marine invertebrates as ground vibration and induce behavioural responses (Roberts et al. 2015, Roberts and Elliott 2017). Many marine invertebrates are permanently, or at least sporadically, in contact with bottom sediment. The sediment, however, does not follow exactly, or at all, the movement of the surrounding water. Therefore, exposure to underwater sound will result in a relative movement between the body of these animals and the oscillating water column. Accordingly, marine benthic invertebrates face a different situation and perception from free-swimming or neutrally buoyant animals such as demersal or pelagic fishes or marine mammals. In a discussion of the pressure-related as well as the particle motion-related sensitivity in marine invertebrates, it is therefore important to also consider the propagation of vibration through the ground. For benthic organisms, it is likely that this type of vibration is of similar if not greater importance than the water-borne vibration or even the compressional component of a sound (Roberts and Elliott 2017). The published scientific information on vibration sensitivity in marine invertebrates is extremely scarce (Roberts et al. 2015, Roberts et al. 2016). Most information on vibration sensitivity has been derived from semi-terrestrial species known to use vibration in mating behaviour (Aicher and Tautz 1990). Only a small number of studies have indicated reception of vibration and behavioural responses in bivalves, which include closing syphons and, in more active molluscs, moving away from the substrate (Mosher 1972, Ellers 1995, Kastelein 2008). Nevertheless, to date, there is no

convincing evidence for any significant effects induced by non-impulsive noise in benthic invertebrates.

Due to the lack of quantitative information on the impacts of such exposure, however, it is impossible to specifically assess the effect of substrate-borne vibration on marine invertebrates. Moreover, given the rapid attenuation of vibrational signals beyond the near field of a sound source (Morley et al. 2014), it is unlikely that these stimuli are causing more than behavioural effects (such as flight or retraction) or physiological (e.g., stress) responses.

In the case of marine invertebrates living at least temporarily in the water column, several studies have investigated their susceptibility to noise-induced effects:
Aguilar de Soto et al. (2013) indicated that New Zealand scallop (*Pecten novaezelandiae*) larvae exposed to extended periods of airgun signals during their ontogeny may be negatively affected. The authors found an increase in abnormality and mortality rates in scallop larvae after continued exposure to playbacks of intense airgun signals in a laboratory experiment. These results indicated that there may be species-specific differences in sensitivity of early life stages to sound exposure.

In a field study, Przeslawski et al. (2016) focused on potential short-term impacts of marine seismic surveys on scallops in the Gippsland Basin. Commercial scallops (*Pecten fumatus*) were not abundant in the study area, and there was no evidence of mortality or change in the condition of scallops two months after a marine seismic survey ended. Analysis of images and samples revealed site-specific variance in scallop abundance, size, condition, and assemblages were higher than the observed effects from exposure. The analysis of the acoustic parameters, however, is likely compromised by unsuitable use of acoustic modelling methods and no close-range recordings.

Morris et al. (2018) assessed the effects of industry scale seismic exposure on catch rates of snow crab (*Chionoecetes opilio*) along the continental slope of the Grand Banks of Newfoundland. In a Before-After-Control-Impact study over two years they did not find evidence supporting the contention that seismic activity negatively affects catch rates in shorter term (i.e., within days) or longer time frames (weeks). However, significant differences in catches were observed across study areas and years. Their results suggest that if effects from exposure to seismic airgun impulses on snow crab harvests do exist, they are smaller than changes related to natural spatial and temporal variation.

Day et al. (2019) tested the impact of seismic surveys on the righting reflex and statocyst morphology of the rock lobster (*Jasus edwardsii*). Their results show that exposure to seismic airgun impulses with calculated received PK levels of up to 205 dB re 1 µPa and maximum SEL of 191 dB re 1 $\mu Pa^2 \cdot s$ can cause morphological damage to the sensory organ of rock lobster. Two reflex behaviours, tail tonicity or extension and righting behaviour, were assessed. These reflexes have been used in lobster fishery industries in grading animals for their likelihood of survival. While results for tail tonicity were inconclusive, there was a significant response to exposure in the righting response, which is a more complex reflex requiring neurological control and muscle coordination. The lobsters showed impaired righting and significant damage to the sensory hairs of the statocyst. Reflex impairment and statocyst damage persisted over the course of the experiments and did not improve following moulting.

Consistent with other studies of high-intensity, low-frequency sound exposure of crustaceans and molluscs (reviewed by Edmonds et al. 2016, Carroll et al. 2017), the study found no evidence of mass mortality directly following airgun exposure. Consequently, the authors rejected the hypothesis that exposure to seismic airguns causes immediate mass mortality.

Day et al. (2017) investigated the effect of exposure to airgun impulses on scallops (*Pecten fumatus*). The authors conclude that exposure to seismic signals significantly increases mortality, particularly over a chronic (months post-exposure) time scale, though not beyond naturally occurring rates of mortality. The calculated maximum PK levels at the position of the bivalves reached 213 dB re 1 µPa and maximum SEL of 198 dB re 1 $\mu Pa^2 \cdot s$.

Attention has also been given to potential impacts of underwater noise on cephalopods; Guerra et al. (2004) found statocyst and organ damage in seven stranded giant squids and considered these

findings as circumstantial evidence for noise-induced effects caused by nearby seismic surveys. McCauley et al. (2000) and Fewtrell and McCauley (2012) conducted controlled exposure experiments with caged squid (*Sepioteuthis australis*) using a single seismic airgun as the sound source. They found that in one trial, where the received level of the first seismic air gun impulse was 162 dB re 1 µPa²·s, the squid inked (an alarm response). This response was not observed again within this trial, however the authors stated that it was unknown if this was due to depleted ink reserves or habituation. In two other trials, the initial received levels were lower (132 and 146 dB re 1 µPa²·s per-pulse SEL), and although the received levels did exceed 162 dB re 1 µPa^{2}s, no inking behaviour was observed. Exposure to airgun impulses at sound levels greater than 147 dB re 1 µPa²·s induced the caged squid to start jetting away from the sound source (i.e., an avoidance behaviour). The authors hypothesised that the results also suggest that a gradual increase in received levels and prior exposure to seismic air gun impulses decreases the severity of the alarm responses in this species, i.e., the animals likely habituated to the sound exposure. This aligns with findings of general habituation in response to predators in squid (Long et al. 1989). While Fewtrell and McCauley (2012) stated that their results were preliminary, the level associated with inking (162 dB re 1 µPa²·s per-pulse SEL) has been considered as a startle response threshold for both squid and octopus (relevant particle motion levels were not reported by the authors).

6.4.2. Dredging

No specific information about effects of sound emitted by offshore drilling activities on bivalves and decapods is available. Instead, information on impacts from vessel noise and other non-impulsive sound sources is used as proxy information for assessing the potential impact of dredging noise on marine invertebrates.

Filiciotto et al. (2016) examined the effects of recorded boat noise on the behaviour and biochemistry of the common prawn (*Palaemon serratus*). The exposure elicited changes in locomotor patterns and caused physiological and behavioural effects that the authors identified as stress-related responses. Two tank-based experiments investigated the physiological and behavioural effects of sound exposure on marine invertebrates. The sound generated by tidal and wind turbines was found to delay the time to metamorphosis between larval stages in estuarine crabs (Pine et al. 2012). Celi et al. (2013) documented statistically significant variations in haemato-immunological parameters as well as a reduction in agonistic behaviour in red swamp crayfish (*Procambarus clarkii*) after constant exposure to frequency sweeps over a duration of 30 min. The signals covered a frequency range between 0.1–25 kHz and reached a peak amplitude 148 dB re 1 µPa at 12 kHz.

Mooney et al. (2016) tested unconditioned behavioural responses to tonal signals in squid (*Doryteuthis pealeii*). The reactions elicited by sound exposure from 80 Hz to 1 kHz ranged from inking and jetting to body pattern changes and fin movements. Animals responded to the lowest sound levels in the 200–400 Hz range.

Morphological impact

André et al. (2011) and Solé et al. (2013) provide evidence of acoustic trauma in different cephalopod species (*Sepia officinalis*, *Octopus vulgaris*, *Loligo vulgaris*, and *Illex condietii*) that they exposed (underwater) for 2 h to low-frequency sweeps between 50–400 Hz (1 s duration) generated by an in-air speaker. The received level at the animals' position was 157 dB re 1 µPa with peak levels (unspecified) up to 175 dB re 1 µPa. Both studies report permanent and substantial morphological and structural alterations of the sensory hair cells of the statocysts following noise exposure with no indication of recovery. In a more recent experiment, Solé et al. (2017) exposed common cuttlefish (*Sepia officinalis*) to tonal sweeps between 100–400 Hz in a controlled exposure experiments in open water. Their results show a clear statistical relationship between the cellular damage detected in the sensory cells of the individuals exposed to the sound sweeps and the distance to the sound source.

The authors measured the particle motion and pressure of the signals received by the animals. Due to the signal type (frequency sweep), they could only provide the maximum received levels or an estimate thereof, respectively; the maximal particle motion level was 0.7 ms^{-2} observed at 1 m depth, the pressure reached levels of 139–142 dB re 1μPa^2. The sound pressure levels reported are only slightly higher than the hearing threshold determined for longfin squid (*Loligo pealeii*), another decapodiforme cephalopod, measured by Mooney et al. (2010). The maximum particle motion (reported in terms of particle acceleration) reported by Solé et al. (2017) is in the same order of magnitude as the behavioural thresholds measured at 100 Hz by (Packard et al. 1990) using a standing wave acoustic tube.

Conclusions

There are limited and inconclusive data available on the potential for behavioural responses and noise-induced physical effects on marine invertebrates. Theoretically, behavioural responses as well as significant sensory impairment or injury can have moderate to major consequences for an individual. In the absence of conclusive scientific information on important aspects such as the relevant physical parameters, sensory system responsible for detecting the noise, the scope of noise-induced effects and the animals' ability to compensate for the effects, however, it is impossible to assess the consequences of behavioural responses and noise-induced impairment or injury.

6.5. Avifauna

Given the small amount of information available on impacts of underwater noise on diving birds this section is assessing the potential impacts of pile driving and dredging together.

The limited scientific information on behavioural responses of flying seabirds to underwater sound indicates that the response can be species- and context-specific, i.e., responses depend on several factors (including but not limited to): life history characteristics of the species, characteristics of the noise source, sound source intensity, onset rate, distance from the noise source, presence or absence of associated visual stimuli, food and habitat availability, and previous exposure. Previous studies documented a range of bird behavioural responses to in-air noise, including no response, head turn, alert behaviour, startle response, flying or swimming away, diving into the water, and increased vocalisations (Larkin et al. 1996, Stalmaster and Kaiser 1997, Pytte et al. 2003, Plumpton et al. 2007).

To date, there have been few studies regarding behavioural responses by flying seabirds to impulsive underwater sound sources. Stemp (1985; as cited in Golde and Houtman (2012) conducted observations on the effects of impulsive sounds generated by a seismic exploration on seabirds and did not observe any negative effects.

Lacroix et al. (2003) investigated the effect of near shore seismic surveys on moulting long-tailed ducks in the Beaufort Sea, Alaska, and found no noticeable impacts on the movements or diving behaviour of ducks. During moult, the ducks' flight abilities are limited, and food requirements are high. The animals may have tolerated the seismic survey noise to stay in preferred feeding areas. Furthermore, Lacroix et al. (2003) noted that seismic (i.e., impulsive) activity did not appear to substantially change the ducks' diving intensity.

Melvin et al. (1999) examined the effect of acoustic deterrence devices (pingers) installed on fishing nets on two species of diving birds, the common murre and rhinoceros auklet (*Cerorhinca monocerata*). Fewer common murres were entangled in gillnets when the gillnets were outfitted with 1.5 kHz pingers with a source level of 120 dB re 1 µPa; however, there was no significant reduction in rhinoceros auklet bycatch in the same nets (Melvin et al. 1999, Melvin et al. 2011). Because the catchability of the nets was not reduced during the pinger trials (as compared to control trials), the murres' behavioural response was likely mediated through its acoustic perception of the signals.

Pichegru et al. (2017) investigated the behavioural response of breeding endangered African penguins to seismic surveys within 100 km of their colony in South Africa. Penguins showed a strong avoidance of their preferred foraging areas during seismic activities; foraging took place significantly farther from the survey vessel when in operation, while increasing their overall foraging effort and energy expenditure. The birds reverted to normal behaviour when the operation ceased.

In a controlled exposure experiment, Sørensen et al. (2020) exposed seven gentoo penguins (*Pygoscelis papua*) to underwater noise bursts (i.e., impulsive signals) and documented that the animals showed a graded reactions ranging from no reactions at 100 dB re 1 µPa SPL to strong reactions in more than 60% of the playbacks at 120 dB re 1 µPa SPL.

There is also insufficient information available to determine the onset thresholds of behavioural responses of diving birds from non-impulsive noise such as vessel or dredger noise; therefore, this assessment has not considered potential effects from non-impulsive noise on behaviour of diving birds.

Impact ranges

Pile driving impulses can be assumed to lead to birds avoiding the area up to a 5.76 km distance (Table 18).

Table 18. Behavioural impact ranges for diving birds for pile driving; horizontal distances (m) from the dolphin pile (Scenario 1a) and mooring pile (dolphin pile (Scenario 1b) to maximum-over-depth per-strike SPL isopleths (Green et al. 2021, Section 4.1.1)

SPL (L_p; dB re 1 µPa)	1a - Dolphin Pile		1b - Mooring Pile	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
140	4.04	2.69	2.20	1.91
130	5.12	4.23	3.70	3.23
124.6[a]	6.04	5.10	4.58	3.92
120[b]	**5.76**	**4.90**	**4.30**	**3.62**
119.6[c]	6.64	5.68	5.46	4.62

[a] Median ambient level
[b] Diving bird behavioural response threshold (OCW weighted) for impulsive noise (Sørensen et al. 2020).
[c] 5th percentile ambient level

The results documented by Sørensen et al. (2020) provide the only data set allowing to define an onset threshold for behavioural responses of birds to underwater noise; however, their results are only applicable to impulsive noise.

There is no criterion for hearing impairment (TTS) for birds; impact ranges for TTS (Table 19) were analysed based on noise exposure criteria for other carnivores in water (OCW) (see rationale in Section 3.2.5).

Table 19. TTS ranges for diving birds for dredging noise based on noise exposure criteria for non-impulsive sounds (Southall et al. 2019). PTS thresholds were not exceeded. Maximum (R_{max}) horizontal distances (m) from the dolphin pile (Scenario 1a) and mooring pile (Scenario 1b) to maximum-over-depth weighted SEL isopleths for marine mammals (Southall et al. 2019) (Green et al. 2021, Section 4.2.1). N/A = not applicable.

Hearing group	SEL_{24h} threshold ($L_{E,\ weighted}$; dB re 1 µPa²s)	1a – Dolphin Pile		1b – Mooring Pile		2a – Berth & swing basin Dredging		2b – Seawater pipe Dredging	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Pile driving									
Diving birds; proxy: Otariid pinnipeds (OCW)	188	0.04	0.04	0.10	0.09	N/A	N/A	N/A	N/A
Dredging									
Diving birds; proxy: Otariid pinnipeds (OCW)	199	N/A	N/A	N/A	N/A	<0.01	<0.01	0.01	0.01

Conclusions

It can be expected that pursuit-diving seabirds such as cormorants and penguins react to underwater sound emissions by altering or abandoning their foraging pursuits; penguins are likely to avoid ensonified areas for the duration of a sound-producing activity before returning to their habitat. It is unrealistic to assume a concrete risk for diving birds to be exposed to TTS-inducing sound levels from pile driving or dredging, as birds would have to dive constantly for 24 h (as per definition of the criterion) in a very small area (between 10 m and 100 m) around the sound sources to exceed the threshold.

6.6. Summary of Construction Impacts

Pile driving and dredging during construction would lead to a temporary and localised increase in underwater noise levels in the vicinity of the project area. Two important aspects must be considered when assessing the noise impacts related to the construction activities in Corio Bay:

1. The existing ambient noise level in the project area is high and may exceed some of the existing noise exposure criteria. Adding another noise source to the existing condition will only slightly increase the noise level in the bay but lead to an increase in levels in the vicinity of the activities.
2. The relevant information on cause-effect relationships between noise emitted by the construction activities and their impact on marine fauna are scarce or non-existent, often not specific to the type of activity (or noise emitted) or species occurring in the project area, or inconclusive. Consequently, some types of impact cannot be assessed, and/or information must be extrapolated from other species, sound sources, and even different sound types.

In an unmitigated ‘worst-case’ scenario, the most significant impacts to be expected are temporary behavioural responses over a range of several hundred metres for most species (fish and marine mammals) and for diving birds (when submerged) up to several kilometres from the project area. The impact ranges presented in this assessment indicate the onset of behavioural responses which are likely of little or no ecological relevance at their lowest level of severity and only become more severe and relevant the closer the animals are to the sound source(s). It can be expected that at received levels above the threshold, animals would react by subtly altering their behaviour. At higher received levels, i.e., closer to the sound source, where noise levels are generally higher, it is likely that animals

would abandon current behaviour. Ultimately, at the highest received levels animals would avoid the area for the duration of the sound-producing activity. The potential avoidance zones are comparatively small relative to the overall habitat of the marine mammals, birds and fishes and being excluded from these areas is not likely to have any ecologically significant consequences for the animals. It is likely that the animals would gradually return into the area after the noise emissions have ceased or abated.
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With a reasonable (proportional) set of mitigation measures implemented, the underwater noise emitted by the construction activities is not likely to have unacceptable impacts on the marine fauna in Corio Bay. Recommended mitigation measures to avoid, minimise and manage potential impacts related to underwater noise are discussed in Section 9.

7. Operation Impacts

The operational scenarios assessed in this report for the new facility include the berthed FSRU (scenario 3a) and the FSRU berthed with an LNG carrier offloading simultaneously (scenario 3b), representing the operation of the new facility during regasification.

There is no empirical information on impacts specific to the activities for either of the two scenarios; instead, general information about the noise impacts of vessel operations is used to inform this assessment (thereby reusing some of the material presented for dredging noise in Sections 6.1.2, 6.2.2, 6.3.2, 6.4.2, and 6.5). That information is replicated in the sections below to provide a complete reference framework.

The results of the propagation modelling and the assessment of acoustic impacts, while similar to those for the dredging assessment, are specific to the noise emitted by the operational activities.

7.1. Marine Mammals

Behavioural reactions

While there is no information available on behavioural responses of marine mammals to FSRUs or LNG carriers, several scientific studies investigated the effect of vessel on marine mammal (mainly cetacean) behaviour. However, an important aspect to consider when trying to extrapolate from these studies to the project is that the FSRU and LNG carrier are stationary while all behavioural observations of marine mammals were conducted on moving vessels. Cetaceans have been shown to react to the received levels (Miller et al. 2012, Kuningas et al. 2013, Miller et al. 2014), proximity of the vessels (Kruse 1991, Williams et al. 2002a, Williams et al. 2002b, Bain et al. 2006, Williams et al. 2009) and its trajectory (Dunlop et al. 2017, Sprogis et al. 2020). In contrast to a moving vessel situation, the animals in Corio Bay determine their proximity and trajectory relative to the moored vessels. There is no empirical information on behavioural responses of marine mammals available for such situations; accordingly, the assessment of project-related behavioural impacts will be limited to a general consideration of published research results from vessel effect studies.

Killer whales (*Orcinus orca*) in British Columbia, Canada, and Washington State, USA, have recently received much attention with regards to impacts from ships, given the steady decline in their population size. Changes in behaviour (i.e., less foraging and increased surface-active behaviour), respiration, and swim speed and direction occurred at received SPL above 130 dB re 1 µPa (0.01–50 kHz), and the Lombard effect (i.e., increased source level and vocalization duration) has been reported in ship noise levels above 98 dB re 1 µPa (1–40 kHz) (Williams et al. 2002b, Foote et al. 2004, Holt et al. 2009, Lusseau et al. 2009, Noren et al. 2009, Holt et al. 2011, Williams et al. 2014). This geographic area has seen a lot of ship noise recording, quantification, and impact modelling studies (e.g. Erbe 2002, Erbe et al. 2012, Erbe et al. 2014, Williams et al. 2015, Cominelli et al. 2018, Joy et al. 2019).

Beluga whales lost pod integrity in response to icebreakers, commenced rapid movement, asynchronous and shallow dives, and changed their vocal behaviour (i.e., vocalisation types) at received SPL of 94–105 dB re 1 µPa (20–1000 Hz), while narwhals changed their locomotion (i.e., exhibited more directed and slower movement, became motionless, and sank) and fell silent at received SPL of about 124 dB re 1 µPa (20–1000 Hz) (Cosens and Dueck 1988, Finley et al. 1990). Since the 1990s, beluga whale responses to boats and ships have been studied more extensively in the St. Lawrence Estuary, Canada. Here, beluga whales have shown increasing avoidance (i.e., increased dive duration and swim speed) with the number of boats, as well as other changes in both physical and acoustic behaviour (Blane and Jaakson 1994, Lesage et al. 1999). The Lombard effect

has been demonstrated as an increase in source level, vocalisation rate, and frequency (i.e., shift to higher frequencies; Lesage et al. 1999, Scheifele et al. 2005).

Dolphins were displaced or changed their site occupancy in response to vessel traffic (Lusseau 2005, Bejder et al. 2006, Rako et al. 2013, Pirotta et al. 2015, Pérez-Jorge et al. 2016). They altered their movement patterns within an area in response to vessel traffic, with animals changing their direction of travel, beginning to travel erratically, or significantly increasing traveling speeds when approached by vessels (Au and Perryman 1982, Nowacek et al. 2001, Mattson et al. 2005, Lemon et al. 2006, Lusseau 2006, Christiansen et al. 2010, Marley et al. 2017b).

Marley et al. (2017a) found that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Fremantle Inner Harbour (WA) significantly increased their average movement speeds in high vessel densities but only for some activity states. Behavioural budgets also changed in the presence of vessels, with animals spending more time travelling and less time resting or socialising.

Hearing impairment

Acoustic emissions from (moving) vessel operations have not been tested for their potential for causing TTS in marine mammals. In the absence of information for these types of acoustic signatures, conclusions on potential effects and thresholds can only be drawn from research on TTS effects of other non-impulsive sounds such as (military) sonar signals, or from studies using tones or band-limited signals as acoustic stimuli (see Finneran 2015 for review). Tonal signals may be used to represent the effects of military sonars, fish finders, depth sounders, and other sources emitting narrowband signals but cannot be taken as proxy for exposure to vessel or dredging noise.

These studies have been performed with bottlenose dolphins and beluga whales, and a harbour porpoise exposed to tones with durations ranging from 1 second to 1 hour. Most of these studies employed non-impulsive exposures, though four studies used intermittent tones (Mooney et al. 2009, Finneran et al. 2010, Kastelein et al. 2014, Kastelein et al. 2015b).

The only generalisations that can be made from the results of these studies is that the temporal pattern of noise exposure affects the resulting threshold shift and for intermittent noise, the quiet periods between noise exposures allow some recovery of hearing thresholds compared to noise that is continuously present with the same total SEL (Ward 1997).

Impact ranges

The behavioural impact ranges for operational FSRU and LNG carrier noise extend to 1.46 km (Table 20) and TTS ranges are limited to a maximum of 40 m (Table 21).

Table 20. Behavioural impact ranges for fishes for operational noise; horizontal distances (m) from the FSRU and LNG carrier (Scenario 3a: FSRU; Scenario 3b: FSRU + LNG carrier) to maximum-over-depth per-strike SPL isopleths based on noise exposure criteria for vessel noise. A dash indicates the threshold was not reached within the limits of the modelling resolution (20 m) (Green et al. 2021, Section 4.2.1).

SPL (L_p; dB re 1 µPa)	3a – FSRU		3b – FSRU + LNG carrier	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170	–	–	–	–
160	<0.01	<0.01	0.03	0.03
150	0.02	0.02	0.04	0.04
140	0.06	0.05	0.09	0.08
130	0.31	0.27	0.44	0.38
125*	0.63	0.54	0.85	0.72
120⁺	**1.10**	**0.98**	**1.46**	**1.26**

* Ambient noise floor.
⁺ Marine mammal behavioural threshold for non-impulsive sounds (NOAA 2019)

Table 21. TTS ranges for marine mammals for operational noise based on noise exposure criteria for non-impulsive sounds (Southall et al. 2019 horizontal distances (m) from the FSRU and LNG carrier (Scenario 3a: FSRU; Scenario 3b: FSRU + LNG carrier) to maximum-over-depth weighted SEL isopleths are given. PTS thresholds were not exceeded; a dash indicates the threshold was not reached within the limits of the modelling resolution (20 m) (Green et al. 2021, Section 4.2.1).

Hearing group	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	3a – FSRU		3b – FSRU + LNG carrier	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
HF cetaceans	178	0.01	0.01	0.04	0.04
Otariid pinnipeds (OCW)	199	–	–	0.03	0.03

Conclusions

Operational noise is expected to induce behavioural responses in marine mammals, most likely an avoidance of a relatively small area surrounding the sound source(s). The predicted ranges of exceedance of the behavioural threshold are however an overestimation of the true extent, given that the average ambient noise level (Wilson and McPherson 2021) already exceeds that threshold (animals in Corio Bay, in other words, are exposed daily to sustained noise levels supposed to elicit behavioural responses). Sound propagation modelling was performed for the operational scenarios in isolation; the impact assessment, however, must put the operational noise levels into context with the already existing acoustic environment. In this case, the ambient noise monitoring reveals that the behavioural impact from the FSRU and LNG carrier would not extend as far as modelled. While hearing related parameters (not elaborated on in this report) require a signal to be a few Decibels above ambient to be perceived, a precautionary estimate of potential behavioural effect range for this assessment would be the range to ambient level.

With TTS ranges of 40 m or below, this impact is not expected to occur in marine mammals because of exposure to operational noise as it is based on the extremely conservative and unrealistic assumption that animals remain stationary within this range around the sound source(s) over 24 h.

7.2. Fishes

Behavioural reactions

Like in the case of marine mammals, moving vessels provide additional sensory stimuli also to fishes and using results from a study involving moving vessel for assessing noise-induced impacts of a stationary vessel (FSRU / LNG carrier) can only be done with strong limitations. Most important in this context is the particle motion signature of a moving vessel, which is believed to cause behavioural responses in fishes (Ona et al. 2007, Sand et al. 2008)

Fishes can respond to approaching vessels by diving towards the seafloor or by moving horizontally out of the vessel's path, with reactions often initiated well before the vessel reaches the fishes (Ona et al. 2007, Berthe and Lecchini 2016). The avoidance of vessels by fishes has been linked to the high levels of infrasonic and low-frequency noise (>10 to 1000 Hz) emitted by the ships. Accordingly, it was suggested that silent ships have a higher chance of encountering more fishes than noisier ones (De Robertis et al. 2010). This assumption was initially contradicted when two research vessels were compared with regard to their effect on schooling herring (Ona et al. 2007). The authors found that the reaction initiated by the silent vessel was stronger and more prolonged than the one initiated by the conventional vessel. In a comment to this publication, Sand et al. (2008) pointed out that fishes are highly sensitive to particle acceleration and that the cue, in this case, may have been low-frequency particle acceleration caused by displacement of water by the moving hull in the near field of the vessel. This fact would explain the stronger response to the larger noise-reduced vessel in the study by Ona et al. (2007), which would have displaced more water as it approached.

Nedelec et al. (2016) investigated the response of reef-associated fishes by exposing them in their natural environment to playback of motorboat noise. They found that juvenile fishes increased hiding and ventilation rate after a short-term boat noise playback, but responses diminished after long-term playback thus indicating habituation to sound exposure over longer durations. These results were corroborated by Holmes et al. (2017) who also observed short-term behavioural changes in juvenile reef fishes after exposure to boat noise as well as desensitisation over longer exposure periods.

Acoustic masking

Scholik and Yan (2001), Vasconcelos et al. (2007), and Codarin et al. (2009) demonstrated masking effects due to vessel noise in several marine fish families. They measured decreased hearing sensitivities between 10 dB and more than 30 dB in the presence of vessel noise.

Codarin et al. (2009) investigated the effects of ambient and ship noise on representatives of three vocal fish families with different hearing abilities. In their laboratory study, they found that the noise emanating from recreational shipping substantially masked the auditory perception in these fish species, with a pronounced effect on the frequencies used for communication.

Stanley et al. (2017) modelled the effective communication range in Atlantic cod and haddock at three spawning locations. These areas are characterised by elevated levels of anthropogenic underwater sound, particularly due to commercial shipping. They found near constant high levels of low-frequency sound and consequentially a reduction in the communication space during times of high vocalisation activity for these fish species.

Hearing impairment

A single study reported temporary threshold shift caused by exposure to vessel noise: Scholik and Yan (2001) exposed fathead minnows (*Pimephales promelas*) for 2 hours to sound playback recorded from small boats at a level of 142 dB re 1 µPa. They measured noise-induced threshold shift of 7.8–13.5 dB at frequencies between 1–2 kHz, the most sensitive hearing range of this species.

Impact ranges

Operational noise, when assessed in isolation (i.e., not account for the existing ambient noise) can be assumed to lead to recoverable injury in fishes up to 30 m from the sound if the receiver is exposed to the noise over 48 hours (Table 22).

Table 22. Impact ranges for fishes for operational noise; horizontal distances (m) from the dredger (Scenario 3a: FSRU; Scenario 3b: FSRU + LNG carrier) to maximum-over-depth per-strike SPL isopleths based on noise exposure criteria for vessel noise (Green et al. 2021, Section 4.2.1)

SPL (L_p; dB re 1 µPa)	3a – FSRU		3b – FSRU + LNG carrier	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170[1]	–	–	–	–
160	<0.01	<0.01	0.03	0.03
158[2]	**<0.01**	**<0.01**	**0.03**	**0.03**
150	0.02	0.02	0.04	0.04
124.6[3]	0.65	0.57	0.90	0.76
119.6[4]	1.14	1.03	1.52	1.30

[1] Temporary threshold shift in fishes, 12 hours exposure (Popper et al. 2014)
[2] Recoverable injury threshold for fishes, 48 hours exposure (Popper et al. 2014)
[3] Median ambient level
[4] 5th percentile ambient level.

Conclusions

The ambient noise floor in Corio Bay is dominated by continuous noise mostly emitted by vessels and reaches median levels of SPL 124.6 dB re 1 µPa, which indicates a substantial existing noise pollution. Even in the quietest situation (represented by the 5th percentile ranges in Figure 3), the ambient noise level is SPL 119.6 dB re 1 µPa. The additional operational noise from the FSRU and LNG carrier would increase the sound field only in the surrounding area; due to the pre-existing noise levels, however, it is less likely that fishes would show ecologically relevant behavioural responses over extended areas around the sound sources. Taking the qualitative criteria for onset of behavioural responses in fishes (Popper et al. 2014) as a baseline, the likelihood for responses should be lowered by one level to reflect this existing condition. For the acoustically most sensitive species in Corio Bay, the Australian anchovy, this would result in a moderate likelihood for behavioural responses within the nearfield (tens of meters) of the sound source(s) while there is a low likelihood for all other species showing behavioural responses.

TTS is unlikely to occur in any fish species from exposure to operational noise as the impact range extends only to 30 m and, moreover, this criterion is highly conservative as it is based on assuming a receiver being stationary in this sound field over 48 hours. More severe impacts such as non-lethal injuries, PTS or mortality are not expected to be caused by operational noise.

7.3. Invertebrates

It remains unclear what physical parameters of underwater sound marine invertebrates are sensing (see Section 4.3.3) and what role and ecological relevance sound has for these species.

Behavioural reactions

Like for other taxa, there is no information on behavioural responses of marine invertebrates to sound by a stationary FSRU and LNG carrier. Instead, information documented for exposures to other non-impulsive noise sources is used for assessing potential impacts of operational activities.

Filiciotto et al. (2016) examined the effects of recorded boat noise on the behaviour and biochemistry of the common prawn (*Palaemon serratus*). The exposure elicited changes in locomotor patterns and caused physiological and behavioural effects that the authors identified as stress-related responses.

Two tank-based experiments investigated the physiological and behavioural effects of sound exposure on marine invertebrates. The sound generated by tidal and wind turbines was found to delay the time to metamorphosis between larval stages in estuarine crabs (Pine et al. 2012). Celi et al. (2013) documented statistically significant variations in haemato-immunological parameters as well as a reduction in agonistic behaviour in red swamp crayfish (*Procambarus clarkii*) after constant exposure to frequency sweeps over a duration of 30 min. The signals covered a frequency range between 0.1–25 kHz and reached a peak amplitude 148 dB re 1 µPa at 12 kHz.

Mooney et al. (2016) tested unconditioned behavioural responses to tonal signals in squid (*Doryteuthis pealeii*). The reactions elicited by sound exposure from 80 Hz to 1 kHz ranged from inking and jetting to body pattern changes and fin movements. Animals responded to the lowest sound levels in the 200–400 Hz range.

