Gas Import Jetty
and Pipeline Project

Environment Effects Statement

July 2020

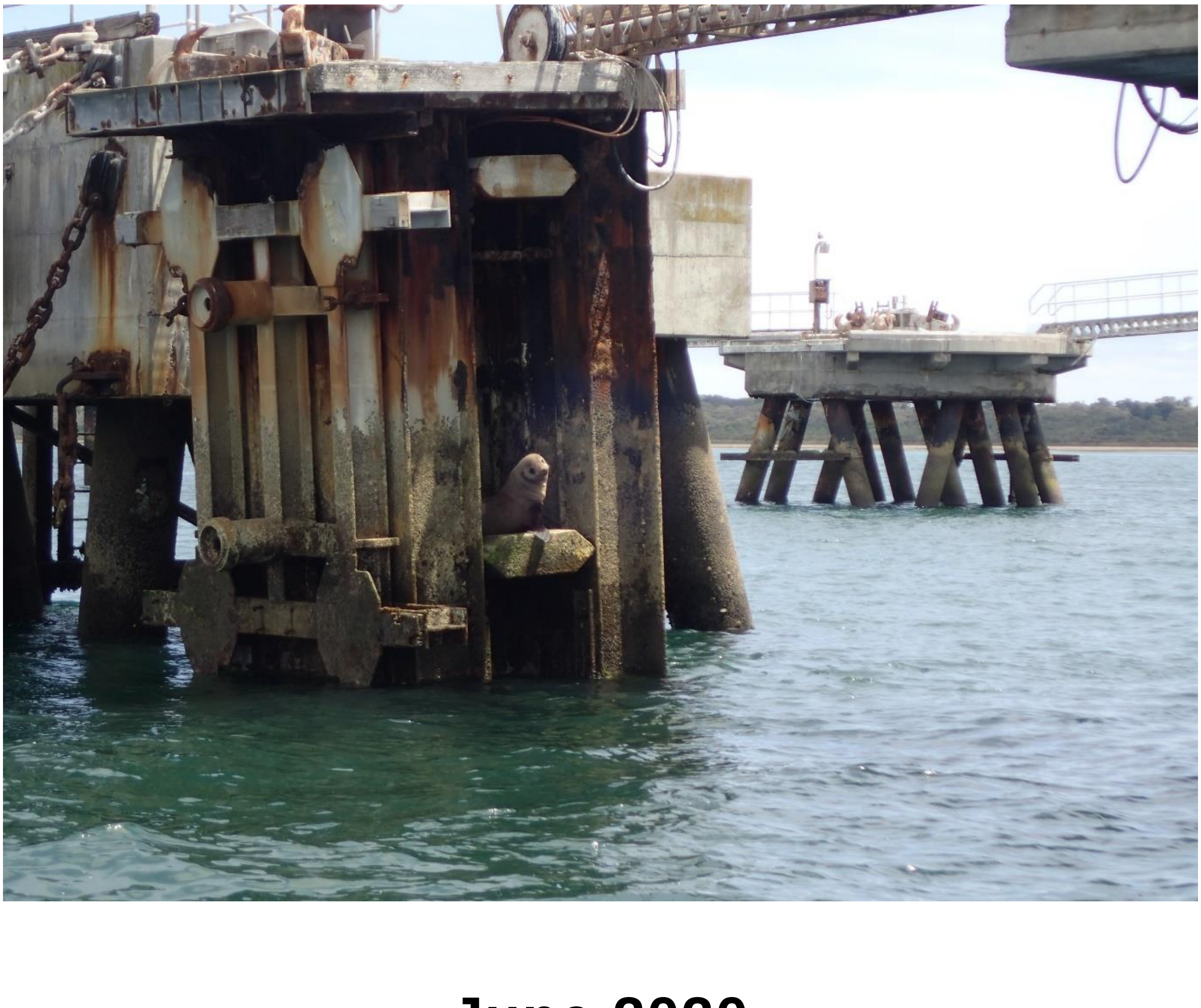
EES Technical Report A

Marine biodiversity impact assessment

Report to: AECOM

Gas Import Jetty and Pipeline Project EES

Technical Report A: Marine biodiversity impact assessment



June 2020

CEE

Abbreviations

Abbreviation	Definition
ADCP	Acoustic Doppler Current Profilers
AECOM	AECOM Australia Pty Ltd
AGL	AGL Wholesale Gas Limited
AHD	Australian Height Datum
AMSA	Australian Maritime Safety Authority
APA	APA Transmission Pty Limited
BoM	Bureau of Meteorology
BSDZCL	Bass Strait Depth Zone Contour Lines
CEE	CEE Pty Ltd
CEMP	Construction Environmental Management Plan
CPB	Chlorination produced by-products
CPO	Chlorine-produced-oxidants
CSIRO	Commonwealth Scientific Industrial Research Organisation
CWIS	Cooling water intake structures
DELWP	Department of Environment, Land, Water and Planning
DMG	Dredged Material Ground
DoAWE	Department of Agriculture, Water and the Environment
EES	Environment Effects Statement
EMF	Environmental Management Framework
EMP	Environmental Management Plan
EPA	Environment Protection Authority Victoria
EOLSS	End of Line Scraper Station
FSRU	Floating storage and regasification unit
GIS	Geographic information systems

Abbreviation	Definition
GL	Gigalitres
ha	Hectare
HAT	Highest astronomical tide
IMO	International Maritime Organization
kg	Kilogram
km	Kilometre
LAT	Lowest astronomical tide
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
m	Metre
m^3	Cubic metres
m^3/d	Cubic metres per day
mm	Millimetres
m/s	Metres per second
mg/L	Milligrams per litre
MLA	Marine loading arm
MMscfd	Million standard cubic feet per day
MNES	Matters of National Environmental Significance
MSL	Mean sea level
NIMS	Non-indigenous marine species
NNE	North-north-east
OEMP	Operational Environmental Management Plan
OHS	Occupational Health and Safety
PoHDA	Port of Hastings Development Authority
PMST	Protected Matters Search Tool
SEMP	Safety and Environment Management Plan

Abbreviation	Definition
SOP	Standard operating procedure
THM	Trihalomethanes
TRG	Technical Reference Group
µg/L	Micrograms per litre
µm	Micrometre
VCDEM	Victorian Coastline Digital Elevation Model
VDP	Victorian Desalination Plant
VRCA	Victorian Regional Channels Authority
VTS	Victorian Transmission System
v/v	Volume per volume
WQI	Water Quality Index

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Report to:	**Report prepared by:**
AECOM Level 10, Tower Two, 727 Collins St Melbourne, VIC 3008	CEE Pty Ltd Unit 4 150 Chesterville Rd Cheltenham, VIC 3192

1 Introduction

This report assesses the potential marine impacts associated with the construction and operation of the proposed Gas Import Jetty and Pipeline Project (the Project).

The Project would provide an additional supply of natural gas into the south-eastern Australian gas market for industrial, commercial and residential customers.

The Australian Energy Market Operator has predicted potential supply gaps in Victoria's gas market from 2024 (AEMO, 2019). The Project would improve energy security for industrial, commercial and domestic customers and would increase competition in the market.

The joint proponents of the Project are AGL Wholesale Gas Limited (AGL) and APA Transmission Pty Limited (APA).

The Project would establish a gas import jetty and pipeline comprising:

- a floating storage and regasification unit (FSRU) at Crib Point Jetty – the Gas Import Jetty Works
- a gas pipeline between Crib Point and Pakenham to connect to the Victorian Transmission System (VTS) east of Pakenham – the Pipeline Works.

The Project was referred by AGL and APA to the Victorian Government under the *Environment Effects Act 1978* (Vic) on 13 September 2018 as two separate projects consisting of the Gas Import Jetty Works and Pipeline Works.

On 8 October 2018 the Minister for Planning issued a decision determining that an Environment Effects Statement (EES) was required for the Project due to the potential for a range of significant environmental effects.

The Gas Import Jetty Works and the Pipeline Works were also referred to the Commonwealth Government under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as separate projects.

Each project was designated as a controlled action requiring impact assessment under the EPBC Act. The EES process is the accredited environmental assessment for the controlled action decisions under the EPBC Act in accordance with the bilateral agreement between the Commonwealth and Victorian governments.

1.1 Purpose of Marine Risk Assessment

The draft evaluation objective for marine biodiversity is – 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.

Other relevant draft evaluation objectives for the marine biodiversity impact assessment are:

- **Water and catchment values –** To minimise adverse effects on water (including groundwater, waterway, wetland, estuarine, intertidal and marine) quality and movement particularly as they might affect the ecological character of the Western Port Ramsar site.

- **Waste** – To minimise generation of wastes by or resulting from the project during construction and operation, including accounting for direct and indirect greenhouse gas emissions.

This report provides the assessment of potential marine water quality and biodiversity impacts of the Project for the EES and sets out mitigation measures for potential impacts. This report will inform the development of an Environmental Management Framework (EMF) for the Project. The mitigation measures listed in the EMF will be implemented in the approvals and management plans for the Project.

Why understanding marine biodiversity 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 Western Port Ramsar site.

Understanding how the Project could impact marine biodiversity 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 at low tide, particularly migratory shorebirds.

Impacts on terrestrial fauna including shorebirds are documented in EES Technical Report B: *Terrestrial and freshwater biodiversity impact assessment*.

1.2 Project Description

The following is a summary of the key features of the Project including those aspects of the Project that are specifically relevant to the assessment of potential marine impacts. A detailed description of the Project is provided in EES Chapter 4 *Project description*.

The Project comprises two sets of works: (1) the Gas Import Jetty Works and (2) the Pipeline Works. AGL would undertake the Gas Import Jetty Works. APA would undertake the Pipeline Works.

1.2.1 Gas Import Jetty Works

The Gas Import Jetty Works would consist of a liquefied natural gas (LNG) import facility comprising:

- Continuous mooring of an FSRU at Berth 2 of the existing Crib Point Jetty to store LNG and regasify LNG into natural gas;
- Jetty Infrastructure on the Crib Point Jetty including marine loading arms (MLAs) and gas piping to transfer the gas from the FSRU to the Crib Point Receiving Facility; and
- Crib Point Receiving Facility, including metering, odorant injection and nitrogen injection, which would be located on land adjacent to the Crib Point Jetty.

The FSRU would be approximately 300 metres long by 50 metres wide. It would have capacity to store 170,000 cubic metres (m^3) of LNG and be moored at Berth 2 of the Crib Point Jetty.

The FSRU would store the LNG as a liquid and when required, convert the LNG into a gaseous state by heating the LNG using seawater or gas-fired boilers (a process known as regasification). The regasification process would normally involve pumping seawater in through intakes or sea chests on the sides of the FSRU, transferring some of the heat in that seawater to the LNG (to convert it back to natural gas), and discharging the cooler seawater back to Western Port through six specially-designed ports on the east side of the FSRU. A description of the discharge ports on the FSRU is provided in Section 6.0. The seawater intakes are 14.5 m long, 2.5 m deep and located at approximate mid-depth in the 14 m deep water column near the rear of the FSRU on the port and starboard sides. The location of the seawater intake is 60 m from the main jetty and almost 100 m south of Berth 2. Further details on the sea chest design is provided in Section 7.

Visiting vessels carrying LNG (LNG carriers) would berth alongside the FSRU to transfer their LNG to the FSRU, which would take 24 to 36 hours. Flexible cryogenic hoses will be used to transfer the LNG from the LNG carriers to the FSRU.

Following regasification, the natural gas would be transferred through gas piping along the jetty from the FSRU to the Crib Point Receiving Facility. The Crib Point Receiving Facility would include facilities to inject odorant and nitrogen (as required) into the natural gas to meet VTS gas quality specifications.

The Crib Point Receiving Facility that forms part of the Gas Import Jetty Works is not expected to result in direct impacts on the marine environment and is therefore not assessed in this report. The potential indirect marine impacts associated with the construction and operation of the Crib Point Receiving Facility are discussed in other technical reports that were prepared for the EES, for example, surface water runoff that may end up in the marine environment is discussed in EES Technical Report C: *Surface water impact assessment*.

1.2.2 Pipeline Works

The Pipeline Works would comprise a gas transmission pipeline to transport gas from the Crib Point Receiving Facility to the VTS east of Pakenham. The pipeline would be approximately 57 kilometres long with a nominal diameter of 600 millimetres. The pipeline would be buried at a depth of generally 1.2 metres below ground (to the top of the pipe).

The Pipeline Works would also comprise the following facilities:

- a pigging facility at the Crib Point Receiving Facility to enable in-line inspections of the pipeline with a pipeline inspection gauge (pig);
- an above-ground Pakenham Delivery Facility situated adjacent to the Pakenham East rail depot to monitor and regulate the gas;
- a below-ground End of Line Scraper Station (EOLSS) located at the connection point to the VTS, north of the Princes Highway in Pakenham; and
- two above-ground mainline valves located along the pipeline alignment to enable isolation of the pipeline in an emergency.

The potential impacts of the Pipeline Works are considered in other EES technical reports. As they are not expected to impact on the marine environment, the Pipeline Works are not assessed in this report.

1.2.3 Construction

The key construction activities for the Project relevant to the marine environment include:

- mooring and commissioning the FSRU at Crib Point Jetty and connecting it to the MLAs prior to operation; and
- installation of Jetty Infrastructure on the Crib Point Jetty, including MLAs, gas piping mounted to the jetty, electrical and instrumentation equipment and a firefighting system.

Other construction activities for the Gas Import Jetty Works would include:

- establishment of construction sites including laydown areas; and
- construction of the Crib Point Receiving Facility.

Construction for the Gas Import Jetty Works would take approximately 18 to 27 months, depending on weather conditions. Construction for the Pipeline Works would take approximately 18 to 24 months, depending on weather conditions. Subject to the staging of the works outlined above, construction for the entire Project is expected to take approximately 18 to 27 months.

1.2.4 Operation and Maintenance

When commissioned, the FSRU would be operated by an experienced third-party operator. The Crib Point Receiving Facility and associated Jetty Infrastructure would be owned and operated by AGL or an experienced third-party operator. The Pipeline Works would be owned and operated by APA.

The FSRU may leave Western Port during the Project lifetime for activities such as scheduled maintenance and extreme weather events.

The gas import jetty would initially receive approximately 12 LNG carriers per year with capacity to increase to approximately 40 LNG carriers per year. The number and frequency of LNG carriers arriving each year would depend on their storage capacity and gas demand.

The Crib Point Receiving Facility is designed to be automated and may be operated unmanned under normal operating conditions.