Morphological impact

André et al. (2011) and Solé et al. (2013) provide evidence of acoustic trauma in different cephalopod species (*Sepia officinalis*, *Octopus vulgaris*, *Loligo vulgaris*, and *Illex condietii*) that they exposed (underwater) for 2 hours to low-frequency sweeps between 50–400 Hz (1 second duration) generated by an in-air speaker. The received level at the animals' position was 157 dB re 1 µPa with peak levels (unspecified) up to 175 dB re 1 µPa. Both studies report permanent and substantial morphological and structural alterations of the sensory hair cells of the statocysts following noise exposure with no indication of recovery. In a more recent experiment, Solé et al. (2017) exposed common cuttlefish (*Sepia officinalis*) to tonal sweeps between 100–400 Hz in a controlled exposure experiments in open water. Their results show a clear statistical relationship between the cellular damage detected in the sensory cells of the individuals exposed to the sound sweeps and the distance to the sound source. The authors measured the particle motion and pressure of the signals received by the animals. Due to the signal type (frequency sweep), they could only provide the maximum received levels or an estimate thereof, respectively; the maximal particle motion level was 0.7 ms^{-2} observed at 1 m depth, the pressure reached levels of 139–142 dB re 1μPa^2. The sound pressure levels reported are only slightly higher than the hearing threshold determined for longfin squid (*Loligo pealeii*), another decapodiforme cephalopod, measured by Mooney et al. (2010). The maximum particle motion (reported in terms of particle acceleration) reported by Solé et al. (2017) is in the same order of magnitude as the behavioural thresholds measured at 100 Hz by (Packard et al. 1990) using a standing wave acoustic tube.

Impact ranges

There are no noise exposure criteria for invertebrates and, accordingly, impact ranges could not be calculated.

Conclusions

As already noted in the assessment of dredging noise impacts (Section 6.4.2), there are limited and inconclusive data available on the potential for behavioural responses and noise-induced physical effects on marine invertebrates. Theoretically, behavioural responses as well as significant sensory impairment or injury can have moderate to major consequences for an individual. In the absence of conclusive scientific information on important aspects such as the relevant physical parameters, sensory system responsible for detecting the noise, the scope of noise-induced effects and the animals' ability to compensate for the effects; however, it is impossible to assess the consequences of behavioural responses and noise-induced impairment or injury.

7.4. Avifauna

As remarked with regard to the potential impact of dredging noise (Section 6.5), the limited scientific information on behavioural responses of diving birds to underwater sound indicates that the response can be species- and context-specific, i.e., responses depend on several factors (including but not limited to): life history characteristics of the species, characteristics of the noise source, sound source intensity, onset rate, distance from the noise source, presence or absence of associated visual stimuli, food and habitat availability, and previous exposure. Previous studies document a range of bird behavioural responses to in-air noise, including no response, head turn, alert behaviour, startle response, flying or swimming away, diving into the water, and increased vocalisations (Larkin et al. 1996, Stalmaster and Kaiser 1997, Pytte et al. 2003, Plumpton et al. 2007). However, these studies cannot be used to inform the potential impact of operational noise on diving birds.

To date, there are no studies on behavioural effects of underwater noise emissions of vessels or any other non-impulsive sound source on diving birds. There is also no criterion for hearing impairment (TTS) for birds; impact ranges for TTS were analysed based on noise exposure criteria for other carnivores in water (OCW) (see Section 3.2.5 for rationale).

Impact ranges

The TTS impact ranges for diving birds are limited to 30 m, i.e., to the immediate vicinity of the FSRU and LNG carrier (Table 23).

Table 23. TTS ranges for diving birds for dredging noise based on noise exposure criteria for other carnivores in water for non-impulsive sounds (Southall et al. 2019). PTS thresholds were not exceeded. Maximum (R_{max}) horizontal distances (m) from the FSRU (Scenario 3a) and FSRU + LNG carrier (Scenario 3b) to maximum-over-depth weighted SEL isopleths for other carnivores in water (Southall et al. 2019) (Green et al. 2021, Section 4.2.1). A dash indicates the threshold was not reached within the limits of the modelling resolution (20 m).

Hearing group	SEL_{24h} threshold ($L_{E,\,weighted}$; dB re 1 µPa²s)	3a – FSRU		3b – FSRU + LNG carrier	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
Diving birds; proxy: Otariid pinnipeds (OCW)	199	—	—	0.03	0.03

Conclusions

It can be expected that pursuit-diving seabirds such as cormorants and penguins react to underwater sound emissions by altering or abandoning their foraging pursuits. Penguins likely avoid ensonified areas for the duration of a sound-producing activity before returning to their habitat. However, due to the existing high ambient noise levels in the project area (Wilson and McPherson 2021) it is unlikely that the operation of the new facility would lead to behavioural responses by birds on an ecologically relevant level. It is unrealistic to assume a concrete risk for diving birds to be exposed to TTS-inducing sound levels from the FSRU and LNGC operations, as birds would have to dive constantly for 24 h (as per definition of the criterion) to exceed the threshold; moreover, the animals would have to perform their dives within the immediate vicinity of (or between) the vessels.

7.5. Summary of Operation Impacts

Operating the FSRU including the offloading of LNG from a carrier during operation would lead to a localised increase in underwater noise levels in the vicinity of the project area. The noise would contribute to the existing soundscape and would raise the overall noise levels slightly. In assessing the potential noise related impacts of the operational activities, the same aspects must be considered as mentioned for the assessment of construction activities, i.e., the existing ambient noise level in the project area is high and already exceeds some of the existing noise exposure criteria and the relevant information on cause-effect relationships between noise and their impact on marine fauna are scarce or non-existent, often not specific to the type of activity or noise emitted or to the species occurring in the project area, or inconclusive. Consequently, some types of impact cannot be assessed and/or information must be extrapolated from other species, sound sources, and even different sound types.

In an unmitigated 'worst-case' scenario, the most significant impact to be expected are behavioural responses occurring over a range of several hundred metres for most species and only for birds up to several kilometres from the project area. However, these ranges indicate the onset of behavioural responses which are likely to be trivial responses of little or no ecological relevance at the and only become more severe the closer the animals are to the sound source(s). Also, they do not take into account the complexity and context-specific nature of behavioural responses and may under- or overestimate the true onset levels. More severe effects such as TTS or non-lethal injury (in fishes) are not likely to occur and stress and acoustic masking, while not quantifiable per se, can be assumed to occur at the same ranges as (ecologically relevant) behavioural responses.

With a reasonable (proportional) set of mitigation measures implemented, the underwater noise emitted by the operation of the FSRU, and the LNG carrier is not likely to have unacceptable impacts on the marine fauna in Corio Bay. Recommended mitigation measures to avoid, minimise and manage potential impacts related to underwater noise are discussed in Section 9.

8. Decommissioning Impacts

8.1. Summary of Residual Decommissioning Impacts

The FSRU, which continues to be an ocean-going vessel throughout the operation of the project, would leave Corio Bay on completion of the project life to be used elsewhere (see Section 1.4.3). Furthermore, it is anticipated that the Refinery Pier berth and facilities would be retained for other port related uses. While decommissioning activities may be subject to change, subject to legislative requirements at the time and potential repurposing of the infrastructure at the end of the project it is anticipated that decommissioning ancillary structures would, assuming the non-project related activities in Corio Bay have not changed, lead to a permanent reduction of emitted noise to levels similar to those measured prior to its construction (Green et al. 2021). Due to the lack of anticipated activities during the decommissioning phase that could lead to additional noise emissions, no mitigation measures are required and/or recommended at this point in time.

9. Recommended Mitigation Measures

The underwater noise generated by the planned construction and operation-related activities can impact marine fauna in several ways; there are, however, no intrinsic noise mitigation measures planned. To minimise or avoid noise-induced impacts a range of mitigation measures can be employed which differ in their effectiveness but also in their applicability and logistical and financial requirements to implement them. These aspects must be considered and assessed for proportionality as measures that come at a high cost but provide small noise reduction effects will not be sensible to use; similarly, high cost/effort measures would not be sensible to suggest if the impact ranges and/or the impact risk are small. These considerations are at the base of assigning the recommended mitigation measures to the project phases. However, no quantitative criteria exist or were developed in this context for this assessment; rather, assigning the mitigation measures to the project phases was conducted by expert judgement taking into account the likelihood of impacts to occur, the ecological relevance of noise-induced impacts and the predicted impact ranges (Green et al. 2021).

The most efficient methods to mitigate the noise exposure for marine mammals and diving birds is implementing and enforcing a safety zone around a sound source during noise-critical activities such as pile driving and constant visual monitoring of the surrounding area. Moreover, a soft start of the pile driving activities and the spatially and temporally limited use of acoustic deterrent devices prior to commencing the pile driving will reduce the likelihood of strong behavioural responses of listed species such as dolphins or penguins.

Mitigation measures recommended to avoid, minimise, and mitigate potential adverse effects on underwater noise are listed in Table 24.

Table 24. Recommended mitigation measures.

MM ID	Mitigation measure	Project phase
MM-UN01	**Minimising underwater noise impacts** • Isolating any piece of machinery from the ship (FSRU) structure can reduce structure-borne noise (Cruz et al. 2021). The level of noise reduction depends on the type of machinery; for medium- and high-speed diesel engines it can be up to 10 and 20 dB, respectively (Baudin and Mumm 2015). • Choosing the quietest operational technique possible and reduce the number and duration of sound exposure periods to the absolute minimum necessary to achieve the construction targets. • Consider use of noise dampening techniques such as air bubble curtains, Hydro Sound Dampers, etc. to reduce the noise propagated through the water column during noise-critical activities such as pile driving (e.g., Würsig et al. 2000, Stokes et al. 2010, Lucke et al. 2011, Saleem 2011, Koschinski and Lüdemann 2013, 2015, Dähne et al. 2017).	Construction + Operation
MM-UN02	**Acoustic Deterrence** • Using acoustic harassment devices (AHDs) during noise-critical activities such as the onset of impact pile driving; the use of AHDs should be temporally and spatially restricted as it introduces additional noise in the water column. • Increasing the power output of the sound source (e.g., increasing in the hammer energy for pile driving) gradually, that results in a gradual increase in the source level (SL) of the activity (Tougaard et al. 2003, JNCC 2004, Von Benda-Beckmann et al. 2014); this allows marine animals in the vicinity to move away to avoid the increasing noise to harmful levels.	Construction
MM-UN03	**Visual monitoring** • Monitoring the area surrounding the sound source visually prior to commencing loud activities (such as impact pile driving) to reducing the risk of exposing marine mammals to intense sound in the vicinity of the source. • Implement and enforcing a safety zone around loud sound sources such as pile driving and stop/delay the activity for 20 minutes based on a/ the last sighting of a listed species.	Construction
MM-UN05	**Awareness Building** Training construction workers and vessel/ machinery operators to understand noise impacts and endorse measures to reduce emissions (e.g., switching off machinery or equipment on a vessel while moored)	Construction + Operation
MM-UN06	**Performance Monitoring** Evaluating the proposed mitigation measures by continuous acoustic monitoring of the underwater sound field and visual monitoring of (noise-) critical activities during the construction- and operational phase of the project. This will provide the necessary information to inform decisions about compliance with keeping the noise exposure within acceptable levels and help in determining additional measures where necessary. The monitoring should be initiated prior to, and continued during, commencing the most critical activities and either routinely repeated throughout the project or conducted as a continuous effort.	Construction + Operation

10. Conclusion

10.1. Residual Impacts

Construction and operational activities would lead to localised increases in underwater noise levels in the vicinity of the project area. Applying the mitigation measures described in Section 9, however, has the potential of reducing the noise levels emitted by the construction activities and future operation and lead to a reduction in the severity and range of the potential noise-induced impacts.

The level or reduction is specific to each measure but not every measure can or should be applied to every activity; rather a differentiated approach is necessary, accounting for the proportionality of benefit (Section **Error! Reference source not found.**). As an example, some taxa such as bottom living invertebrates would not be able to be protected from exposure to ground vibration in the area surrounding the pile driving site; using a soft start during pile driving would allow mobile species to avoid the area before levels reach their maximum.

It is not possible to quantify the level of reduction for each of the mitigation measures and, accordingly, to determine the reduction of impact ranges and severity of impacts. It is likely though that a well-designed mitigation concept would reduce or even eliminate the risk of behavioural responses with the exception of the immediate vicinity of the activities. The potential noise-induced impacts for marine fauna arising from the planned project activities are not considered severe. Since TTS or other physical impacts are not likely and indeed unrealistic to assume, the impact type most expectable for the planned activities are behavioural responses of the exposed animals. Due to the existing acoustic condition, it is very probable that the animals are already accustomed (habituated) to living in a noisy environment and those individuals more sensitive to noise have long left the area.

There is no information available about abundance or densities of marine organisms in the project area which makes it unfeasible to assess the potential population level effects. Based on the relatively small acoustic and impact footprint of the activities it is justifiable to assume that, especially in a mitigated scenario, the ecological effects would be restricted to individuals and would not affect populations negatively. With a reasonable (proportional) set of mitigation measures implemented, the underwater noise emissions generated by the construction and operation of the FSRU are not expected to have unacceptable impacts on the marine fauna in Corio Bay

Abbreviations and Glossary of Terms

Abbreviation/ Term	Definition
ADD	Acoustic Deterrent Device
AEP	auditory evoked potentials
AHD	Acoustic Harassment Device
ANSI	American National Standards Institute
ASA	Acoustical Society of America
Caltrans	California Department of Transportation
CEDA	Central Dredging Association
DAWE	Department of Agriculture, Water and the Environment
DELWP	Department of Environment, Land, Water and Planning
DEWHA	Department of the Environment Water Heritage and the Arts
DOSITS	Discovery of Sound in the Sea
EES	Environment Effects Statement
EOL	End of life
EPBC Act	Commonwealth Environment Protection and Biodiversity Conservation Act 1999
FSRU	Floating storage and regasification unit
HF	High-frequency (cetacean)
HSD	Hydro Sound Damper
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
JNCC	Joint Nature Conservation Committee
LF	Low-frequency (cetacean)
LNG	Liquified natural gas
MHF	Major Hazard Facility
MLA	Marine loading arm

Abbreviation/ Term	Definition
MNES	Matters of national environmental significance
NIOSH	National Institute for Occupational Safety and Health
NITS	Noise-induced threshold shift
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCR	Office of the Conservation Regulator
OCW	Other Marine Carnivores (water)
PCW	Phocid Marine Carnivores (water)
PK	Peak sound pressure level
PTS	Permanent threshold shift
rms	Root mean square
ROW	Right of way
SEL	Sound exposure level
SL	Source Level
SPL	Sound pressure level
SWI	Seawater intake
SWP	South West Pipeline
TRG	Technical Reference Group
TTS	Temporary threshold shift
USA	United States of America
VHF	Very high-frequency
VTS	Victorian Transmission System
WODA	World Organisation of Dredging Associations

Term	Definition
ambient sound	Sound that would be present in the absence of a specified activity, usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity
auditory frequency weighting	The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2019)
background noise	Combination of ambient sound, acoustic self-noise, and sonar reverberation. Ambient sound detected, measured, or recorded with a signal is part of the background noise
bandwidth	The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI S1.13-2005 (R2010))
cetacean	Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises
continuous sound	A sound whose sound pressure level remains above ambient sound during the observation period. A sound that gradually varies in intensity with time, for example, sound from a marine vessel
decibel	Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB
ensonified	Exposed to sound
frequency	The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second

functional hearing group	Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound
Hertz (Hz)	A unit of frequency defined as one cycle per second
level	A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level.
non-impulsive sound	Sound that is not an impulsive sound. A non-impulsive sound is not necessarily a continuous sound
octave	The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz
otariid	A common term used to describe members of the Otariidae, eared seals, commonly called sea lions and fur seals. Otariids are adapted to a semi-aquatic life; they use their large fore flippers for propulsion. Their ears distinguish them from phocids. Otariids are one of the three main groups in the superfamily Pinnipedia; the other two groups are phocids and walrus
peak sound pressure level (zero-to-peak sound pressure level)	The level ($L_{p,pk}$ or L_{pk}) of the squared maximum magnitude of the sound pressure (p^2_{pk}). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2. $$L_{p,\mathrm{pk}} := 10\log_{10}\left(p^2_{\mathrm{pk}}/p_0^2\right)\mathrm{dB} = 20\log_{10}\left(p_{\mathrm{pk}}/p_0\right)\mathrm{dB}$$ The frequency band and time window should be specified. Abbreviation: PK or L_{pk}.
particle motion	Since sound is a mechanical wave, it can also be measured in terms of the vibratory motion of fluid particles. Sound particle motion is the magnitude and direction of movement of particles making up the media due to presence of a sound wave.
phocid	A common term used to describe all members of the family Phocidae. These true/earless seals are more adapted to in-water life than are otariids, which have more terrestrial adaptations. Phocids use their hind flippers to propel themselves. Phocids are one of the three main groups in the superfamily Pinnipedia; the other two groups are otariids and walrus
pressure, acoustic	The deviation from the ambient pressure caused by a sound wave. Also called sound pressure. Unit: pascal (Pa).
received level	The level measured (or that would be measured) at a defined location. The type of level should be specified.
sound	A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium
sound exposure	Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 h) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2·s
sound exposure level	The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s. $$L_E := 10\log_{10}(E/E_0)\,\mathrm{dB} = 20\log_{10}\left(E^{1/2}/E_0^{1/2}\right)\mathrm{dB}$$ The frequency band and integration time should be specified. Abbreviation: SEL
sound field	Region containing sound waves
sound pressure level (rms sound pressure level)	The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p^2_{rms}). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2. $$L_{p,\mathrm{rms}} := 10\log_{10}(p^2_{\mathrm{rms}}/p_0^2)\,\mathrm{dB} = 20\log_{10}(p_{\mathrm{rms}}/p_0)\,\mathrm{dB}$$ The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.
source level (SL)	A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^2
spectrum	An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound

Literature Cited

[ANSI] American National Standards Institute and [ASA] Acoustical Society of America. S1.1-2013. *American National Standard: Acoustical Terminology*. NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS12013.

[ANSI] American National Standards Institute and [ASA] Acoustical Society of America. S1.13-2005 (R2010). *American National Standard: Measurement of Sound Pressure Levels in Air*. NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS1132005R2010.

[Caltrans] California Department of Transportation. 2001. *San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. Pile Installation Demonstration Project. Fisheries Impact Assessment*. PIDP EA 012081. Caltrans Contract 04A0148. Task Order 205.10.90, San Francisco, CA, USA. 59 p. https://www.nrc.gov/docs/ML1434/ML14345A579.pdf.

[Caltrans] California Department of Transportation. 2004. *Fisheries and Hydroacoustic Monitoring Program Compliance Report*. San Francisco - Oakland Bay Bridge East Span Seismic Safety Project. Document EA 012023, 04-SF-80 KP 12.2/KP 14.3, 04-ALA-80 KP 0.0/KP 2.1 Technical report by Strategic Environmental and Illingworth & Rodkin, Inc. for Caltrans District 4. 148 p. http://ocr.org/pdfs/papers/2004_pile_driving_impacts.pdf.

[Caltrans] California Department of Transportation. 2010a. *Effects of pile driving sound on juvenile steelhead*. Prepared by ICF for Jones and Stokes.

[Caltrans] California Department of Transportation. 2010b. *Necropsy and histopathology of steelhead Trout Exposed to Steel Pile Driving at the Mad River Bridges, US Highway 101, July 2009*. Report by Gary D. Marty, Fish Pathology Services.

[CEDA] Central Dredging Association. 2011. *Underwater Sound in Relation to Dredging*. CEDA Position Paper, Delft, The Netherlands. 6 p. http://www.dredging.org/documents/ceda/html_page/2011-11_ceda_positionpaper_underwatersound_v2.pdf.

[DAWE] Department of Agriculture, Water and the Environment. 2021. *Guidance on key terms within the Blue Whale Conservation Management Plan*. https://www.awe.gov.au/environment/epbc/publications/guidance-key-terms-blue-whale-conservation-management-plan.

[DELWP] Department of Environment, Land, Water and Planning. 2020. Ecological character. (Chapter 1.1.1) *In Port Phillip Bay (Western Shoreline) and Bellarine Peninsula: Ramsar Site Management Plan Summary*.

[DEWLP] Department of Environment, Land, Water and Planning. 2018. *Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan*. East Melbourne, AU. 202 p.

[DOSITS] Discovery of Sound in the Sea. 2020. page). University of Rhode Island and Inner Space Center. http://www.dosits.org/. (Accessed 2 Jun 2020).

[IEC] International Electrotechnical Commission. 1994. *IEC 60050-801:1994 International Electrotechnical Vocabulary (IEV) - Part 801: Acoustics and electroacoustics*. https://webstore.iec.ch/publication/257.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

[JNCC] Joint Nature Conservation Committee. 2010. *JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys*. Aberdeen, UK.

[JNCC] Joint Nature Conservation Committee. 2017. *JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys*. Aberdeen, UK. 26 p. http://data.jncc.gov.uk/data/e2a46de5-43d4-43f0-b296-c62134397ce4/jncc-guidelines-seismicsurvey-aug2017-web.pdf.

[NIOSH] National Institute for Occupational Safety and Health. 1998. *Criteria for a recommended standard: Occupational noise exposure. Revised Criteria*. Document 98-126. US Department of Health and Human Services, NIOSH, Cincinnati, OH, USA. 122 p. https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf.

[NMFS] National Marine Fisheries Service (US). 2018. *2018 Revision 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*. US Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-59. 167 p. https://media.fisheries.noaa.gov/dam-migration/tech_memo_acoustic_guidance_(20)_(pdf)_508.pdf.

[NOAA] National Oceanic and Atmospheric Administration (US). 2019. *ESA Section 7 Consultation Tools for Marine Mammals on the West Coast* (web page), 27 Sep 2019. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/esa-section-7-consultation-tools-marine-mammals-west. (Accessed 10 Mar 2020).

[WODA] World Organisation of Dredging Associations. 2013. *Technical Guidance on: Underwater Sound in Relation to Dredging*. 8 p. https://dredging.org/documents/ceda/html_page/2013-06-woda-technicalguidance-underwatersoundlr.pdf.

Abbott, R., J. Reyff, and G. Marty. 2005. *Final report: monitoring the effects of conventional pile driving on three species of fish*. Manson Construction Company, Richmond, CA.

Aguilar de Soto, N., N. Delorme, J. Atkins, S. Howard, J. Williams, and M. Johnson. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. *Scientific Reports* 3(2831): 5. https://doi.org/10.1038/srep02831.

Aicher, B. and J. Tautz. 1990. Vibrational communication in the fiddler crab, *Uca pugilator*. *Journal of Comparative Physiology A* 166(3): 345-353. https://doi.org/10.1007/BF00204807.

Amoser, S. and F. Ladich. 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes. *Journal of the Acoustical Society of America* 113(4): 2170-2179. https://doi.org/10.1121/1.1557212.

Amoser, S., L.E. Wysocki, and F. Ladich. 2004. Noise emission during the first powerboat race in an Alpine lake and potential impact on fish communities. *Journal of the Acoustical Society of America* 116(6): 3789. https://doi.org/10.1121/1.1808219.

Anderson-Hansen, K., A. Maxwell, U. Siebert, O.N. Larsen, and M. Wahlberg. 2017. Great cormorants (*Phalacrocorax carbo*) can detect auditory cues while diving. *The Science of Nature* 104(5): 45. https://doi.org/10.1007/s00114-017-1467-3.

André, M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M. van der Schaar, M. López-Bejar, et al. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. *Frontiers in Ecology and the Environment* 9(9): 489-493. https://doi.org/10.1890/100124.

Au, D.W.T. and W. Perryman. 1982. Movement and speed of dolphin schools responding to an approaching ship. *Fishery Bulletin* 80(2): 371-379. https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/1982/802/au.pdf.

Au, W.W.L. and M.C. Hastings. 2008a. *Principles of Marine Bioacoustics*. Modern Acoustics and Signal Processing. Springer, New York. 510 p. https://doi.org/10.1007/978-0-387-78365-9.

Au, W.W.L. and M.C. Hastings. 2008b. Hearing in Marine Animals. *In Principles of Marine Bioacoustics*. New York, USA. pp. 337-400. https://doi.org/10.1007/978-0-387-78365-9_9.

Bain, D.E., J. Smith, R. Williams, and D. Lusseau. 2006. Effects of vessels on behavior of southern resident killer whales (Orcinus spp.). *NMFS Contract Report No. AB133F03SE0959 and AB133F04CN0040*.

Barth, F.A. 1980. *Campaniform sensilla*: Another vibration receptor in the crab leg. *Naturwissenschaften* 67: 201-202. https://doi.org/10.1007/BF01086310.

Basner, M., W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen, and S. Stansfeld. 2014. Auditory and non-auditory effects of noise on health. *The Lancet* 383(9925): 1325-1332.

Baudin, E. and H. Mumm. 2015. *Guidelines for Regulation on UW Noise from Commercial Shipping*. Prepared by Bureau Veritas, DNV GL for SONIC. Revision 4.3. http://www.aquo.eu/downloads/AQUO-SONIC%20Guidelines_v4.3.pdf.

Bejder, L., A. Samuels, H. Whitehead, and N. Gales. 2006. Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. *Animal Behaviour* 72(5): 1149-1158. https://doi.org/10.1016/j.anbehav.2006.04.003.

Bejder, L., A. Samuels, H. Whitehead, H. Finn, and S. Allen. 2009. Impact assessment research: Use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. *Marine Ecology Progress Series* 395: 177-185. https://doi.org/10.3354/meps07979.

Bellmann, M.A., J. Schuckenbrock, S. Gündert, M. Müller, H. Holst, and P. Remmers. 2017. Is There a State-of-the-Art to Reduce Pile-Driving Noise? *In* Köppel, J. (ed.). *Wind Energy and Wildlife Interactions*. Springer, Cham, Switzerland. pp. 161-172. https://doi.org/10.1007/978-3-319-51272-3_9.

Berghahn, R., K. Wiese, and K. Lüdemann. 1995. Physical and physiological aspects of gear efficiency in North Sea brown shrimp fisheries. *Helgoländer Meeresuntersuchungen* 49(1): 507-518. https://doi.org/10.1007/BF02368378.

Berthe, C. and D. Lecchini. 2016. Influence of boat noises on escape behaviour of white-spotted eagle ray Aetobatus ocellatus at Moorea Island (French Polynesia). *Comptes Rendus Biologies* 339(2): 99-103. https://doi.org/10.1016/j.crvi.2016.01.001.

Bertrand, A. and E. Josse. 2000. Tuna target-strength related to fish length and swimbladder volume. *ICES Journal of Marine Science* 57(4): 1143-1146. https://doi.org/10.1006/jmsc.2000.0881.

Blackwell, S.B., J.W. Lawson, and M.T. Williams. 2004. Tolerance by ringed seals (*Phoca hispida*) to impact pipe-driving and construction sounds at an oil production island. *Journal of the Acoustical Society of America* 115(5): 2346-2357. https://doi.org/10.1121/1.1701899.

Blane, J.M. and R. Jaakson. 1994. The Impact of Ecotourism Boats on the St Lawrence Beluga Whales. *Environmental Conservation* 21(3): 267-269. https://doi.org/10.1017/S0376892900033282.

Bowles, A.E. 1995. Responses of wildlife to noise. (Chapter 8) *In* Knight, R.L. and K.J. Gutzwiller (eds.). *Wildlife Recreationists: Coexistence Through Management and Research*. Volume 57. Island Press, Washington, DC. pp. 109-156.

Brandt, M.J., A. Diederichs, K. Betke, and G. Nehls. 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. *Marine Ecology Progress Series* 421: 205-216. https://doi.org/10.3354/meps08888.

Braun, C.B. and T. Grande. 2008. Evolution of Peripheral Mechanisms for the Enhancement of Sound Reception. *In* Webb, J.F., R.R. Fay, and A.N. Popper (eds.). *Fish Bioacoustics*. Springer, NY, USA. pp. 99-144. https://doi.org/10.1007/978-0-387-73029-5_4.

Bruintjes, R. and A.N. Radford. 2013. Context-dependent impacts of anthropogenic noise on individual and social behaviour in a cooperatively breeding fish. *Animal Behaviour* 85(6): 1343-1349. https://doi.org/10.1016/j.anbehav.2013.03.025.

Bruns, B., C. Kuhn, P. Stein, J. Gattermann, and K. Elmer. 2014. The new noise mitigation system 'Hydro Sound Dampers': History of development with several hydro sound and vibration measurements. *Inter-noise 2014*. Melbourne, Australia.

Buscaino, G., F. Filiciotto, G. Buffa, A. Bellante, V.D. Stefano, A. Assenza, F. Fazio, G. Caola, and S. Mazzola. 2010. Impact of an acoustic stimulus on the motility and blood parameters of European sea bass (*Dicentrarchus labrax* L.) and gilthead sea bream (*Sparus aurata* L.). *Marine Environmental Research* 69(3): 136-142. https://doi.org/10.1016/j.marenvres.2009.09.004.

Caiger, P.E., J.C. Montgomery, and C.A. Radford. 2012. Chronic low-intensity noise exposure affects the hearing thresholds of juvenile snapper. *Marine Ecology Progress Series* 466: 225–232. https://doi.org/10.3354/meps09933.

Carlson, T.J., G.E. Johnson, C.M. Woodley, J.R. Skalski, and A.G. Seaburg. 2011. *Compliance Monitoring of Underwater Blasting for Rock Removal at Warrior Point, Columbia River Channel Improvement Project, 2009/2010*. Report PNNL-20388. Report by Pacific Northwest National Laboratory for the US Army Corps of Engineers, Richland, WA. https://tethys.pnnl.gov/publications/compliance-monitoring-underwater-blasting-rock-removal-warrior-point-columbia-river.

Carroll, A.G., R. Przeslawski, A.J. Duncan, M. Gunning, and B.D. Bruce. 2017. A critical review of the potential impacts of marine seismic surveys on fish & invertebrates. *Marine Pollution Bulletin* 114(1): 9-24. https://doi.org/10.1016/j.marpolbul.2016.11.038.

Casper, B.M., M.B. Halvorsen, and A.N. Popper. 2012a. Are Sharks Even Bothered by a Noisy Environment? *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp. 93-97. https://doi.org/10.1007/978-1-4419-7311-5_20.

Casper, B.M., A.N. Popper, F. Matthews, T.J. Carlson, and M.B. Halvorsen. 2012b. Recovery of barotrauma injuries in Chinook salmon, *Oncorhynchus tshawytscha* from exposure to pile driving sound. *PLOS ONE* 7(6): e39593. https://doi.org/10.1371/journal.pone.0039593.

Casper, B.M., M.E. Smith, M.B. Halvorsen, H. Sun, T.J. Carlson, and A.N. Popper. 2013. Effects of exposure to pile driving sounds on fish inner ear tissues. *Comparative Biochemistry and Physiology Part A* 166(2): 352-360. https://doi.org/10.1016/j.cbpa.2013.07.008.

Celi, M., F. Filiciotto, D. Parrinello, G. Buscaino, M.A. Damiano, A. Cuttitta, S. D'Angelo, S. Mazzola, and M. Vazzana. 2013. Physiological and agonistic behavioural response of *Procambarus clarkii* to an acoustic stimulus. *Journal of Experimental Biology* 216(4): 709-718. https://doi.org/10.1242/jeb.078865.

Cholewiak, D.M., C.W. Clark, D. Ponirakis, A.S. Frankel, L.T. Hatch, D. Risch, J.E. Stanistreet, M. Thompson, E.T. Vu, et al. 2018. Communicating amidst the noise: Modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. *Endangered Species Research* 36: 59-75. https://doi.org/10.3354/esr00875.

Christiansen, F., D. Lusseau, E. Stensland, and P. Berggren. 2010. Effects of tourist boats on the behavior of Indo-Pacific bottlenose dolphins off the south coast of Zanzibar. *Endangered Species Research* 11(1): 91-99. https://doi.org/10.3354/esr00265.

Clark, C.W., W.T. Ellison, B.L. Southall, L.T. Hatch, S.M. Van Parijs, A.S. Frankel, and D.W. Ponirakis. 2009. Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. *Marine Ecology Progress Series* 395: 201-222. https://doi.org/10.3354/meps08402.

Codarin, A., L.E. Wysocki, F. Ladich, and M. Picciulin. 2009. Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). *Marine Pollution Bulletin* 58(12): 1880-1887. https://doi.org/10.1016/j.marpolbul.2009.07.011.

Cominelli, S., R. Devillers, H. Yurk, A.O. MacGillivray, L. McWhinnie, and R. Canessa. 2018. Noise exposure from commercial shipping for the southern resident killer whale population. *Marine Pollution Bulletin* 136: 177-200. https://doi.org/10.1016/j.marpolbul.2018.08.050.

Cosens, S.E. and L.P. Dueck. 1988. Responses of migrating narwhal and beluga to icebreaker traffic at the Admiralty Inlet ice-edge, NWT in 1986. *In* Sackinger, W.M. and M.O. Jeffries (eds.). *Port and ocean engineering under Arctic conditions*. Volume 2. Geophysical Institute, University of Alaska, Fairbanks, AK. pp. 39-54.

Cox, T.M., A.J. Read, A. Solow, and N. Tregenza. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *Journal of Cetacean Research and Management* 3(1): 81-86.

Cranford, T.W. and P. Krysl. 2015. Fin whale sound reception mechanisms: Skull vibration enables low-frequency hearing. *PLOS ONE* 10(1). https://doi.org/10.1371/journal.pone.0116222.

Cruz, E., T. Lloyd, J. Bosschers, F.H. Lafeber, P. Vinagre, and G. Vaz. 2021. *Study on inventory of existing policy, research and impacts of continuous underwater noise in Europe.* WavEC Offshore Renewables and Maritime Research Institute Netherlands. EMSA report EMSA/NEG/21/2020. 104 p.

Cunningham, K.A. and D.C. Mountain. 2014. Simulated masking of right whale sounds by shipping noise: Incorporating a model of the auditory periphery. *Journal of the Acoustical Society of America* 135(3): 1632-1640. https://doi.org/10.1121/1.4864470.

D'Amico, A., R.C. Gisiner, D.R. Ketten, J.A. Hammock, C. Johnson, P.L. Tyack, and J.G. Mead. 2009. Beaked whale strandings and naval exercises. *Aquatic Mammals* 35(4): 452-472. https://doi.org/10.1578/AM.35.4.2009.452.