An operational easement of generally 15 metres wide would apply to the pipeline alignment. The pipeline easement would be routinely inspected for any operational or maintenance issues in accordance with APA procedures.

The pipeline would also be designed and constructed so that pigging could be undertaken to inspect the integrity of the pipeline as required. Pigging would be undertaken around 10 years after construction and then at a frequency determined by the first inspection.

The Pakenham Delivery Facility is also designed to be automated and operate unmanned under normal operating conditions.

The EOLSS would be buried with valves contained within concrete pits. The connection to the VTS would operate unmanned. Excavation of the site to access the EOLSS would be required for the pigging activities.

It is anticipated that initially the FSRU would receive approximately 45 PJ of LNG per annum (from approximately 12 LNG carriers). Over time, the amount of LNG received could increase to 160 PJ per annum (from approximately 40 LNG carriers). The month-by-month production of gas by the FSRU would depend on the demand for gas in south-eastern Australia and the capacity for this demand to be met by the range of available gas supplies.

The FSRU would be able to operate at different production rates (measured in terms of the gas send-out rate in million standard cubic feet of gas per day (MMscfd)). Figure 1-1 is an example of average month-by month gas production rate as an illustration of the variability in production over the year. Typically, the demand for gas in Victoria is seasonal, with highest demand in winter and lowest demand in summer. The maximum production rate of the FSRU is 750 MMscfd. However, the FSRU would mostly operate at a lower production rate and the average over a year is expected to be 500 MMscfd or less.

The FSRU would convert stored LNG into natural gas via a process called regasification. A heat-exchange is used as an interface to transfer heat from a heat source to the LNG in the regasification train, of which there are three onboard the FSRU. The proposed operation scenario is to use open loop production throughout the year, however closed loop production is included in the assessment for comparison purposes.

A range of gas production scenarios were investigated by AGL to provide operating parameters for the FSRU that would meet the environmental evaluation objectives (as established in the scoping requirements for the EES) and ensure the Project can meet the demand for gas and provide security for gas customers in south-eastern Australia.

The marine risk assessment is based on an upper limit of 750 MMscfd of gas production in the peak month and an average of 500 MMscfd over the year. The marine risk assessment also is based on the peak of 40 LNG carrier deliveries over a year. This approach allows for the marine risk assessment to assess a conservative (peak gas production) and typical (average gas production) set of scenarios.

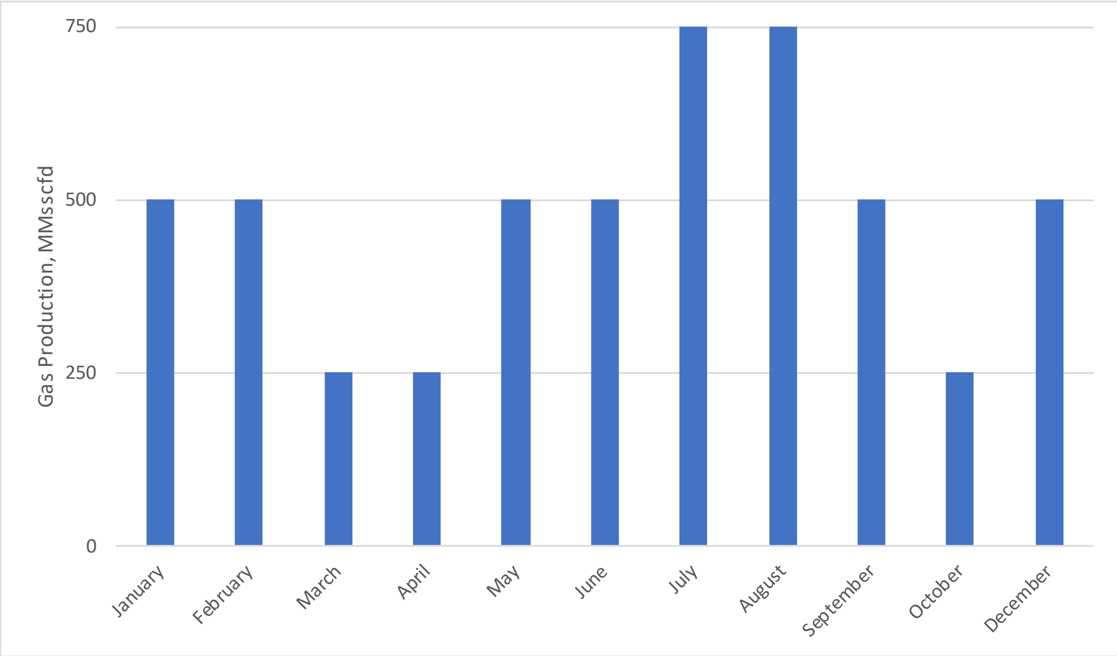


Figure 1-1. FSRU Indicative Daily Production by Month

1.2.5 Decommissioning

The FSRU is proposed to operate for 20 years, although this may be shortened or extended as appropriate to achieve security and stability of gas supply to south-eastern Australia. When the Project is no longer required, the FSRU would disconnect from the MLAs and leave Western Port. The infrastructure installed on the Crib Point Jetty and the Crib Point Receiving Facility would be decommissioned and removed.

The Crib Point Jetty would remain as an operational jetty under the management of the Port of Hastings Development Authority (PoHDA), and, as with other berths at Crib Point, would continue to be used by other vessels.

The pipeline would have a design life of 60 years. If the Pipeline Works were no longer required, they would be decommissioned in accordance with Australian Standard AS2885 *Pipelines – gas and liquid petroleum* and relevant legislative and approval requirements at the time of decommissioning.

1.2.6 Marine Environment Considerations in the Project Design and Operation

Key aspects of the Project would give rise to potential impact pathways for consideration in the assessment of risk and potential impacts on marine biodiversity including:

- **FSRU Operation - Seawater intake**
  - Open-loop regasification would use ambient seawater from Western Port, which has a natural temperature range of approximately 11°C to 23°C, to heat the LNG from a temperature of -163°C to gas at ambient temperature. At peak production, open-loop regasification would involve the use of approximately 468,000 m^3 per day of seawater in the regasification process.

  - Closed-loop regasification would use boilers on the FSRU as the source of heat for regasification. Ambient seawater from Western Port would be heated using steam from gas-fired boilers and recirculated through heat exchangers. At peak production, closed-loop regasification would involve the use of up to 187,000 m^3 per day of seawater in the regasification process.
  - A small additional volume of seawater would be used for ballast water, fire control, and auxiliary machinery systems and generators, which would be returned to Western Port.
- **FSRU Operation - Chlorination**
  - To prevent the growth of biota in the internal pipework and heat exchanger of the FSRU, the seawater would be chlorinated at the intake. This would be done using an electrolytic cell to convert chloride ions, naturally present in seawater salt, into chlorine oxidants at an initial concentration of 500 micrograms per litre (500 µg/L).
- **LNG delivery**:
  - Shipping movements: the FSRU would receive gas from 12 LNG delivery carriers per year. This could increase to 40 LNG carriers per year, depending on future gas demand in south-eastern Australia.
  - LNG loading: during the transfer of LNG from the delivery carrier to the FSRU, the FSRU would discharge ballast water to maintain buoyancy and stability.
- **FSRU Operation - Discharge**
  - Open-loop regasification, approximately 468,000 m^3 per day of cooler seawater would be discharged from the regasification process at peak production with a residual concentration of chlorine oxidants of 100 µg/L. The discharged seawater would be approximately 7˚C below the ambient seawater temperature.
  - Closed-loop regasification, up to 187,000 m^3 per day of warmer seawater would be discharged from the regasification process at peak production with a residual concentration of chlorine oxidants of 100 µg/L. This discharged seawater would be about 4.1˚C above the ambient seawater temperature.
  - At the point of discharge, the residual concentration of chlorine-derived oxidants with open loop or closed loop would be 0.1 milligrams per litre (mg/L) (equal to 100 micrograms per litre (µg/L)).
  - Other seawater discharges include ballast water, operation of the freshwater generator and firefighting system testing water (see EES Chapter 4 *Project Description)*.

1.3 Marine Environment Impact Pathways

1.3.1 Key Impact Pathways

In developing the EES referral for the Project, the risks for Western Port biodiversity were examined based on existing information and initial hydrodynamic and conceptual models. The key impact pathways were determined for the Project as well as other minor impact pathways (Jacobs, 2018).

Key impact pathways that were identified in the EES referral included:

- Intake of seawater through the FSRU seawater intake with the consequent entrainment of plankton and other small marine biota;
- Discharge of cooler seawater from the proposed open loop process that would be around 7 degrees Celsius below ambient seawater temperature from the FSRU;
- Residual chlorine in all discharges (except ballast water) of up to 100 µg /L.

Less significant potential impact pathways that were identified from the processes of the FSRU and the movement of LNG carriers included:

- Discharge of warmer seawater if the closed loop process is used, with the discharge around 4.1 degrees Celsius above ambient seawater temperature;
- Effects of the FSRU on local scour and shading of the seabed;
- Underwater noise and surface lights;
- Contamination from leaks and spills;
- Other impacts on marine biota through interaction with the FSRU or LNG carriers (such as whale strike).

A separate underwater noise impact assessment has been carried out for the Project and is included in Annexure I to this report (Jasco, 2020). This underwater noise impact assessment is accompanied by an Underwater Acoustic Modelling Report at Annexure J to this report (Jasco, 2019).

Based on the initial assessment of the Project as part of the EES referral preparation and a review of similar operations in other parts of the world, several primary mitigation measures were identified for incorporation into the Project design relating to seawater intake and discharge. The seawater intake and discharge arrangements for the FSRU is described below, including the primary mitigation measures incorporated into the Project.

1.3.2 Intake for Seawater – Primary Mitigation Measures

The intake of seawater would entrain biota into the pipe network and heat exchangers on the FSRU. The living biota entering the seawater intake of the FSRU could include:

- Larger actively swimming biota such as fish and small biota;
- Less mobile planktonic biota such as very small animals (zooplankton);
- Larger animals such as jellyfish;
- Microscopic plants (phytoplankton);
- Larvae and eggs; and
- Propagules of marine plants such as mangroves and seagrasses.

Entrainment risks can be mitigated through the design of the intake sea chests on the FSRU. The important parameters on the sea chest design that impact entrainment rates are:

- Locating the sea chest near mid-depth in the water column and away from the water surface (2 m below surface) and seabed (3 m above seabed);
- Limiting the intake velocity to 0.15 metres per second (m/s), allowing most mobile biota to avoid being entrained;
- Locating the intake so the intake velocity is horizontal, allowing fish and other mobile biota to detect the flow and swim away;
- 100 millimetres (mm) x 100mm screen to prevent larger organisms from being entrained.

1.3.3 Discharge of Seawater – Primary Mitigation Measures

As the seawater enters the FSRU it would pass through an electric cell where an electrolysis reaction would convert natural chlorine ions in the water to oxidative chlorine products that prevent the growth or encrusting of marine biota on the internal components of the FSRU. When the seawater is discharged back into the environment, it contains a residual amount (up to 100 µg/L) of chlorine oxidants. Also, as the seawater is used to transfer heat to the LNG, the seawater that is discharged in open loop mode is approximately 7°C cooler than the ambient seawater.

The seawater discharge risks are mitigated by increasing the initial dilution. This would be achieved by discharging at high lateral velocity through six ports spaced along the side of the FSRU. The momentum of the jets greatly increases the mixing of the seawater discharge with the tidal currents. The six discharge are located on the starboard (east) side of the FSRU discharging into the main channel of North Arm.

The option of locating the ports on the port (west) side was considered but has not been adopted for several reasons including:

- there is less depth of water on the west side and hence lower initial dilution;
- a FSRU seawater discharge (cooler temperature and residual chlorine) would be closer to the higher biodiversity areas in shallow and intertidal waters.

To provide a scientific basis for the assessment of the alternative discharge port location (on the port (west) side), a computer dispersion model for that option was completed and the results are presented in Section 6.0.

1.4 Project Area

The Project Area is situated between Crib Point and Pakenham East in Victoria within the local government areas of Mornington Peninsula Shire, the City of Casey and Cardinia Shire. The Project Area includes the construction and operation footprints for the Gas Import Jetty Works and the Pipeline Works.

The Project Area is detailed in EES Attachment VII *Map book*. An overview of the Project showing the proposed pipeline alignment and current options is shown in Figure 1-2.

The Gas Import Jetty Works would be located within Western Port at the existing Crib Point Jetty and on land immediately adjacent. The Crib Point Jetty is located within the Port of Hastings and within an area designated as a wetland of international significance under the Ramsar Convention on Wetlands of International Importance (the Western Port Ramsar site).

The FSRU is proposed to be moored at the existing Berth 2 of Crib Point Jetty.

The Pipeline Works would be located on land between the Crib Point Receiving Facility and a connection point to the VTS east of Pakenham.

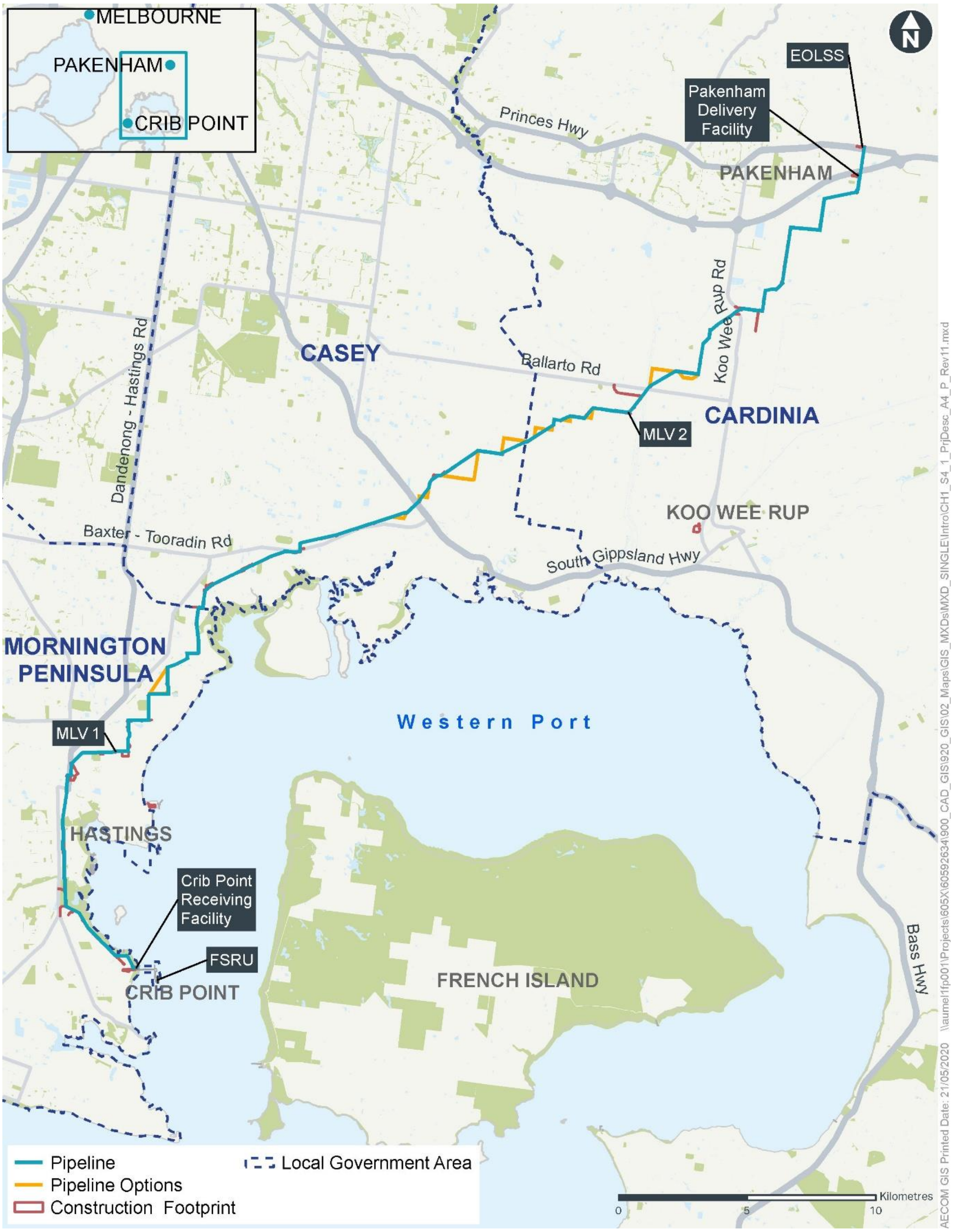


Figure 1-2 Project Area overview

1.4.1 Study area

All Project activities relevant to potential marine biodiversity impacts occur at the Crib Point Jetty. This includes the construction area for installation of Jetty Infrastructure, and at Berth 2 where the FSRU would be continuously moored (Figure 1-3).

The study area for the marine biodiversity impact assessment encompasses the whole of Western Port, with particular focus on the Lower North Arm in which Crib Point is situated.

Figure 1-3 Marine Study Area

2.0 Scoping Requirements

The EES scoping requirements for the Project were issued by the Victorian Minister for Planning in February 2019.

The scoping requirements set out the specific matters to be investigated and documented in the EES in accordance with the *Ministerial Guidelines for assessment of environmental effects under the Environment Effects Act 1978*.

The EES is an accredited assessment process for the purposes of the assessment of the Project under the EPBC Act, and the EES scoping requirements also include matters to be assessed under the EPBC Act.

2.1 Evaluation Objectives

The following draft evaluation objectives are relevant to the marine biodiversity impact assessment and identify the desired outcomes in the context of potential Project effects.

The draft evaluation objectives, as set out in the final scoping requirements, provide a framework to guide integrated assessment of the environmental effects of the Project.

These draft evaluation objectives are to be used in the context of the relevant legislative requirements set out in Section 3.0.

Draft evaluation objectives for marine biodiversity

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.
Water and catchment values – To minimise adverse effects on water (including groundwater, waterway, wetland, estuarine, intertidal and marine) quality and movement particularly as they might affect the ecological character of the Western Port Ramsar site.
Waste – To minimise generation of wastes by or resulting from the project during construction and operation, including accounting for direct and indirect greenhouse gas emissions.

2.2 Assessment of Specific Environmental Effects

The following extracts from the scoping requirements, issued by the Minister for Planning, are relevant to the draft evaluation objectives listed above.

Table 2-1. Scoping Requirements for the Marine Biodiversity Impact Assessment

Aspect	Scoping requirement	Refer
Biodiversity		
Key issues	Direct loss of native vegetation and any associated listed threatened flora and fauna species and communities known or likely to occur in or adjacent to the project works. Direct loss of, or degradation to, habitat for flora and fauna species listed as threatened or migratory under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act), *Flora and Fauna*	Section 7

	Guarantee Act 1988 (FFG Act) and/or Department of Environment, Land, Water and Planning (DELWP) advisory lists, including listed whales, turtles, fish and birds. Indirect loss of vegetation or habitat quality, that may support any listed species or other protected fauna, resulting from hydrological or hydrogeological change, edge effects, habitat fragmentation, loss of connectivity, or other disturbance impacts arising from construction or operation, including noise, vibration and lights. Potential for adverse effects on the ecological character and biodiversity values of the Western Port Ramsar site including, but not limited to, the species above and terrestrial and marine conservation reserves. Potential for indirect effects on biodiversity values including but not limited to those effects associated with changes in hydrology (including surface and groundwater changes), water quality (i.e. on water dependent ecosystems), contaminants and pollutants, environmental weeds, pathogens and pest animals including, but not limited to declared weeds, pathogens and pest animals under the *Catchment and Land Protection Act 1994*. Potential for significant short and long-term impacts on marine biota due to entrainment of organisms in seawater for regasification or due to discharge of cooled seawater 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. Potential for impacts resulting from increased shipping activity on cetaceans and other large marine animals, including acoustic impacts and potential collisions. 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).	
Priorities for characterising the 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, as well as. Identify the existing or likely presence of any protected species, and especially species listed under the FFG Act and DELWP advisory lists, as well as environmental weeds, pathogens and pest animals. Characterise the listed threatened and migratory species, other protected species, ecological communities and potentially threatening processes that are likely to be present, in the Western Port Ramsar site or in other wetlands nearby. This characterisation is to be informed	Section 5

	by the literature and suitable available data 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. 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. 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. Identify exotic marine organisms that are already present or established near the project. 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. Describe the biodiversity values that could be affected by the project, including: • native vegetation and any ecological communities listed under the EPBC Act or FFG Act; • presence of, or suitable habitats for, native flora and fauna species, especially those listed under the EPBC Act, FFG Act, and DELWP advisory lists; and • use of the site and its environs for movement by EPBC Act, FFG Act, and DELWP advisory list listed fauna species, including migratory species, and other protected species. Describe the existing threats present to biodiversity values, including: • direct removal of individuals or destruction of habitat; • 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 FFG Act.	
Design and mitigation measures	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 Western Port Ramsar site and habitat values within or adjacent to the pipeline alignment.	Section 8

	Best practice guidelines and standards must be considered when designing mitigations, including those referred to in Section 3.5.	
Assessment of 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, in particular any species listed under the EPBC Act, FFG Act or DELWP advisory lists. Assess likely direct and indirect effects of the project on the ecological character and habitat values of the Western Port Ramsar wetland site, including but not limited to effects of entrainment, potential introduction of exotic organisms, wastewater discharges, other waste streams, noise, vibration and light. 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, FFG 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. 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.	Section 7 Section 8
Approach to manage performance	Describe and evaluate proposed measures to manage the residual effects of the project on biodiversity values, including an outline of an offset strategy that sets out and includes evidence of the offsets that can be secured or are proposed to satisfy Commonwealth and Victorian offset policy or guideline requirements. Describe and evaluate the approach to monitoring and the proposed contingency measures to be implemented in the event of adverse residual effects on flora, fauna and ecological community values requiring further management. Identify any further methods proposed to manage risks and effects on other biodiversity values and native vegetation, to form part of the EMF.	Section 8
Water and catchment values		
Key issues	The potential for adverse effects on the functions, values and beneficial uses of surface water environments, especially the Western Port Ramsar site, such as interception or diversion of flows or changed water quality or flow regimes during construction and operation. The potential for adverse impacts on water-related values due to spills or other incidents during construction of operation The potential for adverse effects on biodiversity values of the Western Port Ramsar site.	Section 7

Existing environment	Describe marine, estuarine, intertidal and freshwater waters and their beneficial uses that could be affected from changed water quality, or water movement due to the project. Detail and evaluate the hydrological/hydro-geological modelling techniques utilised.	Section 5 Section 6.0
Design and mitigation measures	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, waterway or wetland environments.	Section 7 Section 8
Assessment of likely effects	Identify and evaluate effects of the project and alternatives on groundwater, surface water, waterways and 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.	Section 7
Approach to manage performance	Describe and evaluate the approach to monitoring and the proposed contingency measures to be implemented in the event of adverse residual effects on water quality and catchment values requiring further management. Describe and evaluate the approach to monitoring and the proposed ongoing management measures to be implemented to avoid adverse residual effects on the Western Port Ramsar site.	Section 8
Waste management		
Key issues	Potential for discharge of cooled water or other pollutants including chlorine resulting from regasification. Potential for unplanned spills of product or other pollutants including bilge or ballast water that could contain exotic organisms.	Section 7
Existing environment	Identify the sensitivity of receiving waters to cooled seawater discharge or other polluting or toxic constituents of discharged water, including determining the geographical extent over which changed temperatures and contaminants may cause adverse environmental effects.	Section 5 Section 6.0 Section 7
Design and mitigation measures	Describe measures proposed to be implemented to treat discharge seawater and to minimise the extent of the mixing zone. Describe measures to minimise the risk of spills including of water from vessels which might contain contaminants or exotic organisms.	Section 7 Section 8
Assessment of likely effects	Identify potential impacts resulting from contaminants or water temperature change due to discharge of seawater used for regasification, regarding the ecological character of the Western Port Ramsar site, for example due to effects on plankton and larvae productivity and resultant changes in bird food resources.	Section 7

Approach to manage performance	Describe proposed measures to reduce, monitor and audit discharges to water from the project.	Section 8

In the context of this report, 'effects' includes all potential direct, indirect, on-site and off-site environmental impacts resulting from the Project.

The description and assessment of effects is not confined to the immediate area of the Project – it also considers the potential of the Project to impact on adjacent or other areas that could be affected, in the context of a systems-based approach.

The effects on Matters of National Environmental Significance (MNES) and an analysis of the acceptability of impacts on MNES are summarised in Section 7 and 8 of this report.

3.0 Legislation, Policy and Guidelines

Table 3-1 summarises the primary legislation that is relevant to the marine environment of Western Port, as well as the implications to the Project and required approvals.

Table 3-1. Key marine environmental legislation relating to the Project

Document	Description	Implications for the Project
Commonwealth		
Legislation		
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	The EPBC Act is the Commonwealth Government's principal environmental protection and biodiversity conservation legislation. It provides for the conservation of biodiversity and the protection of the environment, particularly those aspects that are among the nine MNES, including World Heritage properties, National Heritage places, Ramsar wetlands, listed nationally threatened species and ecological communities and listed native migratory species. The EPBC Act states that if significant impacts on MNES are likely, then an action is known as a 'controlled action' and assessment and approval under the EPBC Act is required.	The Gas Import Jetty Works and Pipeline Works are each 'controlled actions' requiring assessment and approval under the EPBC Act, due to the following relevant controlling provisions: • wetlands of international importance (Sections 16 and 17B) • listed threatened species and communities (Sections 18 and 18A) • listed migratory species (Sections 20 and 20A) A range of threatened species, and migratory species having been identified as being present within the Project Area; and the Project Area being located within the Western Port Ramsar site. The MNES for assessment under the EPBC Act are being assessed as part of the EES under the bilateral agreement between the Commonwealth and Victorian Governments.
Biosecurity Act 2015 (Biosecurity Act)	The Biosecurity Act sets out the legal framework for managing biosecurity threats (pests, weeds and diseases) to plant, animal and human health, and the environment.	The Biosecurity Act prescribes how ballast water should be managed within Australian seas, establishing obligations for vessels to: • manage ballast water before their 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.
Policy / guidelines / standards		
Significant Impact Guidelines 1.1 – Matters of National Environmental Significance (Significant Impact Guidelines)	The Significant Impact Guidelines provide overarching guidance on determining whether an action is likely to have a significant impact on a matter protected under the EPBC Act	The Commonwealth Government Minister for the Environment has determined that Gas Import Jetty Works and the Pipeline Works are 'controlled actions' with the potential to impact on MNES and that each of these requires assessment under the EPBC Act.