Dahlheim, M.E. and D.K. Ljungblad. 1990. Preliminary Hearing Study on Gray Whales (*Eschrichtius Robustus*) in the Field. *In* Thomas, J.A. and R.A. Kastelein (eds.). *Sensory abilities of Cetaceans*. Volume 196. Springer Science+Business Media, Boston. pp. 335-346. https://doi.org/10.1007/978-1-4899-0858-2_22.

Dähne, M., A. Gilles, K. Lucke, V. Peschko, S. Adler, K. Krügel, J. Sundermeyer, and U. Siebert. 2013. Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. *Environmental Research Letters* 8(2). https://doi.org/10.1088/1748-9326/8/2/025002.

Dähne, M., J. Tougaard, J. Carstensen, A. Rose, and J. Nabe-Nielsen. 2017. Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. *Marine Ecology Progress Series* 580: 221-237. https://doi.org/10.3354/meps12257.

Dale, J.J., M.D. Gray, A.N. Popper, P.H. Rogers, and B.A. Block. 2015. Hearing thresholds of swimming Pacific bluefin tuna *Thunnus orientalis*. *Journal of Comparative Physiology A* 201(5): 441-454. https://doi.org/10.1007/s00359-015-0991-x.

Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann, and J.M. Semmens. 2017. Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop *Pecten fumatus*. *Proceedings of the National Academy of Sciences of the United States of America* 114(40): E8537-E8546. https://doi.org/10.1073/pnas.1700564114.

Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann, and J.M. Semmens. 2019. Seismic air guns damage rock lobster mechanosensory organs and impair righting reflex. *Proceedings of the Royal Society B* 286(1907). https://doi.org/10.1098/rspb.2019.1424.

De Robertis, A., C.D. Wilson, N.J. Williamson, M.A. Guttormsen, and S. Stienessen. 2010. Silent ships sometimes do encounter more fish. 1. Vessel comparisons during winter pollock surveys. *ICES Journal of Marine Science* 67(5): 985-995. https://doi.org/10.1093/icesjms/fsp299.

Diederichs, A., M. Brandt, and G. Nehls. 2010. Does sand extraction near Sylt affect harbour porpoises? *Wadden Sea Ecosystem* 26: 199-203.

Dooling, R.J. 2010. *Animal hearing [abstract]*. *Joint 159th Meeting of the Acoustical Society of America/NOISE-CON 2010*. Volume 127, 19-23 Apr 2010. Journal of the Acoustical Society of America, Baltimore, MD. https://doi.org/10.1121/1.3383951.

Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. *Journal of Experimental Biology* 220(16): 2878-2886. https://doi.org/10.1242/jeb.160192.

Dunlop, R.A. 2018. The communication space of humpback whale social sounds in wind-dominated noise. *Journal of the Acoustical Society of America* 144: 540-551. https://doi.org/10.1121/1.5047744.

Dunlop, R.A. 2019. The effects of vessel noise on the communication network of humpback whales. *Royal Society Open Science* 6(11). https://doi.org/10.1098/rsos.190967.

Dutson, G., S. Garnett, and C. Gole. 2009. *Australia's Important Bird Areas: Key sites for bird conservation.* . Report by Birds Australia, BirdLife International, and Rio Tinto. Conservation Statement No. 15. 40 p.

Edmonds, N.J., C.J. Firmin, D. Goldsmith, R.C. Faulkner, and D.T. Wood. 2016. A review of crustacean sensitivity to high amplitude underwater noise: Data needs for effective risk assessment in relation to UK commercial species. *Marine Pollution Bulletin* 108(1–2): 5-11. https://doi.org/10.1016/j.marpolbul.2016.05.006.

Ellers, O. 1995. Discrimination Among Wave-Generated Sounds by a Swash-Riding Clam. *The Biological Bulletin* 189(2): 128-137. https://doi.org/10.2307/1542463.

Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2012. A New Context-Based Approach to Assess Marine Mammal Behavioral Responses to Anthropogenic Sounds. *Conservation Biology* 26(1): 21-28. https://doi.org/10.1111/j.1523-1739.2011.01803.x.

Engås, A., S. Løkkeborg, E. Ona, and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). *Canadian Journal of Fisheries and Aquatic Sciences* 53(10): 2238-2249. https://doi.org/10.1139/f96-177.

Engineering-Environmental Management, Inc. 2008. *United States Coast Guard and Maritime Administration draft environmental impact statement for Port Dolphin LLC Deepwater Port licence application*. USCG Deepwater Ports Standards Division, Washington, DC.

Erbe, C. and D.M. Farmer. 1998. Masked hearing thresholds of a beluga whale (*Delphinapterus leucas*) in icebreaker noise. *Deep Sea Research Part II* 45(7): 1373-1388. https://doi.org/10.1016/S0967-0645(98)00027-7.

Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science* 18(2): 394-418. https://doi.org/10.1111/j.1748-7692.2002.tb01045.x.

Erbe, C. 2008. Critical ratios of beluga whales (*Delphinapterus leucas*) and masked signal duration. *Journal of the Acoustical Society of America* 124(4): 2216-2223. https://doi.org/10.1121/1.2970094.

Erbe, C., A.O. MacGillivray, and R. Williams. 2012. Mapping cumulative noise from shipping to inform marine spatial planning. *Journal of the Acoustical Society of America* 132(5): EL423-EL428. https://doi.org/10.1121/1.4758779

Erbe, C., R.D. McCauley, C.R. McPherson, and A. Gavrilov. 2013. Underwater noise from offshore oil production vessels. *Journal of the Acoustical Society of America* 133(6): EL465-EL470. https://doi.org/10.1121/1.4802183.

Erbe, C., R. Williams, D. Sandilands, and E. Ashe. 2014. Identifying modeled ship noise hotspots for marine mammals of Canada's Pacific Region. *PLOS ONE* 9(3): 1-10. https://doi.org/10.1371/journal.pone.0114362.

Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, and R.J. Dooling. 2016. Communication masking in marine mammals: A review and research strategy. *Marine Pollution Bulletin* 103(1): 15-38. https://doi.org/10.1016/j.marpolbul.2015.12.007.

Erbe, C., S.A. Marley, R.P. Schoeman, J.N. Smith, L.E. Trigg, and C.B. Embling. 2019. The Effects of Ship Noise on Marine Mammals—A Review. *Frontiers in Marine Science* 6. https://doi.org/10.3389/fmars.2019.00606.

Fewtrell, J.L. and R.D. McCauley. 2012. Impact of air gun noise on the behaviour of marine fish and squid. *Marine Pollution Bulletin* 64(5): 984-993. https://doi.org/10.1016/j.marpolbul.2012.02.009.

Filiciotto, F., M. Vazzana, M. Celi, V. Maccarrone, M. Ceraulo, G. Buffa, V. Arizza, G. de Vincenzi, R. Grammauta, et al. 2016. Underwater noise from boats: Measurement of its influence on the behaviour and biochemistry of the common prawn (*Palaemon serratus*, Pennant 1777). *Journal of Experimental Marine Biology and Ecology* 478: 24-33. https://doi.org/10.1016/j.jembe.2016.01.014.

Finley, K.J., G.W. Miller, R.A. Davis, and C.R. Greene, Jr. 1990. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high arctic. *Canadian Bulletin of Fisheries and Aquatic Sciences*.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. *Journal of the Acoustical Society of America* 108(1): 417-431. https://doi.org/10.1121/1.429475.

Finneran, J.J., C.E. Schlundt, R.L. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *Journal of the Acoustical Society of America* 111(6): 2929-2940. https://doi.org/10.1121/1.1479150.

Finneran, J.J., R. Dear, D.A. Carder, and S.H. Ridgway. 2003. Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. *Journal of the Acoustical Society of America* 114(3): 1667. https://doi.org/10.1121/1.1598194.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and R.L. Dear. 2010. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. *Journal of the Acoustical Society of America* 127(5): 3267-3272. https://doi.org/10.1121/1.3377052.

Finneran, J.J. 2015. Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. *Journal of the Acoustical Society of America* 138(3): 1702-1726. https://doi.org/10.1121/1.4927418.

Finneran, J.J., C.E. Schlundt, B.K. Branstetter, J.S. Trickey, V. Bowman, and K. Jenkins. 2015. Effects of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior. *Journal of the Acoustical Society of America* 137(4): 1634-1646. https://doi.org/10.1121/1.4916591.

Finneran, J.J. 2016. *Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise*. Technical Report for Space and Naval Warfare Systems Center Pacific, San Diego, CA, USA. 49 p. https://apps.dtic.mil/dtic/tr/fulltext/u2/1026445.pdf.

Finneran, J.J., E.E. Henderson, D.S. Houser, K. Jenkins, S. Kotecki, and J. Mulsow. 2017. *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III)*. Technical report by Space and Naval Warfare Systems Center Pacific (SSC Pacific). 183 p. https://nwtteis.com/portals/nwtteis/files/technical_reports/Criteria_and_Thresholds_for_U.S._Navy_Acoustic_and_Explosive_Effects_Analysis_June2017.pdf.

Foote, A.D., R.W. Osborne, and A.R. Hoelzel. 2004. Whale-call response to masking boat noise. *Nature* 428(6986): 910. https://doi.org/10.1038/428910a.

Francis, C.D., C.P. Ortega, and A. Cruz. 2009. Noise Pollution Changes Avian Communities and Species Interactions. *Current Biology* 19(16): 1415-14199. https://doi.org/10.1016/j.cub.2009.06.052.

Gabriele, C.M., D.W. Ponirakis, C.W. Clark, J.N. Womble, and P.B.S. Vanselow. 2018. Underwater acoustic ecology metrics in an alaska marine protected area reveal marine mammal communication masking and management alternatives. *Frontiers in Marine Science* 5: 270. https://doi.org/10.3389/fmars.2018.00270.

Golde, H.M. and B. Houtman. 2012. *Environmental assessment of marine geophysical surveys by the R/V Marcus G. Langseth in the Northeastern Pacific Ocean, June-July 2012*. Report by LGL. Ltd.; National Science Foundation (US), Division of Ocean Sciences; Lamont-Doherty Earth Observatory; and National Oceanic and Atmospheric Administration., Office of Program Planning and Integration. https://repository.library.noaa.gov/view/noaa/19732.

Graves, M. 1968. Air-bubble curtain in sub-aqueous blasting at Muddy Run. *Civil Engineering* June: 59-61.

Green, M.C., M. Wood, and C. McPherson. 2021. *Viva Energy Gas Terminal: Underwater Acoustic Modelling*. Technical report by JASCO Applied Sciences for AECOM. Document 02534, Version 1.0.

Guerra, A., A.F. González, E.G. Dawe, and F. Rocha. 2004. Records of giant squid in the north-eastern Atlantic, and two records of male Architeuthis sp. off the Iberian Peninsula. *Journal of the Marine Biological Association of the United Kingdom* 84(2): 427-431. https://doi.org/10.1017/S0025315404009397h.

Halvorsen, M.B., B.M. Casper, C.M. Woodley, T.J. Carlson, and A.N. Popper. 2011. Predicting and mitigating hydroacoustic impacts on fish from pile installations. Project 25–28. *National Cooperative Highway Research Program Research Results Digest* 363: 2011. https://doi.org/10.17226/14596.

Halvorsen, M.B., B.M. Casper, F. Matthews, T.J. Carlson, and A.N. Popper. 2012a. Effects of exposure to pile-driving sounds on the lake sturgeon, Nile tilapia and hogchoker. *Proceedings of the Royal Society B* 279(1748): 4705-4714. https://doi.org/10.1098/rspb.2012.1544.

Halvorsen, M.B., B.M. Casper, C.M. Woodley, T.J. Carlson, and A.N. Popper. 2012b. Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. *PLOS ONE* 7(6): e38968. https://doi.org/10.1371/journal.pone.0038968.

Hastings, M.C., C.A. Reid, C.C. Grebe, R.L. Hearn, and J.G. Colman. 2008. The effects of seismic airgun noise on the hearing sensitivity of tropical reef fishes at Scott Reef, Western Australia. *Underwater Noise Measurement, Impact and Mitigation, Proceedings of the Institute of Acoustics* 30(5).

Hastings, M.C. and J.L. Miksis-Olds. 2012. Shipboard Assessment of Hearing Sensitivity of Tropical Fishes Immediately After Exposure to Seismic Air Gun Emissions at Scott Reef. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp. 239-243. https://doi.org/10.1007/978-1-4419-7311-5_53.

Hawkins, A.D., L. Roberts, and S. Cheesman. 2014. Responses of free-living coastal pelagic fish to impulsive sounds. *Journal of the Acoustical Society of America* 135(5): 3101-3116. https://doi.org/10.1121/1.4870697.

Hawkins, A.D., A.E. Pembroke, and A.N. Popper. 2015. Information gaps in understanding the effects of noise on fishes and invertebrates. *Reviews in Fish Biology and Fisheries* 25(1): 39-64. https://doi.org/10.1007/s11160-014-9369-3.

Heinisch, P. and K. Wiese. 1987. Sensitivity to Movement and Vibration of Water in the North Sea Shrimp *Crangon Crangon* L. *Journal of Crustacean Biology* 7(3): 401-413. https://doi.org/10.2307/1548290.

Holmes, L.J., J. McWilliam, M.C.O. Ferrari, and M.I. McCormick. 2017. Juvenile damselfish are affected but desensitize to small motor boat noise. *Journal of Experimental Marine Biology and Ecology* 494: 63-68. https://doi.org/10.1016/j.jembe.2017.05.009.

Holt, M.M., D.P. Noren, V. Veirs, C.K. Emmons, and S. Veirs. 2009. Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. *Journal of the Acoustical Society of America* 125(1): EL27-EL32. https://doi.org/10.1121/1.3040028.

Holt, M.M., D.P. Noren, and C.K. Emmons. 2011. Effects of noise levels and call types on the source levels of killer whale calls. *Journal of the Acoustical Society of America* 130(5): 3100-3106. https://doi.org/10.1121/1.3641446.

Houghton, J., J. Starkes, J. Stutes, M. Havey, J.A. Reyff, and D. Erikson. 2010. Acoustic monitoring of in situ exposures of juvenile coho salmon to pile driving noise at the port of Anchorage Marine Terminal redevelopment project, Knik Arm, Alaska. *Alaska Marine Sciences Symposium, Anchorage*.

Houser, D.S., D.A. Helweg, and P.W.B. Moore. 2001. A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals* 27(2): 82-91. https://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/2001/AquaticMammals_27-02/27-02_Houser.PDF.

Houser, D.S., W. Yost, R. Burkard, J.J. Finneran, C. Reichmuth, and J. Mulsow. 2017. A review of the history, development and application of auditory weighting functions in humans and marine mammals. *Journal of the Acoustical Society of America* 141(3): 1371-1413. https://doi.org/10.1121/1.4976086.

Houser, D.S., S. Martin, D.E. Crocker, and J.J. Finneran. 2020. Endocrine response to simulated U.S. Navy mid-frequency sonar exposures in the bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America* 147(3): 1681-1687. https://doi.org/10.1121/10.0000924.

Hu, M.Y., H.Y. Yan, W.-S. Chung, J.-C. Shiao, and P.-P. Hwang. 2009. Acoustically evoked potentials in two cephalopods inferred using the auditory brainstem response (ABR) approach. *Comparative Biochemistry and Physiology Part A* 153(3): 278-283. https://doi.org/10.1016/j.cbpa.2009.02.040.

Hughes, A.R., D.A. Mann, and D.L. Kimbro. 2014. Predatory fish sounds can alter crab foraging behaviour and influence bivalve abundance. *Proceedings of the Royal Society B* 281(1788). https://doi.org/10.1098/rspb.2014.0715.

Hwang, P.A. and W.J. Teague. 1999. Low-frequency resonant scattering of bubble clouds. *Journal of Atmospheric and Oceanic Technology* 17: 847-853.

Jacobsen, R.C. 1972. Air-bubble curtain to cushion blasting. *Ontario Hydro Research News* 1: 17-23.

Jepson, P.D., R. Deaville, K. Acevedo-Whitehouse, J. Barnett, A. Brownlow, R.L. Brownell, Jr., F.C. Clare, N. Davison, R.J. Law, et al. 2013. What caused the UK's largest common dolphin (*Delphinus delphis*) mass stranding event? *PLOS ONE* 8(4): e60953. https://doi.org/10.1371/journal.pone.0060953.

Jézéquel, Y., I.T. Jones, J. Bonnel, L. Chauvaud, J. Atema, and T.A. Mooney. 2021. Sound detection by the American lobster (Homarus americanus). *Journal of Experimental Biology* 224(6): jeb240747.

JNCC. 2004. *Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys*. Joint Nature Conservation Committee, Aberdeen.

Johansen, S., O.N. Larsen, J. Christensen-Dalsgaard, L. Seidelin, T. Huulvej, K. Jensen, S.-G. Lunneryd, M. Boström, and M. Wahlberg. 2016. In-air and underwater hearing in the great cormorant (*Phalacrocorax carbo sinensis*). *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Volume 875. Springer, New York. pp. 505-512. https://doi.org/10.1007/978-1-4939-2981-8_61.

Joy, R., D.J. Tollit, J.D. Wood, A.O. MacGillivray, Z. Li, K. Trounce, and O. Robinson. 2019. Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales. *Frontiers in Marine Science* 6: 344. https://doi.org/10.3389/fmars.2019.00344.

Kaplan, M.B. and T.A. Mooney. 2016. Coral reef soundscapes may not be detectable far from the reef. *Scientific Reports* 6(1): 31862. https://doi.org/10.1038/srep31862.

Kastelein, R.A. 2008. Effects of vibrations on the behaviour of cockles (bivalve molluscs). *Bioacoustics* 17(1-3): 74-75. https://doi.org/10.1080/09524622.2008.9753770.

Kastelein, R.A., D. van Heerden, R. Gransier, and L. Hoek. 2013. Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to playbacks of broadband pile driving sounds. *Marine Environmental Research* 92: 206-214. https://doi.org/10.1016/j.marenvres.2013.09.020.

Kastelein, R.A., L. Hoek, R. Gransier, M. Rambags, and N. Claeys. 2014. Effect of level, duration, and inter-pulse interval of 1–2 kHz sonar signal exposures on harbor porpoise hearing. *Journal of the Acoustical Society of America* 136(1): 412-422. https://doi.org/10.1121/1.4883596.

Kastelein, R.A., R. Gransier, M.A.T. Marijt, and L. Hoek. 2015a. Hearing frequency thresholds of harbor porpoises (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds. *Journal of the Acoustical Society of America* 137(2): 556-564. https://doi.org/10.1121/1.4906261.

Kastelein, R.A., R. Gransier, J. Schop, and L. Hoek. 2015b. Effects of exposure to intermittent and continuous 6–7 kHz sonar sweeps on harbor porpoise (*Phocoena phocoena*) hearing. *Journal of the Acoustical Society of America* 137(4): 1623-1633. https://doi.org/10.1121/1.4916590.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. *In* Kastelein, R.A., J.A. Thomas, and P.E. Nachtigall (eds.). *Sensory Systems of Aquatic Mammals*. De Spil Publishers, Woerden, The Netherlands. pp. 391-407.

Kight, C.R. and J.P. Swaddle. 2011. How and why environmental noise impacts animals: An integrative, mechanistic review. *Ecology Letters* 14(10): 1052-1061. https://doi.org/10.1111/j.1461-0248.2011.01664.x.

Klages, M., S. Muyakshin, T. Soltwedel, and W.E. Arntz. 2002. Mechanoreception, a possible mechanism for food fall detection in deep-sea scavengers. *Deep Sea Research Part I* 49(1): 143-155. https://doi.org/10.1016/S0967-0637(01)00047-4.

Knight, R.L. and D.N. Temple. 1995. Origin of Wildlife Responses to Recreationists. *In* Knight, R.L. and K.J. Gutzwiller (eds.). *Wildlife and recreationists: Coexistence through mangement and research*. Island Press. Washington DC 372s, Washington, DC. pp. 81–91.

Koschinski, S. and K. Lüdemann. 2013. *Development of Noise Mitigation Measures in Offshore Wind Farm Construction*. Commissioned by the Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN). Original report (in German) published Jul 2011, updated Feb 2013, Nehmten and Hamburg, Germany. 97 p. https://www.bfn.de/fileadmin/MDB/documents/themen/meeresundkuestenschutz/downloads/Berichte-und-Positionspapiere/Mitigation-Measures-Underwater-Noise_2013-08-27_final.pdf.

Koschinski, S. and K. Lüdemann. 2015. Quieting technologies for offshore pile driving. *4th International Conference on Progress in Marine Conservation in Europe*. 14-18 Sep 2015, Stralsund, Germany. pp. 217-220.

Kruse, S. 1991. The interactions between killer whales and boats in Johnstone Strait, B.C. *In* Pryor, K. and K.S. Norris (eds.). *Dolphin societies: Discoveries and puzzles*. University of California Press, Berkeley. pp. 149-159.

Kuhn, C., B. Bruns, J. Fischer, J. Gattermann, and K.-H. Elmer. 2012. Development of a new underwater piling noise mitigation system using Hydro Sound Dampers (HSD). *International Conference on Ocean, Offshore and Arctic Engineering*. 1–6 Jul 2012, Rio de Janeiro, Brazil. p. 8.

Kuningas, S., P.H. Kvadsheim, F.-P.A. Lam, and P.J. Miller. 2013. Killer whale presence in relation to naval sonar activity and prey abundance in northern Norway. *ICES Journal of Marine Science* 70(7): 1287-1293.

Lacroix, D.L., R.B. Lanctot, J.A. Reed, and T.L. Mcdonald. 2003. Effect of underwater seismic surveys on molting male Long-tailed Ducks in the Beaufort Sea, Alaska. *Canadian Journal of Zoology* 81(11): 1862-1875. https://doi.org/10.1139/z03-185.

Ladich, F. and A.N. Popper. 2004. Parallel evolution in fish hearing organs. *In* Manley, G.A., A.N. Popper, and R.R. Fay (eds.). *Evolution of the Vertebrate Auditory System* Springer-Verlag, NY, USA. pp. 98-127.

Ladich, F. 2013. Effects of Noise on Sound Detection and Acoustic Communication in Fishes. *In* Brumm, H. (ed.). *Animal Communication and Noise*. Springer Berlin Heidelberg, Berlin, Heidelberg. pp. 65-90. https://doi.org/10.1007/978-3-642-41494-7_4.

Ladich, F. and R.R. Fay. 2013. Auditory evoked potential audiometry in fish. *Reviews in Fish Biology and Fisheries* 23(3): 317-364. https://doi.org/10.1007/s11160-012-9297-z.

Lagardère, J.P., S. Millot, and E. Parmentier. 2005. Aspects of sound communication in the pearlfish *Carapus boraborensis* and *Carapus homei* (Carapidae). *Journal of Experimental Zoology Part A* 303A(12): 1066-1074. https://doi.org/10.1002/jez.a.230.

Landsberg, P.G. 2000. Underwater blast injuries. *Trauma & Energy Medicine* 17(2).

Larkin, R.P., L.L. Pater, and D.J. Tazik. 1996. *Effects of Military Noise on Wildlife: A Literature Review*. Report TR 96/21. Report by Construction Engineering Research Laboratories of the US Army Corps of Engineers Champaign, IL, USA. https://apps.dtic.mil/sti/pdfs/ADA305234.pdf.

Lemon, M., T.P. Lynch, D.H. Cato, and R.G. Harcourt. 2006. Response of travelling bottlenose dolphins (*Tursiops aduncus*) to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia. *Biological Conservation* 127(4): 363-372. https://doi.org/10.1016/j.biocon.2005.08.016.

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. *Marine Mammal Science* 15(1): 65-84. https://doi.org/10.1111/j.1748-7692.1999.tb00782.x.

Long, T.M., R.T. Hanlon, A. Ter Maat, and H.M. Pinsker. 1989. Non-associative learning in the squid *Lolliguncula brevis* (Mollusca, Cephalopoda). *Marine Behaviour and Physiology* 16(1): 1-9. https://doi.org/10.1080/10236248909378736.

Lovell, J.M., M.M. Findlay, R.M. Moate, and H.Y. Yan. 2005. The hearing abilities of the prawn *Palaemon serratus*. *Comparative Biochemistry and Physiology Part A* 140(1): 89-100. https://doi.org/10.1016/j.cbpb.2004.11.003.

Lucke, K., U. Siebert, P.A. Lepper, and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. *Journal of the Acoustical Society of America* 125(6): 4060-4070. https://doi.org/10.1121/1.3117443.

Lucke, K., P.A. Lepper, M.-A. Blanchet, and U. Siebert. 2011. The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena*). *Journal of the Acoustical Society of America* 130(5): 3406-3412. https://doi.org/10.1121/1.3626123.

Lusseau, D. 2005. Residency pattern of bottlenose dolphins *Tursiops spp*. in Milford Sound, New Zealand, is related to boat traffic. *Marine Ecology Progress Series* 295: 265-272. https://www.int-res.com/abstracts/meps/v295/p265-272/.

Lusseau, D. 2006. The short-term behavioural reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. *Marine Mammal Science* 22(4): 802-818. https://doi.org/10.1111/j.1748-7692.2006.00052.x.

Lusseau, D., D.E. Bain, R. Williams, and J.C. Smith. 2009. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. *Endangered Species Research* 6(3): 211-221. https://doi.org/10.3354/esr00154.

MacGillivray, A.O. 2018. Underwater noise from pile driving of conductor casing at a deep-water oil platform. *Journal of the Acoustical Society of America* 143(1): 450-459. https://doi.org/10.1121/1.5021554.

Markov, V.I. 1977. Underwater sounds in Macaroni Penguins. *In Adaptations of Penguins*. Moscow, Nauka. pp. 111-121.

Marley, S.A., C.P. Salgado Kent, C. Erbe, and I.M. Parnum. 2017a. Effects of vessel traffic and underwater noise on the movement, behaviour and vocalisations of bottlenose dolphins in an urbanised estuary. *Scientific Reports* 7: 13437. https://doi.org/10.1038/s41598-017-13252-z.

Marley, S.A., C.P. Salgado Kent, C. Erbe, and D. Thiele. 2017b. A Tale of Two Soundscapes: Comparing the Acoustic Characteristics of Urban Versus Pristine Coastal Dolphin Habitats in Western Australia. *Acoustics Australia* 45(2): 159-178. https://doi.org/10.1007/s40857-017-0106-7.

Mattson, M.C., J.A. Thomas, and D. St Aubin. 2005. Effects of boat activity on the behavior of bottlenose dolphins (*Tursiops truncatus*) in waters surrounding Hilton Head Island, South Carolina. *Aquatic Mammals* 31(1): 133-140. https://doi.org/10.1578/AM.31.1.2005.133.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, et al. 2000. *Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid*. Report R99-15. Prepared for Australian Petroleum Production Exploration Association by Centre for Maine Science and Technology, Western Australia. 198 p. https://cmst.curtin.edu.au/wp-content/uploads/sites/4/2016/05/McCauley-et-al-Seismic-effects-2000.pdf.

McIver, E.L., M.A. Marchaterre, A.N. Rice, and A.H. Bass. 2014. Novel underwater soundscape: Acoustic repertoire of plainfin midshipman fish. *Journal of Experimental Biology* 217(13): 2377-2389. https://doi.org/10.1242/jeb.102772.

McPherson, C.R., H. Yurk, G.R. McPherson, R. Racca, and P. Wulf. 2017. *Great Barrier Reef Underwater Noise Guidelines: Discussion and Options Paper*. Document 01130. Technical report by JASCO Applied Sciences for Great Barrier Reef Marine Park Authority. http://hdl.handle.net/11017/3245.

Melvin, E.F., J.K. Parrish, and L.L. Conquest. 1999. Novel Tools to Reduce Seabird Bycatch in Coastal Gillnet Fisheries. *Conservation Biology* 13(6): 1386-1397. https://doi.org/10.1046/j.1523-1739.1999.98426.x.

Melvin, E.F., K.S. Dietrich, S. Fitzgerald, and T. Cardoso. 2011. Reducing seabird strikes with trawl cables in the pollock catcher-processor fleet in the eastern Bering Sea. *Polar Biology* 34(2): 215-226. https://doi.org/10.1007/s00300-010-0873-1.

Miller, P.J.O., P.H. Kvadsheim, F.-P.A. Lam, P.J. Wensveen, R. Antunes, A.C. Alves, F. Visser, L. Kleivane, P.L. Tyack, et al. 2012. The severity of behavioral changes observed during experimental exposures of killer

(*Orcinus orca*), long-finned pilot (*Globicephala melas*), and sperm (*Physeter macrocephalus*) whales to naval sonar. *Aquatic Mammals* 38(4). https://doi.org/10.1578/AM.38.4.2012.362.

Miller, P.J.O., R.N. Antunes, P.J. Wensveen, F.I.P. Samarra, A. Catarina Alves, P.L. Tyack, P.H. Kvadsheim, L. Kleivane, F.-P.A. Lam, et al. 2014. Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. *Journal of the Acoustical Society of America* 135(2): 975-993. https://doi.org/10.1121/1.4861346.

Mooney, T.A., P.E. Nachtigall, and S.A. Vlachos. 2009. Sonar-induced temporary hearing loss in dolphins. *Biology Letters* 5(4): 565-567. https://doi.org/10.1098/rsbl.2009.0099.

Mooney, T.A., R.T. Hanlon, J. Christensen-Dalsgaard, P.T. Madsen, D.R. Ketten, and P.E. Nachtigall. 2010. Sound detection by the longfin squid (*Loligo pealeii*) studied with auditory evoked potentials: Sensitivity to low-frequency particle motion and not pressure. *Journal of Experimental Biology* 213(21): 3748-3759. https://doi.org/10.1242/jeb.048348.

Mooney, T.A., J.E. Samson, A.D. Schlunk, and S. Zacarias. 2016. Loudness-dependent behavioral responses and habituation to sound by the longfin squid (*Doryteuthis pealeii*). *Journal of Comparative Physiology A* 202(7): 489-501. https://doi.org/10.1007/s00359-016-1092-1.

Mooney, T.A., A.B. Smith, O.N. Larsen, K. Anderson Hansen, M. Wahlberg, and M.H. Rasmussen. 2019. Field-based hearing measurements of two seabird species. *Journal of Experimental Biology* 222(4). https://doi.org/10.1242/jeb.190710.

Morley, E.L., G. Jones, and A.N. Radford. 2014. The importance of invertebrates when considering the impacts of anthropogenic noise. *Proceedings of the Royal Society B* 281(1776). https://doi.org/10.1098/rspb.2013.2683.

Morris, C.J., D. Cote, S.B. Martin, and D.G. Kehler. 2018. Effects of 2D seismic on the snow crab fishery. *Fisheries Research* 197: 67–77. https://doi.org/10.1016/j.fishres.2017.09.012.

Mosher, J.I. 1972. The responses of *Macoma balthica* (bivalvia) to vibrations. *Journal of Molluscan Studies* 40(2): 125-131. https://doi.org/10.1093/oxfordjournals.mollus.a065209.

Mueller-Blenkle, C., P.K. McGregor, A.B. Gill, M.H. Andersson, J. Metcalfe, V. Bendall, P. Sigray, D.T. Wood, and F. Thomsen. 2010. *Effects of Pile-driving Noise on the Behaviour of Marine Fish*. COWRIE Ref: Fish 06-08; Cefas Ref: C3371. 62 p. https://dspace.lib.cranfield.ac.uk/handle/1826/8235.

Mulsow, J., C. Reichmuth, F.M.D. Gulland, D.A.S. Rosen, and J.J. Finneran. 2011. Aerial audiograms of several California sea lions (*Zalophus californianus*) and Steller sea lions (*Eumetopias jubatus*) measured using single and multiple simultaneous auditory steady-state response methods. *Journal of Experimental Biology* 214: 1138-1147. https://doi.org/10.1242/jeb.052837.

Nedelec, S.L., J. Campbell, A.N. Radford, S.D. Simpson, and N.D. Merchant. 2016. Particle motion: The missing link in underwater acoustic ecology. *Methods in Ecology and Evolution* 7: 1-7. https://doi.org/10.1111/2041-210X.12544.

Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

Nedwell, J.R., A.W.H. Turnpenny, J. Langworthy, and B. Edwards. 2003. *Measurements of underwater noise during piling at the Red Funnel Terminal, Southampton, and observations of its effect on caged fish*. Document 558 R 0207 Report 558 R 0207. Report by Subacoustech Ltd for Red Funnel. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-2003.pdf.

Nedwell, J.R., B. Edwards, A.W.H. Turnpenny, and J. Gordon. 2004. *Fish and Marine Mammal Audiograms: A summary of available information*. *In*: Subacoustech (ed.). Document 534R0214. 278 pp. p.

Nedwell, J.R., A.W.H. Turnpenny, J.M. Lovell, and B. Edwards. 2006. An investigation into the effects of underwater piling noise on salmonids. *Journal of the Acoustical Society of America* 120(5): 2550-2554. https://doi.org/10.1121/1.2335573.

Nedwell, J.R., A.W. Turnpenny, J. Lovell, S.J. Parvin, R. Workman, J.A.L. Spinks, and D. Howell. 2007. *A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise*. Document 534R1231 Report prepared by Subacoustech Ltd. for Chevron Ltd, TotalFinaElf Exploration UK PLC, Department of Business, Enterprise and Regulatory Reform, Shell UK Exploration and Production Ltd, The Industry Technology Facilitator, Joint Nature Conservation Committee, and The UK Ministry of Defence. 74 p. https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-et-al-2007.pdf.

Nehls, G., A. Rose, A. Diederichs, M.A. Bellmann, and H. Pehlke. 2016. Noise Mitigation During Pile Driving Efficiently Reduces Disturbance of Marine Mammals. (Chapter 92) *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Volume 875. Springer, NY, USA. pp. 755-762. https://doi.org/10.1007/978-1-4939-2981-8_92.