Document	Description	Implications for the Project
National Water Quality Management Strategy - Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Revised 2018) (ANZECC Guidelines)	The ANZECC Guidelines set 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 values.	The ANZECC Guidelines provide quantitative guideline values for water and sediment quality to support the protection of community values, and the context in which they should apply. Regulatory authorities would have regard for the Guidelines in assessing the Project's impacts on water quality.
State		
Legislation		
Environment Effects Act 1978 (Environment Effects Act)	The Environment Effects Act provides a regime where projects with potentially significant environmental impacts may require the preparation of an EES for assessment by the Minister for Planning. An EES may be required for declared 'public works' or works determined by the Minister for Planning to require an EES following referral. Where an EES is required, the Minister for Planning will issue scoping requirements to guide preparation of the EES. Once the EES is prepared it is placed on exhibition for public comment. The Minister for Planning may appoint an inquiry to assess the impacts of the Project, taking into account the EES studies and any public submissions. This can involve a formal hearing. The Minister for Planning subsequently provides an assessment (typically within 25 business days of the inquiry report being received), having considered the proponent's response, public submissions, EES documents and the inquiry report. The relevant statutory decision-makers must consider the Minister for Planning's Assessment when deciding whether to approve the Project and, if so, on what conditions.	On 8 October 2018, the Victorian Minister for Planning determined that an EES was required for the Gas Import Jetty Works and Pipeline Works (as a single joint project). In February 2019, the Minister for Planning issued the scoping requirements for the Project. The EES has been prepared in accordance with these scoping requirements, which require the assessment of a range of specific environmental effects. The EES would be placed on public exhibition and an inquiry would be appointed to consider the environmental effects of the projects. At the conclusion of the EES assessment process the Minister for Planning's Assessment Report would be provided to the relevant statutory decision-makers to inform their decisions whether to grant approvals for the projects.
Flora and Fauna Guarantee Act 1988 (FFG Act)	The FFG Act is the primary legislation dealing with biodiversity conservation and sustainable use of native ecology in Victoria. The FFG Act provides a legal framework to promote conservation of Victoria's native flora	The FFG Act establishes the process for identifying, listing and managing threatened species that must be considered in the impact assessments prepared as part of the EES for the Project. A range of FFG Act-listed species are present within the Project Area. An FFG Act permit is required for

Document	Description	Implications for the Project
	and fauna and enable management of potentially threatening processes. Threatened species and communities of flora and fauna, as well as threatening processes, are listed under the FFG Act. Section 47 provides that a permit is required for the removal of any listed protected flora from public land.	several locations along the proposed pipeline alignment and potentially the Crib Point Receiving Facility. In addition, an FFG Act or Fisheries Act 1995 permit may be required for 'taking' of fish by the operation of the FSRU.
Marine and Coastal Act 2018 (Marine and Coastal Act)	The Marine and Costal Act aims to protect Victoria's marine and coastal environment. The Marine and Coastal Act provides an integrated and coordinated approach to planning and managing the marine and coastal environment by enabling protection of the coastline and the ability to address the long-term challenges of climate change, population growth and ageing coastal structures.	The Minister for Energy, Environment and Climate Change's consent is required under the Marine and Coastal Act for components of the Gas Import Jetty Works and Pipeline Works, where the pipeline alignment traverses coastal Crown land, to 'use or develop, or undertake works on, marine and coastal Crown land'. Policies and plans developed under the Marine and Coastal Act will inform the Minister for Energy, Environment and Climate Change's decision.
Fisheries Act 1995 (Fisheries Act)	The Fisheries Act provides a legislative framework for the regulation, management and conservation of Victorian fisheries including aquatic habitats.	The Fisheries 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 Protection Act 1970 (Environment Protection Act)	The Environment Protection Act provides a legal framework to protect the environment in Victoria, including the protection of air, land and water from pollution. The Environment Protection Act is outcome oriented, with a basic philosophy of preventing pollution and environmental damage by setting environmental quality objectives and establishing programs to meet them. The Environment Protection Act establishes the EPA Victoria to administer the Act and any regulations and orders made under the Act, including orders declaring SEPPs.	The Environment Protection Act regulates discharges to the environment by a system of licences and Works Approvals. With regard to the marine environment, this includes the discharge of seawater from the FSRU. Given the FSRU would be scheduled premises as a result of air emissions, the FSRU would require a Works Approval and an EPA Licence under the Environment Protection Act. As a result, any wastewater discharges to marine waters from the FSRU would also be regulated by EPA approvals.
Port Management Act 1995 (Port Management Act)	The Port Management Act includes provisions for the establishment, management and operation of commercial trading ports and local ports within Victoria.	PoHDA's responsibility for safety, environment and hazard management within the Port of Hastings under the Port Management Act requires the preparation of the Safety and Environment Management Plan (SEMP) and Health, Safety and Environment (HSE) system.

Document	Description	Implications for the Project
		Gas Import Jetty Works within the defined port boundary would need to comply with the PoHDA SEMP. Project safety and environment management plans for the Gas Import Jetty Works would need to be approved by PoHDA.
National Parks Act 1975 (National Parks Act)	The National Parks Act makes provisions for the preservation, protection and management of declared areas of the natural environment, including marine areas.	In Western Port, Yaringa, French Island and Churchill Island Marine National Parks are protected under the National Parks Act. These marine parks are not within the Project Area but are considered in the marine biodiversity impact assessment.
Crown Land (Reserves) Act 1978 (Crown Land (Reserves) Act)	The Crown Land (Reserves) Act provides for the reservation and management of Crown lands for certain purposes, including nature conservation reserves.	The Western Port Intertidal Coastal Reserve, near Corinella and Grantville, is reserved under the Crown Land (Reserves) Act. It is not within the Project Area but may be considered in the marine biodiversity impact assessment.
Policy / guidelines / standards		
State Environment Protection Policy (Waters) (SEPP (Waters)) (2018)	SEPPs are subordinate to the Environment Protection Act. SEPP (Waters) provides a framework for the protection and management of water resources in Victoria, covering surface waters, estuarine and marine waters and groundwater across the State. SEPP (Waters) aims to protect the beneficial uses of water resources, set water quality indicators and objectives, and establish rules and obligations to achieve these objectives.	Compliance with SEPP (Waters) is required under the Environment Protection Act. The SEPP (Waters) defines the requirements for the application for licenses for wastewater discharges to surface waters and the approval considerations for such applications. The SEPP (Waters) requires the Project to minimise the potential adverse impacts on beneficial uses by meeting the environmental quality objectives for biological indicators and pollutant target loads for Western Port, as far as reasonably practicable. The Gas Import Jetty Works requires a Works Approval from EPA Victoria under the Environment Protection Act. Once the works are constructed in accordance with the Works Approval to the satisfaction of EPA Victoria, the EPA would issue the proposed EPA Licence.
Western Port Ramsar Site Management Plan (2017)	The Western Port Ramsar Site Strategic Management Plan (Parks Victoria 2003) originally established the framework for the maintenance of this site's unique ecological character through conservation and wise use. Western Port Ramsar Site Management Plan (2017) revises the original document with the primary objective 'to maintain, and where necessary improve, the ecological character of the Western Port Ramsar	The Western Port Ramsar Site Strategic Management Plan sits within a framework for the management of aquatic ecosystems within Australia and the State of Victoria. At the national level, the EPBC Act establishes the basis for managing Ramsar sites. In Victoria the Victorian Waterway Management Strategy (VWMS; Department of Environment and Primary Industries 2013) guides the management of rivers, estuaries and wetlands, and the renewal of the Western Port Ramsar Site Management

Document	Description	Implications for the Project
	site and promote wise and sustainable use'.	Plan addresses Action no. 12.3 of the VWMS. No approval is required under this Plan, but it would be taken into account as part of the EPBC Approval.
Healthy Waterways Strategy (2018 to 2028) (Healthy Water Strategy)	The Healthy Waterways Strategy is a shared strategy across Melbourne Water, state and local government, water corporations and the community. The strategy provides direction towards a regional vision for the health of rivers, estuaries and wetlands in the Port Phillip and Westernport region.	The Westernport and Mornington Peninsula Region is one of five major catchments covered by the strategy. There are eight goals established for this region that are aimed at protecting key waterway values including environmental, social, cultural and economic values within the catchment. Regulatory authorities would have regard to this strategy in assessing the Project's impacts on waterways.
Protecting Victoria's Environment – Biodiversity 2037 (Biodiversity Plan)	The Biodiversity Plan is the Victorian Government's ambitious plan to stop the decline of our biodiversity and achieve overall biodiversity improvement over the next 20 years. The Biodiversity Plan establishes a long-term vision and goals. Specific targets have been developed to deliver on these goals.	The Biodiversity Plan presents a long-term vision for Victoria's biodiversity: • Victorians value nature • Victoria's natural environment is healthy The plan sets out state-wide targets and contributing targets to achieve these two goals. This includes stopping the overall decline of threatened species and improving the overall extent and condition of native habitats across the land, waterways, coasts and seas. Regulatory authorities would have regard to this Strategy in assessing the Project's impacts on biodiversity
Marine and Coastal Policy (March 2020) (Note this policy replaces the 'policy for decision making' parts of the Victorian Coastal Strategy (2014))	The Marine and Coastal Policy guides the planning, management and sustainable use of the marine and coastal environment in Victoria and informs consents issued under the Marine and Coastal Act.	The Project would need to align with the strategic directions and provisions of the Marine and Coastal Policy. The preparation of the Marina and Coastal Act consent applications for the Project would consider this policy.

4.0 Methodology

A risk-based approach was applied to documenting and understanding the existing environment, the potential impacts of the Project and how to avoid, minimise or manage the risk of impact.

The following sections outline the method for the marine biodiversity impact assessment.

4.1 Literature Review

Existing conditions in Western Port were established from review of relevant scientific reports, literature and Commonwealth, State and Federal government publications. These included:

- The Western Port Marine Environment (EPA,1996);
- Westernport Bay Environmental Study 1973 to 1974 (Ministry for Conservation, 1975);
- Western Port Ramsar Wetland Ecological Character Description (DSEWPaC, 2010);
- Understanding the Western Port Environment 2011: A summary of current knowledge and priorities for future research (Melbourne Water, 2011);
- Western Port Ramsar Site Management Plan (DELWP, 2017);
- Previous Project referral documentation (Jacobs, 2018);
- Understanding the Western Port Environment 2018: A summary of research findings from the Western Port Environment Research Program 2011-2017 and priorities for future research (Melbourne Water, 2018);
- Marine and Coastal Policy (DWELP, 2020)
- Department of Agriculture, Water and the Environment (DoAWE) and DELWP conservation or listing advices, action statements, recovery plans and threat abatement plans for nationally and state listed threatened species and communities; and
- Published scientific reports and articles (refer to References).

Other management, planning and guidance documents considered relevant to the assessment of marine biodiversity impacts include:

- Healthy Waterways Strategy (2018 to 2028);
- Protecting Victoria's Environment – Biodiversity 2037.

Together, these documents provide a comprehensive synthesis of the current knowledge of Western Port's marine biodiversity and ecology. This information was used to develop the scope of further site investigations and inform the description of the existing environment and assessment of potential for significant impacts from the proposed works.

4.1.1 Desktop Review for Threatened Species

A high-level, geographic information systems (GIS)-based desktop assessment was used to identify the potential occurrence of threatened marine flora, fauna, communities and marine habitats within the Study Area. Database searches were centred on Crib Point, with a buffer of 100 kilometre (km) radius on the construction footprint of the Gas Import Jetty Works. Databases accessed as part of this assessment included:

- An 'EPBC Act Protected Matters' search was undertaken using the Commonwealth Department of Agriculture, Water and the Environment's (DoAWE) online Protected Matters Search Tool (PMST) to determine the likely presence of any Matters of National Environmental Significance (MNES) within or in close proximity to the site;
- NatureKit, including Victorian Biodiversity Atlas (VBA) records, was interrogated to generate a list of species protected under the EPBC Act, FFG Act, and the current Victorian Department of Environment, Land, Water and Planning (DELWP) Advisory Lists for flora;
- Atlas of Living Australia (2017), CSIRO and NCRIS. https://www.ala.org.au/ accessed September 2017;
- Australian Wetlands Database (2017) Ramsar Wetlands: Western Port. http://www.environment.gov.au/cgi-bin/wetlands/ramsardetails.pl?refcode=19 accessed September 2017; and
- SeaMaps Australia (2019).

4.1.2 Conceptual Model and Processes

Western Port is a diverse but compact marine environment. It comprises large intertidal mudflats with saltmarsh, seagrass and mangrove habitats, steep subtidal sloping banks with seagrass and deep channels that connect the north of the bay with the oceanic waters of Bass Strait. The ecosystem components associated with the habitats are closely connected by spatial proximity and the strong tidal currents that transport water back and forth through the channels and over and off the intertidal flats.

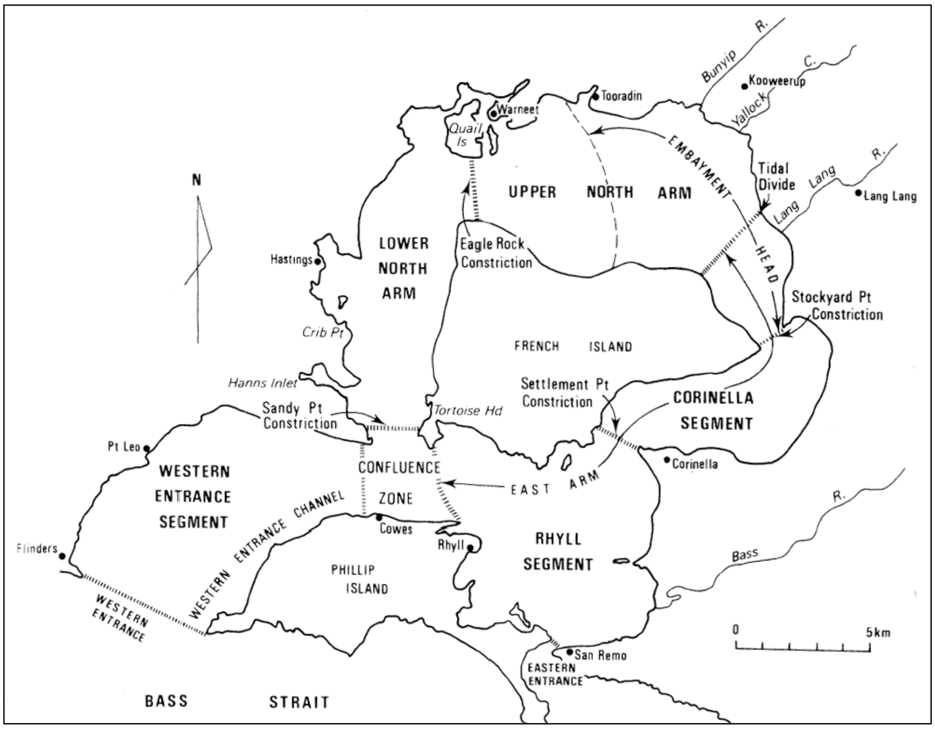


Figure 4-1. General marine geographic segments of Western Port
(Source: Marsden 1979, Harris et al 1979)

Western Port was divided into marine geographic segments on the basis of multidisciplinary studies in the 1970s (Figure 4-1). These segments were based on topographic features and hydrodynamic and sediment transport processes. The names and basis of naming of these segments remains appropriate to environmental descriptions, processes and concepts that were developed or discussed over the decades to the present.

A conceptual model of ecological pathways (refer to Figure 4-2) in Lower North Arm of Western Port was used to inform identification and assessment of key potential impact pathways for this Project. In Figure 4-2, the green shape depicts the seagrass and shallow water ecosystem. The blue ellipse depicts the plankton and pelagic ecosystem. The red ellipse depicts the demersal and benthic ecosystem.

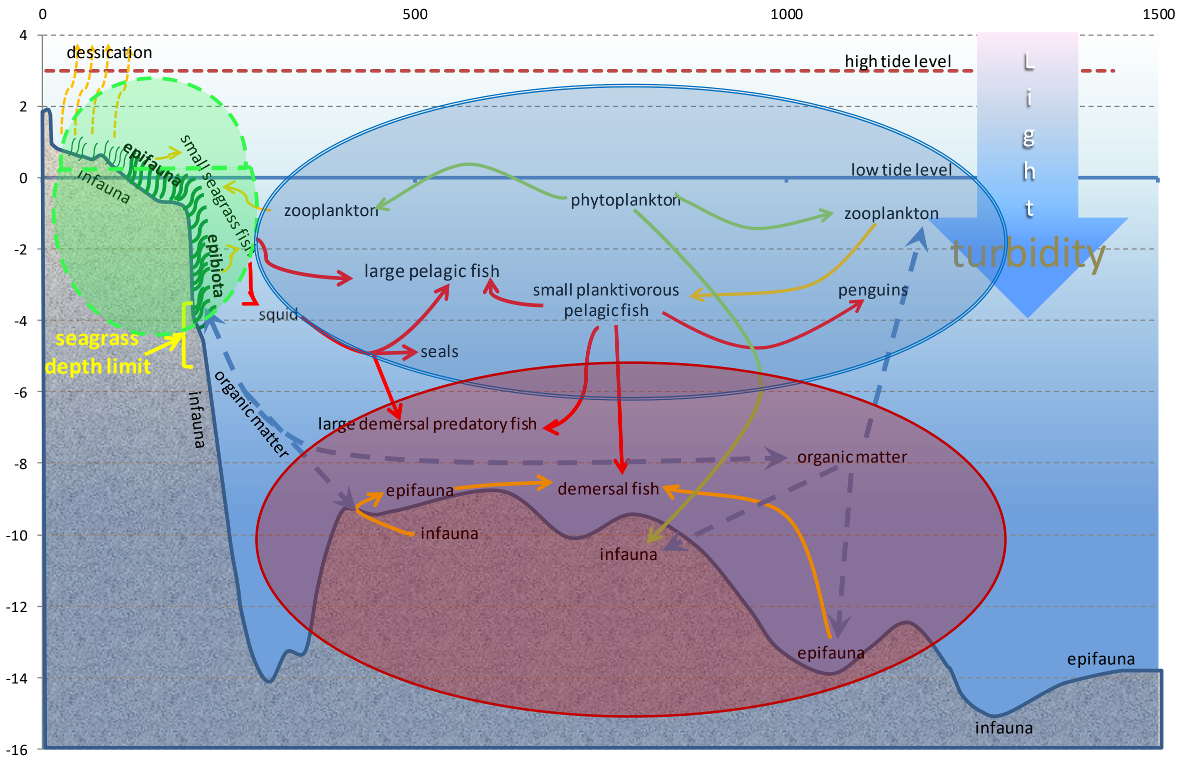


Figure 4-2. Conceptual Ecological Pathways in Lower North Arm, Western Port

This is a simplified model to clarify the key components and processes. It is recognised that the interactions between physical, chemical and ecological processes within and between the Western Port segments and into Bass Strait are complex. The food web within intertidal and subtidal seagrass areas near Crib Point is provided as an example (Figure 4-3).

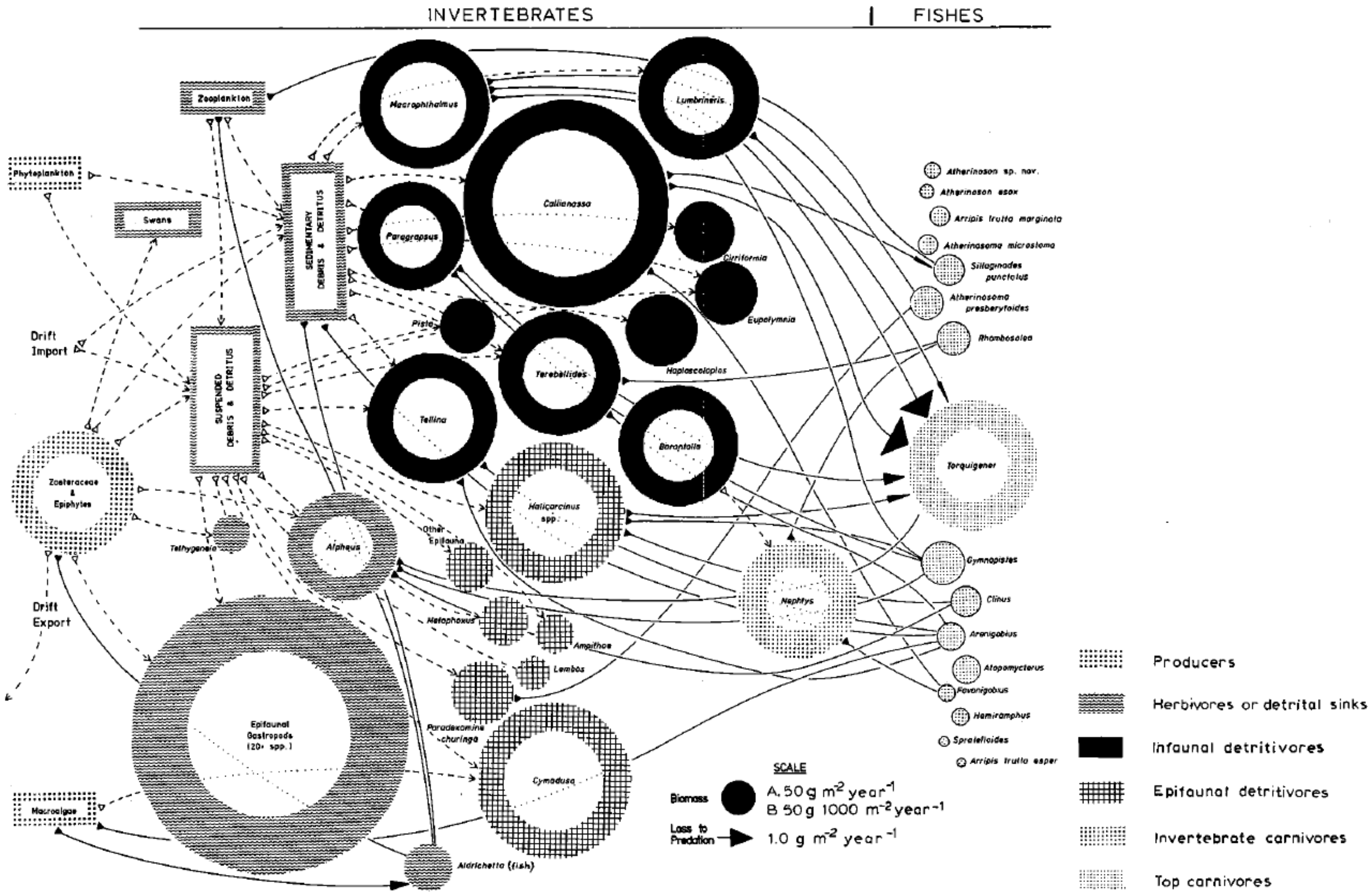


Fig. 3. Simplified food web of the eelgrass ecosystem. Where possible quantitative representations have been used. Mean annual biomass is shown by the area of the circles (two scales have been used; except for Zosteraceae and epiphytes, g 1000 m^{-2} is used, for seagrasses, g m^{-2} is used). Solid lines indicate a measured loss to predation with the maximum width of the arrow showing amount in g m^{-2} year^{-1}. Where losses were between 0.1 and 0.01 g m^{-2} year^{-1} no arrow is shown. Losses of less than 0.01 g m^{-2} year^{-1} have not been shown. Where quantitative values are lacking, paths of energy transfer are shown by dashed lines and components of the system are shown in rectangular boxes.

Figure 4-3. Example of food web in seagrasses near Crib Point Source: Watson, 1984

CEE's understanding of the processes and consequences as illustrated in Figure 4-1 and Figure 4-2 provide the conceptual basis for many of the models and processes that are further developed and described in this report.

Previous hydrodynamic studies have shown that the waters of Bass Strait exchange with the various arms and segments of Western Port at different rates according to the distance from Bass Strait at the Western Entrance (Figure 4-1). The shortest flushing times are in the Western Entrance Segment and the longest flushing times are closest to the tidal divide that separates the division between Upper North Arm and Upper East Arm Segments. Freshwater inputs to Western Port are small and intermittent. They have negligible effect on water column structure. Hence, Western Port is considered to be a tidal embayment rather than an estuary.

Environmental factors are substantially different between the northern parts of Western Port and Bass Strait. The most notable are the higher concentrations of suspended solids, shallower water and the wider temperature range in the north of Western Port compared to the Bass Strait.

A gradient in these and other physico-chemical characteristics is expected to reflect the variation in flushing rate along and between the major arms and segments. Changes in ecological characteristics, including planktonic communities, occur in response to the variation in ambient physico-chemical characteristics. Studies of zooplankton in Port Phillip and East Arm of Western Port in the 1980s showed differences between the zooplankton community of Port Phillip and East Arm of Western Port, as well as changes along the major axis from Corinella to Cowes in East Arm (Kimmerer and McKinnon; Kimmerer and McKinnon 1985, 1987i).

These findings and information contributed to the design of investigations, interpretation of information and assessment of potential Project effects that are presented in this report.

In addition to the existing physico-chemical, biological and ecological processes, a wide range of human activities have affected and will continue to affect environmental conditions in the Western Port marine environment. These include a range of every-day port and shipping activities, recreational and industrial activities, human activities on land along the Western Port coastline and catchment, and the pressures of human population over a much wider area.

4.2 Site Investigations and Field Studies

Based on the review of information available, the conceptual model and the key impact pathways, four studies were undertaken to increase understanding of existing conditions within the Study Area and inform the development, calibration and verification of the hydrodynamic modelling used as the basis of the impact assessment. These studies are summarised below.

4.2.1 Currents Near Crib Point

Current data was required to assess current speeds and direction through Lower North Arm and specifically at Crib Point and to check the hydrodynamic modelling. Royal HaskoningDHV was engaged to provide instruments to monitor currents over a 30-day period at three locations across Lower North Arm offshore from Crib Point (Figure 4-4). Currents were measured using Acoustic Doppler Current Profilers (ADCP). ADCP #1 was placed adjacent to Crib Point Jetty Berth 2 (proposed FSRU location), ADCP #2 was placed to the east of the main shipping channel, and ADCP #3 was placed in the centre of the channel between Middle Bank and French Island. Site coordinates are listed in Table 4-1.

Following the directions from the Port of Hastings Harbour Master, the instruments were sited outside operational areas of the Port. Current monitoring program results are provided in a detailed report by Royal HaskoningDHV (*Royal HaskoningDHV, 2019. Current Monitoring Crib Point: ADCP Deployment and Data Analysis, Royal HaskoningDHV)*. A summary of the results for hydrodynamic monitoring purposes can be found in Section 5.

These three monitoring sites were chosen to acquire measurements of tidal currents at and around the site where the FSRU would be berthed and over the cross-section of Lower North Arm extending east from Crib Point.

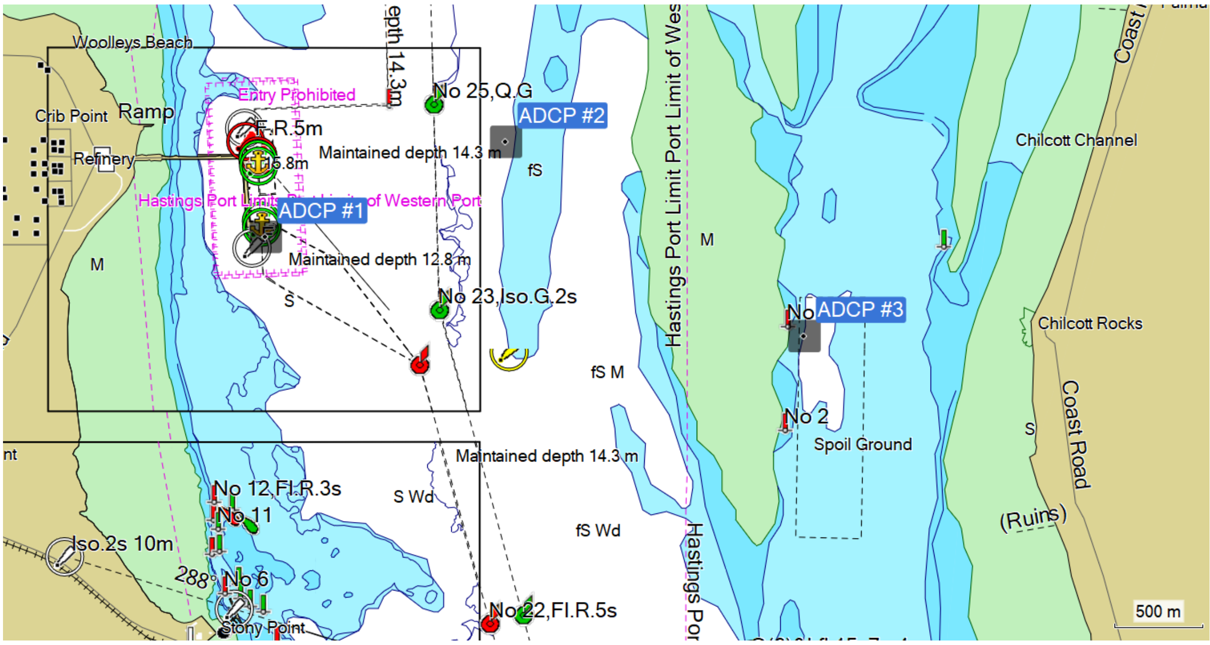


Figure 4-4. Current Meter Location Map

The ADCP instruments were deployed from 19 March 2019 to 17 April 2019 (a 28-day neap-spring tidal cycle). The ADCPs measured current speed and direction every 10 minutes at 1 metre (m) intervals through the water column (from the seabed to the surface). The data presented in Section 5 describe currents at 2 m from the seabed, 5 m from the seabed and 9 m from the seabed representing the bottom, mid-depth and surface currents.

Table 4-1. Current Meter Site Coordinates

Current Meter	Position (WGS84)
ADCP #1	55 H 345038 5753511
ADCP #2	55 H 346323 5754068
ADCP #3	55 H 347951 5753009

4.2.2 Water Quality

An EPA Victoria monthly monitoring program has measured water quality at three sites in Western Port: Hastings and Barralier Island in North Arm (north-west corner of French Island) and Corinella in East Arm. These data are published along with a 'Water Quality Index' on the Yarra and Bay website (*yarraandbay.vic.gov.au*) and on-request from EPA directly.

Seawater temperature at Crib Point

Although monthly data on temperature are available for several sites in the Bay, a continuous record was required to assess the potential impacts of the cooler and warmer discharges on water quality and biodiversity. Thus, a temperature logger was installed near the seabed adjacent to Crib Point Jetty Berth 2. The temperature logger was in place from January 2019 to January 2020 and recorded seawater temperature at 15-minute intervals throughout this period. The instrument was retrieved, downloaded and serviced monthly throughout the deployment. Apart from one or two missing records each month (while the instrument was serviced) a full 12 months record of seawater temperature at 15-minute intervals was obtained. A vertical profile of temperature was also measured using a hydro profiler. The results showed no stratification of temperature with depth.