Nisbet, I.C.T. 2000. Disturbance, Habituation, and Management of Waterbird Colonies. *Waterbirds* 23(2): 312-332. www.jstor.org/stable/4641163.

Noren, D.P., A.H. Johnson, D. Rehder, and A. Larson. 2009. Close approaches by vessels elicit surface active behaviors by southern resident killer whales. *Endangered Species Research* 8: 179-192. https://doi.org/10.3354/esr00205

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review* 37(2): 81-115. https://doi.org/10.1111/j.1365-2907.2007.00104.x.

Nowacek, S.M., R.S. Wells, and A.R. Solow. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science* 17(4): 673-688.

Ona, E., O.R. Godø, N.O. Handegard, V. Hjellvik, R. Patel, and G. Pedersen. 2007. Silent research vessels are not quiet. *Journal of the Acoustical Society of America* 121(4): EL145-EL150. https://doi.org/10.1121/1.2710741.

Packard, A., H.E. Karlsen, and O. Sand. 1990. Low frequency hearing in cephalopods. *Journal of Comparative Physiology A* 166(4): 501-505. https://doi.org/10.1007/BF00192020.

Paiva, E.G., C.P.S. Kent, M.M. Gagnon, R.D. McCauley, and H. Finn. 2015. Reduced detection of indo-pacific bottlenose dolphins (*Tursiops aduncus*) in an inner harbour channel during pile driving activities. *Aquatic Mammals* 41(4): 455-468. https://doi.org/10.1578/AM.41.4.2015.455.

Parks, S.E., D.R. Ketten, J.T. O'Malley, and J. Arruda. 2007. Anatomical predictions of hearing in the North Atlantic right whale. *The Anatomical Record* 290(6): 734-744. https://doi.org/10.1002/ar.20527.

Pérez-Jorge, S., I. Gomes, K. Hayes, G. Corti, M. Louzao, M. Genovart, and D. Oro. 2016. Effects of nature-based tourism and environmental drivers on the demography of a small dolphin population. *Biological Conservation* 197: 200-208. https://doi.org/10.1016/j.biocon.2016.03.006.

Picciulin, M., L. Sebastianutto, A. Codarin, A. Farina, and E.A. Ferrero. 2010. In situ behavioural responses to boat noise exposure of *Gobius cruentatus* (Gmelin, 1789; fam. Gobiidae) and *Chromis chromis* (Linnaeus, 1758; fam. Pomacentridae) living in a marine protected area. *Journal of Experimental Marine Biology and Ecology* 386(1-2): 125-132. https://doi.org/10.1016/j.jembe.2013.05.012.

Pichegru, L., R. Nyengera, A.M. McInnes, and P. Pistorius. 2017. Avoidance of seismic survey activities by penguins. *Scientific Reports* 7: 16305. https://doi.org/10.1038/s41598-017-16569-x.

Pine, M., D.E. Hannay, S.J. Insely, W.D. Halliday, and F. Juanes. 2018a. Assessing vessel slowdown as an option for reducing acoustic masking for Arctic cod in the western Canadian Arctic. *Journal of the Acoustical Society of America* 144(3). https://doi.org/10.1121/1.5067412.

Pine, M.K., A.G. Jeffs, and C.A. Radford. 2012. Turbine sound may influence the metamorphosis behaviour of estuarine crab Megalopae. *PLOS ONE* 7(12). https://doi.org/10.1371/journal.pone.0051790.

Pine, M.K., D.E. Hannay, S.J. Insley, W.D. Halliday, and F. Juanes. 2018b. Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the western Canadian Arctic. *Marine Pollution Bulletin* 135: 290-302. https://doi.org/10.1016/j.marpolbul.2018.07.031.

Pirotta, E., B.E. Laesser, A. Hardaker, N. Riddoch, M. Marcoux, and D. Lusseau. 2013. Dredging displaces bottlenose dolphins from an urbanised foraging patch. *Marine Pollution Bulletin* 74(1): 396-402. https://doi.org/10.1016/j.marpolbul.2013.06.020.

Pirotta, E., N.D. Merchant, P.M. Thompson, T.R. Barton, and D. Lusseau. 2015. Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. *Biological Conservation* 181: 82-89. https://doi.org/10.1016/j.biocon.2014.11.003.

Plumpton, D.L., S.E. Sheaffer, D. Hunsaker, and S.A. Petrie. 2007. *Review of Studies Related to Aircraft Noise Disturbance of Waterfowl: A Technical Report in Support of the Supplemental Environmental Impact Statement (SEIS) for Introduction of F/A-18 E/F (Super Hornet) Aircraft to the East Coast of the United States*. US Department of the Navy, Naval Facilities Engineering Command Atlantic, Norfolk, VA, USA.

Popov, V.V., A.Y. Supin, A.P. Gvozdeva, D.I. Nechaev, M.B. Tarakanov, and E.V. Sysueva. 2020. Spatial release from masking in a bottlenose dolphin Tursiops truncatus. *Journal of the Acoustical Society of America* 147(3): 1719-1726. https://doi.org/10.1121/10.0000909.

Popper, A.N. and N.L. Clarke. 1976. The auditory system of the goldfish (*Carassius auratus*): Effects of intense acoustic stimulation. *Comparative Biochemistry and Physiology Part A* 53(1): 11-18. https://doi.org/10.1016/S0300-9629(76)80003-5.

Popper, A.N., J. Fewtrell, M.E. Smith, and R.D. McCauley. 2003. Anthropogenic sound: Effects on the behavior and physiology of fishes. *Marine Technology Society Journal* 37(4): 35-40. https://doi.org/10.4031/002533203787537050.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. *Journal of the Acoustical Society of America* 117(6): 3958-3971. https://doi.org/10.1121/1.1904386.

Popper, A.N., M.B. Halvorsen, A. Kane, D.L. Miller, M.E. Smith, J. Song, P. Stein, and L.E. Wysocki. 2007. The effects of high-intensity, low-frequency active sonar on rainbow trout. *Journal of the Acoustical Society of America* 122(1): 623-635. https://doi.org/10.1121/1.2735115.

Popper, A.N. and M.C. Hastings. 2009. The effects of anthropogenic sources of sound on fishes. *Journal of Fish Biology* 75(3): 455-489. https://doi.org/10.1111/j.1095-8649.2009.02319.x.

Popper, A.N. and R.R. Fay. 2011. Rethinking sound detection by fishes. *Hearing Research* 273(1): 25-36. https://doi.org/10.1016/j.heares.2009.12.023.

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

Popper, A.N., A.D. Hawkins, and M.B. Halvorsen. 2019. *Anthropogenic Sound and Fishes*. Document WA-RD 891.1. Report by ICF for Washington State Department of Transportation, Research Office. 170 p.

Przeslawski, R., L. Hurt, A. Forrest, A. Carroll, and Geoscience Australia. 2016. *Potential short-term impacts of marine seismic surveys on scallops in the Gippsland Basin*. Report 2014-041. CC BY 3.0, Canberra. http://frdc.com.au/research/Final_Reports/2014-041-DLD.pdf.

Putland, R.L., N.D. Merchant, A. Farcas, and C.A. Radford. 2018. Vessel noise cuts down communication space for vocalizing fish and marine mammals. *Global Change Biology* 24(4): 1708-1721. https://doi.org/10.1111/gcb.13996.

Pye, H.J. and W.H. Watson, III. 2004. Sound detection and production in the American lobster, *Homarus americanus*: Sensitivity range and behavioral implications. *Journal of the Acoustical Society of America* 115(5): 2486-2486. https://doi.org/10.1121/1.4782805.

Pytte, C.L., K.M. Rusch, and M.S. Ficken. 2003. Regulation of vocal amplitude by the blue-throated hummingbird, *Lampornis clemenciae*. *Animal Behaviour* 66(4): 703-710. https://doi.org/10.1006/anbe.2003.2257.

Rako, N., C.M. Fortuna, D. Holcer, P. Mackelworth, M. Nimak-Wood, G. Pleslić, L. Sebastianutto, I. Vilibić, A. Wiemann, et al. 2013. Leisure boating noise as a trigger for the displacement of the bottlenose dolphins of the Cres-Lošinj archipelago (northern Adriatic Sea, Croatia). *Marine Pollution Bulletin* 68(1-2): 77-84. https://doi.org/10.1016/j.marpolbul.2012.12.019.

Ramcharitar, J., D.P. Gannon, and A.N. Popper. 2006. Bioacoustics of fishes of the family Sciaenidae (croakers and drums). *Transactions of the American Fisheries Society* 135(5): 1409-1431. https://doi.org/10.1577/T05-207.1.

Reichmuth, C.J., A. Ghoul, J.M. Sills, A. Rouse, and B.L. Southall. 2016. Low-frequency temporary threshold shift not observed in spotted or ringed seals exposed to single air gun impulses. *Journal of the Acoustical Society of America* 140(4): 2646-2658. https://doi.org/10.1121/1.4964470.

Reine, K.J., D. Clarke, and C. Dickerson. 2014. Characterization of underwater sounds produced by hydraulic and mechanical dredging operations. *Journal of the Acoustical Society of America* 135(6): 3280-3294. https://doi.org/10.1121/1.4875712.

Reinhall, P.G. and P.H. Dahl. 2011. Underwater Mach wave radiation from impact pile driving: Theory and observation. *Journal of the Acoustical Society of America* 130(3): 1209-1216. https://doi.org/10.1121/1.3075600.

Remmers, P. and M.A. Bellmann. 2013. *Untersuchung und Erprobung von Hydroschalldämpfern (HSD) zur Minderung von Unterwasserschall bei Rammarbeiten für Gründungen von OffshoreWindenergieanlagen*. Auswertung der Hydroschallmessungen im OWP London Array. Project number1918-c-bel version 3. Report by Itap GmbH, Oldenburg, Germany.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine Mammals and Noise*. Academic Press, San Diego, CA, USA. 576 p. https://doi.org/10.1016/C2009-0-02253-3.

Ridgway, S.H. and D. Carder. 1997. Hearing deficits measured in some *Tursiops truncatus*, and discovery of a deaf/mute dolphin. *Journal of the Acoustical Society of America* 101(1): 590-594. https://doi.org/10.1121/1.418122.

Roberts, L., S. Cheesman, T. Breithaupt, and M. Elliott. 2015. Sensitivity of the mussel *Mytilus edulis* to substrate-borne vibration in relation to anthropogenically generated noise. *Marine Ecology Progress Series* 538: 185-195. https://doi.org/10.3354/meps11468.

Roberts, L., S. Cheesman, M. Elliott, and T. Breithaupt. 2016. Sensitivity of *Pagurus bernhardus* (L.) to substrate-borne vibration and anthropogenic noise. *Journal of Experimental Marine Biology and Ecology* 474: 185-194. https://doi.org/10.1016/j.jembe.2015.09.014.

Roberts, L. and M. Elliott. 2017. Good or bad vibrations? Impacts of anthropogenic vibration on the marine epibenthos. *Science of The Total Environment* 595: 255-268. https://doi.org/10.1016/j.scitotenv.2017.03.117.

Robinson, S.P., P.A. Lepper, and J. Ablitt. 2007. The measurement of the underwater radiated noise from marine piling including characterisation of a" soft start" period. *OCEANS 2007*. 18-21 Jun 2007. IEEE, Aberdeen, UK. pp. 732-737. https://doi.org/10.1109/OCEANSE.2007.4302326.

Ruggerone, G.T., S.E. Goodman, and R. Miner. 2008. *Behavioral response and survival of juvenile coho salmon to pile driving sounds*. Report by Natural Resources Consultants, Inc. for Port of Washington, Seattle, WA, USA.

Russell, D.J.F., G.D. Hastie, D. Thompson, V.M. Janik, P.S. Hammond, L.A.S. Scott-Hayward, J. Matthiopoulos, E.L. Jones, and B.J. McConnell. 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology* 53(6): 1642-1652. https://doi.org/10.1111/1365-2664.12678.

Ryals, B.M., R.J. Dooling, E. Westbrook, M.L. Dent, A. MacKenzie, and O.N. Larsen. 1999. Avian species differences in susceptibility to noise exposure. *Hearing Research* 131(1-2): 71-88. https://doi.org/10.1016/S0378-5955(99)00022-2.

Saleem, Z. 2011. *Alternatives and modifications of Monopile foundation or its installation technique for noise mitigation*. Report by Delft Univeristy of Technology and Stichting De Noordzee for the North Sea Foundation. http://www.vliz.be/imisdocs/publications/223688.pdf.

Salgado Kent, C.P., R.D. McCauley, I.M. Parnum, and A.N. Gavrilov. 2012. Underwater noise sources in Fremantle inner harbour: Dolphins, pile driving and traffic. *Acoustics 2012*. 21-23 Nov 2012, Fremantle, Australia.

Sand, O., H.E. Karlsen, and F.R. Knudsen. 2008. Comment on "Silent research vessels are not quiet" [J. Acoust. Soc. Am. 121, EL145–EL150]. *Journal of the Acoustical Society of America* 123(4): 1831-1833. https://doi.org/10.1121/1.2839134.

Saunders, J. and R.J. Dooling. 1974. Noise-induced threshold shift in the parakeet (*Melopsittacus undulatus*). *Proceedings of the National Academy of Sciences of the United States of America* 71(5): 1962-1965. https://doi.org/10.1073/pnas.71.5.1962.

Saunders, J.C. and R.J. Dooling. 2018. Characteristics of Temporary and Permanent Threshold Shifts in Vertebrates. (Chapter 4) *In* Slabbekoorn, H., R.J. Dooling, A.N. Popper, and R.R. Fay (eds.). *Effects of Anthropogenic Noise on Animals*. Volume 66. Springer, New York. pp. 83-108. https://doi.org/10.1007/978-1-4939-8574-6_4.

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. *Journal of the Acoustical Society of America* 117(3): 1486-1492. https://doi.org/10.1121/1.1835508.

Scholik, A.R. and H.Y. Yan. 2001. Effects of underwater noise on auditory sensitivity of a cyprinid fish. *Hearing Research* 152(1-2): 17-24. https://doi.org/10.1016/S0378-5955(00)00213-6.

Scholik, A.R. and H.Y. Yan. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. *Environmental Biology of Fishes* 63(2): 203-209. https://doi.org/10.1023/A:1014266531390.

Sierra-Flores, R., T. Atack, H. Migaud, and A. Davie. 2015. Stress response to anthropogenic noise in Atlantic cod *Gadus morhua* L. *Aquacultural Engineering* 67: 67-76. https://doi.org/10.1016/j.aquaeng.2015.06.003.

Simpson, S.D., J. Purser, and A.N. Radford. 2015. Anthropogenic noise compromises antipredator behaviour in European eels. *Global Change Biology* 21(2): 586-593. https://doi.org/10.1111/gcb.12685.

Sisneros, J.A., A.N. Popper, A.D. Hawkins, and R.R. Fay. 2016. Auditory Evoked Potential Audiograms Compared with Behavioral Audiograms in Aquatic Animals. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Volume 875. Springer, New York. pp. 1049-1056. https://doi.org/10.1007/978-1-4939-2981-8_130.

Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A.N. Popper. 2010. A noisy spring: The impact of globally rising underwater sound levels on fish. *Trends in Ecology & Evolution* 25(7): 419-427. https://doi.org/10.1016/j.tree.2010.04.005.

Slabbekoorn, H., J. Dalen, D. de Haan, H.V. Winter, C. Radford, M.A. Ainslie, K.D. Heaney, T. van Kooten, L. Thomas, et al. 2019. Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge. *Fish and Fisheries* 20(4). https://doi.org/10.1111/faf.12367.

Smith, M.E., A.S. Kane, and A.N. Popper. 2004. Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). *Journal of Experimental Biology* 207(3): 427-435. https://doi.org/10.1242/jeb.00755.

Smith, M.E., A.B. Coffin, D.L. Miller, and A.N. Popper. 2006. Anatomical and functional recovery of the goldfish (*Carassius auratus*) ear following noise exposure. *Journal of Experimental Biology* 209(21): 4193-4202. https://doi.org/10.1242/jeb.02490.

Smith, M.E. and J.D. Monroe. 2016. Causes and Consequences of Sensory Hair Cell Damage and Recovery in Fishes. *In* Sisneros, J.A. (ed.). *Fish Hearing and Bioacoustics*. Volume 877. pp. 393-417. https://doi.org/10.1007/978-3-319-21059-9_17.

Solan, M., C. Hauton, J.A. Godbold, C.L. Wood, T.G. Leighton, and P. White. 2016. Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. *Scientific Reports* 6: 20540. https://doi.org/10.1038/srep20540.

Solé, M., M. Lenoir, M. Durfort, M. López-Bejar, A. Lombarte, and M. André. 2013. Ultrastructural Damage of *Loligo vulgaris* and *Illex coindetii* statocysts after Low Frequency Sound Exposure. *PLOS ONE* 8(10): e78825. https://doi.org/10.1371/journal.pone.0078825.

Solé, M., P. Sigray, M. Lenoir, M. Van Der Schaar, E. Lalander, and M. André. 2017. Offshore exposure experiments on cuttlefish indicate received sound pressure and particle motion levels associated with acoustic trauma. *Scientific Reports* 7: 45899. https://doi.org/10.1038/srep45899.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of northern Canadian freshwater fishes following exposure to seismic air gun sounds. *Journal of the Acoustical Society of America* 124(2): 1360-1366. https://doi.org/10.1121/1.2946702.

Sørensen, K., C. Neumann, M. Dähne, K.A. Hansen, and M. Wahlberg. 2020. Gentoo penguins (*Pygoscelis papua*) react to underwater sounds. *Royal Society Open Science* 7(2): 191988. https://doi.org/10.1098/rsos.191988.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521. https://doi.org/10.1578/AM.33.4.2007.411.

Southall, B.L., T. Rowles, F. Gulland, R.W. Baird, and P.D. Jepson. 2013. *Final report of the Independent Scientific Review Panel investigating potential contributing factors to a 2008 mass stranding of melon-headed whales (Peponocephala electra) in Antsohihy, Madagascar*.

Southall, B.L., D.P. Nowaceck, P.J.O. Miller, and P.L. Tyack. 2016. Experimental field studies to measure behavioral responses of cetaceans to sonar. *Endangered Species Research* 31: 293-315. https://doi.org/10.3354/esr00764.

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

Sprogis, K.R., S. Videsen, and P.T. Madsen. 2020. Vessel noise levels drive behavioural responses of humpback whales with implications for whale-watching. *eLife* 9: e56760. https://doi.org/10.7554/eLife.56760.

Stalmaster, M.V. and J.L. Kaiser. 1997. Flushing responses of wintering bald eagles to military activity. *Journal of Wildlife Management* 61(4): 1307-1313. https://doi.org/10.2307/3802130.

Stanley, J.A., S.M. Van Parijs, and L.T. Hatch. 2017. Underwater sound from vessel traffic reduces the effective communication range in Atlantic cod and haddock. *Scientific Reports* 7(1): 14633. https://doi.org/10.1038/s41598-017-14743-9.

Stein, P., H. Sychla, J. Gattermann, and J. Degenhardt. 2015. Hydro sound emissions during impact driving of monopiles using Hydro Sound Dampers and Big Bubble Curtain. *RAVE Offshore Wind R&D Conference*. 13-15 Oct 2015, Bremerhaven, Germany.

Stokes, A., K. Cockrell, J. Wilson, D. Dwight, and D. Warwick. 2010. *Mitigation of underwater pile driving noise during offshore construction: Final report*. Report M09PC00019-8. Report by Applied Physical Sciences Corp. for Department of the Interior, Minerals Management Service. http://users.ece.utexas.edu/~ling/4A_US5.pdf.

Tavolga, W.N. and J. Wodinsky. 1963. Auditory capacities in fishes: Pure tone thresholds in nine species of marine teleosts. *Bulletin of the American Museum of Natural History* 126: 177-240.

Tennessen, J.B. and S.E. Parks. 2016. Acoustic propagation modeling indicates vocal compensation in noise improves communication range for North Atlantic right whales. *Endangered Species Research* 30: 225-237. https://doi.org/10.3354/esr00738.

Terhune, J.M., R.E.A. Stewart, and K. Ronald. 1979. Influence of vessel noises on underwater vocal activity of harp seals. *Canadian Journal of Zoology* 57(6): 1337-1338. https://doi.org/10.1139/z79-170.

Thomsen, F., S. McCully, D. Wood, F. Pace, and P. White. 2009. *A generic investigation into noise profiles of marine dredging in relation to the acoustic sensitivity of the marine fauna in UK waters with particular emphasis on aggregate dredging: PHASE 1 Scoping and review of key issues*. . Document MEPF/08/P21. Technical report by Marine Aggregate Levy Sustainability Fund (MALSF).

Thorpe, W.H. 1963. *Learning and instinct in animals*. Methuen & Co., London.

Tougaard, J., J. Carstensen, O.D. Henriksen, H. Skov, and J. Teilmann. 2003. *Short-term effects of the construction of wind turbines on harbour porpoises at Horns Reef*. Report by Danish Hydraulic Institute (DHI), National Environmental Research Institute (NERI), and TechWise A/S, Røskilde, Denmark. 72 p. https://tethys.pnnl.gov/publications/short-term-effects-construction-wind-turbines-harbour-porpoises-horns-reef.

Tougaard, J., J. Carstensen, J. Teilmann, H. Skov, and P. Rasmussen. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). *Journal of the Acoustical Society of America* 126(1): 11-14. https://doi.org/10.1121/1.3132523.

Tubelli, A.A., A. Zosuls, D.R. Ketten, and D.C. Mountain. 2012. Prediction of a mysticete audiogram via finite element analysis of the middle ear. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life*. Volume 730. Springer, New York. pp. 57-59. https://doi.org/10.1007/978-1-4419-7311-5_12.

Vasconcelos, R.O., M.C.P. Amorim, and F. Ladich. 2007. Effects of ship noise on the detectability of communication signals in the Lusitanian toadfish. *Journal of Experimental Biology* 210(12): 2104-2112. https://doi.org/10.1242/jeb.004317.

Vasconcelos, R.O., P.J. Fonseca, M.C.P. Amorim, and F. Ladich. 2011. Representation of complex vocalizations in the Lusitanian toadfish auditory system: Evidence of fine temporal, frequency and amplitude discrimination. *Proceedings of the Royal Society B* 278(1707): 826-834. https://doi.org/10.1098/rspb.2010.1376.

Vinh, P.C. 2013. Scholte-wave velocity formulae. *Wave Motion* 50(2): 180-190. https://doi.org/10.1016/j.wavemoti.2012.08.006.

Voellmy, I.K., J. Purser, D. Flynn, P. Kennedy, S.D. Simpson, and A.N. Radford. 2014. Acoustic noise reduces foraging success in two sympatric fish species via different mechanisms. *Animal Behaviour* 89: 191-198. https://doi.org/10.1016/j.anbehav.2013.12.029.

Voellmy, I.K., J. Purser, S.D. Simpson, and A.N. Radford. 2016. Effects of Previous Acoustic Experience on Behavioral Responses to Experimental Sound Stimuli and Implications for Research. *In* Popper, A.N. and A.D. Hawkins (eds.). *The Effects of Noise on Aquatic Life II*. Springer New York. pp. 1191-1196. https://doi.org/10.1007/978-1-4939-2981-8_149.

Von Benda-Beckmann, A.M., P.J. Wensveen, P.H. Kvadsheim, F.-P.A. Lam, P.J.O. Miller, P.L. Tyack, and M.A. Ainslie. 2014. Modeling effectiveness of gradual increases in source level to mitigate effects of sonar on marine mammals. *Conservation Biology* 28(1): 119-128. http://dx.doi.org/10.1111/cobi.12162.

Ward, W.D. 1997. Effects of high-intensity sound. (Chapter 119) *In* Crocker, M.J. (ed.). *Encyclopedia of acoustics*. Volume III. John Wiley and Sons, New York. pp. 1497-1507. https://doi.org/10.1002/9780470172537.ch119.

Wartzok, D. and D.R. Ketten. 1999. Marine Mammal Sensory Systems. (Chapter 4) *In* Reynolds, J. and S. Rommel (eds.). *Biology of Marine Mammals*. Smithsonian Institution Press, Washington, DC. pp. 117-175.

Wever, E.G., P.N. Herman, J.A. Simmons, and D.R. Hertzler. 1969. Hearing in the blackfooted penguin, Pheniscus demersus, as represented by cochlear potentials. *Proceedings of the National Academy of Sciences of the United States of America* 63(3): 676-680. https://doi.org/10.1073/pnas.63.3.676.

Williams, R., D.E. Bain, J.K.B. Ford, and A.W. Trites. 2002a. Behavioral responses of male killer whales to a "leapfrogging" vessel. *Journal of Cetacean Research and Management* 4(3): 305-310.

Williams, R., A.W. Trites, and D.E. Bain. 2002b. Behavioural reponses of killer whales (*Orcinus orca*) to whale-watching boats: Opportunistics observations and experimental approaches. *Journal of Zoology* 256(2): 255-270. https://doi.org/10.1017/S0952836902000298.

Williams, R., D.E. Bain, J.C. Smith, and D. Lusseau. 2009. Effects of vessels on behaviour patterns of individual southern resident killer whales *Orcinus orca*. *Endangered Species Research* 6(3): 199-209. https://doi.org/10.3354/esr00150.

Williams, R., C. Erbe, E. Ashe, A. Beerman, and J. Smith. 2014. Severity of killer whale behavioral responses to ship noise: A dose–response study. *Marine Pollution Bulletin* 79(1-2): 254-260. https://doi.org/10.1016/j.marpolbul.2013.12.004.

Williams, R., C. Erbe, E. Ashe, and C.W. Clark. 2015. Quiet(er) marine protected areas. *Marine Pollution Bulletin* 100(1): 154-161. https://doi.org/10.1016/j.marpolbul.2015.09.012.

Wilson, C.C. and C. McPherson. 2021. *Viva Energy Gas Terminal Project: Baseline Monitoring of Ambient Environment*. Document 02580, Version 1.0 DRAFT. Technical report by JASCO Applied Sciences for AECOM.

Würsig, B., C.R. Greene, Jr., and T.A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. *Marine Environmental Research* 49(1): 79-93. https://doi.org/10.1016/S0141-1136(99)00050-1.

Supplement A. Physical Characteristics of Underwater Sound

The following subsections provide a brief overview of the most important aspects of underwater sound and introduce the most relevant terms and metrics.

A.1. Sound Characteristics

Sound is a physical phenomenon consisting of minute vibrations that travel through a supporting medium, such as air or water. When the surface of a vibrating object (sound source) moves forward into the medium, it compresses the surrounding molecules, thereby creating a region of higher pressure. As the surface then moves back toward and past its neutral position, the molecules of the surrounding medium expand back and a region of lower pressure results. These cycles are called compressions and rarefactions, respectively (see Figure A-1).

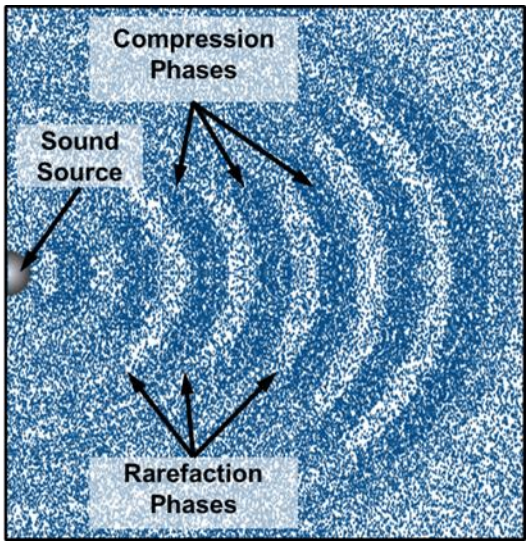


Figure A-1. Cession and rarefaction phases of a travelling sound wave.

The successive compressions and rarefactions result in sound waves. The speed at which these compressions and rarefactions travel away from the source depends on the compressibility and density of the medium and defines the speed of sound in that medium. Sound waves travel much faster in water than in air.

Sound is generally described in terms of frequency (or pitch), intensity, and temporal properties (e.g., short or long in duration, impulsive and non-impulsive). The following text provides a general description of these terms. For more details, there are several publications and books that provide detailed overviews of underwater acoustics, such as Richardson et al. (1995) and Au and Hastings (2008a), and some internet sources such as the Discovery of Sound in the Sea (DOSITS 2020), which is a highly recommended source of information on the subject.

Frequency is a measure of how many times the crest of a sound pressure wave passes a fixed point over the duration of a second; it is measured in Hertz (Hz). Some mysticetes (baleen whales) produce and may hear sounds below 20 Hz, while odontocetes (toothed whales) produce and hear sounds at frequencies much higher (up to 180 kHz for some species).

Sound intensity is defined as the acoustic power per unit area. The intensity, power, and energy of a sound wave are proportional to the average of the squared pressure. Measurement instruments and

most receivers (humans, animals) sense changes in pressure, which is measured in Pascals (Pa). While pressure changes due to sound waves can be measured in Pascals, they are more commonly expressed in decibels (dB). The decibel is a logarithmic scale that is based on the ratio of the sound pressure relative to a standard reference pressure. The logarithmic decibel scale is used to allow comparison of extremely large sound pressure differences between sources.

Different standard reference pressures are used for airborne sounds and underwater sounds. The airborne standard pressure reference is $p_{ref(air)}$ = 20 micropascals (µPa), while the underwater standard reference pressure is $p_{ref(water)}$ = 1 µPa. The formula used to convert a pressure p measured in micropascals to sound pressure level *P* measured in dB is $P = 20 \log10 [p/p_{ref}]$. Because of the logarithmic nature of the decibel scale, sound levels cannot be added or subtracted directly. (If a sound's pressure is doubled, its sound level increases by 6 dB, regardless of the initial sound level.)

Impulsive Sounds versus Non-impulsive Sounds

Impulsive and non-impulsive sounds are primarily distinguished by their temporal pattern: Impulsive or 'pulsed' sounds can be described as discrete (single pulses) and sometimes intermittent sounds (multiple pulses) produced by sources such as airguns and pile driving. These sounds, sometimes also termed transients, are typically brief signals consisting of high peak sound pressure with a rapid rise time and a rapid decay (NIOSH 1998).

Non-impulsive sounds, which can be intermittent or continuous, produced by sound sources such as ships and pumps. Non-impulsive sounds are longer than impulsive ones and usually do not have the high peak sound pressure and rapid rise/decay time that impulsive sounds do (NIOSH 1998). However, especially in respect to their auditory effects, the term non-impulsive does not imply long duration signals.

Particle Motion

Since sound is a mechanical wave, it can also be measured in terms of the vibratory motion of fluid particles. Particle motion can be measured in terms of three different (but related) quantities: displacement, velocity, or acceleration. Acoustic particle velocity is the time derivative of particle displacement, and likewise acceleration is the time derivative of velocity. The most relevant particle motion metrics regarding potential effects on marine fauna are acceleration and velocity.

Acoustic Metrics

Three metrics are commonly used for analysing underwater sound propagation and evaluating underwater sound impacts on marine wildlife: peak pressure (PK), sound pressure level (SPL), and sound exposure level (SEL). Terminology in this field should refer to the ISO standard International Organization for Standardization (2017). For impulsive sources, SPL is gradually being supplemented or replaced by fast time-weighted average SPL.

Figure A-2 shows a representation of a sinusoidal (single frequency) pressure wave to illustrate the various metrics. The amplitude of the pressure is shown along the vertical axis, and time is shown along the horizontal axis. The pressure of the wave fluctuates around the neutral point. The peak pressure is the absolute value of the maximum variation from the neutral position of a wave oscillation; therefore, it can result from either a compression or a rarefaction. The peak-to-peak sound pressure is the difference between the maximum and minimum pressures. The average amplitude is the average of absolute value of pressure over the period of interest.

The rms amplitude is a type of average determined by squaring all the amplitudes over the period of interest, determining the mean of the squared values, and then taking the square root of this mean. The rms amplitude of an impulsive signal will vary significantly depending on the length of the period of interest.

SEL is a metric related to the sound energy per area received over time, though it does not have energy units; it is proportional to the square of the sound pressure and the time over which a sound is received.

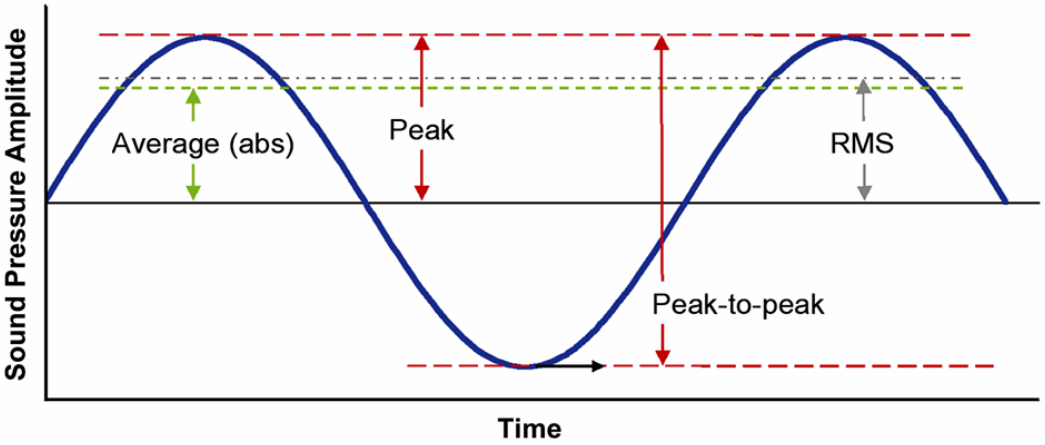


Figure A-2. Sound level metrics.