Temperature data is provided in a detailed report by CEE (*CEE, 2019d).* The results of the seawater temperature study are discussed in Section 5.

4.2.3 Plankton Monitoring Program

Plankton in Western Port includes phytoplankton, zooplankton and ichthyoplankton. Existing information on the Western Port environment shows that the planktonic community of Lower North Arm channel including Crib Point has not been described recently, if at all (Melbourne Water 2009, Shapiro 1974).

Purpose of plankton monitoring program

Planktonic biota are considered to be the marine ecological component most susceptible to entrainment in the seawater used for regasification. It was recognised at the referral-stage of the Project that documentation of the present composition, seasonality and horizontal spatial distribution of the characteristics of the plankton community would be required to inform the assessment process. The information would inform:

- baseline data collection;
- the design of subsequent targeted investigations;
- the interpretation of hydrodynamic modelling predictions of discharge and entrainment effects;
- potential seasonal sensitivities to operation of the FSRU;
- impact assessment programs; and
- operational-stage monitoring.

A fit-for-purpose plankton sampling program was developed to allow a data-supported description of plankton community composition and seasonal variation in plankton community components, assessment of longitudinal and lateral distributional patterns in the Lower North Arm and integration of ecological characteristics and hydrodynamic modelling outputs to assess potential impacts. The plankton monitoring methodology is explained in detail in the supporting technical documents for plankton (CEE 2019a, CEE 2019b, CEE 2019f). A summary of the monitoring program is explained below.

Rationale and limitations of the plankton monitoring program

The sample site distribution and sampling methods were informed by:

- concepts described in Section 4.1.2;
- understanding of plankton marine community monitoring and studies in Victoria and elsewhere in Western Port (Kimmerer and McKinnon 1985, 1987i, Melbourne Water 2011);
- initial modelling of potential characteristics and extent of physical effects from operation of the FSRU, as described in the Project referral documents (CEE 2018f); and
- discussions with experts at University of Melbourne, University of Tasmania and independent organisations.

The predominant effort of the monitoring program was to sample all major planktonic community components, relatively frequently (fortnightly) over January 2019 to January 2020 at sites dispersed over Lower North Arm, focusing on Crib Point. This informed the design of more detailed investigations, monitoring and associated statistically-based analysis following risk-based assessment of the EES ecological investigations.

The following sampling constraints and limitations were recognised as inherent to the design of a plankton monitoring program in Western Port:

- Daylight sampling;
- Sampling during safe conditions;
- Sampling procedures and equipment;
- Taxonomic discrimination; and
- Sampling under different tidal conditions.

The first four constraints are common to all surveys, hence data quality and usability between surveys were comparable with each other in these respects. The last constraint in the list above was unavoidable due to the combined requirement to sample during daylight hours, safe working conditions and a monthly and fortnightly schedule. The sequence of sites sampled (north to south or south to north) were adjusted during each survey to reduce flood/ebb biases on data, as explained below.

Sampling frequency

The plankton study characterised the diversity, abundance and variability of plankton in Western Port. The study began in December 2018 and was completed in December 2019.

The plankton monitoring program comprised two components:

- Monthly sampling of plankton (phytoplankton, zooplankton and ichthyoplankton) at eight sites distributed across Lower North Arm and the confluence zone, together with concurrent measurement of water quality (temperature, salinity and dissolved oxygen profiles and chlorophyll-a measurements).
- Fortnightly sampling of plankton (phytoplankton, zooplankton and ichthyoplankton and other meroplankton) at Crib Point Berth 2 (proposed FSRU location) together with concurrent measurement of water quality (temperature, salinity and dissolved oxygen profiles).

Monthly sampling sites

The locations of the monthly plankton sampling sites are shown in Figure 4-5. The sites were distributed along a north-south axis from the confluence zone to near Upper North Arm and a west-east axis between the 10 m depth contours west and east of Crib Point Jetty.

The north-south axis sites were designed to document plankton community characteristics along the tidal gradient or potential ecotone from near the intertidal and shallow subtidal seagrass beds in Upper North Arm, to sites near the wave and current-exposed deep channels in the confluence zone. Sites along the north-south axis were N2, N1, C1, S1 and S2.

Site S2 in the confluence zone was added in August 2019 to assess plankton where distinctly more oceanic conditions prevail. Site N1 is near a long-term water quality monitoring site used by EPA Victoria (Hastings) while site C1 is in the middle of the channel directly east of Crib Point Jetty Berth 2.

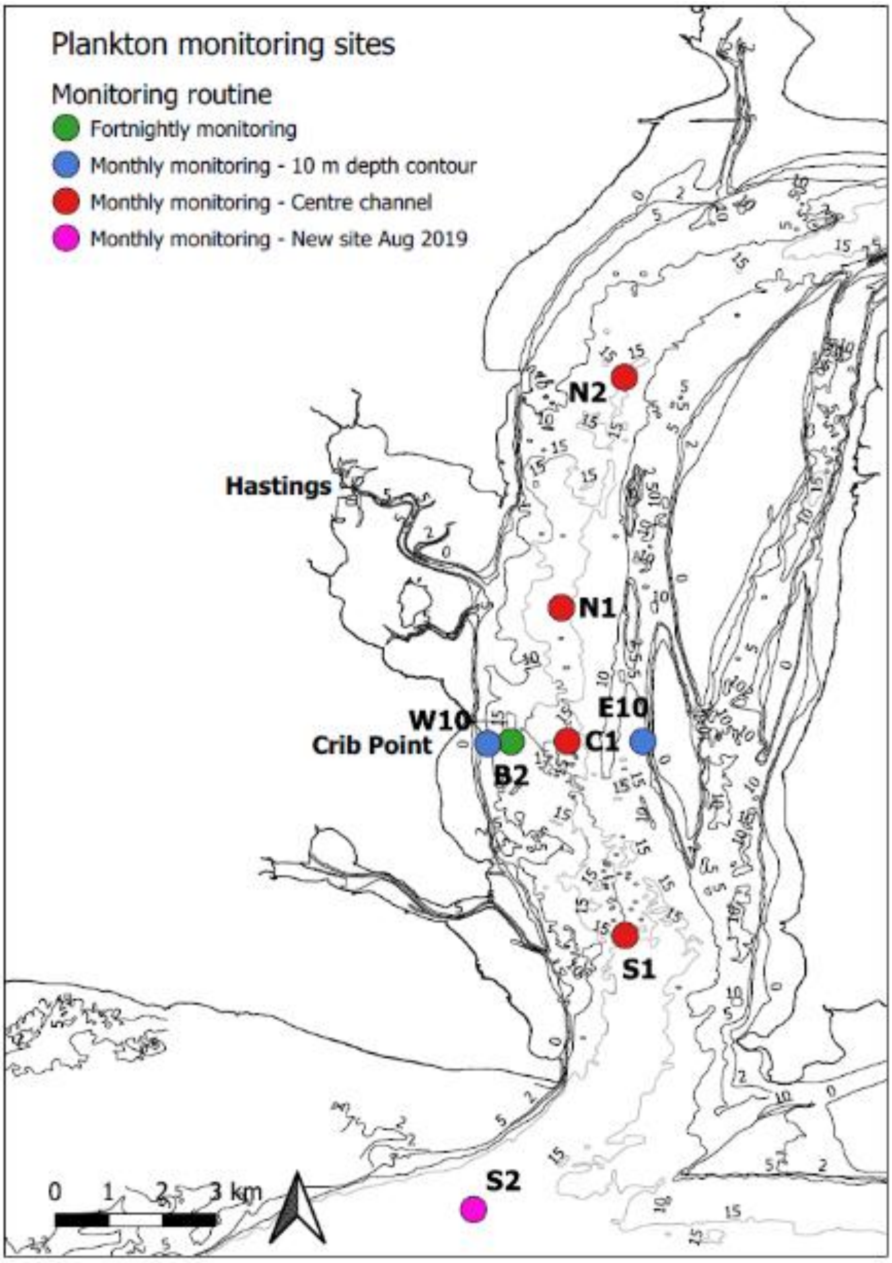


Figure 4-5. Plankton sampling sites used in regular monitoring

Sites on the east-west axis were designed to document plankton community characteristics at positions over different benthic habitats across the main North Arm channel at Crib Point. Sites located at the 10 m seabed depth contour east (E10) and west (W10) of Crib Point are each around 100 m from shallow subtidal and intertidal seagrass beds. The Crib Point Berth 2 site (B2) is the proposed FSRU location where entrainment would occur and is adjacent to the hard substrate habitat provided by the jetty piles. C1 is located over soft seabed, mid-channel habitat.

Selection of the 10 m depth contour for the east and west sites also considered the extent of discharge plumes from the FSRU. Initial hydrodynamic modelling during preparation of the EES referral showed that the cooler seawater from FSRU discharge would be highly diluted before reaching shoreward depths less than 10 m.

Plankton at all eight monitoring sites were sampled monthly between December 2018 and December 2019 inclusive (13 monthly surveys). Each monthly survey was separated by a minimum of three and a maximum of five weeks. As shown in Table 4-2, plankton at the Crib Point Jetty Berth 2 site (B2) were sampled also every other fortnight (total of 26 surveys including pilot survey at this site).

Waters in Lower North Arm move 6 km on average with each ebb and flood tide. The north-south monitoring transect spans 16 km, or 2.7 times the tidal excursion. A single plankton survey takes around 6 hours, about the same time as an ebb or flood tide. The state of the tide was considered during monthly surveys to maximise the effective spatial coverage of the survey where possible.

Broad-scale sampling event

A broad-scale study to characterise the phytoplankton and zooplankton community from the north of Lower North Arm into East Arm as far as Corinella (and into the Western Entrance) was planned for October 2019. Sites sampled in the broad-scale study are shown in Figure 4-6. Sites P1 to P5 are in the same locations as those used by Kimmerer and McKinnon (1985) for which there is existing data on zooplankton communities. Sites S2 to N2 were the same sites as those used in the CEE monthly sampling.

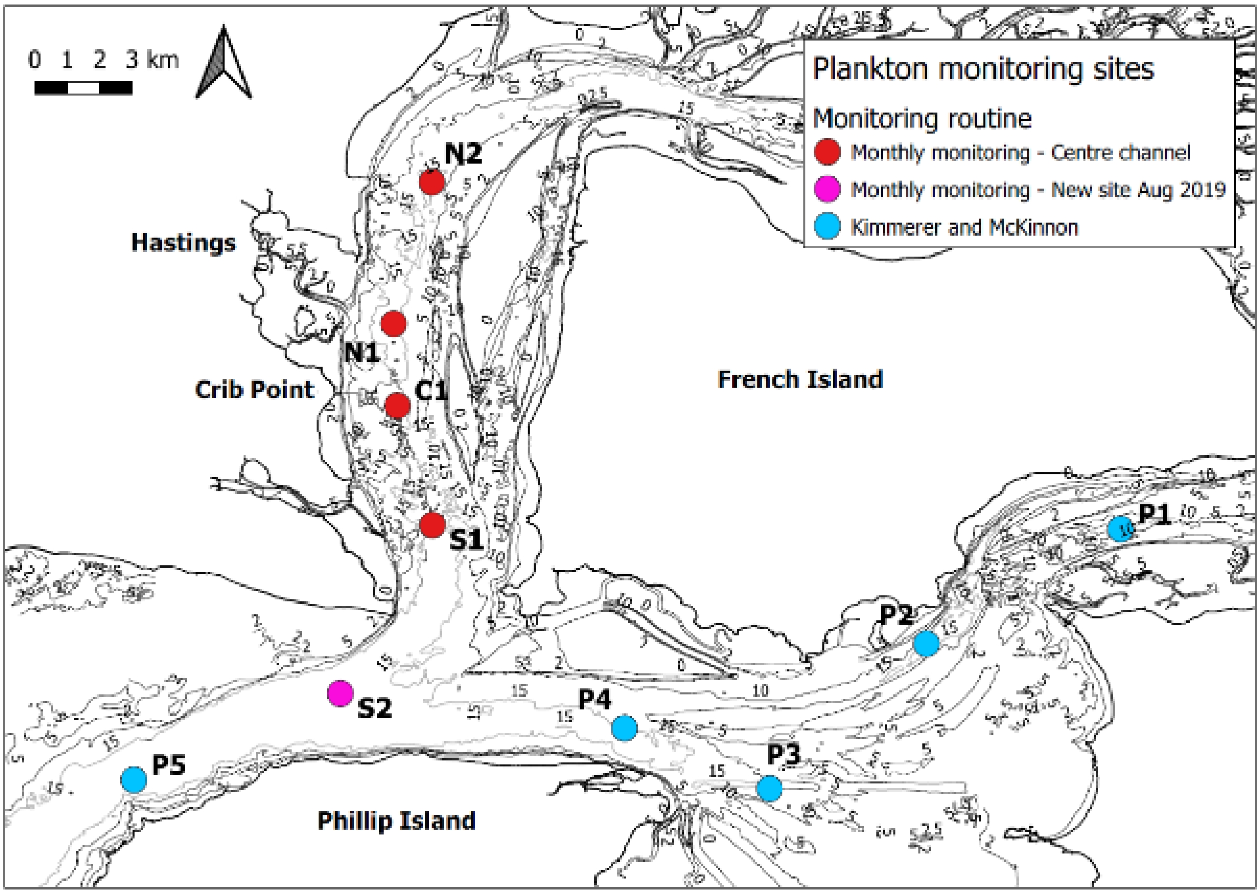


Figure 4-6. Broad-scale plankton study sites including 5 locations from Kimmerer and McKinnon (1987i)

Sampling methods and procedures

The sampling design included consideration of the likely configuration of the seawater intake to the FSRU. It was likely that the combination of the environmentally preferred, practically feasible options for the position of seawater intakes as well as operational and tidal level variables would result in intake of seawater from about 2 m above the seabed to 2 m below the water surface in a water column varying in depth from approximately 13 m at low tide to 16 m at high tide. Hence, depth integrated sampling from approximately surface to 2 m above the seabed was planned for the two plankton monitoring program components.

The order in which sites were sampled depended on the direction of tidal flow during the survey. For example, when sampling during a flood (incoming) tide, the survey commenced at the northern most site (N2) to sample water that had recently been further south. This meant that it was around high tide when the southern-most site (S2) was sampled, and waters there had recently been closer to Bass Strait. When sampling during an ebb tide, the reverse strategy was used: sampling commenced at S2 and finished at N2.

Table 4-2. Plankton Sampling Summary, December 2018 to December 2019.

Date	Survey	S2	S1	B2	W10	E10	C1	N1	N2*
06/12/2018	**Pilot			✓	✓				
11/12/2018	Monthly Survey 1		✓	✓	✓	✓	✓	✓	✓
28/12/2018	Fortnightly Survey 1			✓					
10/01/2019	Monthly Survey 2		✓	✓	✓	✓	✓	✓	✓
22/01/2019	Fortnightly Survey 2			✓					
04/02/2019	Monthly Survey 3		✓	✓	✓	✓	✓		
11/02/2019	Monthly Survey 3							✓	✓
11/02/2019	Fortnightly Survey 3			✓					
07/03/2019	Monthly Survey 4		✓	✓	✓	✓	✓	✓	✓
20/03/2019	Fortnightly Survey 4			✓					
04/04/2019	Monthly Survey 5		✓	✓	✓	✓	✓	✓	✓
18/04/2019	Fortnightly Survey 5			✓					
03/05/2019	Monthly Survey 6		✓	✓	✓	✓	✓	✓	✓
15/05/2019	Fortnightly Survey 6			✓					
07/06/2019	Monthly Survey 7		✓	✓	✓	✓	✓	✓	✓
21/06/2019	Fortnightly Survey 7			✓					
03/07/2019	Monthly Survey 8		✓	✓	✓	✓	✓	✓	✓
18/07/2019	Fortnightly Survey 8			✓					
02/08/2019	Monthly Survey 9	✓	✓	✓	✓	✓	✓		✓

Date	Survey	S2	S1	B2	W10	E10	C1	N1	N2*
13/08/2019	Fortnightly Survey 9			✓					
03/09/2019	Monthly Survey 10	✓	✓	✓	✓	✓	✓	✓	✓
18/09/2019	Fortnightly Survey 10			✓					
1/10/2019	Monthly Survey 11	✓	✓	✓	✓	✓	✓	✓	✓
16/10/2019	Fortnightly Survey 11			✓					
30/10/2019	Monthly Survey 12	✓	✓	✓	✓	✓	✓	✓	✓
20/11/2019	Fortnightly Survey 12			✓					
11/12/2019	Monthly Survey 13	✓	✓	✓	✓	✓	✓	✓	✓
Total number of surveys		**5**	**13**	**25**	**13**	**13**	**13**	**12**	**13**

**Site N2 results based on the average of two nearby locations. This report uses the average for the two sites as data for site N2 prior to March 2019, data for site N2 from April onwards are from the intermediate location*.

*** The pilot survey is included in the above table, however is not counted in the total number of surveys for each site.*

Sampling preparation and procedures

Standard operating procedures (SOPs) and pro-forma field sheets were prepared for sampling surveys and followed for all survey events. SOPs and pro-formas were updated according to lessons learned during previous surveys.

Phytoplankton method

Phytoplankton sampling methods were appropriate for the Western Port environment and provision of data for the purposes of the EES program. The methods used were consistent with those used throughout Victorian marine waters in the Victorian Marine Biotoxin Management Plan (Victorian Fisheries Authority, 2019).

A depth-integrated water sample was collected for phytoplankton identification and counts and chlorophyll-a analysis at each sampling site in each survey. Samples were collected using a 15 m long, 19 mm diameter clear polyvinyl chloride (PVC) hose with valves on both ends and a 1.5 kilogram (kg) weight on one end. The hose was lowered to within 2 m of the seabed of a maximum of 15 m at each site. The contents were emptied into a clean rinsed bucket and mixed to fill two, one litre, HDPE, labelled bottles. Phytoplankton sample bottles were immediately preserved with Lugol's potassium iodide solution at a concentration of approximately 0.5 % volume per volume (v/v). Samples for chlorophyll-a analysis were kept cool and in the dark prior to delivery to the laboratory within 24 hours of collection.

Phytoplankton from each site were identified and enumerated by a National Association of Testing Authorities (NATA) accredited specialist marine phytoplankton laboratory (Microalgal Services). Phytoplankton were concentrated using a centrifuge, and the concentrated samples were placed in counting chambers and examined using microscopy. 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.

Chlorophyll-a in waters samples was analysed by the Water Studies Centre at Monash University. The chlorophyll-a method involves filtering the 1L sample, mechanical rupturing of cells, extraction of the chlorophyll (and other photosynthetic pigments) using acetone and analysis of the extract by spectrophotometry. The method is accurate over the range 0.2 to 100 µg/L chlorophyll-a.

Survey results were reported to CEE individually as the sampling program progressed. Data were re-compiled by CEE and added to the project database for further analysis and presentation.

Phytoplankton samples were sorted and identified by specialists at Microalgal Services, who also provided a report on the general characteristics of the phytoplankton communities based on the phytoplankton sampling program. Drs Brett, Hill and Smith-Harding's report informed CEE's discussions of phytoplankton communities in Sections 5 and 7 and is attached to CEE's phytoplankton Technical Report (CEE, 2019a).

Zooplankton method

The zooplankton sampling equipment and collection method followed the procedure used in Western Port from 1982 to 1984 (Kimmerer and McKinnon 1987i), so that results could be compared directly with the 1982 to 1984 sampling program. All samples were collected using a 3 m long and 0.5 m diameter conical net made with 210 micrometre (µm) mesh. A 90 mm diameter by 150 mm long cod-end and a 1.5 kg lead weight were fitted to the bottom of the net (Figure 4-7).

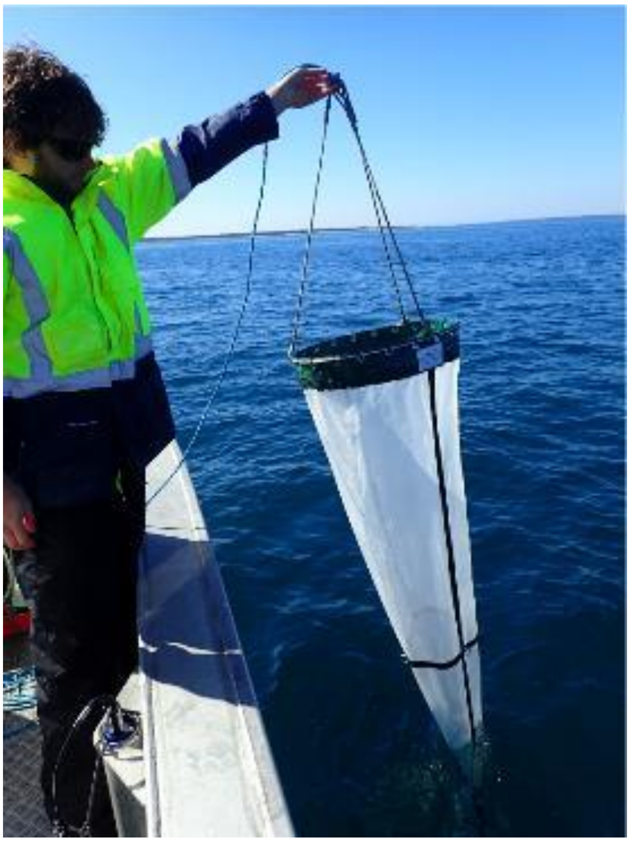


Figure 4-7. Zooplankton Net

Single samples were collected at each site by lowering the net to the seabed and retrieving the net vertically up through the water column at around 1 m/s. The survey vessel was manoeuvred according to current and wind to achieve a vertical tow. The length of the tow warp was recorded so that the volume of the sample could be calculated and the results of the analysis standardised to cubic metre. Zooplankton were sampled at the same sites as phytoplankton (sites are shown in Figure 4-6). Samples were concentrated to less than 400 mL and fixed in 2% v/v buffered formalin. The second sample collected at Crib Point Berth 2 was stained with vital stain (neutral red) for 10 minutes (following the methods of Elliott and Tang 2009) prior to fixing in formalin. The vital stain was used to differentiate live and dead zooplankton during laboratory analysis.

Zooplankton samples were sorted to the lowest practical taxonomic level and counted at the Institute of Marine and Antarctic Science, University of Tasmania. Abundances were reported to CEE as count per cubic metre. Data were re-compiled by CEE and added to the Project database for further analysis and presentation.

The zooplankton methods are discussed in detail in the zooplankton technical report (CEE, 2019b). The results of the plankton studies are presented and discussed in Section 5.

Ichthyoplankton method

Ichthyoplankton (fish larvae) were sampled using a conical, 500 µm mesh, net attached to a rigid metal ring fitted with a weight depressor at the bottom of the ring (Figure 4-8). The tow warp was attached to a bridle attached to the top of the ring to reduce interference of larvae being captured in the mouth of the net. All ichthyoplankton samples were collected using a stepped double oblique tow from near the surface (~2 m) to near the seabed and back to the surface. Initial trials using an inclinometer on the towing warp and logging depth gauge on the net optimised the towing configuration. The net was towed into the tidal current at an in-water speed of approximately 1 m/s. This gave each tow a parabolic depth profile and lasted 10 to 15 minutes.

Figure 4-8. Fish Larvae Sampling Net

A General Oceanics mechanical flow meter with a low velocity impeller was fixed across the mouth of the net to measure the flow of water passing through the net. This allowed the total volume of water passing through the net to be calculated for each tow and the number of biota collected to be standardised to number per 1,000 m^3 of seawater. Samples in the recovered net were further sieved to a volume of less than 2 litres and preserved in 5 % v/v buffered formalin.

Preserved labelled ichthyoplankton samples were coarse-sorted into fish larvae, Syngnathids and post-larvae, fish eggs and cephalopods by CEE. The sorted samples were sent to ichthyoplankton and cephalopod taxonomy specialists at the Australian Museum (Sydney) for identification to the lowest practical taxonomic level and counting. Samples were archived at the Australian Museum in a reference collection.

The ichthyoplankton methods are discussed in detail in the ichthyoplankton technical report (CEE, 2019f). The results of the plankton studies are presented and discussed in Section 5.

4.3 Seabed and Habitat Surveys in North Arm of Western Port

The seabed of Lower North Arm in Western Port comprises predominantly soft sediments (Coleman *et al* 1978, Harris et al 1979, Marsden *et al* 1979). Rock outcrops are small and only known at the Eagle Rock constriction (Figure 4-1) between Lower and Upper North Arm (Shepherd et al 2009). The only hard substrate for attachment of macroalgae and sessile

invertebrates are the artificial surfaces of the jetties (Bok *et al* 2017) and shell material and rubble scattered sparsely or patchily over the seabed.

The characteristics of the seabed habitat and associated biota in the vicinity of Crib Point Jetty where the cooler seawater discharge containing some residual chlorine may be most likely to affect benthic biota was investigated for the EES. The investigations included:

1. Documentation of the seabed and associated epibiota using towed underwater video
2. Sampling of infauna using a ponar grab
3. Sampling of sediments for the presence of threatened ghost shrimp species using diver operated water lift sampler

The methods and results of these investigations are presented in CEE Technical Report *"Marine Benthic Habitats, Epibiota and Infauna in North Arm, Western Port, Melbourne 2019"* and CEE Technical Report "*Threatened ghost shrimp survey, North Arm, Western Port, December 2019*".

The outcomes of these reports are summarised in Section 5.

4.4 Hydrodynamic Modelling

A key part of the assessment involved the application of near-field and regional hydrodynamic models to predict the path and dispersion of the discharge plumes from the FSRU.

The near-field model predicts the path and dilution of plumes within 80 m of the discharge points. The regional model predicts the subsequent travel and mixing of the plumes over a 28-day period, for a range of discharge scenarios. The 28-day period was sufficient to include two spring and two neap tidal cycles, and for the long-term distribution of chlorine oxidation products and temperature to be predicted on a fine grid (CEE, 2018).

HydroNumerics was commissioned to prepare a 3D model of Western Port to:

- Assess the extent of the plume of cooler seawater on the sea floor;
- Assess the distribution of residual chlorine in the discharged seawater; and
- Assess the extent of entrainment of larvae released from various points in Western Port into the FSRU.

An existing Aquatic Ecosystem Model 3D (AEM3D) model of Western Port that was previously developed for Melbourne Water and EPA Victoria was applied in the Project (Hydrodynamics 2019). The details of the hydrodynamic model, and the results of the near-field and regional hydrodynamic modelling are presented in Section 6.0 – Hydrodynamic Modelling.

4.5 Risk Assessment Method

The EES scoping requirements for the Project require a risk-based approach for assessment of the potential impacts. A risk assessment was carried out using an approach that is consistent with the AS/NZS ISO 31000:2018 *Risk Management Process* and EPA Victoria Publication 1287 - Guidelines for Risk Assessment of Wastewater Discharge to Waterways (EPA 2009).

The risk assessment process provides a method for:

- facilitating a consistent approach to risk assessment across the various specialist studies in the EES

- identifying key Project risks to inform where detailed investigations are required
- ensuring the level of investigation is proportionate to the relative environmental risk
- assessing the effectiveness of proposed mitigation measures and whether additional measures may be required.

Risk can be defined as a combination of:

- the magnitude of potential consequences of an event
- the likelihood of the event occurring.

The risk assessment process involved the assignment of consequence and likelihood ratings which were combined to give an overall risk level for each identified impact.

The initial findings of the impact assessment were used to identify and describe cause-and-effect pathways for the Project to determine links between Project activities and their subsequent environmental consequences (known as risk pathways). These risk pathways were identified considering the assets, values and uses requiring protection identified during the existing conditions assessment (refer to Section 5).

4.5.1 Assigning Consequence of Risks

In this risk assessment, the consequences of a risk occurring were assigned using a consequence guide. Specific consequence categories were developed considering existing benthic and plankton conditions in the study area. The consequence rating criteria used in the risk assessment specifically for risks relating to benthic habitats and communities is shown in Table 4-3 and the consequence rating criteria used in the risk assessment specifically for risks relating to entrainment is shown in Table 4-4.

Consequence ratings – benthic habitats

The consequence ratings for benthic habitats were developed taking into consideration:

The consequence ratings for benthic habitats were developed taking into consideration:

- the area of channel in North Arm at low tide is about 6,900 hectares (ha)
- the area of the Port of Hastings that is dredged to maintain the access channels and turning basin for the Crib Point Jetty berths is about 90 ha
- the area that would be occupied by the FSRU and LNG carrier is about 3 ha.