Sources of underwater noise, such as ship propellers or marine mammal vocalisations, generate radiating sound waves whose intensity generally decays with distance from the source. The reduction in sound level measured in decibels that results from propagation of sound away from an acoustic source is called propagation loss (PL) or transmission loss (TL). The loudness or sound volume of a noise source is quantified in terms of the source level (SL), which is the sound level referenced to some fixed distance from a noise source. The standard reference distance for underwater sound is 1 m. By convention, transmission loss is quoted in units of dB and underwater acoustic source levels are specified in units of dB re 1 µPa.

Appendix F

Greenhouse gas impact assessment

Prepared for
Viva Energy Gas Australia Pty Ltd
ABN: N/A

Technical Report C: Greenhouse Gas Impact Assessment

Viva Energy Gas Terminal Project

25-Feb-2022
Viva Energy Gas Terminal Project

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Delivering a better world

Technical Report C: Greenhouse Gas Impact Assessment

Viva Energy Gas Terminal Project

Client: Viva Energy Gas Australia Pty Ltd

ABN: N/A

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Executive summary

This technical report provides a greenhouse gas impact assessment conducted to support the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the *Environment Effects Act 1978* (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic, and transport as well as visual amenity.

In January 2021, the project was also determined to require assessment and approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999 (Cth)* ('EPBC Act') due to the potential for the project to have a significant impact on wetlands of international importance, listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

Overview

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a floating gas terminal using a ship known as a floating storage and regasification unit (FSRU) which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas for the South-East Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU), and regasify the LNG as required to meet industrial, commercial, and residential customer demand. For the project the usual FSRU operating mode is open loop regasification which would use seawater to heat the LNG with some modification such that the FSRU seawater discharge would be transferred to the adjacent refinery for reuse within the cooling water process. The FSRU would also be able to operate in closed loop mode using gas-fired boilers to generate steam to heat the LNG and this operating mode would only be used in in very limited instances where discharge water may not be able to be transferred to the refinery A combined loop regasification process involving a combination of modes to heat the seawater could also potentially be used if the ambient seawater temperature is too low for open loop regasification to operate effectively.

A 7-kilometre gas pipeline would transfer the gas from the FSRU to the Victorian Transmission System (VTS) at Lara.

The gas terminal would be located adjacent to, and on, Viva Energy's Geelong Refinery in a heavily industrialised setting and would benefit from Viva Energy's experience and capability as an existing Major Hazard Facility (MHF) operator and potential synergies between the two facilities such as reuse of the FSRU seawater discharge within the refinery operations.

Methodology

The greenhouse gas impact assessment methodology followed the principles set out in the following documents:

- *National Greenhouse and Energy Reporting Act 2007* (Cth) ('NGER Act'*) and National Greenhouse and Energy Reporting (Measurement) Determination 2008* (as amended), Commonwealth Department of Environment and Energy
- *The Greenhouse Gas Protocol (GHG Protocol),* the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI)
- *American Petroleum Institute (API) Compendium of GHG Emissions Methodologies for the Oil and Natural Gas Industry,* August 2009
- *ISO 14064-1:2018 Greenhouse gases – Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals*

- *ISO 14040:2006 Environmental management – Lifecycle assessment – Principles and framework* and *ISO 14044:2006 Environmental management – Lifecycle assessment – Requirements and guidelines*. These standards are applicable to the calculation of materials lifecycle impacts using the Infrastructure Sustainability (IS) Materials Calculator.

Greenhouse gas (GHG) emissions were estimated in accordance with the principles of the internationally accepted GHG Protocol. According to the GHG Protocol, greenhouse gas emissions are split into three categories, known as 'Scopes'. Scope 1, Scope 2, and Scope 3 are defined by the GHG Protocol as:

- Scope 1 – Direct emissions of greenhouse gas from sources that are owned or operated by a reporting organisation (examples include combustion of diesel in company-owned vehicles or used in on-site plant and equipment)
- Scope 2 – Indirect emissions associated with the import of energy from another source (examples include import of electricity from the grid, or heat)
- Scope 3 – Other indirect emissions, other than energy imports (above) which are a direct result of the operations of the organisation, but from sources not owned or operated by them and due to upstream or downstream activities (examples include indirect upstream emissions associated with the extraction, production, and transport of purchased construction materials; and business travel (by ship, air or rail)).

The study, in accordance with the EES scoping requirements, has considered both direct and indirect greenhouse gas emissions that would result from the project. Direct Scope 1 emissions, and indirect Scope 2 and Scope 3 emissions identified as material for the project (in accordance with GHG Protocol criteria) and within the proponent's ability to control, were considered for construction and operation scenarios.

Existing conditions

The context of the existing conditions for the greenhouse gas impact assessment is the current Victorian emissions profile. In the *State and Territory Greenhouse Gas Inventories 2019* report, Victoria's total emissions were 91.33 million-tonnes of carbon dioxide equivalent (Mt CO_2-e). Energy industries (i.e., direct combustion) accounted for 51 per cent of Victoria's total emissions or 46.88 Mt CO_2-e.

Construction impact assessment

The total construction emissions (Scope 1, 2, and relevant Scope 3) for the project are estimated to be 62,168 t CO2-e.

Operation impact assessment

The open and closed loop scenarios assumed the supply of natural gas at 250 terajoules per day (TJ/day) during summer (90 days per year), 350 TJ/day during spring and autumn (183 days per year), 500 TJ/day during the winter (86 days per year) and 620 TJ/day during peak demand days in winter (6 days per year), delivering a total of up to 45 cargos of LNG into the VTS. This equates to approximately 160 petajoules (PJ) of natural gas delivery per annum.

The usual operating mode for the FSRU is open loop however closed loop has also been assessed on the basis that it represents the 'worst case' operating scenario.

The combined loop regasification process would potentially be used if the seawater falls below a specified temperature. This has been assumed to be 30 days a year.

The total annual operational emissions (Scope 1, 2 and relevant Scope 3) for the project would be as follows:

- Open loop operating mode (using seawater to heat the LNG) – 47,906 t CO_2-e
- Closed loop operating mode (using gas fired boilers to heat the LNG) – 178,985 t CO_2-e
- Combined loop operating mode – 65,280 t CO_2-e.

The closed loop operational mode would trigger requirements under the *National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015*.

Summary of impacts on Victoria's Scope 1 and Scope 2 emissions

The total Scope 1 and 2 emissions during the construction period equates to 0.01 per cent of Victoria's annual greenhouse gas emissions.

Table 1-1 presents a comparison of the project's annual Scope 1 and 2 operational emissions to Victoria's annual Scope 1 and 2 greenhouse gas emissions. The most significant opportunity to minimise emissions would be, as proposed, to adopt open loop as the usual mode of FSRU regasification operation, as this would emit four times less greenhouse gas emissions than closed loop.

Table 1-1 Comparison of the project's annual operational greenhouse gas emissions to Victoria's annual emissions

Emissions source	Total annual Scope 1 and 2 greenhouse gas emissions (kt CO_2-e)	% of Victoria's annual total greenhouse gas emissions
Victoria 2019	**91,330**	**100**
Project during operation - Open loop operating mode	47	0.05
Project during operation - Closed loop operating mode	179	0.20
Project during operation - Combined loop operating mode	65	0.07

Summary of recommended mitigation measures

This report details recommended mitigation measures that, if adopted, would reduce the emissions impact of the project both during construction and operation. It is anticipated that the project would adopt mitigation measures utilising the mitigation hierarchy in order to first avoid then minimise emissions produced during construction and operation, before considering offsets. All efforts to reduce emissions should be considered given the ongoing impact of climate change on society.

Table 1-2 Project mitigation measures for greenhouse gas emissions

MM ID	Mitigation measure	Project phase
MM-GG01	**Minimise embodied and transport emissions of materials** Low embodied energy and locally sourced materials should be considered and used where practicable to minimise embodied and transport emissions. The proponent could develop criteria for a minimum proportion of supplementary cementitious material content in concrete, recycled steel, and recycled aggregates. The criteria should consider the location materials are being sourced from to minimise associated transport emissions.	Design and construction
MM-GG02	**Managing quality of materials** Materials that are low maintenance and durable should be selected to avoid unnecessary replacement. The quality of key materials (i.e., pipe and mooring infrastructure) should be inspected before supplying	Construction

MM ID	Mitigation measure	Project phase
	to site to avoid additional transport and handling of materials.	
MM-GG03	**Source local plant and equipment** Locally sourced plant and equipment (i.e., within Victoria) should be considered and used where practicable to reduce emissions associated with transport. Sourcing local plant and equipment where practicable should be included in the selection criteria for tendering of works associated with plant and equipment.	Construction
MM-GG04	**Coordination of construction activities** Construction activities should be coordinated to reduce unnecessarily extending the construction period and to avoid inefficient use of equipment.	Construction
MM-GG05	**Sustainable procurement and resource management practices** Sustainable procurement and resource management practices should be adopted to avoid the inefficient use of materials, fossil fuels, and electricity. The proponent should refer to ISO 20400:2017 Sustainable procurement which provides guidance on integrating sustainability within procurement.	Construction and operation
MM-GG06	**Local workforce** Local workforce should be engaged where possible. Interstate and international travel should be minimised and where appropriate replaced by virtual engagement. The proponent could complete a transport plan to detail how fuel emissions from employee transport would be minimised.	Construction and operation
MM-GG07	**Plant and equipment fuel efficiency** Selection of plant and equipment should incorporate consideration of fuel efficiency to reduce the consumption of fossil fuels.	Construction and operation
MM-GG08	**Waste – avoid, reduce, reuse** Design should reduce the total quantum of materials required through design refinement and incorporate reuse materials during construction and operation of the project. The proponent could develop a waste management plan that considers waste reduction, segregation of waste, and disposal of waste to ensure that waste is correctly separated and diverted from landfill where appropriate.	Design, construction, and operation

MM ID	Mitigation measure	Project phase
MM-GG09	**Implementation of Energy Management Systems** An energy management system will be implemented in accordance with the International Organisation for Standardisation (ISO) 50001 *Energy Management Systems* (ISO 50001) for the operation of the FSRU. The ISO 50001 provides a framework for organisations to take a systematic approach to achieve continual improvement of energy performance and efficiency and reductions in greenhouse gas emissions. This framework is considered global best practice, and involves: • developing energy use baselines • developing energy management plans • identifying performance indicators • setting targets for improvement. Progress will be regularly monitored, reported, and reviewed. Implementation of this system will also involve external certification by ISO-accredited auditors (typically on a three year cycle) in which both compliance with the ISO standard and performance improvement will need to be demonstrated to maintain certification.	Operation
MM-GG10	**Emergency management procedures** Safety controls and emergency management practices should be put in place in the case of unplanned activities, incidents, and emergencies (i.e., unplanned maintenance or venting) to minimise the release of fugitive greenhouse gas emissions.	Operation
MM-GG11	**Certified carbon offsets** The project could consider purchasing certified carbon offset to compensate for emissions produced during construction and annual emissions produced during operation. A strategy to offset certain emissions could be implemented (e.g., offsetting all Scope 1 and 2 emissions). Note that offsets would only be considered for project emissions after measures that aim to avoid or minimise emissions have been adopted.	Construction and operation

Abbreviations and glossary of terms

Abbreviation/Term	Definition
API	American Petroleum Institute
CO_2	Carbon Dioxide
CH_4	Methane
EES	Environment Effects Statement
EMF	Environmental Management Framework
EPA	Environmental Protection Authority
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
ERF	Emissions Reduction Fund
FSRU	Floating Storage and Regasification Unit
GHG	Greenhouse Gas Emissions
HDD	Horizontal Directional Drilling
IS	Infrastructure Sustainability
ISO	International Organisation for Standardisation
LGA	Local Government Area
LNG	Liquefied Natural Gas
MDO	Marine Diesel Oil
MHF	Major Hazard Facility
MM	Mitigation Measure
NGAF	National Greenhouse Account Factors
NGER	National Greenhouse and Energy Reporting
N_2O	Nitrous Oxide
Operational boundary	Operational boundary is the terminology used to describe the scope of activities (during both construction and operation) that are within the proponent's ability to control.
PJ	Petajoules
ROW	Right of Way
SWP	South West Pipeline
TJ	Terajoules
T	Tonnes
TRG	Technical Reference Group
VTS	Victorian Transmission System

1.0 Introduction

This technical report provides a greenhouse gas impact assessment conducted to support the Environment Effects Statement (EES) for the Viva Energy Gas Terminal Project (the project).

Viva Energy Gas Australia Pty Ltd (Viva Energy) is planning to develop a gas terminal using a ship known as a floating storage and regasification unit (FSRU), which would be continuously moored at Refinery Pier in Corio Bay, Geelong. The key objective of the project is to facilitate supply of a new source of gas for the south-east Australian gas market where there is a projected supply shortfall in coming years.

The FSRU would store liquefied natural gas (LNG) received from visiting LNG carriers (that would moor directly adjacent to the FSRU) and would convert LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification) as required to meet industrial, commercial, and residential customer demand. A 7-kilometre gas transmission pipeline would transfer the gas from the FSRU to the Victorian Transmission System (VTS) at Lara.

The project would be situated adjacent to, and on, Viva Energy's Geelong Refinery, within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. Co-locating the project with the existing Geelong Refinery and within the Port of Geelong offers significant opportunity to minimise potential environmental effects and utilise a number of attributes that come with the port and industrial setting.

In December 2020, the Victorian Minister for Planning determined that the project requires assessment through an EES under the *Environment Effects Act 1978* (Vic). The reasons for the decision were primarily related to the potential for significant adverse effects on the marine environment of Corio Bay and the potential for contributing to greenhouse gas emissions. Secondarily, the EES was required to assess the effects of the project on air quality, noise, land use, Aboriginal and historic heritage, native vegetation, groundwater, traffic, and transport as well as visual amenity.

In January 2021 the project was also determined to require assessment and approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999 (Cth)* ('EPBC Act') due to the potential for the project to have a significant impact on the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site (a wetland of international importance), listed threatened species and communities, and listed migratory species. The EES process is the accredited environmental assessment process for the controlled action decision under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

1.1 Purpose

This greenhouse gas impact assessment identifies, assesses, and characterises the potential environmental impacts of greenhouse gas emissions associated with the construction and operation of the project to inform the preparation of the EES required for the project.

The report identifies and recommends mitigation measures to avoid, minimise and manage potential impacts which will inform the development of an Environmental Management Framework (EMF) for the project. The mitigation measures listed in the EMF would be implemented in the approvals and management plans for the project.

1.2 Why understanding greenhouse gas emissions is important

Australia's climate is changing, and greenhouse gas emissions are a key contributor to climate change. More intense and frequent storms, heatwaves, droughts, sea level rise, bushfires and other extreme weather events are impacting our natural and built environments. Climate impacts are already observable and there is broad scientific consensus that further changes will occur and that impacts are likely to increase. Australia's 2015 Paris Agreement target is to reduce greenhouse gas emissions by 26-28 per cent below 2005 levels by 2030. The *Climate Change Act 2017 (Vic)* sets the legislative foundation to manage climate change risks and drive Victoria's transition to net zero emissions by 2050. The Victorian government has set interim targets to reduce emissions by 28 – 33 per cent below 2005 levels by 2025, and 45 – 50 per cent by 2030. The Victorian government has also committed to 50 per

cent of Victoria's electricity to be from renewable sources by 2030. The energy industries sector accounted for approximately 51 per cent of Victoria's overall greenhouse gas emissions in 2019 (Commonwealth of Australia, 2021).

Greenhouse gases are generally measured as tonnes (t) or kilo tonnes (kt) of carbon dioxide equivalent (CO_2-e). This represents the amount of greenhouse gases emitted as an equivalent amount of CO_2 which has a global warming potential of one. For example, one tonne of CH_4 released into the atmosphere will cause the same amount of global warming as 25 tonnes of CO_2. Therefore, one tonne of CH_4 is expressed as 25 t CO_2-e (Department of the Environment, 2018).

Direct project activities that would cause the release of greenhouse gases into the atmosphere include:

- burning fossil fuels in vehicles, plant, and equipment
- consumption of electricity produced by burning fossil fuels (such as coal or natural gas)
- consumption of materials where the manufacturing processes involve greenhouse gas emissions (for example manufacturing steel or cement)
- disposal of construction and operational waste
- dredging of seabed sediment
- clearance of vegetation.

1.3 Project area

The project would be located adjacent to, and on, the Geelong Refinery and Refinery Pier in the City of Greater Geelong, 75 kilometres (km) south-west of Melbourne. The project area is within a heavily developed port and industrial area on the western shores of Corio Bay between the Geelong suburbs of Corio and North Shore. The Geelong central business district is located approximately 7km south of the project.

Corio Bay is the largest internal bay in the south-west corner of Port Phillip Bay and is a sheltered, shallow basin at the western end of the Geelong Arm with an area of 43 square kilometres (km^2). The Point Wilson/Limeburners Bay section of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site is located along the northern shoreline of Corio Bay approximately one kilometre to the north-east of the project.

The Port of Geelong has been in operation for over 150 years and is the largest industrial bulk cargo port in Victoria attracting over 600 ship visits and handling more than 14 million tonnes of product annually. Geelong's shipping channels extend 18 nautical miles through Corio Bay from Point Richards through to Refinery Pier. Ports Victoria (formerly Victorian Regional Channels Authority) manages commercial navigation in the port waters in and around Geelong and is responsible for the safe and efficient movement of shipping, and for maintaining shipping channels and navigation aids. The channels are man-made having been deepened and widened through periodic dredging to support port trade development.

Refinery Pier is the primary location within the Port of Geelong for movement of bulk liquids. Vessels up to 265 metres in length currently utilise the four berths at Refinery Pier which service Viva Energy refinery operations. The majority of ship visits to the port are to Refinery Pier, with Viva Energy accounting for over half of the trade through the Port of Geelong.

The Geelong Refinery has been operating since 1954 with both the refinery and the co-located LyondellBasell plant being licensed Major Hazard Facilities (MHFs). A range of industrial activities are situated in the Port environs including wood fibre processing and chemical, fertiliser and cement manufacture.

To the north of the Geelong Refinery along the proposed underground pipeline corridor, the area is predominantly rural. There are several other existing Viva Energy-owned underground pipelines running between the refinery and the connection point to the South West Pipeline (SWP) at Lara. The proposed pipeline route follows already disturbed pipeline corridors, where possible, through a mix of land uses.

The project area is shown in Figure 1-1.

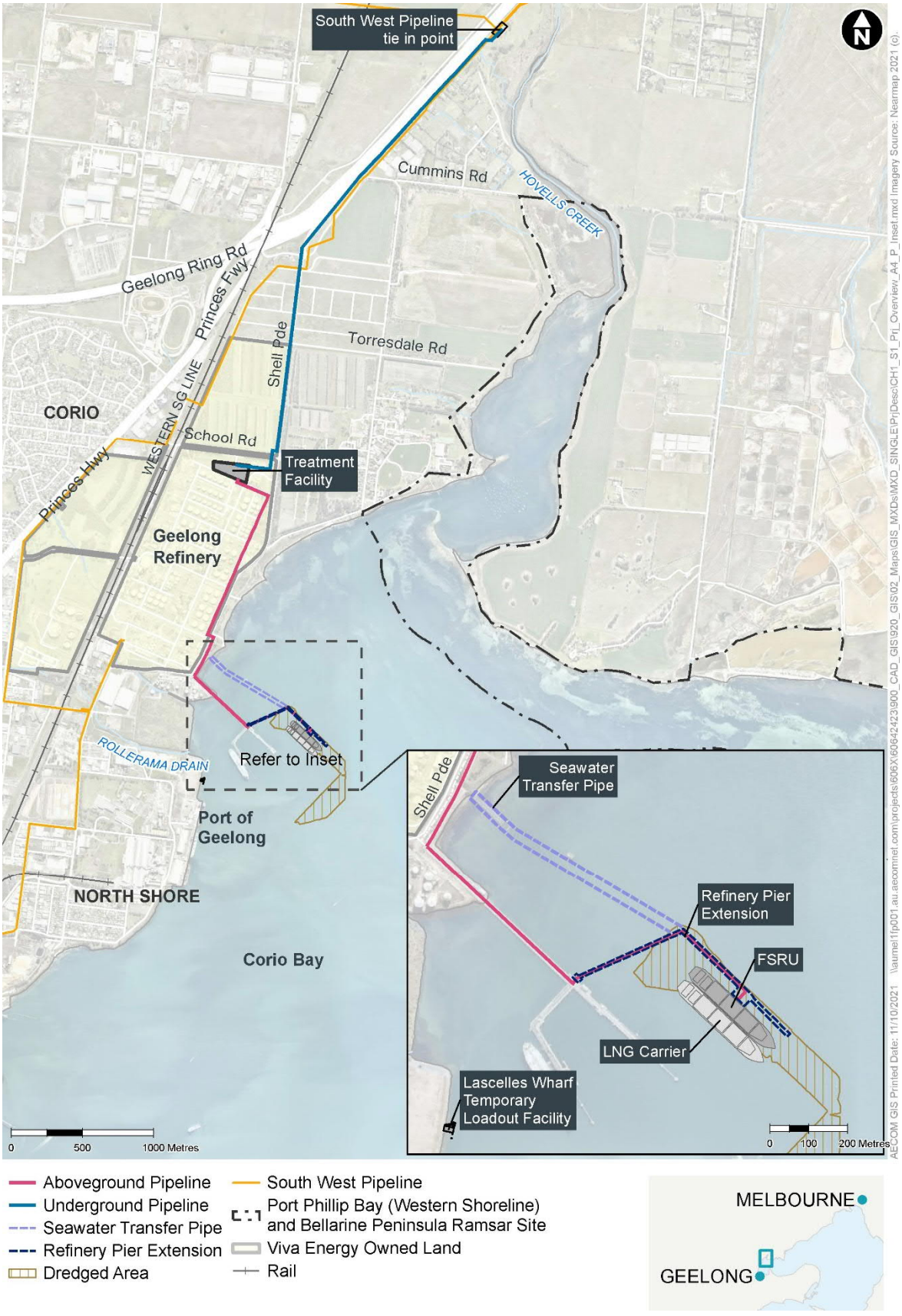


Figure 1-1: Project overview

1.4 Project description

This section summarises the project as described in Chapter 4: *Project description*. Key components of the project include:

- extension of the existing Refinery Pier with an approximately 570 metre (m) long angled pier arm, new berth and ancillary pier infrastructure including high pressure gas marine loading arms (MLAs) and a transfer line connecting the seawater discharge points on the FSRU to the refinery seawater intake
- continuous mooring of an FSRU at the new Refinery Pier berth to store and convert LNG into natural gas. LNG carriers would moor alongside the FSRU and unload the LNG.
- construction and operation of approximately 3 km of aboveground gas pipeline on the pier and within the refinery site connecting the FSRU to the new treatment facility
- construction and operation of a treatment facility on refinery premises including injection of nitrogen and odorant (if required)
- construction and operation of an underground gas transmission pipeline, approximately 4 km in length, connecting to the SWP at Lara.

The Refinery Pier extension would be located to the north-east of Refinery Pier No. 1. The new pier arm would be positioned to allow for sufficient clearance between an LNG carrier berthed alongside the FSRU and a vessel berthed at the existing Refinery Pier berth No. 1. Dredging of approximately 490,000 cubic metres of seabed sediment would be required to allow for the new berth pocket and swing basin.

The FSRU vessel would be up to 300m in length and 50m in breadth, with the capacity to store approximately 170 000 cubic metres (m^3) of LNG. The FSRU would receive LNG from visiting LNG carriers and store it on board in cryogenic storage tanks at about – 160 °C.

The FSRU would receive up to 160 PJ per annum (approximately 45 LNG carriers) depending on demand. The number of LNG carriers would also depend on their storage capacity, which could vary from 140,000 to 170,000 m^3.

When gas is needed, the FSRU would convert the LNG back into a gaseous state by heating the LNG using seawater (a process known as regasification). The natural gas would then be transferred through the aboveground pipeline from the FSRU to the treatment facility where odorant and nitrogen would be added, where required, to meet Victorian Transmission System (VTS) gas quality specifications. Nitrogen injection would occur when any given gas cargo needs to be adjusted (diluted) to meet local specifications. Odorant is added as a safety requirement so that the normally odourless gas can be smelt when in use. From the treatment facility, the underground section of the pipeline would transfer the natural gas to the tie-in point to the SWP at Lara.

1.4.1 Key construction activities

Construction of the project would occur over a period of up to 18 months. The key construction activities relate to:

- localised dredging of seabed sediments to enable the FSRU and LNG carriers to berth at Refinery Pier and excavation of a shallow trench for the seawater transfer pipe
- construction of a temporary loadout facility at Lascelles Wharf
- construction of the new pier arm and berthing infrastructure, and aboveground pipeline along Refinery Pier and through the refinery
- construction of the treatment facility on a laydown area at the northern boundary of the refinery site
- construction of the buried pipeline
- construction at the tie-in point to the SWP at Lara.

There are no construction activities required for the FSRU component of the project. The vessel would be built, commissioned and all production and safety systems verified prior to being brought to site.

An estimated 490,000 cubic metres (m^3) of dredging would be required, over an area of approximately 12 hectares (ha), adjacent to the existing shipping channel to provide sufficient water depth at the new berth and within the swing basin for visiting LNG carriers to turn. Dredging within the new berth would be undertaken to a depth of 13.1 metres and the swing basin would be dredged to a depth of 12.7 metres. The dredging physical footprint is shown in Figure 1-1. It is planned to deposit the dredged material within the existing dredged material ground in Port Phillip to the east of Point Wilson, approximately 26 km from Refinery Pier.

The temporary loadout facility at Lascelles Wharf would be the first construction activity to take place in order to facilitate the Refinery Pier extension. This would involve the installation of 10 piles using hydraulic hammers.

Construction of the pier arm would be carried out once dredging was complete, primarily from the water using barge-mounted cranes. Steel piles would be driven into the seabed by barge-mounted cranes and pre-cast concrete and pre-fabricated steel components would be transported to site by barge and lifted into position. The installation of pier infrastructure such as the marine loading arms (MLAs), piping from the FSRU to the existing refinery seawater intake (SWI) and aboveground pipeline would also be undertaken from the water using barge-mounted cranes and construction support boats.

Installation of the 3 km above ground pipeline along the pier and through the refinery is anticipated to take 3.5 months to complete. The above ground pipeline would run along the pier to the existing pipe track east of Shell Parade within the pier foreshore compound. It would then pass through a road under-crossing to the existing refinery pipe track. The pipeline would then run north along the existing refinery pipe track to an existing laydown area where the treatment facility would be located.

The treatment facility would be located within an existing laydown area in the refinery site and cover an area of approximately 80 m x 120 m. Construction of the treatment facility would take up to 18 months and would be undertaken by specialist crews across distinct phases of work. These would include initial earthworks and civil construction, mechanical installation and electrical and instrumentation works.

The 4 km underground pipeline would be installed in stages over a 4 month period within a corridor which has been selected so as to avoid watercourses or other environmental sensitivities, where possible. Firstly, a construction right of way (ROW) would be established, clearly identified and fenced off where required. Typically, this would be between 15 and 20 m wide, and minimised where possible to reduce disturbance. Once the construction ROW is established, vegetation would be removed, and a trench excavated to a maximum depth of 2 m and a maximum width of 1 m for the pipeline to be placed. Following the placement of the pipeline, the construction ROW would be rehabilitated to its pre-existing condition as far as practicable for the purposes for which it was used immediately before the construction of that part of the pipeline.

Trenchless construction (including thrust boring or horizontal directional drilling (HDD)) would be used to install the underground pipeline in areas that are not suited to open trenching techniques, such as at intersections with major roads. Trenchless construction would involve boring or drilling a hole beneath the ground surface at a shallow angle and then pushing or pulling a welded length of pipe through the hole without disturbing the surface. It is anticipated that the maximum depth of the trenchless section would be 25 m.

The anticipated trenching, HDD and thrust bore locations are presented in Figure 1-2. It is possible that along the northern section of Macgregor Court the pipeline would also be constructed using HDD, however, this would be confirmed during detailed design. Therefore, for the purpose of this assessment it has been assumed that trenching would be used along the northern section of Macgregor Court as per Figure 1-2 noting that this would not have a material impact on the calculated emissions.

Construction at the tie-in point to the SWP at Lara would be undertaken by specialist crews across the distinct phases of works, as with the treatment facility.

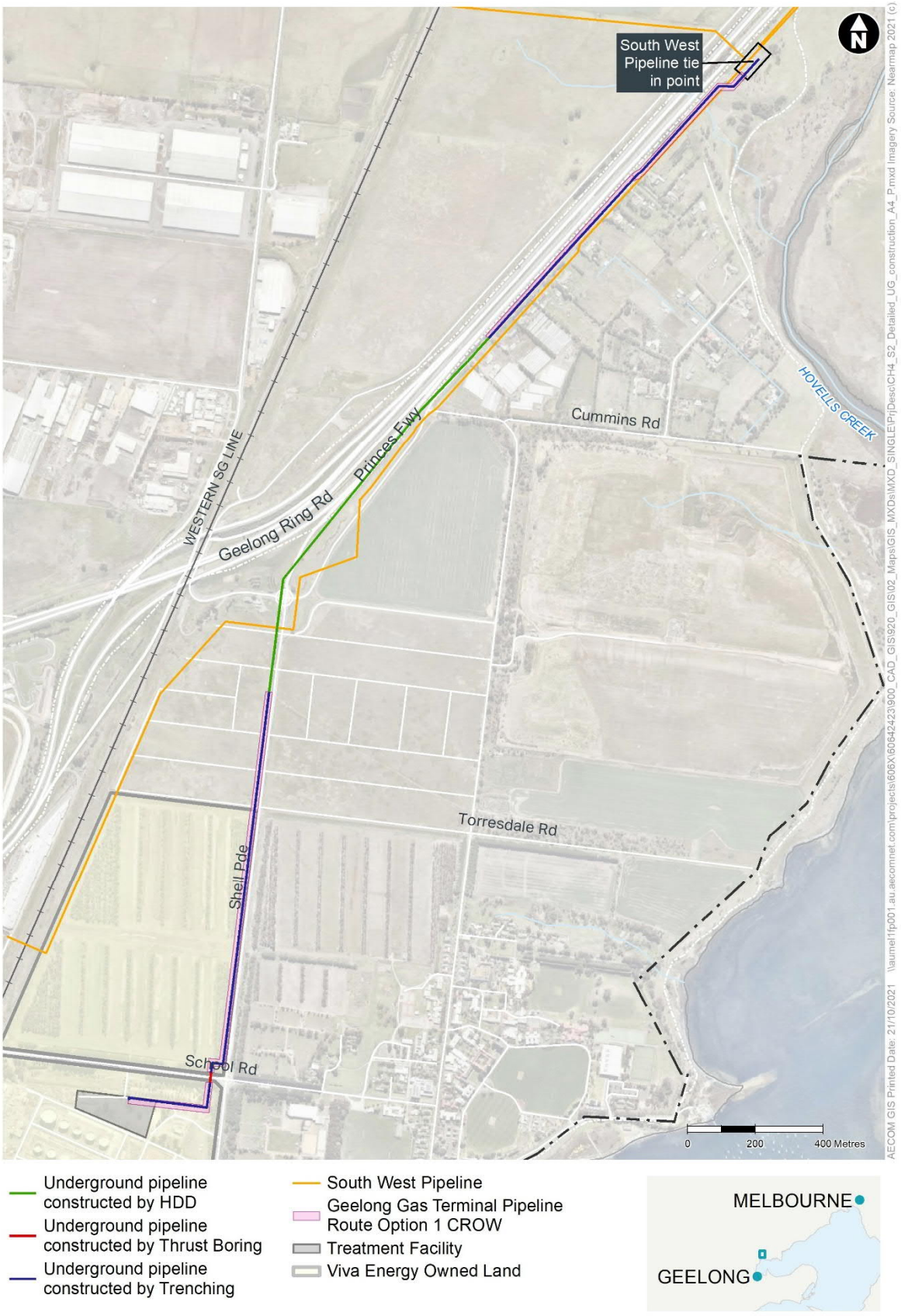


Figure 1-2: Proposed location of trenching construction techniques for the underground pipeline including open trenching, HDD and thrust boring

1.4.2 Key operation activities

The project is expected to be in operation for approximately 20 years. Key activities relating to project operation include:

- receipt of up to 45 LNG carriers each year at Refinery Pier – the number and frequency of LNG carriers arriving each year would depend on their storage capacity and gas demand
- regasification of LNG onboard the FSRU using seawater as a heat source, which would then be reused within the refinery as cooling water (two proposed operational scenarios are described below)
- injection of nitrogen and odorant into the gas prior to distribution via the VTS
- monitoring and maintenance of the pipeline easement.

1.4.2.1 Operational regasification scenarios

For the project the usual regasification mode of the FSRU is for operation in open loop mode (using seawater to heat the LNG as shown in Figure 1-3), with the modification so that the FSRU seawater discharge from the regasification process can be redirected and reused within the adjacent refinery. The FSRU would also have the ability to operate in close loop mode (using a gas-fired boiler to generate steam to heat the LNG as shown in Figure 1-4). However, due to the environmental and economic implications, closed loop is not the preferred mode of regasification for the project and would only be used in in very limited instances where the FSRU was unable to discharge water through the seawater transfer pipe to the refinery for example, during FSRU maintenance or due to a pump or pipe failure.

The combined loop regasification process would potentially be used when the ambient seawater temperature is too low for open loop regasification to operate effectively. This would involve running two boilers to heat the seawater for up to 30 days a year.

The FSRU would deliver up to approximately 160 PJ of natural gas into the VTS annually. This equates to approximately 45 carriers of LNG per annum. The FSRU can operate at different send out rates (between 250 and 750 terajoules per day (TJ/day) to meet demand). However, the maximum send out rate proposed for the FSRU is 620 TJ/day.

The FSRU operational profile is described in Chapter 4: *Project description*.

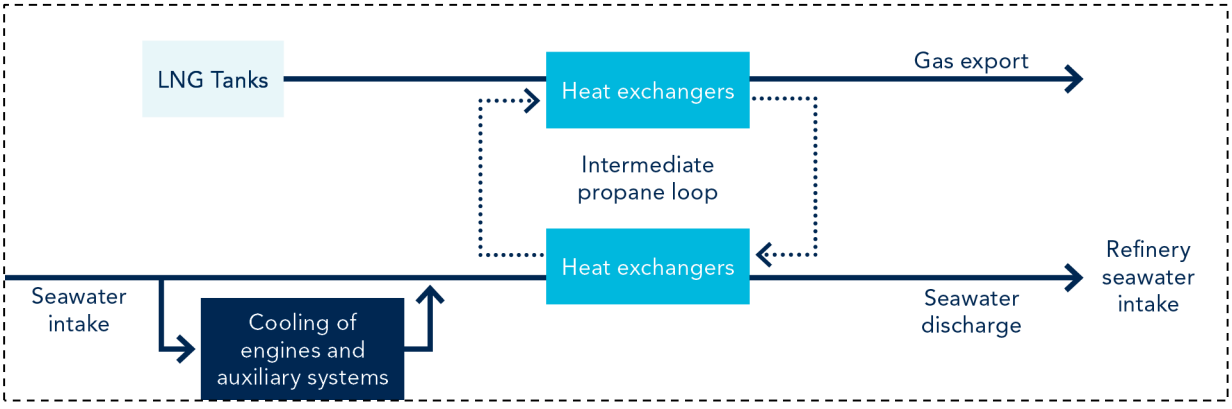


Figure 1-3 Simplified diagram of the open loop mode onboard the FSRU

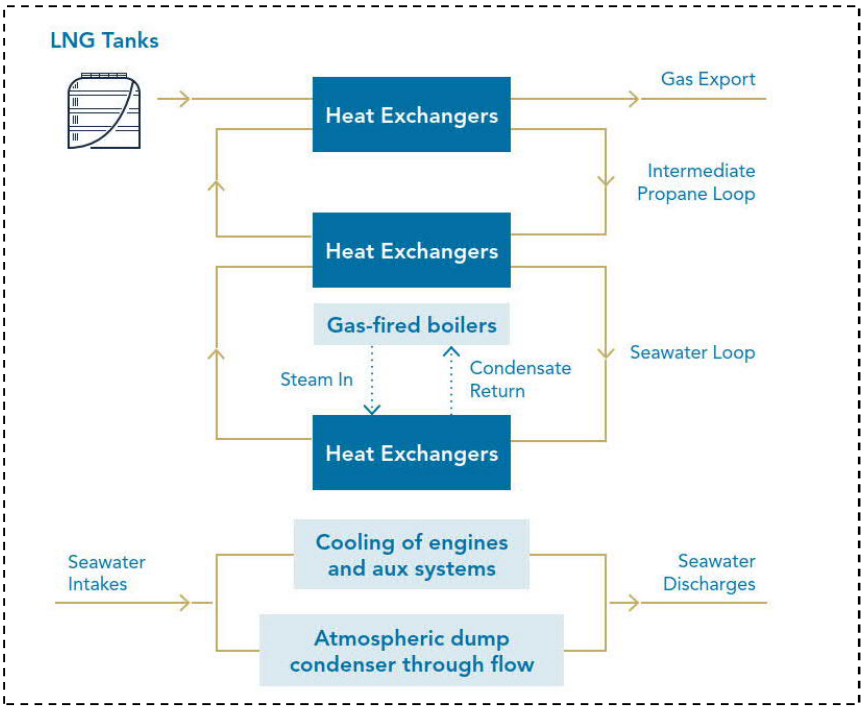


Figure 1-4 Simplified diagram of the closed loop mode onboard the FSRU

1.4.3 Key decommissioning activities

The FSRU, which continues to be an ocean-going vessel throughout the operation of the project, would leave Corio Bay on completion of the project life to be used elsewhere.

It is anticipated that the Refinery Pier berth and facilities would be retained for other port related uses. The underground pipeline would likely remain in situ subject to landholder agreements and either decommissioned completely or placed into care and maintenance arrangements.

Decommissioning activities may be subject to change, subject to legislative requirements at the time and potential repurposing of the infrastructure at the end of the project. Decommissioning activities are not included in the scope of this assessment.

1.5 Project activities relevant to the assessment

The scope of the greenhouse gas emissions assessment for the construction and operation activities of the project includes all direct (Scope 1), and indirect (Scope 2 and Scope 3) emissions within the proponent's ability to control (the operational boundary i.e., the scope of activities (during both construction and operation) that are within the proponent's ability to control).

As set out in the GHG Protocol Corporate Standard, a key criterion in determining an operational boundary for assessment was the proponent's ability to control or influence activity. Scope 3 emissions, such as those from embodied emissions relating to construction materials, transport of employees and materials, and from the disposal of waste, are determined to be within the proponent's ability to control or influence. It is determined that the proponent does not have the ability to control or influence the locations or processes involved in the production or transportation of gas prior to transfer from the LNG carrier to the FSRU. It is also determined that the proponent does not have the ability to control or influence the end-use consumption of gas. The methodology used to determine the operational boundary for the assessment is described in Section 4.0.

The construction phase and operation phase emissions sources, within, and outside, the operational boundary are illustrated in Figure 1-5 and Figure 1-6 respectively.

Despite exclusion from the project's operational boundary, Scope 3 emissions from the production and transportation of gas prior to transfer from the LNG carrier to the FSRU, and from the end-use

consumption of the gas, are provided for context. These are presented separately from the impact assessment in Appendix A.

1.5.1 Construction activities and emission sources

The scope of the greenhouse gas emissions assessment of the construction phase of the project includes all direct (Scope 1), and indirect (Scope 2 and Scope 3) emissions within the proponent's ability to control associated with the construction and installation of equipment for the FSRU and Refinery Pier, treatment facility and pipeline (see Figure 1-5). This includes the following:

- localised dredging of seabed sediments for the new Refinery Pier berth
- construction of the temporary loadout facility at Lascelles Wharf
- construction of the new pier arm and berthing infrastructure
- transportation of FSRU vessel to Geelong
- construction of aboveground pipeline section along Refinery Pier and through the refinery to the treatment facility
- construction of the treatment facility
- construction of the underground pipeline section from the treatment facility to the SWP at Lara
- construction at the pipeline tie-in point at Lara City Gate
- embodied greenhouse gas emissions in construction materials and installed equipment
- transportation of construction materials and equipment
- construction worker transportation
- disposal of construction waste.

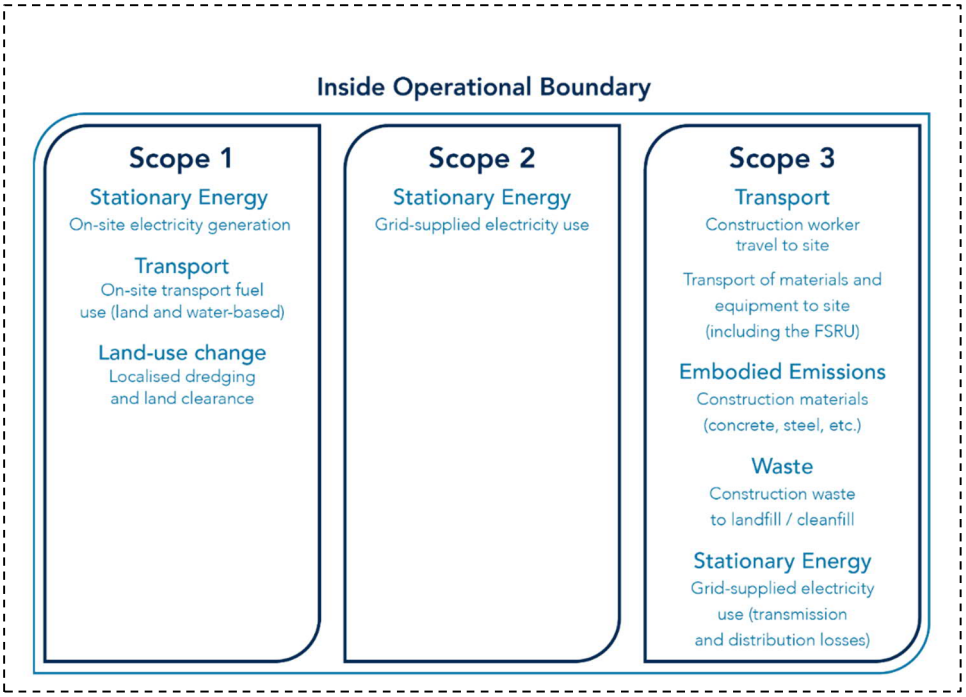


Figure 1-5 Construction phase emissions sources within the project's operational boundary

1.5.2 Operation activities and emission sources

The scope of the greenhouse gas emissions assessment of the operation phase of the project includes all direct (Scope 1) and indirect (Scope 2 and 3) emissions within the proponent's ability to control, associated with the operation of the FSRU and Refinery Pier, treatment facility, and pipeline (see Figure 1-6). This includes the following:

- operation of the FSRU and Refinery Pier
- operation of the treatment facility
- transport of odorant and nitrogen to the treatment facility
- operation of the pipeline
- fugitive emissions from the transfer of LNG from the LNG carriers to the FSRU, from the treatment facility, and from the pipeline
- transport of operators and other personnel to the gas terminal
- operational waste and wastewater disposal.

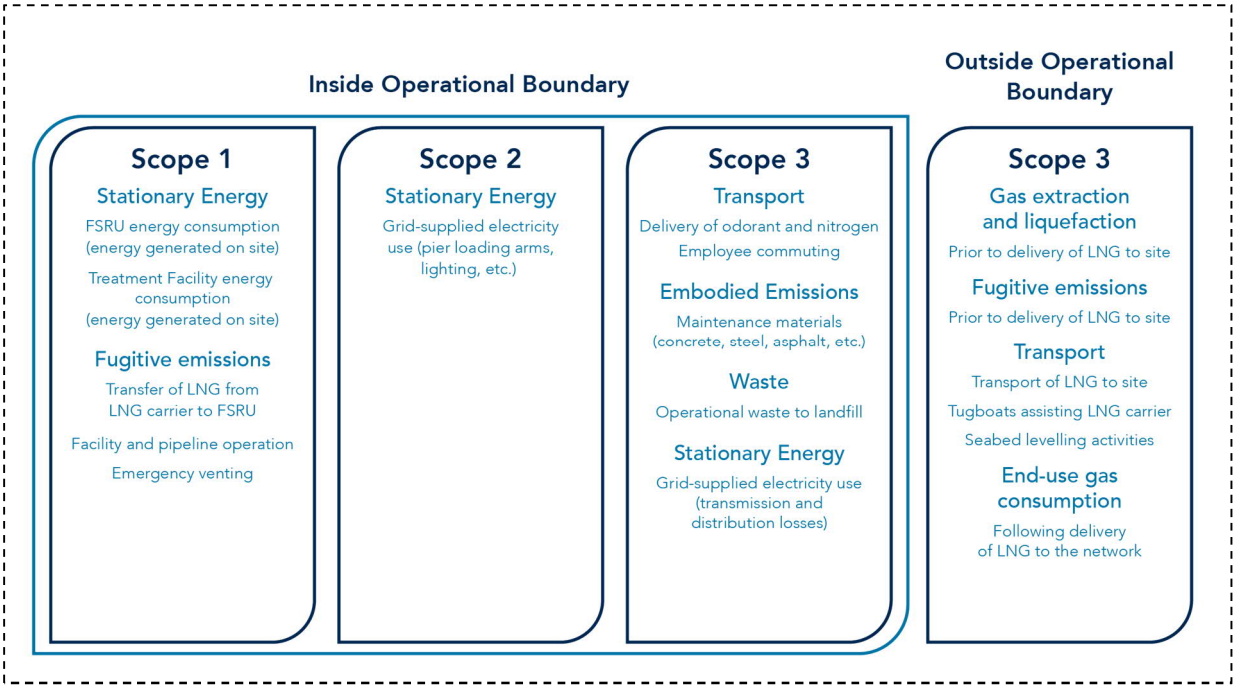


Figure 1-6 Operation phase emissions sources within the project's operational boundary

2.0 Scoping requirements

The scoping requirements for the EES set out the specific environmental matters to be investigated in the EES. The scoping requirements include a set of evaluation objectives. These objectives identify the desired outcomes to be achieved in managing the potential impacts of constructing and operating the project.

The following evaluation objective is relevant to the greenhouse gas impact assessment:

- **Waste management** – To minimise generation of wastes by or resulting from the project during construction and operation, including dredging, and accounting for direct and indirect greenhouse gas emissions

The scoping requirements of relevance to this greenhouse gas impact assessment and where they are addressed in the report are shown in Table 2-1.

Table 2-1: Scoping requirements relevant to greenhouse gas impact assessment

Aspect	Scoping requirement	Section addressed
Key issues	Potential for adverse environmental or health effects from waste materials/streams generated from project works.	Section 6.0 and Section 7.0 (Construction and Operational impact assessments)
	Potential for emissions of greenhouse gases to result from the project, including embodied emissions due to construction materials and processes as well as direct and indirect emissions from construction and operation.	
Existing environment	Nil	Section 5.0 (Existing conditions)
Likely effects	Quantify anticipated greenhouse gas emissions from the project relative to time including Scope 1 and Scope 2 emissions as well as an estimate of potential fugitive emissions through infrastructure spills or leakages.	Section 6.0 and Section 7.0 (Construction and Operational impact assessments)
Mitigation measures	Identify options for avoiding or reducing direct and indirect greenhouse gas emissions resulting from the construction and operation of the project.	Section 8.0 (Mitigation measures)
	Identify the measures to be taken in design, construction, and operational management to eliminate or minimise the likelihood or extent of fugitive emissions.	
Performance objectives	Describe proposed measures to avoid, reduce, monitor, and audit greenhouse gas emissions from the project.	Section 8.0 (Mitigation measures)

3.0 Legislation, policy, and guidelines

Table 3-1 to Table 3-4 summarises the key environmental legislation and policy that apply to the project in the context of this greenhouse gas impact assessment, as well as the implications for the project and the required approvals.

Table 3-1: International legislation and policy relevant to the assessment

Legislation/policy	Description	Implications for the project	Approval required
International			
Legislation			
Paris Agreement	The Paris Agreement builds upon the United Nations Framework Convention on Climate Change and aims to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future. The central aim of the Paris Agreement 'is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius'.	The Paris Agreement is a driver for setting Commonwealth and State greenhouse gas legislation, policy and targets. The Paris Agreement has no direct impact on the approval decisions.	No approvals required.
Policy			
Greenhouse Gas Protocol by the World Business Council for Sustainable Development and the World Resources Institute (**Greenhouse Gas Protocol**)	The Greenhouse Gas Protocol provides guidance, standards, tools and training for government and businesses to measure and manage emissions and build effective programs to tackle climate change. The Greenhouse Gas Protocol establishes comprehensive global standardised frameworks for private and public sectors to measure and manage greenhouse gas emissions. It is a widely used international accounting tool for government and business leaders to understand, quantify and manage emissions.	The Greenhouse Gas Protocol methodology was used for this greenhouse gas impact assessment.	No approvals required.
ISO 14064-1:2018: Greenhouse Gases (**ISO 14064-1**)	ISO 14064-1 specifies principles and requirements at the organisational level for the quantification and reporting of greenhouse gas emissions and removals. ISO 14064-1 includes requirements for the design, development, management, reporting and verification of an organisation's greenhouse gas inventory.	ISO 14064-1 was used in the greenhouse gas impact assessment methodology as outlined in Section 4.3.	No approvals required.

Table 3-2: Commonwealth legislation and policy relevant to the assessment

Legislation/ policy	Description	Implications for the project	Approval required
Commonwealth			
Legislation			
National Greenhouse and Energy Reporting Act 2007 (Cth) ('NGER Act') National Greenhouse and Energy Reporting (Measurement) Determination 2008	The NGER Act establishes the legislative framework for the NGER Scheme which is a national framework for reporting greenhouse gas emissions and projects and energy consumption and production by corporations in Australia. Several legislative instruments sit under the NGER Act including this Determination. This Determination describes the methods, standards and criteria to be applied when estimating greenhouse gas emissions, energy production and energy consumption.	Methodology described in the Determination was used for the greenhouse gas impact assessment. Viva Energy are required to annually report energy use and greenhouse gas emissions under the NGER Act.	No approvals required.
National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015 (NGER Rule)	The NGER Rule is a legal mechanism aimed at preventing significant increases in emissions above business as usual from major facilities (i.e., facilities with direct (Scope 1) greenhouse gas emissions greater than 100,000 t (CO_2-e a year).	The proposed regasification mode of the FSRU is for operation in open loop mode. Greenhouse gas emissions for open loop mode would not trigger requirements under the NGER rule, as direct (Scope 1) greenhouse gas emissions are not expected to be greater than 100,000 t (CO_2-e a year). The closed loop operational mode would trigger requirements under the NGER rule, as direct (Scope 1) greenhouse gas emissions are expected to be greater than 100,000 t (CO_2-e a year) The proponent would be required to submit an application for a calculated-emissions baseline determination to the regulator. This application would require the quantity of emissions and emissions intensity expected per annum for the facility.	No approvals required.
Policy			
Emissions Reduction Fund (**ERF**) as part of the	The ERF came into effect on 13 December 2014 and involves a 'reverse auction' mechanism, where businesses can sell their carbon	The aim of the ERF is to encourage businesses to invest in the most cost-efficient emissions reduction	No approvals required.

Legislation/ policy	Description	Implications for the project	Approval required
Direct Action Plan	abatement, with the government purchasing the lowest cost per tonne of abatement. In February 2019, the Commonwealth Government established a Climate Solutions Fund to provide an additional $2 billion to continue purchasing low-cost abatement.	methods, and while it does not have any implications for the project, it is part of the broader policy context for the project.	

Table 3-3: State policy and legislation relevant to the assessment

Legislation/policy	Description	Implications for the project	Approval required
State			
Legislation			
Environment Protection Act 2017 (Vic) ('Environment Protection Act')	The Environment Protection Act aims to protect Victoria's air, water and land by adopting a 'general environment duty' (GED) which imposes a broad obligation on entities and individuals to take proactive steps to minimise risks of harm to human health and the environment from pollution or waste. The Environment Protection Authority administers the Environment Protection Act and subordinate legislation.	The Environment Protection Act regulates discharges to air, land, surface water or groundwater by a system of Development and Operating Licenses. Any discharge during the construction or operation of the project must be in accordance with the requirements of the Environment Protection Act. The GED requires all reasonably practicable steps to be taken to minimise impacts from the construction and operation of the project. The Environment Protection Act follows the provisions of the *Climate Change Act 2017(Vic)* whereby account must be given to GHG emissions as a result of project construction and operation.	The FSRU component of the project would require a Development and Operating Licence. The Geelong Refiner would require a Development Licence or exemption.
Pipelines Act 2005 (Vic) ('Pipelines Act')	This is the primary act governing the construction and operation of pipelines in Victoria. The Pipelines Act covers 'high transmission' pipelines for the conveyance of gas, oil, and other substances. The Department of Environment, Land, Water and Planning (DELWP) and Energy Safe Victoria (ESV) are responsible for administering the Pipelines Act and the Pipelines Regulations 2017.	The project requires a Pipeline Licence(s) under the Pipelines Act for the construction and operation of the pipeline.	Approval required.

Legislation/policy	Description	Implications for the project	Approval required
Climate Change Act 2017 (Vic) ('Climate Change Act')	The Climate Change Act provides Victoria with a legislative foundation to manage climate change risks and drive the transition to a climate resilient community and economy with net zero emissions by 2050. The Act embeds the 2050 net zero emissions target and provides for the setting of five-yearly interim greenhouse gas emissions reduction targets, climate change strategies, and adaptation action plans to ensure the 2050 target is achieved and vulnerabilities to climate change impacts are reduced while potential opportunities are realised.	A person making certain decisions or taking specified actions must have regard to— (a) the potential impacts of climate change relevant to the decision or action (b) the potential contribution to the State's greenhouse gas emissions of the decision or action (c) any guidelines. The decisions listed in the Schedule to the Climate Change Act that are relevant, are the decisions by the EPA Victoria as to whether a Development Licence or Operating Licence should be granted under the Environment Protection Act.	No approvals required
Guidelines			
EPA Victoria, Guideline for managing greenhouse gas emissions *Draft for consultation, January 2022*	The guideline forms part of the 'state of knowledge' intended to provide guidance on minimising risks as far as reasonably practicable, in line with the Environment Protection Act. The guidance is designed to provide information to help compliance obligations be understood and met but does not impose new compliance obligations. The guideline outlines a risk management approach that can be applied to GHG emissions, by providing guidance in how to identify, assess, control and check GHG emissions.	The approach outlined in the guideline to identify, assess and propose measures to minimise emissions is consistent with the approach undertaken for this GHG impact assessment.	No approvals required

Table 3-4: Local policy relevant to the assessment

Legislation/ policy	Description	Implications for the project	Approval required
Local			
Policy			
City of Greater Geelong Sustainability Framework, Action Plan 2020 - 2022	This document sets out the objectives and actions for the council and community for three key priority areas. Of relevance includes the objective to support the community and the city to reduce carbon emissions.	The project should consider the objectives set out in the action plan.	No approval required
City of Greater Geelong Zero Carbon Emissions Strategy (2017 – 2020)	The City of Greater Geelong have set the objective to support community sector greenhouse gas emissions reductions. The City has a goal to be carbon neutral by 2047. The strategy identifies that 6.2% of community emissions were from industrial processes in 2015 and is projected to decrease to 4.7% in 2035 due to planned closures of heavy manufacturing sites.	The project should consider the emission reduction targets set out in the strategy.	No approval required

4.0 Methodology

This section describes how the greenhouse gas assessment was conducted to understand the existing environment, and potential impacts of the project on greenhouse gas emissions. The following sections outline the assessment methodology.

4.1 Existing conditions assessment method

The existing conditions assessment considered state level greenhouse gas emissions using the 2019 reporting reference year. This provided a base case against which the emissions from the project could be compared. The project is intended to facilitate supply of a new source of gas for the South-East Australian gas market where there is a projected supply shortfall in coming years. As such, the State level emissions context and was considered as the most relevant to the scope.

Victorian emissions data was sourced from *Australian National Greenhouse Accounts: State and Territory Greenhouse Gas Inventories, 2019* report (Commonwealth of Australia, 2021).

4.2 Risk screening method

A risk-based screening approach has been used for the EES assessment in accordance with the requirements outlined in the 'Ministerial guidelines for assessment of Environmental Effects under the *Environment Effects Act 1978 (Vic)'* (page 14). The risk screening is undertaken to ensure that the level of investigation conducted in each technical study is adequate to inform an assessment of the significance and acceptability of the project's potential environmental impacts.

An environmental, social, and economic issues risk screening tool has been used to prioritise and focus the proposed investigations, assessments, and approaches to avoiding, minimising, or managing potential impacts. The issue screening process involved an evaluation of the potential environmental, social, and economic issues associated with the project based on the information collected through a series of initial assessments undertaken into the potential effects of the project.

A risk workshop convened by a qualified risk practitioner and comprising technical specialists from the proponent, project design team and EES team conducted the initial risk screening. The risk screening process utilised knowledge of the project infrastructure and design, existing environment and land use setting to assess potential risks based on the specialised knowledge of the technical experts.

The purpose of the issues screening approach was to assist in identifying:

- Significant issues, uncertainties and/or potential impacts that require more detailed characterisation and/or assessment within the EES
- Matters or potential impacts considered to be already well understood or less significant.

A high, medium, or low screening value was assigned to potential issues to determine the level of assessment required to identify and investigate impacts.

Each potential issue was given a score (1, 2 or 3) against the categories of:

- Community and stakeholder interest
- Significance of assets, values and uses
- Potential impact (spatial, temporal and severity).

The scores were added together, or the highest score across the three contributing categories was used, to give a 'screening value' of high, medium or low, which gives an indication of the level of impact assessment that is required. Issues that were assigned a screening value of high or medium required detailed assessment in the EES at a level commensurate with them being considered primary level issues.

Issues that were assigned a screening value of low were proposed to be documented and managed with some investigation and assessment in the EES at a level commensurate with them being considered secondary level issues.

4.2.1 Criteria and consequence ratings

Risks, issues, and potential impact pathways were identified for both construction and operation of the project. Table 4-1 defines the criteria and consequence ratings for each of the three categories that have been used to inform the issues screening. The sum of the scores against each of the three categories or the highest rating across any of the three contributing categories gives the 'screening value'.

Table 4-1: Issues screening criteria and consequence ratings

Rating	Community and stakeholder interest	Significance of assets, values and uses	Potential impact (spatial, temporal and severity)
1	Low interest and perceived impact	Locally significant asset, value, or use	Potential for localised, temporary impact
2	Some interest and targeted perceived impacts	Regionally significant asset, value, or use	Potential for significant temporary, or localised permanent impact
3	Broad community and stakeholder interest or impacts	State or nationally significant asset, value, or use	Potential for significant permanent impact

The screening values are then used to determine the level of assessment required as shown in Table 4-2.

Table 4-2: Issue investigation categories

Screening score	Screening value	Potential consequences	Complexity of mitigation	Level of assessment
7, 8 or 9 or the highest rating across any one of the three contributing categories is 3	High	Potential for elevated, longer term impacts, significant assets or values may be affected with enduring changes. Considers both impacts and benefits, or Issue may not be well defined and insufficient information is available for the impact assessment, or High level of community interest.	Stringent management measures may be required	Detailed assessment required
4, 5 or 6 or the highest rating across any one of the three contributing categories is 2	Medium	Potential for moderate level impacts, significant assets or values may be affected over an extended time frame with some resultant changes. Considers both impacts and benefits, or Issue may be moderately understood, and some information is available, however more is required for the impact assessment, or Medium level of community interest.	Standard management measures are available that can be adopted with some modification	Moderate assessment required
3 or the highest rating across any one of the three contributing categories is 1	Low	Potential for short term and localised impact. Asset or values may be temporarily affected but recovery expected, or Issue is well understood and there is enough information available for the impact assessment, or Low level of community interest.	Standard management measures are available.	Some assessment required

Further information about the risk screening process is detailed in Chapter 7: *Assessment framework.*

Outcomes from the risk screening process are outlined in Section 4.2.2 below.

4.2.2 Risk screening results

Table 4-3 provides the key potential issues related to greenhouse gas emissions identified as part of the risk screening process for the project and presents the screening value for each issue.

Table 4-3 Greenhouse gas issues screening results

Aspect	Issue	Community & stakeholder perceived impacts	Significance of assets, values & uses	Potential impact (spatial, temporal & severity)	Screening Score	Screening Value
Construction						
Greenhouse gas	GHG emissions from construction plant and equipment	1	1	1	3	Low
Operation						
Greenhouse gas	Operation of the FSRU (closed loop) results in generation of GHG emissions	3	3	3	9	High
Greenhouse gas	Operation of the FSRU (open loop) results in generation of GHG emissions	2	2	2	6	Medium
Greenhouse gas	GHG emissions from unplanned activities, incidents or emergencies	2	1	1	4	Medium

4.3 Impact assessment method

The greenhouse gas impact assessment methodology followed the principles set out in the following documents:

- *NGER (Measurement) Determination 2008 (as amended)* under the NGER Act, Commonwealth Department of Environment and Energy
- *The Greenhouse Gas Protocol (GHG Protocol),* the World Business Council for Sustainable Development and the World Resources Institute
- *American Petroleum Institute (API) Compendium of GHG Emissions Methodologies for the Oil and Natural Gas Industry,* August 2009
- *ISO 14064-1:2018 Greenhouse gases – Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals*
- *ISO 14040:2006 Environmental management – Lifecycle assessment – Principles and framework and ISO 14044:2006 Environmental management – Lifecycle assessment – Requirements and guidelines*. These standards are applicable to the calculation of materials lifecycle impacts using the Infrastructure Sustainability (IS) Materials Calculator.
- *Guideline for managing greenhouse gas emissions,* Environment Protection Authority Victoria, Draft for consultation, January 2022.

4.3.1 Greenhouse gas emission scopes

Greenhouse gas emissions were estimated in accordance with the principles of the internationally accepted GHG Protocol. According to the GHG Protocol, greenhouse gas emissions are split into three categories, known as ‘Scopes’. Scope 1, Scope 2, and Scope 3 are defined by the GHG Protocol as:

- Scope 1 – Direct emissions of greenhouse gas from sources that are owned or operated by a reporting organisation (examples include combustion of diesel in company-owned vehicles or used in on-site plant and equipment)
- Scope 2 – Indirect emissions associated with the import of energy from another source (examples include import of electricity from the grid, or heat)
- Scope 3 – Other indirect emissions, other than energy imports (above) which are a direct result of the operations of the organisation, but from sources not owned or operated by them and due to upstream or downstream activities (examples include indirect upstream emissions associated with the extraction, production and transport of purchased construction materials; and business travel (by ship, air or rail)).

Figure 4-1 illustrates the various activities that are relevant to each of the Scope categories.

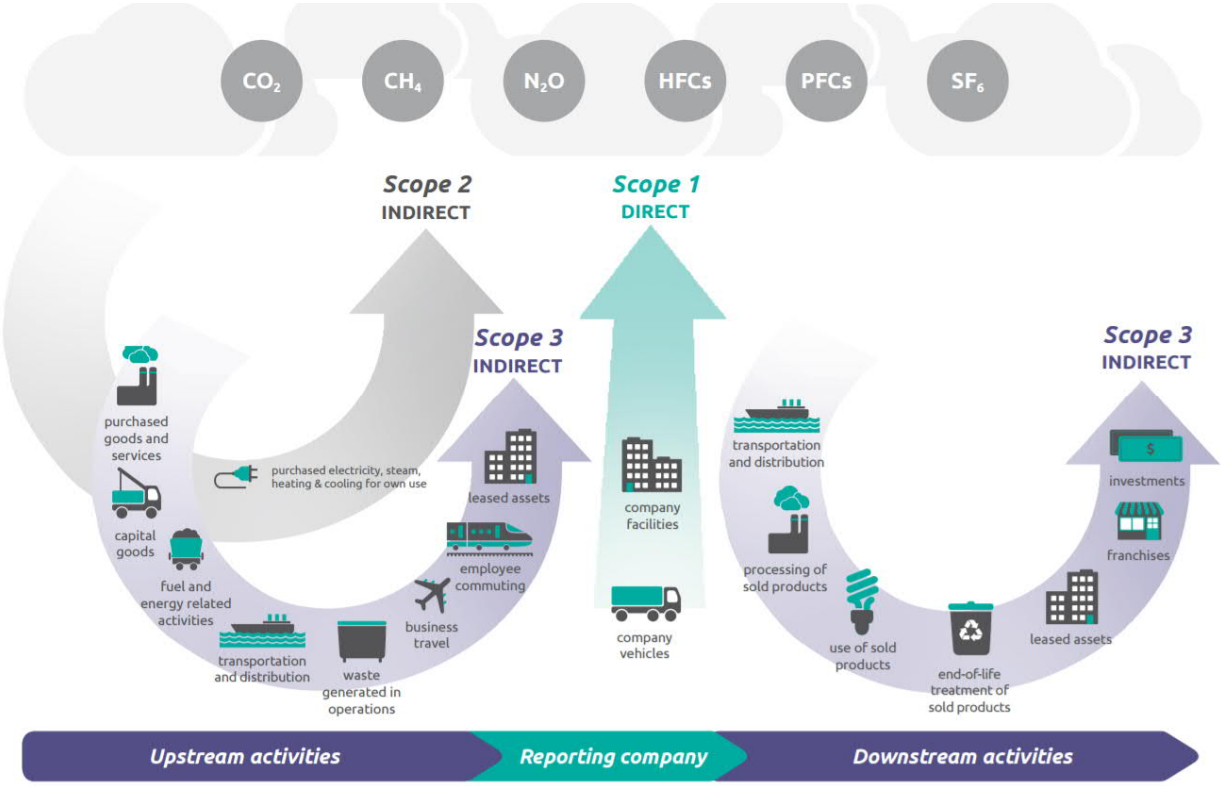


Figure 4-1 Direct and indirect emissions as defined by the GHG Protocol (Source: GHG Protocol, 2013)

For the purpose of this assessment, Scope 1, Scope 2, and significant Scope 3 emissions have been determined for the assessed construction and operation scenarios. All Scope 1 and Scope 2 direct and indirect emissions are required to be reported under both the NGER and GHG Protocol reporting schemes. Some Scope 3 emissions have been included as they represent a material contribution to the overall greenhouse gas construction and operational footprints and are determined to be within the proponent's ability to control or influence.

Determining which Scope 3 emissions to include in the inventory (i.e., setting the operational boundary) is an important decision in the inventory process. The GHG Protocol Corporate Standard allows companies flexibility in choosing which, if any, Scope 3 activities to include in the GHG inventory when the company defines its operational boundaries. The GHG Protocol Scope 3 Standard is designed to create additional completeness and consistency in Scope 3 accounting and reporting by defining Scope 3 boundary requirements.

The criteria for including Scope 3 emissions within the project's operational boundary, according to the GHG Protocol, are outlined in Table 4-4, which has been used to identify material and immaterial emissions for the project.

Table 4-4: GHG Protocol criteria for inclusion of Scope 3 emissions in the operational boundary

Criteria	Description
Size	They contribute significantly to the company's total anticipated Scope 3 emissions
Influence	There are potential emissions reductions that could be undertaken or influenced by the company
Risk	They contribute to the company's risk exposure (e.g., climate change related risks such as financial, regulatory, supply chain, product and customer, litigation, and reputational risks)
Stakeholders	They are deemed critical by key stakeholders (e.g., customers, suppliers, investors, or civil society)
Outsourcing	They are outsourced activities previously performed in-house or activities outsourced by the reporting company that are typically performed in-house by other companies in the reporting company's sector
Sector guidance	They have been identified as significant by sector-specific guidance
Other	They meet any additional criteria for determining relevance developed by the company or industry sector

4.3.2 Construction emission sources

The sources of greenhouse gas emissions included in the construction phase are provided in Table 4-5. A 'dot' (○) denotes whether the emission is Scope 1, Scope 2, or Scope 3. The rationale for exclusion of activities in the assessment is detailed in Table 4-7 with explanation in Section 4.4.2

Table 4-5: Summary of construction greenhouse gas emissions included in assessment

Source of greenhouse gas emission	Activity	Direct	Indirect	
		Scope 1	Scope 2	Scope 3
Stationary energy	Fuel consumed by construction plant and equipment	○		○
	Electricity consumed by construction plant and equipment		○	○
Transport fuel	Fuel consumed by construction plant and equipment	○		○
	Fuel consumed for construction material delivery			○
	Fuel used in the transportation of the FSRU			○
	Employee commute from home to site			○
	Employee air travel			○
Embodied emissions	Embodied emissions of materials used in Lascelles Wharf, Refinery Pier extension and pipeline construction (e.g., steel and concrete)			○
	Embodied emissions of materials used in treatment facility construction (e.g., steel and concrete)			○
Waste	Construction waste disposed in landfill			○
Land use, land use change and forestry	Land clearing	○		
	Emissions associated with sediment removal during localised dredging at Refinery Pier			○

4.3.3 Operation emission sources

The sources of greenhouse gas emissions included in the operational phase are provided in Table 4-6. A 'dot' (○) denotes whether the emission is Scope 1, Scope 2, or Scope 3. The rationale for exclusion of activities in the assessment is detailed in Table 4-7.

Table 4-6: Summary of operational greenhouse gas emissions included in assessment

Source of greenhouse gas emission	Activity	Direct	Indirect	
		Scope 1	Scope 2	Scope 3
Stationary energy	Fuel consumed by FSRU during operation	○		○
	Electricity consumed by onsite plant and equipment (including Refinery Pier ancillary infrastructure such as MLAs, and within the treatment facility)		○	○
	Fuel consumed for operational supply and material delivery			○
	Employee commute to and from home to site			○
	Employee air travel			○
Fugitive emissions	Fugitive emissions from transfer of LNG from carrier to FSRU	○		
	Fugitive emissions from plant and pipeline operations	○		
	Fugitive emissions from maintenance and emergency venting	○		
Waste	Operational liquid waste disposal			○

4.3.4 Calculation methods and emissions factors

The following sub-sections briefly outline the calculation methods and emissions factors used in the impact assessment. A detailed list of emission factors is included in Appendix C.

4.3.4.1 Stationary energy emissions

Stationary energy emissions relate to the fuel consumed by plant / equipment during construction and fuel consumed by the FSRU reciprocating gas engines and boilers during operation. The calculation methodology applied for the combustion of natural gas were determined in accordance with the NGER Scheme (Measurement) Determination 2008, Division 2.2.2, 2.3.2 and 2.4.2, Method 1. Emissions factors related to fuel consumption were drawn from the National Greenhouse Account Factors (NGAF) August 2021, Section 2.1.

4.3.4.1.1 Indirect emissions from grid electricity

On-grid electricity generation emissions are included as Scope 2 emissions and are related to the consumption of electricity sourced from the Victorian electricity grid. The calculation methodology applied for grid supplied electricity were determined in accordance with the NGER Scheme (Measurement) Determination 2008, Section 7.2 using method 1. Emissions factors for the consumption of grid electricity were drawn from the National Greenhouse Account Factors (NGAF) August 2021, Section 2.3 and Appendix 4.

4.3.4.2 Transport fuel emissions

Construction transport fuel emissions relate to general staff movements and the transport of materials and equipment. Operational transport fuel emissions relate to the transport of LNG to the Refinery Pier via LNG carriers, nitrogen and odorant delivery vehicles and general staff movements to Viva Energy

Geelong Refinery. The calculation methodology applied for the combustion of natural gas was determined in accordance with the NGER Scheme (Measurement) Determination 2008, Division 2.2.2, 2.3.2 and 2.4.2, Method 1. Emissions factors related to fuel consumption were drawn from the National Greenhouse Account Factors (NGAF) August 2021, Section 2.2.

4.3.4.3 Embodied emissions

Embodied emissions are the emissions produced and released during manufacture of materials. Embodied emissions from concrete / cement and steel (such as for the pipeline and the new pier arm) have been calculated in this assessment. Embodied emissions are calculated using the emissions factors and methodology determined in the Infrastructure Sustainability (IS) Materials Calculator.

4.3.4.4 Waste emissions

Waste emissions from municipal solid waste, commercial and industrial waste, and construction and demolition waste, during construction, were determined in accordance with the NGER Scheme (Measurement) Determination 2008, Division 5.3.4, Method 3. Emissions factors related to waste transportation fuel consumption were drawn from the National Greenhouse Account Factors (NGAF) August 2021, Appendix 4.

Wastewater emissions were calculated using an emissions factor for commercial wastewater from the Greenhouse Gas Protocol. This generic emission factor was chosen due to the relative immateriality of wastewater emissions for this project.

4.3.4.5 Fugitive emissions

Fugitive emissions (i.e., gas leaking from pipes or valves) related to the transmission of natural gas in the pipeline were determined in accordance with the NGER Scheme (Measurement) Determination 2008, Section 3.76 using Method 1. Fugitive emissions related to the FSRU operations and the treatment facility were determined in accordance with the NGER Scheme (Measurement) Determination 2008, Section 3.77 using Method 2.

These methods require adoption of the emission factors and methodology in American Petroleum Institute's (API) Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry 2009, with reference to Sections 5 and 6.1.2.

4.3.4.6 Land use, land use change and forestry

Within this assessment, land use, land use change, and forestry emissions include emissions related to dredging of the seabed and removal of vegetation for the construction of the pipeline and facilities. Calculations have been developed based on ecology reports for the relevant areas, the carbon content of land and seabed cover, and guidance from the Transport Authorities Greenhouse Group (2013).

4.4 Impact assessment assumptions and limitations

Activities excluded from the scope of calculations, and key assumptions and limitations relating to this impact assessment are provided below. Further detailed assumptions and inputs used in the impact assessment are outlined in Appendix B.

4.4.1 Activities excluded

This section includes a list of items that were not included within the scope of the assessment, as per the guidance set out in Table 4-4. A rationale for exclusion of select emissions sources is provided in Table 4-7.

Table 4-7: Rationale for exclusion of select emissions sources

Emissions category	Emissions description	Rationale for exclusion
Construction		
Stationary energy	Fuel consumed by offsite construction plant and equipment	Immaterial due to expected Scope 3 emissions contribution of less than 1%.
Stationary energy	Electricity used in onsite and offsite project offices	Immaterial due to expected Scope 2 and 3 emissions contribution of less than 1%.
Transport fuel	Change in road traffic use by the public due to traffic impacts around construction zones	Immaterial due to expected Scope 3 emissions contribution of less than 1%.
Operation		
Stationary energy	Electricity used in project offices	Immaterial due to expected Scope 2 and 3 emissions contribution of less than 1%.
Transport	Fuel emissions associated with maintenance activities	Immaterial due to expected Scope 1 and Scope 3 emissions contribution of less than 1%
Fugitive emissions	Fugitive emissions from vent stacks during maintenance and the FSRU operation	The FSRU captures boil-off gas, rather than venting it during operations. Cold venting may occur during non-routine maintenance or disruption to normal operating parameters.

4.4.2 Key assumptions and limitations

4.4.2.1 Construction equipment

Equipment frequency of use (days/use) and duration of use (hrs/day) was provided by the proponent. Refinement of the predicted usage of equipment may result in a reduction in associated emissions due to the use of a ‘maximum-usage’ approach in calculation of emissions. The assessment was also limited by availability of equipment specifications to understand more accurate fuel and power demands.

4.4.2.2 Embodied emissions

Embodied emissions of materials (concrete and steel) for the construction of the Refinery Pier, aboveground and below ground pipeline, Refinery Pier equipment, temporary loadout facility at Lascelles Wharf and the Treatment Facility have been calculated using data provided by the proponent. The assessment was limited by availability of equipment specifications to understand equipment weight and therefore the proportion of fuel consumption during transport. Where assumptions are made, such as with estimating the weight of equipment, a worst-case approach is taken to ensure that GHG emissions are not underestimated.

4.4.2.3 Transportation of construction equipment and FSRU to Geelong Refinery

The origin of equipment and the FSRU, and mode of transport was provided by the proponent. For equipment originating overseas and being transported by ship, it has been assumed that each piece of equipment will travel separately. The assessment was limited by availability of equipment specifications to understand equipment weight and therefore the proportion of fuel consumption during transport. Where assumptions are made, such as with estimating the weight of equipment, a worst-case approach is taken to ensure that GHG emissions are not underestimated.

Transport of the FSRU assumes that the vessel will return to its origin at the end of its operating life. Transport of equipment assumes the mode of transport (i.e., truck) will return to origin after delivery of materials.

4.4.2.4 Staff and construction worker transport

Staff and construction workers during construction would travel to Geelong Refinery from Melbourne and Geelong. For this assessment, it is assumed that 50 per cent of workers would travel from Melbourne, and 50 per cent from within the Geelong local government area. A return distance of 133 km (Melbourne) and 76 km (outer Geelong) have been assumed.

The origin and amount of interstate construction employee travel has been provided by the proponent. It has been assumed that there will be 50 interstate flights for the entire campaign (25 from Perth and 25 from Brisbane). It is assumed that there will be no international travel related to the construction of this project.

4.4.2.5 Construction and operation waste

Construction waste volume data has been provided by the proponent. Three waste types have been provided, construction materials, waste from equipment and material deliveries, and general site office waste.

Operational wastewater volume was provided by the proponent. A Greenhouse Gas Protocol emissions factor per volume of commercial wastewater was used to estimate wastewater emissions. Further study could improve accuracy of this emissions calculation based on the specific wastewater produced and the method of treatment. It is deemed that due to the immateriality of the expected emissions from wastewater, this is not necessary for this emissions impact assessment.

4.4.2.6 Operation of FSRU

The assessment of stationary energy emissions for the operation of the FSRU was limited by the FSRU equipment specifications and operational data provided by Höegh and Viva Energy. Fuel demand during open loop at a send out rate of 620 terajoules (TJ)/day has been calculated using linear interpolation. Fuel demand during closed loop operation has used linear interpolation of publicly available data from a similar project.

4.4.2.7 Maintenance activities

Equipment and material required for maintenance activities of the FSRU, Refinery Pier, treatment facility, and pipeline have not been included due to the unavailability of information covering these activities. Emissions from these sources are considered to be immaterial compared to other emission sources in the assessment.

Equipment emissions associated with ongoing dredging requirements (seabed levelling required every 5 years for a duration of 7 days to maintain level) has been calculated and is incorporated in Appendix A. No emissions associated with the release of carbon from disturbed sediment due to ongoing dredging have been calculated.

4.5 Stakeholder and community engagement

Stakeholders and the community were consulted to support the preparation of the project's EES and to inform the development of the project and understanding of its potential impacts. EES Chapter 6: *Stakeholder and community engagement* provides a summary of the project's key engagement activities.

In accordance with the scoping requirements, a Technical Reference Group (TRG) was convened and chaired by Department of Environment, Land, Water and Planning on behalf of the Minister for Planning. The TRG has provided input throughout the EES process.

4.6 Linkages to other technical studies

The greenhouse gas impact assessment should be read in conjunction with other relevant technical reports prepared in support of the project EES.

Impacts associated with non-greenhouse gas waste, including waste spoil are addressed in Technical Report G: *Contamination and acid sulfate soils impact assessment*. Other air quality impacts relating to non-greenhouse gas emissions during construction and operation of the project have been considered and addressed in Technical Report H: *Air quality impact assessment*. Consideration of the implications of climate change on the design, construction, and operation of the project are addressed in Attachment II: *Risk to the project from climate change*.

Data for vegetation type and extent is included in Technical Report D: *Terrestrial ecology impact assessment*.

5.0 Existing conditions

5.1 Victorian greenhouse gas emissions

In the *State and Territory Greenhouse Gas Inventories* 2019 report, Victoria's total Scope 1 and 2 greenhouse gas emissions were 91 million-tonnes of carbon dioxide equivalent (Mt CO_2-e). Table 5-1 provides a breakdown of emissions by source and sink category. The total consisted of emissions from energy industries, manufacturing, transport, other energy sectors, fugitive emissions from fuels, industrial processes and produce use, agriculture, land use, land use change and forestry, and waste. The operational Scope 1 and 2 emissions associated with the project would primarily contribute to the energy industries and transport categories presented in the table.

The project greenhouse gas emissions (from construction and annual operation) are compared to Victoria's annual emissions in Section 6.6 and 7.5.

Table 5-1: Victorian greenhouse gas emissions by source for 2019 (Commonwealth of Australia, 2021)

Emissions source and sink category	Annual greenhouse gas emissions (Mt CO_2-e)	Percentage (%)
Energy industries	46.88	51
Manufacturing	4.77	5
Transport	22.69	25
Other energy sectors	9.68	11
Fugitive emissions from fuels	2.97	3
Industrial processes and product use	3.34	4
Agriculture	15.57	17
Land use, land use change, and forestry	-17.40[1]	-19
Waste	2.83	3
Total	**91.33**	**100**

[1] Land use, land use change and forestry in this reporting year is a net-emissions sink, and therefore a negative value is representative of emissions absorbed rather than emitted.

6.0 Construction impacts

This section presents the greenhouse gas emissions associated with the construction of the project. The total construction Scope 1, 2 and Scope 3 emissions within the project's operational boundary for the project is estimated to be 62,168 t CO_2-e. Scope 1 and 2 emissions during the construction period is estimated to be 6,878 t CO_2-e. A summary of the total greenhouse gas emissions for the construction of the project are presented in Table 6-1.

Detail on the total emissions for each emission source are outlined in Sections 6.1 to 6.5. All summaries of the emissions totals have been rounded to the nearest 1 t CO_2-e.

Emission factors and detailed inputs and assumptions are provided in Appendix B and C.

Table 6-1: Summary of greenhouse gas emissions associated with the construction of the project

Emissions category	Total emissions (t CO_2-e)		
	Scope 1	Scope 2	Scope 3
Stationary energy	537	391	71
Transport fuel	3,466	-	19,879
Embodied emissions	-	-	35,264
Waste	-	-	76
Land use, Land use change and Forestry	2,484	-	-
Total	**6,487**	**391**	**55,290**

6.1 Stationary energy

Table 6-2: Stationary energy emissions during construction

Emissions source	Project activity	Total emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Diesel fuel	Fuel consumed by plant/equipment during Refinery Pier infrastructure construction works	349	-	18
Electricity	Electricity consumed by plant/equipment during Refinery Pier infrastructure construction works	-	346	38
Diesel fuel	Fuel consumed by construction plant/equipment during pipeline and treatment facility construction works	189	-	10
Electricity	Electricity consumed during pipeline and treatment facility construction works	-	45	5
Total		**538**	**391**	**71**

6.2 Transport fuel

Table 6-3: Transport fuel emissions during construction

Emissions source	Project activity	Total emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Diesel fuel	Fuel consumed by vessels / equipment associated with dredging activities	749	-	38
Fuel oil and diesel	Fuel consumed for transport of Refinery Pier infrastructure construction equipment to/from Geelong	-	-	117
Fuel oil and diesel	Fuel consumed for transport of Refinery Pier and Treatment Facility materials to Geelong	-	-	779
Diesel fuel	Fuel consumed by vehicles/equipment during Refinery Pier infrastructure construction works	1,126	-	58
Diesel fuel	Fuel consumed for transport of pipeline and treatment facility construction equipment to/from Geelong	-	-	21
Diesel fuel	Fuel consumed for transport of pipeline and treatment facility materials to Geelong	-	-	441
Diesel fuel	Fuel consumed by vehicles/equipment during pipeline and treatment facility construction works	1,591	-	82
Bunker fuel	Fuel consumed for transport of FSRU to Geelong	-	-	15,901
Diesel fuel	Fuel consumed by employee travel to and from Geelong project site	-	-	2,428
Aviation Fuel	Fuel consumed by employee air travel to and from Geelong project site	-	-	14
Total		**3,466**	**-**	**19,879**

6.3 Embodied emissions

Table 6-4: Embodied emissions during construction

Emissions source	Project activity	Total emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Embodied carbon	Embodied carbon in concrete and steel Refinery Pier infrastructure	-	-	28,696
Embodied carbon	Embodied carbon in concrete and steel pipeline infrastructure	-	-	5,299
Embodied carbon	Embodied carbon in concrete and steel of Treatment facility infrastructure	-	-	1,269
Total		**-**	**-**	**35,264**

6.4 Waste

Table 6-5: Emissions from construction waste materials

Emissions source	Project activity	Total emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Diesel fuel	Fuel consumed for transport of waste from construction of Refinery Pier extension, pipeline, and treatment facility	-	-	< 1
Landfill	Waste from construction of Refinery Pier extension, pipeline, and treatment facility	-	-	76
Total				**76**

6.5 Land use, Land use change and Forestry

Table 6-6: Emissions associated with vegetation removal and dredging during construction

Emissions source	Project activity	Total emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Carbon sink	Carbon sequestration lost due to cleared vegetation during construction	1,122	-	-
Seabed carbon	Emissions associated with sediment removal during dredging and trenching	1,362	-	-
Total		**2,484**	**-**	**-**

6.6 Summary of residual construction impacts

Residual impacts are defined as those impacts that remain following the implementation of mitigation measures. Without the impact of mitigation measures, the total Scope 1, 2 and Scope 3 construction emissions within the project's operational boundary for the project is estimated to be 62,168 t CO_2-e. Scope 1 and 2 emissions during the construction period is estimated to be 6,878 t CO_2-e which equates to 0.01 per cent of Victoria's annual Scope 1 and 2 greenhouse gas emissions.

To reduce the total emissions produced during construction, the project should implement the recommended mitigation measures as described in Section 8.0. The recommendations enable the proponent to develop clear, actionable, and measurable outcomes to reduce the emissions associated with construction.

The majority of total Scope 1 and Scope 2 emissions for construction are those associated with transport fuel. Diesel fuel consumed by vehicles, vessels and plant and equipment during construction of the Refinery Pier extension, treatment facility and pipeline, as well as dredging activities are the key contributing activities to greenhouse gas emissions during the construction phase. While the use of plant and equipment is unavoidable, environmental management measures will be implemented including the consideration of fuel-efficient plant and equipment and transport distances where appropriate (MM-GG07 and MM-GG03).

Removal of vegetation in the pipeline construction corridor also contributes to Scope 1 emissions. It was assessed that the pipeline construction corridor contained approximately 0.09 hectares (ha) of native vegetation and approximately 10.11 ha of non-native vegetation. The majority of the cleared vegetation would be exotic grassland. Following installation of the pipeline, the construction corridor would be revegetated and rehabilitated to its pre-existing condition.

The majority of the Scope 3 emissions are associated with fuel consumed for the transport of the FSRU to Geelong and the embodied emissions in concrete and steel for Refinery Pier and pipeline infrastructure.

Other recommended measures to minimise emissions include utilising low embodied energy and locally sourced materials where practicable to minimise embodied and transport emissions (MM-GG01). To enable the best emissions outcome, the project should develop criteria that considers the proportion of supplementary cementitious material content in concrete, recycled steel, and recycled aggregates, the location materials are being sourced from, and maintenance requirements of materials (MM-GG01 and MM-GG02). To further reduce transport emissions, the project should engage a local workforce where possible (MM-GG06) and source local plant and equipment (MM-GG03).

Additionally, construction activities should be coordinated to reduce unnecessarily extending the construction period and to avoid inefficient use of equipment (MM-GG04). The selection of plant and equipment should also consider fuel / energy efficiency. Together, this would reduce plant and equipment stationery and transport emissions associated with construction.

To ensure sustainable procurement and resource management practices the proponent should refer to ISO 20400:2017 Sustainable procurement which provides guidance on integrating sustainability within procurement (MM-GG05).

The implementation of recommended mitigation measures would enable the reduction of construction-related greenhouse gas emissions. The extent of the emissions reduction and residual impacts would only be able to be measured following implementation of recommended mitigation measures during the construction phase of the project. Following implementation of the above mitigation measures, consideration should be given to developing a strategy to offset emissions (e.g., offsetting Scope 1 and 2 emissions) (MM-GG11). This would ensure that the residual impacts of emissions produced during construction are quantified and offset.

7.0 Operation impacts

This section presents the greenhouse gas emissions associated with the operation of the project. Greenhouse gas emissions for the FSRU have been assessed based on the three operational scenarios, open loop, closed loop, and a combined system as defined in Section 1.4.2.1.

The proposed operating mode for the FSRU is open loop but closed loop has also been assessed on the basis that it represents the 'worst case' GHG scenario as it utilises gas fired boilers to generate steam for the regasification process.

The open and closed loop scenarios assumed the supply of natural gas at 250 TJ/day during summer (90 days per year), 350 terajoules per day (TJ/day) during spring and autumn (183 days per year), 500 TJ/day during the winter (86 days per year) and 620 TJ/day during peak demand days in winter (6 days per year), delivering a total of up to 45 cargos of liquefied natural gas (LNG) into the VTS. This equates to approximately 160 petajoules (PJ) of natural gas delivery per annum.

The combined loop regasification process would potentially be used when the ambient seawater temperature is too low for open loop regasification to operate effectively. This has been assumed to be 30 days a year. Should the combined loop be required it would lead to a further 17,374 t CO_2-e per annum in addition to the emissions associated with the open loop mode

The total annual Scope 1, 2 and Scope 3 operational emissions within the project's operational boundary for the project would be as follows:

- Open loop – 47,906 t CO_2-e
- Closed loop – 178,985 t CO_2-e
- Combined system – 65,280 t CO_2-e

A summary of the total annual greenhouse gas emissions for the operation of the project are presented in Table 7-1. Detail on the total emissions for each emission source are outlined in Sections 7.1 to 7.3. Emission factors and detailed inputs and assumptions are provided in Appendix B and C.

Table 7-1: Summary of annual operational greenhouse gas emission for the project

Emissions category	Total annual emissions (t CO_2-e)		
	Scope 1	Scope 2	Scope 3
Open loop			
Stationary energy	41,235	3,268	359
Transport fuel	-	-	1,600
Fugitive emissions	1,442	-	-
Waste	-	-	3
Total	**42,676**	**3,268**	**1,962**
Closed loop			
Stationary energy	172,313	3,268	359
Transport fuel	-	-	1,600
Fugitive emissions	1,442	-	-
Waste	-	-	3
Total	**173,755**	**3,268**	**1,962**
Combined loop			
Stationary energy	58,608	3,268	359
Transport fuel	-	-	1,600
Fugitive emissions	1,442	-	-

Emissions category	Total annual emissions (t CO_2-e)		
	Scope 1	Scope 2	Scope 3
Waste	-	-	3
Total	**60,050**	**3,268**	**1,962**

7.1 Stationary energy

The stationary energy use during the operation of the project is provided for the three different operational scenarios, detailed in Section 1.4.2.1.

The change in Scope 1 emissions between the operational scenarios is related to the gaseous fuel consumed by the FSRU during the different operational scenarios.

The emissions related to electricity use at the Refinery Pier and treatment facility are not dependent on the operational scenario and therefore are the same.

The closed loop operational mode would trigger requirements under the *National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015* as direct (Scope 1) greenhouse gas emissions are expected to be greater than 100,000 t (CO_2-e a year). The proponent would be required to submit an application for a calculated-emissions baseline determination to the regulator.

Table 7-2: Stationary energy emissions during operation (open loop)

Emissions source	Project activity	Total annual emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Fuel gas	Gaseous fuel consumed by the FSRU during open loop operation	41,235	-	-
Electricity	Electricity consumed at Refinery Pier	-	534	59
Electricity	Electricity consumed at the treatment facility	-	2,734	300
Total		**41,235**	**3,268**	**359**

Table 7-3: Stationary energy emissions during operation (closed loop)

Emissions source	Project activity	Total annual emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Fuel gas	Gaseous fuel consumed by the FSRU during closed loop operation	172,313	-	-
Electricity	Electricity consumed at Refinery Pier	-	534	59
Electricity	Electricity consumed at the treatment facility	-	2,734	300
Total		**172,313**	**3,268**	**359**

Table 7-4: Stationary energy emissions during operation (combined loop)

Emissions source	Project activity	Total annual emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Fuel gas	Gaseous fuel consumed by the FSRU during combined system operation	58,608	-	-
Electricity	Electricity consumed at Refinery Pier	-	534	59
Electricity	Electricity consumed at the treatment facility	-	2,734	300
Total		**58,608**	**3,268**	**359**

7.2 Transport fuel

Table 7-5: Transport fuel emissions during operation

Emissions source	Project activity	Total annual emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Diesel fuel	Fuel consumed by operators and staff travel to and from site	-	-	559
Diesel fuel	Fuel consumed by supply delivery vehicles to the treatment facility	-	-	1,041
Total		**-**	**-**	**1,600**

7.3 Waste

Table 7-6: Waste emissions during operation

Emissions source	Project activity	Total annual emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Waste	Operational wastewater	-	-	3
Total		**-**	**-**	**3**

7.4 Fugitive emissions

Table 7-7: Fugitive emissions during operation

Emissions source	Project activity	Total annual emissions (t CO_2-e)		
		Scope 1	Scope 2	Scope 3
Fugitive	Fugitive emissions from transfer of LNG from LNG carrier to FSRU	1,411	-	-
Fugitive	Fugitive emissions from the treatment facility	29		
Fugitive	Fugitive emissions from the transmission pipeline	2	-	-
Fugitive	Fugitive emissions from emergency venting	< 1	-	-
Total		**1,442**	**-**	**-**

7.5 Summary of residual operation impacts

Residual impacts are defined as those impacts that remain following the implementation of mitigation measures.

Table 7-8 presents a comparison of the project's annual operational Scope 1 and 2 emissions without the implementation of mitigation measures to Victoria's annual greenhouse gas emissions. The project's estimated Scope 1 and Scope 2 emissions during operation are estimated to contribute the equivalent of 0.05 per cent (open loop), 0.19 per cent (closed loop), and 0.07 per cent (combined system) of Victoria's annual greenhouse gas emissions per annum.

Table 7-8: Comparison of the project's operational greenhouse gas emissions to Victoria's annual emissions

Emissions source	Total annual greenhouse gas emissions (kt CO_2-e)	% of Victoria's annual total greenhouse gas emissions
Victoria 2019 (Scope 1 + 2)	**91,330.0**	**100**
Open loop (Scope 1 + 2)	47	0.05
Closed loop (Scope 1 + 2)	179	0.19
Combined system (Scope 1 + 2)	65	0.07

To reduce the total emissions produced during operation, the project should implement the recommended mitigation measures as described in Section 8.0. The most significant opportunity to minimise operation emissions from the project would be, as proposed, to adopt an open loop as the usual mode of operation of the FSRU, as this would emit four times less greenhouse gas emissions than closed loop.

The measures recommended include selection of plant and equipment (i.e., choice of FSRU) based on fuel efficiency and quality to reduce associated stationary and transport emissions. Additionally, engaging a local workforce where possible will reduce transport emissions associated with air travel (MM-GG06). Safety controls and emergency management practices should be put in place in the case of unplanned activities, incidents, and emergencies (i.e., unplanned maintenance or venting) to reduce the likelihood of releasing fugitive greenhouse gas emissions (MM-GG10).

The implementation of recommended mitigation measures would enable the reduction of operational greenhouse gas emissions. The extent of the emissions reduction and residual impacts would only be able to be measured following implementation of recommended mitigation measures during the operational phase of the project. Therefore, following implementation of the above measures to avoid or minimise emissions, consideration should be given to developing a strategy to offset emissions (e.g., offsetting Scope 1 and 2 emissions) (MM-GG11). This would ensure that the residual impacts of emissions produced during operation are quantified and offset.

8.0 Mitigation measures

8.1 Recommended mitigation measures

This report details recommended mitigation measures that, if adopted, would reduce the emissions impact of this project both in construction and operation. These recommendations enable the proponent to develop clear, actionable, and measurable mitigation measures to reduce the emissions impact of this project.

The recommended mitigation measures should be incorporated into the Environmental Management Framework (EMF) for the project. The EMF would be implemented as described in Chapter 14: *Environmental Management Framework* to effectively manage the environmental performance of the project.

Mitigation measures recommended to avoid, minimise, and mitigate potential adverse effects are listed in Table 8-1. It is anticipated that the project would adopt mitigation measures utilising the mitigation hierarchy and therefore offsets would be considered for project emissions after measures that aim to avoid or minimise emissions have been adopted. All efforts to reduce emissions should be considered given the ongoing impact of climate change on society.

Table 8-1: Proposed mitigation measures

MM ID	Mitigation measure	Project phase
MM-GG01	**Minimise embodied and transport emissions of materials** Low embodied energy and locally sourced materials should be considered and used where practicable to minimise embodied and transport emissions. The proponent could develop criteria for a minimum proportion of supplementary cementitious material content in concrete, recycled steel, and recycled aggregates. The criteria should consider where the location materials are being sourced from to minimise associated transport emissions.	Design and construction
MM-GG02	**Managing quality of materials** Materials that are low maintenance and durable should be selected to avoid unnecessary replacement. The quality of key materials (i.e., pipe and mooring infrastructure) should be inspected before supplying to site to avoid additional transport and handling of materials.	Construction
MM-GG03	**Source local plant and equipment** Locally sourced plant and equipment (i.e., within Victoria) should be considered and used where practicable to reduce emissions associated with transport. Sourcing local plant and equipment where practicable should be included in the selection criteria for tendering of works associated with plant and equipment.	Construction
MM-GG04	**Coordination of construction activities** Construction activities should be coordinated to reduce unnecessarily extending the construction period and to avoid inefficient use of equipment.	Construction

MM ID	Mitigation measure	Project phase
MM-GG05	**Sustainable procurement and resource management practices** Sustainable procurement and resource management practices should be adopted to avoid the inefficient use of materials, fossil fuels, and electricity. The proponent should refer to ISO 20400:2017 Sustainable procurement which provides guidance on integrating sustainability within procurement.	Construction
MM-GG06	**Local workforce** Local workforce should be engaged where possible. Interstate and international travel should be minimised and where appropriate replaced by virtual engagement. The proponent could complete a transport plan to detail how fuel emissions from employee transport would be minimised.	Construction and operation
MM-GG07	**Plant and equipment fuel efficiency** Selection of plant and equipment should incorporate consideration of fuel efficiency to reduce the consumption of fossil fuels.	Construction and operation
MM-GG08	**Waste – avoid, reduce, reuse** Design should reduce the total quantum of materials required through design refinement and incorporate reuse materials during construction and operation of the project. The proponent could develop a waste management plan that considers waste reduction, segregation of waste, and disposal of waste to ensure that waste is correctly separated and diverted from landfill where appropriate.	Design, construction, and operation
MM-GG09	**Implementation of Energy Management Systems** An energy management system will be implemented in accordance with the International Organisation for Standardisation (ISO) 50001 *Energy Management Systems* (ISO 50001) for the operation of the FSRU. The ISO 50001 provides a framework for organisations to take a systematic approach to achieve continual improvement of energy performance and efficiency and reductions in greenhouse gas emissions. This framework is considered global best practice, and involves: • developing energy use baselines • developing energy management plans • identifying performance indicators • setting targets for improvement. Progress will be regularly monitored, reported, and reviewed. Implementation of this system will also involve external certification by ISO-accredited auditors (typically on a three year cycle) in which both compliance with the ISO standard and performance improvement will need to be demonstrated to maintain certification.	Operation

MM ID	Mitigation measure	Project phase
MM-GG10	**Emergency management procedures** Safety controls and emergency management practices should be put in place in the case of unplanned activities, incidents, and emergencies (i.e., unplanned maintenance or venting) to minimise the release of fugitive greenhouse gas emissions.	Operation
MM-GG11	**Certified carbon offsets** The project could consider purchasing certified carbon offset to compensate for emissions produced during construction and annual emissions produced during operation. A strategy to offset certain emissions could be implemented (e.g., offsetting all Scope 1 and 2 emissions). Note that offsets would only be considered for project emissions after measures that aim to avoid or minimise emissions have been adopted.	Construction and operation

8.2 Offsetting emissions

The National Carbon Offset Standard and Carbon Neutral Program was launched by the Australian Government in 2010 and rebranded under the Climate Active name in 2019. The standard(s) provide a credible framework for managing emissions and achieving carbon neutrality.

The Climate Active Standard(s) provide a list of eligible offset units that have been assessed using a decision framework based on offset integrity principles outlined in the standard(s). These principles are designed to ensure that eligible offset units represent genuine and credible emission reductions. Offset options described included:

- Australian Carbon Credit Units (ACCUs) issued by the Clean Energy Regulator
- Certified Emissions Reductions (CERs) issued as per rules of the Kyoto Protocol from Clean Development Mechanism projects
- Verified Emissions Reductions (VERs) issued by the Gold Standard
- Verified Carbon Units (VCUs) issued by the Verified Carbon Standard
- GreenPower®

9.0 Pipeline-only impacts

This section presents the greenhouse gas emissions for the construction and operation of the pipeline. This estimate has been done to inform decision making for a Pipeline Licence under the *Pipelines Act 2005 (Vic).*

It has been assumed that 50% of emissions from sources covering the construction and operation of the pipeline and facility are due to the construction and operation of the pipeline only. These emissions have then been added to pipeline-only emission sources as shown in Table 9-1.

Table 9-1 Summary of greenhouse gas emissions associated with the construction and operation of the pipeline

	Total emissions (t CO_2-e)		
	Scope 1	Scope 2	Scope 3
Construction	1451	23	5,616
Operation (annual)	2	-	-

10.0 Conclusion

A greenhouse gas emissions impact assessment has been undertaken to determine the potential impacts of the project and to identify recommended mitigation measures where appropriate to reduce the potential impacts of the project on the receiving environment.

10.1 Construction impacts

The estimated emissions from construction activities associated with the project are summarised in Table 10-1. The total construction Scope 1, 2 and Scope 3 emissions within the project's operational boundary for the project is estimated to be 62,168 t CO_2-e. Scope 1 and 2 emissions during the construction period is estimated to be 6,878 t CO_2-e.

Table 10-1 Summary of greenhouse gas emissions associated with the construction of the project

Emissions category	Total emissions (t CO_2-e)		
	Scope 1	Scope 2	Scope 3
Stationary energy	537	391	71
Transport fuel	3,466	-	19,879
Embodied emissions	-	-	35,264
Waste	-	-	76
Land use, Land use change and Forestry	2,484	-	-
Total	**6,487**	**391**	**55,290**

10.2 Operation impacts

This assessment calculated the emissions associated with three operational scenarios of the FSRU and emissions associated with other operational activities.

The total annual Scope 1, 2 and Scope 3 operational emissions within the project's operational boundary for the project would be as follows:

- Open loop – 47,906 t CO_2-e
- Closed loop – 178,985 t CO_2-e
- Combined system – 65,280 t CO_2-e

The closed loop operational mode is anticipated to be the highest greenhouse gas emitting operational scenario related to the project. The closed loop operational mode would trigger requirements under the *National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015* as direct (Scope 1) greenhouse gas emissions are expected to be greater than 100,000 t (CO_2-e a year). The proponent would be required to submit an application for a calculated-emissions baseline determination to the regulator.

A summary of the total annual greenhouse gas emissions for the operation of the project are presented in Table 10-2.

Table 10-2 Summary of the operational greenhouse gas emissions

Emissions category	Total annual emissions (t CO_2-e)		
	Scope 1	Scope 2	Scope 3
Open loop			
Stationary energy	41,235	3,268	359
Transport fuel	-	-	1,600
Fugitive emissions	1,442	-	-
Waste	-	-	3
Total	**42,676**	**3,268**	**1,962**
Closed loop			
Stationary energy	172,313	3,268	359
Transport fuel	-	-	1,600
Fugitive emissions	1,442	-	-
Waste	-	-	3
Total	**173,755**	**3,268**	**1,962**
Combined Loop			
Stationary energy	58,608	3,268	359
Transport fuel	-	-	1,600
Fugitive emissions	1,442	-	-
Waste	-	-	3
Total	**60,050**	**3,268**	**1,962**

10.3 Impact on Victoria's annual emissions

The context of the existing conditions for the greenhouse gas impact assessment was the current Victorian emissions profile. In the 2018/2019 NGER reporting year, Victoria's total Scope 1 and 2 emissions were 91.33 Mt CO_2-e. Energy industries (i.e., direction combustion) accounted for 51 per cent of Victoria's total Scope 1 and 2 emissions or 46.88 Mt CO_2-e.

To enable comparison, the project's total Scope 1 and 2 emissions are compared with Victoria's annual Scope 1 and 2 emissions. The total Scope 1 and 2 emissions during the construction period equates to 0.01 per cent of Victoria's annual greenhouse gas emissions, which is negligible.

The project's estimated Scope 1 and Scope 2 emissions during operation are estimated to contribute the equivalent of 0.19 per cent (closed loop), 0.05 per cent (open loop) and 0.07 per cent (combined system) of Victoria's annual greenhouse gas emissions per annum. Table 10-3 presents a comparison of the project's annual operational emissions to Victoria's annual greenhouse gas emissions.

Table 10-3 Comparison of the project's operational greenhouse gas emissions to Victoria's annual emissions

Emissions source	Total greenhouse gas emissions (kt CO_2-e)	% of Victoria's annual total
Victoria 2019 (Scope 1+2)	**91,330**	**100**
Open loop (Scope 1 + 2)	47	0.05
Closed loop (Scope 1 + 2)	179	0.19
Combined system (Scope 1 + 2)	65	0.07

To reduce the total emissions produced during construction and operation, the project should implement the recommended mitigation measures. It is anticipated that the project would adopt mitigation measures utilising the mitigation hierarchy in order to first avoid or minimise emissions produced during construction and operation. Such measures include utilising low embodied energy materials, sourcing materials, plant and equipment locally and of a high quality, engaging a local workforce, implementing sustainable procurement, avoiding or minimising waste and coordinating construction activities. The most significant opportunity to minimise emissions during operation would be as proposed to adopt open loop as the usual mode during FSRU regasification operation, as this would emit four times less greenhouse gas emissions than closed loop. The extent to which mitigation measures would reduce emissions, is not quantifiable at this time. However, following implementation of measures to avoid or minimise emissions, the project should consider developing and implementing an offset strategy. This would ensure that the residual impacts of emissions produced during construction and operation are offset.

11.0 References

API, 2009, *API Compendium of GHG Emissions Methodologies for the Oil and Natural Gas Industry*, API, August 2009

Budget Direct 2021, Latest fuel consumption in Australia, https://www.budgetdirect.com.au/car-insurance/research/average-fuel-consumption australia.html#:~:text=The%20average%20vehicle%20in%20Victoria,made%20up%20the%20remaining%205%25.https://www.budgetdirect.com.au/car-insurance/research/average-fuel-consumption australia.html#:~:text=The%20average%20vehicle%20in%20Victoria,made%20up%20the%20remaining%205%25. (accessed 21 June 2021)

City of Greater Geelong 2016, Zero Carbon Emissions Strategy 2017 – 2020, https://www.geelongaustralia.com.au/zerocarbon/documents/item/8d4907ba88b12ba.aspx#:~:text=The%20City%20of%20Greater%20Geelong,guide%20us%20in%20this%20endeavor.https://www.geelongaustralia.com.au/zerocarbon/documents/item/8d4907ba88b12ba.aspx#:~:text=The%20City%20of%20Greater%20Geelong,guide%20us%20in%20this%20endeavor. (accessed 3 June 2021)

City of Greater Geelong 2021, Sustainability Framework and Action Plan, https://geelongaustralia.com.au/sustainability/documents/item/8d7bc2a4bd8bbf5.aspx (accessed 10 July 2021)

Climate Active 2019, What is Climate Active?, https://www.climateactive.org.au/what-climate-active (accessed 10 July 2021)

Commonwealth of Australia, 2021, *State and Territory Greenhouse Gas Inventories 2019*

Department of Energy and Environment, 2019*, Emissions Reduction Fund Update*, http://www.environment.gov.au/climate-change/publications/emissions-reduction-fund-update (accessed 21 June 2021)

Environment Protection Authority Victoria, January 2022, *Guideline for managing greenhouse gas emissions*, Draft for consultation

Greenhouse Gas Protocol, 2021, *Corporate Accounting and Reporting Standard*, World Resources Institute and World Business Council, Washington, USA.

Greenhouse Gas Protocol, 2011, *Corporate Value Chain (Scope 3) Accounting and Reporting Standard*, World Resources Institute and World Business Council, Washington, USA.

Greenhouse Gas Protocol, 2013, *Technical Guidance for Calculating Scope 3 Emissions; Version 1.0*, World Resources Institute, World Business Council and The Carbon Trust, Washington, USA.

ISO *14064-1:2018 Greenhouse gases -- Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*

NGER, 2016, *National Greenhouse and Energy Reporting Scheme Measurement, Technical Guidelines for the estimation of emissions by facilities in Australia* NGERS Technical Guidelines, Australian Government, Department of the Environment and Energy, August 2016

NGER, 2021, *National Greenhouse Accounts Factors, Australian National Greenhouse Accounts*, Australian Government, Department of the Environment and Energy, October 2018

Appendix A

Scope 3 emissions outside of the operational boundary

Appendix A Scope 3 emissions outside of the operational boundary

This section presents an estimate of Scope 3 emissions which are outside the project's operational boundary. While outside the scope of the study, the emissions from the production and transportation of the LNG and the end-use consumption of the natural gas have been estimated for context.

The decisions around the sourcing of LNG cargoes will be made by the customers of the terminal and not by Viva Energy as the operator. The proponent has no ability to control or influence where, or how, the gas is produced or the distance over which the LNG is transported to reach the terminal. Terminal customers will however be commercially driven to source the most economic cargoes of LNG, with the cost of these being determined by a number of factors including the shipping distance from the terminal. In reality it is likely that there will be a mix of sourcing including from Australian locations, other regional locations such as Malaysia and Papa New Guinea, and further afield such as from the Middle East. For the purposes of this estimation, two sourcing scenarios have been selected. The first scenario assumes that all gas will be sourced from Qatar, and the second assumes that all gas will be sourced within Australia, with producers in Darwin, Gladstone, and Dampier each supplying a third.

It is estimated that the annual emissions associated with the production of 160 PJ range between 942,400 t CO_2-e for the Australian sourcing scenario, and 1,064,000 t CO_2-e for gas sourced from Qatar. The emissions associated with these activities would represent Scope 1 emissions for the company that undertakes the production activities, and it is assumed that the extraction and liquefaction of gas would be undertaken irrespective of the project.

Estimated emissions from transportation of gas to the terminal range from 165,500 t CO_2-e for the Australian sourcing scenario, to 553,400 t CO_2-e for gas sourced from Qatar. It is estimated that emissions associated with the end use of natural gas equivalent to the project's maximum annual supply are 8,884,800 t CO_2-e. The objective of the project is to meet an expected shortfall in natural gas availability in Victoria rather than create a higher demand. If the project does not proceed it is assumed that another gas provider would fill the forecast shortfall by the mid-2020s.If the project proceeds, the proponent would not have any ability to influence the end-use consumption of the gas.

Emissions from port-related activities outside the scope of the study have also been estimated. Emissions from the fuel consumed by tugboats assisting LNG carriers berthing at Refinery Pier are 77 t CO_2-e and emissions from fuel consumed during seabed levelling for maintenance of the depth of the Refinery Pier berth are 1 t CO_2-e. These activities are not controlled by the proponent but are directly linked to the operation of the project.

The inputs and assumptions for these calculations can be found in Appendix B.

Appendix B

Inputs and assumptions

Appendix B Inputs and assumptions

Inputs and assumptions were collected from a number of sources including equipment and technical specifications, websites, calculators, and Viva Energy directly. To determine inputs, Viva Energy used a conservative approach and estimated values based on the design of the project and construction methodologies selected. In addition, Viva Energy sought advice from equipment providers and construction contractors.

Table 11-1 Construction stationary energy inputs and assumptions

Item/input	Units	Value	Source
Fuel / electricity consumed by construction plant/equipment to build Refinery Pier extension			
Generator fuel demand	L/day	100	Item list provided by Viva Energy, fuel / electricity consumption assumed based on publicly available information
Compressor fuel consumption	L/day	250	
Pumps fuel consumption	L/day	139	
Welding machine power	kW	32	
Hydraulic torque wrench power	kW	1	
Angle grinder power	kW	2.5	
Fuel / electricity consumed by construction plant/equipment to build pipeline and treatment facility			
Genset equipment fuel demand	L/day	100	Item list provided by Viva Energy; fuel / electricity assumed based on publicly available information
Compressor fuel consumption	L/day	250	
Pumps power	kW	1	

Table 11-2 Construction Transport fuel inputs and assumptions

Item/input	Units	Value	Source
Fuel consumed for FSRU vessel transportation to Geelong			
Shipping distance from Egypt to Geelong	Nautical miles	19,076	Distance sourced from ports.com
Shipping speed	Knots	18	Hoegh specifications
Average fuel consumption of FSRU	t/day	103.2	Hoegh specifications
Fuel consumed by employee travel to and from project site			
Labour force breakdown: Local/Melbourne	#	50/50	Viva Energy
Total staff movements across construction program	#	73,467	Viva Energy
Local/Melbourne transport mode	-	Passenger Vehicle	Assumption
Fuel consumed by employee air travel to and from project site			
Brisbane to Melbourne (return)	Total journeys	25	Viva Energy
Perth to Melbourne (return)	Total journeys	25	Viva Energy
Fuel consumed by vehicles / equipment during dredging			
Equipment type	#	-	Viva Energy
Equipment fuel demand	L/day	-	Assumption

Item/input	Units	Value	Source
Operating period, variable	days/month & hours/day	-	Viva Energy
Total fuel consumption (Diesel)	kL	276	AECOM Calculation
Fuel consumed by vehicles / equipment during construction of Refinery Pier extension			
Equipment type	#	-	Viva Energy
Equipment fuel demand	L/day	-	Assumption
Construction period, variable	day/month	-	Viva Energy
Total fuel consumption (Diesel)	kL	415.55	AECOM Calculation
Fuel consumed by equipment during treatment facility and pipeline construction			
Equipment type	#	-	Viva Energy
Equipment fuel demand	L/day	-	Assumption
Construction period, variable	day/month	-	Viva Energy
Total fuel consumption (Diesel)	kL	587	AECOM Calculation
Fuel consumed by vehicles/ships bringing materials to site			
Steel source location	-	China	Viva Energy
Transportation method	-	Ship	Viva Energy
Transportation distance (return)	km	9,427	ports.com
Pipeline steel shipping weight	Tonnes	1,727	Viva Energy
Refinery Pier extension steel shipping weight	Tonnes	8,388	Viva Energy
Temporary loadout facility at Lascelles Wharf Steel	Tonnes	150	Viva Energy
Treatment Facility steel	Tonnes	194	Viva Energy
Concrete source location	-	Geelong LGA	Assumption
Pipeline concrete	m^3	347	Viva Energy
Refinery Pier precast concrete	m^3	1,221	Viva Energy
Refinery Pier cast in-situ concrete	m^3	2,007	Viva Energy
Temporary loadout facility at Lascelles Wharf concrete	m^3	66	Viva Energy
Treatment Facility concrete	m^3	1,392	Viva Energy
Transportation distance (return)	km	38	Assumption

Table 11-3 Construction embodied emissions inputs and assumptions

Component	Material	Volume (m^3)	Embodied emissions (t CO_2-e)	Source
Embodied carbon in Refinery Pier infrastructure				

Component	Material	Volume (m^3)	Embodied emissions (t CO_2-e)	Source
Precast concrete	Ready mix – 50 MPa	2006.9	1,166	Viva Energy
Cast in-situ	Strength grade – 50MPa	1221.4	710	Viva Energy
Steel pipe and tube – imported	-	8,388.16 (Tonnes, total mass)	26,171	Viva Energy
Embodied carbon in temporary loadout facility at Lascelles Wharf				
Precast concrete	Strength grade – 50MPa	66	26	Viva Energy
Steel	-	150 (Tonnes)	468	Viva Energy
Embodied carbon in pipeline				
Pipeline DN600	Steel	220.04	5,132	Viva Energy
Precast concrete	Strength grade – 50MPa	347	168	Viva Energy
Embodied carbon in treatment facility				
Precast concrete	Strength grade – 50MPa	1,392	673	Viva Energy
Steel	-	194	596	Viva Energy
Embodied carbon in seawater transfer pipeline				
Pipeline DN1200	HDPE	149 (Tonnes)	469	Viva Energy

Table 11-4 Construction land clearing inputs and assumptions

Vegetation type	Area to be cleared (ha)	Emissions factor[2] (t CO_2-e/ha)	Carbon sink lost (t CO_2-e)	Source
Carbon sink emissions				
Exotic vegetation	10.11	110	1112.1	Technical Report D: *Terrestrial ecology impact assessment*
Native vegetation (Plains Grassland)	0.09	110	10	
Total	**10.20**	**-**	**1,122**	

[2] Emissions factors sourced from the VicRoads Carbon Gauge GHG Model v01.8, 2014

Table 11-5 Construction waste inputs and assumptions

Waste type	Weight of material (tonnes)	Fuel consumption (L/year)	Emissions factor[3] (t CO_2-e/t) waste	Landfill emissions (t CO_2-e)	Source
Construction materials	10	3,112	0.2	2	Viva Energy
Equipment and material deliveries	20	3,112	1.3	26	
General site office waste	30	6,223	1.6	48	

Table 11-6 Construction dredging and trenching inputs and assumptions

Type	Hectare	Mg (megagrams of carbon)	Emissions in the study area (t CO_2)	Source
Sediment removal from dredging	3.74	80	1,101	Viva Energy
Sediment removal from trenching	0.88	80	261	Viva Energy

Table 11-7 Operation stationary fuel emissions inputs and assumptions

Item/input	Units	Value	Source
LNG carrier delivery globally to Geelong			
Total natural gas delivery	PJ	160	Viva
Total LNG carriers	per annum	45	Viva Energy
Carrier volume	m^3 of LNG	125,000	Viva Energy
Time to transfer one cargo	Hours	36	Viva Energy
LNG carriers received at FSRU at 250 mmscf/d send out rate	number of	8	AECOM calculator
LNG carriers received at FSRU at 350 mmscf/d send out rate	number of	21	AECOM calculator
LNG carriers received at FSRU at 500 mmscf/d send out rate	number of	14	AECOM calculator
LNG carriers received at FSRU at 620 mmscf/d send out rate	number of	2	AECOM calculator
FSRU demand whilst LNG carrier unloading; closed loop			
250 mmscf/d send out rate	tonne/hr	5.39	AECOM calculator
350 mmscf/d send out rate	tonne/hr	7.55	AECOM calculator
500 mmscf/d send out rate	tonne/hr	10.79	AECOM calculator
620 mmscf/d send out rate	tonne/hr	13.37	AECOM calculator
FSRU demand whilst LNG carrier not unloading; closed loop			
250 mmscf/d send out rate	tonne/hr	5.29	AECOM calculator

[3] Emissions factors sourced from the VicRoads Carbon Gauge GHG Model v01.8, 2014

Item/input	Units	Value	Source
350 mmscf/d send out rate	tonne/hr	7.41	AECOM calculator
500 mmscf/d send out rate	tonne/hr	10.59	AECOM calculator
620 mmscf/d send out rate	tonne/hr	13.13	AECOM calculator
FSRU demand whilst LNG carrier unloading; open loop			
250 mmscf/d send out rate	tonne/hr	1.23	AECOM calculator
350 mmscf/d send out rate	tonne/hr	1.73	AECOM calculator
500 mmscf/d send out rate	tonne/hr	2.46	AECOM calculator
620 mmscf/d send out rate	tonne/hr	3.06	AECOM calculator
FSRU demand whilst LNG carrier not unloading; open loop			
250 mmscf/d send out rate	tonne/hr	1.28	AECOM calculator
350 mmscf/d send out rate	tonne/hr	1.73	AECOM calculator
500 mmscf/d send out rate	tonne/hr	2.56	AECOM calculator
620 mmscf/d send out rate	tonne/hr	3.18	AECOM calculator
Additional fuel demand by FSRU when running in combined loop			
Fuel demand of two boilers	tonne/hr	9.52	Assumed using publicly available data from a similar project. This assumes a high demand case.

Table 11-8 Operational transport activities inputs and assumptions

Item/input	Units	Value	Source
Nitrogen delivery vehicles to and from Geelong			
Nitrogen delivery return trip Dandenong to Geelong Refinery (33%)	km	197	Viva Energy
Nitrogen delivery return trip Altona to Geelong Refinery (33%)	km	114	Viva Energy
Nitrogen delivery return trip Port Kembla to Geelong Refinery (34%)	km	1794	Viva Energy
Trucks per year	#	960	Viva Energy
Fuel efficiency of nitrogen delivery vehicle	L/100km	53.1	Budget direct latest fuel consumption in Australia[4]
Odorant delivery vehicles to and from Geelong			
Odorant delivery return trip	km	197	Viva Energy
Trucks per year	#	10	Viva Energy
Fuel efficiency of odorant delivery vehicle	L/100km	53.1	Budget direct latest fuel consumption in Australia[5]

[4] https://www.budgetdirect.com.au/car-insurance/research/average-fuel-consumption-australia.html, accessed 28/06/2021
[5] https://www.budgetdirect.com.au/car-insurance/research/average-fuel-consumption-australia.html, accessed 28/06/2021

Item/input	Units	Value	Source
Staff travel to Geelong			
Driven return distance (combined)	km	217,360	Viva Energy
Fuel consumption	kL	24.13	AECOM calculator
Dubai to Melbourne (return)	Total return journeys / year	338	Viva Energy
Perth to Melbourne (return)	Total return journeys / year	39	Viva Energy

Table 11-9 Operational fugitive emissions inputs and assumptions

Item/input	Units	Value	Source
Unloading of LNG to FSRU			
Number of flanged connections	#	12	2 liquid and 2 vapour hoses - Viva Energy
Hours of operation	per annum	1,548	Based on 45 carriers
Transfer of natural gas from FSRU to treatment facility			
Pipeline length	km	3.0	Viva Energy
Hours of operation	per annum	8,760	Viva Energy
Treatment facility			
Number of metering stations	#	1	Viva Energy
Hours of operation	per annum	8,760	Viva Energy
Pipeline			
Pipeline length	km	4.0	Viva Energy
Hours of operation	per annum	8,760	Viva Energy

Table 11-10 LNG carrier delivery globally to Geelong inputs and assumptions (presented separately to the impact assessment in Appendix A)

Item/input	Units	Value	Source
LNG carrier delivery globally to Geelong			
Total LNG carriers	per annum	45	Viva Energy
Carrier size	m^3 of LNG	125,000	Volume size assuming 45 LNG carriers
Average transport distance return ocean voyage from Ras Laffan Port, Qatar	Nautical miles	16,220	Ports.com
Average transport distance return ocean voyage from Port of Darwin	Nautical miles	6,412	Ports.com
Average transport distance return ocean voyage from Port of Gladstone	Nautical miles	2,836	Ports.com

Item/input	Units	Value	Source
Average transport distance return ocean voyage from Port of Dampier	Nautical miles	5,304	Ports.com
Average LNG carrier speed	Knots	17	Assumption
Average fuel consumption of LNG carrier	MMBtu/trip	Ras Laffan Port, Qatar 203,161 Port of Darwin: 80,313 Port of Gladstone: 35,522 Port of Dampier: 66,435	AECOM calculator
Fuel used in LNG carrier	-	LNG and MDO pilot fuel	Assumption

Table 11-11 Exploration, extraction, and liquefaction of gas upstream inputs and assumptions (presented separately to the impact assessment in Appendix A)

Item/input	Units	Value	Source
Qatar (High-emissions scenario)	Emission factor	0.35	https://www.qatargas.com/english/sustainability/Sustainability%20Reports/Sustainability%20Report%202019_English.pdf
Woodside (Low-emissions scenario)	Emission factor	0.31	https://files.woodside/docs/default-source/investor-documents/major-reports-(static-pdfs)/2020-sustainable-development-report/sustainable-development-report-2020.pdf

Table 11-12 End use consumption inputs and assumptions (presented separately to the impact assessment in Appendix A)

Item/input	Units	Value	Source
Total annual gas supply	PJ/year	160	Viva Energy
Emission factor	kg CO2e/GJ	Scope 1 – 51.53 Scope 4 – 4	National Greenhouse Accounts Factors 2021

Appendix C

Emission Factors

Appendix C Emission Factors

Viva Energy Refinery Pier Works
GHG Emissions Factors

Revision	R01
Completed By	A.S./T.M
Checked By	L.L
Checked date	19/10/2021

National Greenhouse Account Factors - August 2021
https://www.industry.gov.au/sites/default/files/August%202021/document/national-greenhouse-accounts-factors-2021.pdf

2.1 Stationary Energy emissions (non-transport)
2.1.2 Fuel combustion emissions - gaseous fuels

Fuel combusted	Energy content factor GJ/m3	Emission factor (kg CO_2e/GJ)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Natural gas distributed in a pipeline	0.0393	51.40	0.10	0.03	51.53	0.00	4.00
Liquefied natural gas	25.3 GJ/kL	51.40	0.10	0.03	51.53	0.00	0.00

2.1.3 Fuel combustion emissions - liquid fuels

Fuel combusted	Energy content factor GJ/kL	Emission factor (kg CO_2e/GJ)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Diesel oil	38.60	69.90	0.10	0.20	70.20	0.00	3.60
Petroleum based products other than me	34.40	69.80	0.02	0.10	69.92	0.00	3.60

2.2 Transport fuel emissions (post-2004)

Fuel combusted	Energy content factor GJ/kL	Emission factor (kg CO_2e/GJ)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Gasoline (other than for use as fuel in an	34.20	67.40	0.02	0.20	67.62	0.00	3.60
Diesel oil	38.60	69.90	0.01	0.50	70.41	0.00	3.60
Liquefied petroleum gas	26.20	60.20	0.50	0.30	61.00	0.00	3.60
Diesel oil - Euro iv or higher (Heavy vehi	38.60	69.90	0.07	0.40	70.37	0.00	3.60

2.3 Indirect emissions from electricity

State or Territory		Emission factor (kg CO2e/kWh)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Victoria					0.00	0.91	0.10

2.4.2.7 Natural gas transmission
Transmission mains are defined as high-pressure pipelines greater than 1050 kilopascals, as used in the Energy Supply Association of Australia natural gas statistics.

Operation or process source		Emission factor (tonnes CO_2-e/km pipeline length)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Natural gas transmission tCO2e/km pipe		0.02	11.60	0.00	11.62	0.00	0.00
Gas flared tCO2e/t flared		2.70	0.13	0.03	2.86	0.00	0.00

3.19 Industrial processes - emissions of hydroflurocarbons and sulphur hexaflouride gases

Equipment type	Default HFCs annual leakage rates of gas			
Commercial air conditioning—chillers	0.09			
Commercial refrigeration - supermarket systems	0.23			
Industrial refrigeration including food processing and cold storage	0.16			

Appendix 4 - Emissions from waste disposal to landfill and wastewater treatment

Operation or process source		Emission factor (t CO_2-e/t waste)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Municipal solid waste							1.6
Commercial and industrial waste							1.3
Construction and demolition waste							0.2

API Compendiminium

Table 6-6. Fugitive emissions factors for natural gas transmission and storage equipment (American Petroleum Institute (API), Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry, p6-17)

Equipment basis	Units	Emission factor					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
					CO_2-e		
Compressor stations	t/station-hr		0.00702000		0.17550000		
Storage Stations	t/station-hr		0.01720000		0.43000000		
Metering/regulation stations	t/station-hr		0.00013100		0.00327500		
Metering/regulation stations transmission	t/station-hr		0.00318000		0.07950000		
Gas transmission pipeline	**t/km-hr**	**0.00000029**	**0.00000120**		**0.00003029**		
CO2 from oxidation	t/km-hr	0.00000024			0.00000024		
CO2 from leaks	t/km-hr	0.00000005			0.00000005		

Table 13. Default Methane Emission Factors per Component Population For LNG Storage and Import/Export Terminals
(American Petroleum Institute (API), 2015, Liquefied Natural Gas (LNG) Operations Consistent Methodology for Estimating Greenhouse Gas Emissions (api-lng-ghg-emissions-guidelines-05-2015.pdf, p61)

Equipment basis	Units	scf	m3		tCO_2-e/hr/component
Valve	scf/hour/component	1.19	0.034		0.381

Viva Energy Refinery Pier Works

GHG Emissions Factors

Pump Seal	scf/hour/component	4	0.113		1.281
Connectors, flanges, threaded fittings	scf/hour/component	0.34	0.010		0.109
Other	scf/hour/compressor	1.77	0.050		0.567
Vapor Recovery Compresssors	scf/hour/compressor	4.17	0.118		1.336

Source: (American Petroleum Institute (API), 2015, Liquefied Natural Gas (LNG) Operations Consistent Methodology for Estimating Greenhouse Gas Emissions (api-lng-ghg-emissions-guidelines-05-2015.pdf, p61)

Appendix B - Unit Conversion		
From	Multiply by	to obtain
Average Emissions		
Combustion of 1 tonne of LNG	2.5372	t CO_2

Table 15. GHG Emission Factors for Combustion of Fuels for LNG Transportation

Operation or process source	Units	Emission factor					
		CO_2	CH_4	N_2O			CO_2-e
Ocean Tanker							
Bunker fuel	tonnes/TJ	80.11	0.00434				80.2185
Diesel	tonnes/TJ	73.59	0.00434				73.6985
Natural Gas / Boil-off gas	tonnes/TJ	54.57	0.08684				56.741
Ocean Tanker							
Bunker fuel	tonnes/Mmbtu	0.0845	0.0000046				0.084615
Diesel	tonnes/Mmbtu	0.0776	0.0000046				0.077715
Natural Gas / Boil-off gas	tonnes/Mmbtu	0.0576	0.0000916				0.05989

Source: (American Petroleum Institute (API), 2015, Liquefied Natural Gas (LNG) Operations Consistent Methodology for Estimating Greenhouse Gas Emissions (api-lng-ghg-emissions-guidelines-05-2015.pdf, p61)

Embodied Carbon in Materials - ISCA Materials Calculator	
	tCO2/tonne of material
Steel pipe and tube - international	3.12

Source: IS_Materials_Calculator_Version 2.0

Heogh Speed / Fuel consumption of FSRU

Source: Hoegh Giant FORM C (002).pdf		
	Maximum fuel consumption (kg/hour)	
Speed (knots)	Laden	Ballast
13.5	2700	2600
16	3700	3500
18	4600	4300

Fuel properties

Source: DEFRA 2019		
Fuel Type		Unit conversion
Fuel Oil	40.66	GJ/tonne
LNG	452.49	kg/m^3
Natural Gas	0.799	kg/m^3

Air travel

Source: DEFRA 2019 International non-uk Economy (with Radiative forcing)		Source
0.138445	kg/km	

Fuel combustion emission factors (transport energy)

Source: NGAF - https://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/publications/national-greenhouse-accounts-factors-august-2019		
Fuel Type	Energy content factor	Unit
Fuel Oil	39.7	GJ/kL
	39.3	GJ/Tonne

Emission factor (kg CO_2e/GJ)					
CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
73.60	0.07	0.60	74.27	0.00	3.60

Viva Energy Gas Pipeline and Facility Works
GHG Emissions Factors

Revision	R01
Completed By	A.S//T.M.
Checked By	L.L.
Date checked	19/10/2021

National Greenhouse Account Factors - August 2021
https://www.industry.gov.au/sites/default/files/August%202021/document/national-greenhouse-accounts-factors-2021.pdf

2.1 Stationary Energy emissions (non-transport)
2.1.2 Fuel combustion emissions - gaseous fuels

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Natural gas distributed in a pipeline	0.0393	51.40	0.10	0.03	51.53	0.00	4.00
Liquefied natural gas	25.3 GJ/kL	51.40	0.10	0.03	51.53	0.00	0.00

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Fuel combusted	Energy content factor GJ/kL	Emission factor (kg CO_2-e/GJ)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Diesel oil	38.60	69.90	0.10	0.20	70.20	0.00	3.60
Petroleum based products other than mentioned in the item	34.40	69.80	0.02	0.10	69.92	0.00	3.60

2.2 Transport fuel emissions (post-2004)

Fuel combusted	Energy content factor GJ/kL	Emission factor (kg CO_2.e/GJ)					
		CO_2	CH_4	N_2O	Scope 1	Scope 2	Scope 3
Gasoline (other than for use as fuel in an aircraft)	34.20	67.40	0.02	0.20	67.62	0.00	3.60
Diesel oil	38.60	69.90	0.01	0.50	70.41	0.00	3.60
Liquefied petroleum gas	26.20	60.20	0.50	0.30	61.00	0.00	3.60
Diesel oil - Euro iv or higher (Heavy vehicles conforming to	38.60	69.90	0.07	0.40	70.37	0.00	3.60

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Appendix 4 - Emissions from waste disposal to landfill and wastewater treatment

Operation or process source		Emission factor (t CO_2-e/t waste)					
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Construction and demolition waste							0.2

API Compendiminium

Table 6-6. Fugitive emissions factors for natural gas transmission and storage equipment (American Petroleum Institute (API), Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry, p 6-17)

Equipment basis	Units	Emission factor					
		CO_2	CH_4	N_2O	Scope 1 (CO_2-e)	Scope 2	Scope 3
Compressor stations	t/station-hr		0.0070200		0.1755000		
Storage Stations	t/station-hr		0.0172000		0.4300000		
Metering/regulation stations	t/station-hr		0.0001310		0.0032750		
Metering/regulation stations transmission interconnects	t/station-hr		0.0031800		0.0795000		
Gas transmission pipeline	**t/km-hr**	**0.0000003**	**0.0000012**		**0.0000303**		
CO2 from oxidation	t/km-hr	0.0000002			0.0000002		
CO2 from leaks	t/km-hr	0.0000000			0.0000000		

LNG Operations Consistent Methodology for Estimating Greenhouse Gas Emissions (Source: International Maritime Organization (IMO), 2009, Second IMA GHG Study 2009: Table 9.1 page 131)

Operation or process source	Units	Emission factor					
		CO_2	CH_4	N_2O	Scope 1 (CO_2-e)	Scope 2	Scope 3
Transport of LNG (Liquefied natural gas) by tanker	kg/tonne-km travelled	14.5	0.02	0.1	0.0448		