The areas of impact with negligible and minor consequences are entirely contained within the dredged port area. The areas of impact with major or severe consequences may impact on intertidal or other sensitive areas.

Table 4-3. Benthic Habitats Consequence Rating Criteria

Level	Qualitative description
Negligible	Impacts not detectable against natural variability or detectable impacts within 9 ha zone around FSRU. Recovery within 1 year.
Minor	Detectable impact over up to 45 ha around FSRU.
Moderate	Detectable impact over up to 250 ha around FSRU.
Major	Detectable impact over more than 250 ha around FSRU.
Severe	Detectable impact over North Arm.

Discussion of Consequence ratings - entrainment

The process of developing consequence ratings for entrainment is described in Section 4.5.4. The consequence ratings for entrainment were developed taking into consideration:

- natural mortality and flushing rates
- that the effects of entrainment can be:
  - to reduce primary productivity in North Arm
  - reduce plankton and fish larvae

As shown in Table 4-4, a more stringent consequence was defined for the fish breeding months in spring and summer with a less stringent consequence for months outside the principal fish breeding season.

Table 4-4. Plankton and Larvae Entrainment Consequence Rating Criteria

Level	Qualitative description
Negligible	Impacts not detectable against natural variability
Minor	Change in population up to 0.2 per cent (Spring/Summer) Change in population up to 0.3 per cent (Autumn/Winter)
Moderate	Change in population of 0.2 to 0.4 per cent (Spring/Summer) Change in population of 0.3 to 0.6 per cent (Autumn/Winter)
Major	Change in population of 0.4 to 1 per cent (Spring/Summer). Change in population of 0.6 to 1 per cent (Autumn/Winter)
Severe	Change in population of more than 1 per cent.

4.5.2 Assigning Likelihood of Risks

A likelihood rating for each identified risk pathway were assigned using the guide in Table 4-5. The likelihood criteria in the risk assessment range across a scale from 'almost certain' where 'the event is expected to occur in most circumstances or is planned to occur' to 'rare' where 'the event may occur only in exceptional circumstances.'

Table 4-5. Likelihood Guide

Level	Description
Rare	The event may occur only in exceptional circumstances
Unlikely	The event could occur but is not expected
Possible	The event could occur
Likely	The event will probably occur in most circumstances
Almost certain	The event is expected to occur in most circumstances or is planned to occur

4.5.3 Risk Assessment Matrix and Risk Rating

The consequence and likelihood were combined to arrive at a risk rating, using the matrix shown in Table 4-6.

Table 4-6. Risk Assessment Matrix

		Consequence ratings				
		Negligible	Minor	Moderate	Major	Severe
Likelihood rating	Rare	Very low	Very low	Low	Medium	Medium
	Unlikely	Very low	Low	Low	Medium	High
	Possible	Low	Low	Medium	High	High
	Likely	Low	Medium	Medium	High	Very high
	Almost certain	Low	Medium	High	Very high	Very high

Further information regarding the risk assessment process and the risk register for the Project is detailed in EES Attachment III *Environmental risk report*.

4.5.4 Developing Entrainment Consequence Criteria

The consequence ratings for entrainment shown in Table 4-4 were developed taking into consideration that the consequence of entrainment could be to reduce plankton primary productivity in North Arm and the potential reduction in fish larvae with entrainment.

A minor level of consequence for entrainment was defined by CEE biological specialists as a change in the plankton population of 0.2 per cent in spring/summer or a change of 0.3 per cent in autumn/winter. A more stringent limit was defined for the fish breeding season in spring and summer when there are high numbers of fish larvae.

As precedents, there are currently licenced seawater intakes/discharges in Victoria for:

- Wonthaggi desalination plant (1,164,000 m^3/d from Bass Strait);
- Newport power station (1,709,000 m^3/d from Hobsons Bay); and
- Viva refinery (228,000 m^3/d from Corio Bay).

The proposed location for the FSRU at Crib Point will not interact with the extent of entrainment impacts for the other licenced seawater intakes/discharges in Victoria.

A very similar gas importation project at Port Kembla was recently assessed by NSW Planning. The project involves the intake and discharge of 240,000 m^3/d of seawater from Port Kembla Harbour. The proposed discharge is through a single outlet in the hull of the vessel at 7°C cooler than ambient seawater (the same temperature reduction as in this project). Entrainment from the intake of 240,000 m^3/d of seawater from Port Kembla Harbour (a much smaller embayment than Western Port) was not considered to be a significant effect in the assessment.

Up to 64,000,000 m^3/d of seawater per day is used to cool thermal power stations in California. There are statutory rules in the United States to regulate seawater intakes and a range of model outputs are used to describe the effects of power station cooling water entrainment on marine biota (*Proportion of seawater entrained; Probability of mortality; Area of production foregone and Adult equivalent loss*).

Monitoring of biota entrainment with cooling water intake structures (CWIS) at thermal power stations in California were reported in several studies - Huntington Beach Generation Station Entrainment and Impingement Study - MBC 2005, EPRI 2007, Foster 2007 and Steinbeck et al 2007. The effects of entrainment and impingement were modelled for populations of selected fish or invertebrates (crabs) that have commercial or recreational importance or are considered ecologically important or of conservation significance. The modelling is based on extensive sampling programs with direct sampling of biota entrained into the cooling systems and in ocean currents over the period of sampling. There is considerable available scientific information on the biology of the targeted species.

Steinbeck et al 2007 concluded that the ecosystem extent of entrainment is relatively limited:

> *Although almost all planktonic forms (phyto, zoo, and ichthyoplankton) are affected by entrainment, these studies and most other 316(b) studies have focused on a few organism groups, typically ichthyoplankton and zooplankton. The effects on phytoplankton and invertebrate holoplankton are typically not studied because their large abundances, wide distributions, and short generation times should make them less susceptible to CWIS impacts.*
>
> *The groups of organisms selected for assessment in these studies included larval fishes and larvae from commercially or recreationally important invertebrates such as Cancer spp. Crabs and California spiny lobster (Panulirus interruptus).*
>
> *The workgroup looked at including kelp spores, fish eggs, squid paralarvae, and abalone and bivalve larvae in the assessment. The risk of a significant impact on adult kelp populations by entrainment of kelp spores was determined to be negligible due to the large number of spores produced along the coast. Additionally, it is not possible to identify the species of kelp based on gametes or spores.*
>
> *Fish eggs were not included because they are difficult to identify to species, and the most abundant fishes in these studies had egg stages that were not likely to be entrained; they either have demersal/adhesive eggs or are internally fertilized and extrude free swimming larvae.*
>
> *Squid paralarvae are also unlikely to be entrained because they are competent swimmers immediately after hatching. Abalone larvae were not included because they*

are at low risk of entrainment and cannot be effectively sampled or identified during early life stages when they would be susceptible to entrainment.

The final list of fish and invertebrates analysed in each of the studies (Table 4) was determined by technical workgroups after all the samples had been processed and data from the entrainment samples summarized. The assessments included taxa from the organism groups that were in highest abundance in the entrainment samples (generally those comprising up to 90 percent of the total abundance) and commercially or recreationally important fishes and invertebrates that were in high enough abundances.

The results for the Empirical Transport Model ranged from very small levels (<1.0 per cent) of proportional mortality due to entrainment for wide ranging pelagic species, such as northern anchovy, to levels as high as 50 per cent for fishes with limited habitat that spawned near power plant intake structures.

It seems fair to conclude that the Californian studies in the marine environment do not lead to an appropriate level of entrainment for plankton for use in assessing potential impacts of the Project. Thus, the most suitable guide comes from the marine assessment for the Wonthaggi desalination project, located on the open Bass Strait coast.

The Wonthaggi study used a particle tracking model (ASR, 2008) to calculate the entrainment rates and areas for larval durations from 1 day to 28 days. The findings are summarised in Table 4-7.

Table 4-7. Summary of Findings – Wonthaggi Entrainment Assessment

Duration	Proportion	Area	Species	Finding
1 day	0.5 to 1 %	1.8 km by 1 km	reef invertebrates and algae	OK
2 days	0.5 to 1 %	2.8 km by 1 km	reef invertebrates and algae	OK
	0.1 %	7 km by 1.5 km		OK
7 days	0.5 to 1 %	2.8 km by 1 km	reef invertebrates, algae and reef fish	OK
	1 % to 1.5 %	1 km by 0.5 km		OK
14 days	0.5 to 1 %	8 km by 2 km	invertebrates, reef fish and pelagic fish	OK
	0.15%	22 km by 2.5 km		OK
30 days	0.5 %	7.4 km wide	King George whiting	OK

The percentage losses of various biota considered as acceptable at Wonthaggi ranged from 0.1 % to 1.5 %, with the common range listed being 0.5 % to 1 %.

As Western Port would be classed as a more sensitive (and more spatially confined) environment than Bass Strait, the acceptable level of entrainment in Western Port should be smaller.

4.5.4.1 Entrainment consequence criteria for the Project

The development of consequence criteria for entrainment associated with seawater intake by the FSRU has considered potential effects on phytoplankton, zooplankton and fish eggs and

larvae. In addition, an analysis of the variation in flushing rates of small marine biota using the hydrodynamic and particle modelling carried out for the Project has further informed these criteria. Further discussion on each of these aspects is provided in the following sections.

Phytoplankton

The phytoplankton populations in Lower North Arm have a high proportion of small, chain forming diatoms that are characteristic of high turnover populations. They provide about one-third of the primary productivity of Western Port (other contributors are mangroves, seagrass and microbenthic organisms).

Phytoplankton populations in Western Port rapidly respond to changing natural marine environmental conditions. The rapid growth rate of phytoplankton (in excess of 100 % per day) allows them to quickly take advantage of surpluses of limiting resources (i.e. food availability and temperature) and ecological space. This means that loss due to entrainment may be partly compensated for by higher growth of the remaining population.

For this dynamic population in Western Port, where the natural variation in abundance can be +/- 5 % per day, a “significant” loss by entrainment is assessed as 2 % per day and a “minor” loss as 0.5 % per day.

Zooplankton

The zooplankton population of Lower North Arm was characterised by a pair of *Acartia* species. *Acartia* is widely distributed in south-eastern Australia. *Acartia* (and all zooplankton populations in Western Port) are food limited. They are omnivorous and graze on phytoplankton, small copepod adults, copepod larvae and organic particles. Females produce up to 12 eggs per day and the adult replacement rate is from 3 to 30 days (3 % to 33 % per day). For this dynamic population, a “major” loss by entrainment is assessed as 2 % per day and a “minor” loss as 0.5 % per day.

Fish eggs and larvae

The abundance of fish eggs and larvae was highest during the spring and summer breeding season for most fish and was substantially lower in autumn and winter. The typical mortality rate for fish eggs and larvae is around 10 % per day and the extra effect of flushing from North Arm to Bass Strait is around 1 % per day. There is, however, a relatively short period of egg and larval production each year from which adult populations are replenished. For this seasonal cohort of eggs and larvae, a “major” loss by entrainment is assessed as 0.5 % per day and a “minor” loss as 0.2 % per day.

Variation in flushing rates to Bass Strait

Another perspective that provides a guide to the entrainment consequence assessment is to examine the predicted variation in the rate of flushing of plankton from Western Port to Bass Strait.

The hydrodynamic modelling carried out for the Project modelled the movement of neutrally-buoyant particles in Western Port (refer to Section 6.0) including the proportion of particles that were flushed to Bass Strait over two periods of 28 days. The number of particles that were flushed to Bass Strait every time step over 28 days was derived from the model and the flushing rate per 12.2-hour tide cycle was determined. The flushing rate was then normalised by the initial number of particles.

The results of this assessment of the variation in the rate of flushing of plankton from Western Port to Bass Strait are summarised in Table 4-8.

The results show the percentage of flushing of particles from various zones of Western Port over a period of two months (two periods of 28 days). Higher proportions are flushed in spring tides than in ebb tides.

The range of flushing rates varies from 0.05 % (5th percentile) to 1.5 per cent (95th percentile) of the particles from a particular zone per tide cycle. For North Arm as a whole, the range is defined by:

- 25th percentile flushing rate of 0.29 per cent (per tide cycle)
- 75th percentile flushing rate of 0.54 per cent (per tide cycle).

The 25th percentile to 75th percentile is used as a measure of the natural variation biota are predicted to experience. For North Arm as a whole, and Hastings Bay, this range is 0.25 per cent. For the Crib Point zone, the range is 0.53 per cent.

Based on the outcomes of this assessment, selection of an extra mortality rate of 0.2 per cent to 0.3 per cent (minor consequence) is appropriate as it is within the natural range of variation in loss from the population due to flushing between spring and neap tides.

Table 4-8. Percentage flushing of particles from Western Port to Bass Strait

Parameter/ Zone	***Crib Point***	***Hastings Bay***	***Middle North Arm***	***Sandy Point***	**All of North Arm**
25 % flushing	0.21	0.30	0.21	0.58	0.29
75 % flushing	0.74	0.55	0.41	1.25	0.54
Difference	0.53	0.25	0.20	0.67	0.25
Average	0.48	0.54	0.31	0.94	0.60

4.5.5 Application of Mitigation Measures

As described in Section 1.3, an initial set of mitigation measures were developed as part of this impact assessment. These mitigation measures are based on avoiding and minimising potential impacts to the extent practicable. As the Project design was well progressed at the commencement of this impact assessment, mitigating measures that were already incorporated in the design were included as primary mitigation measures. Risk ratings were applied to each of the identified risk pathways assuming that these initial mitigation measures are in place.

Risk levels were categorised as very low, low, medium, high or very high as per risk assessment matrix in Section 4.5.3.

Additional mitigation measures were developed as part of this impact assessment, prioritising risks where the initial risk ratings are categorised as medium or higher. These additional mitigation measures were incorporated into the Project description or Project design (where relevant) by AGL/APA and/or included in the EMF for the Project to ensure that they will be adopted and implemented.

The risk and impact assessment process are iterative. Potential impacts were reassessed after the risk assessment and after mitigation measures were refined to confirm the potential impacts that the Project may have on the environment. Following the adoption of additional mitigation measures, the level of risk were reassessed using the same methodology to confirm the mitigating measure has the effective in lowering the residual risk to ensure the Project is able to satisfy the draft evaluation objectives as set out in the EES scoping requirements.

4.6 Impact Assessment Method

The impact assessment methodology involved the following steps:

- Conduct of a screening risk assessment to identify minor and major risks relating to the marine environment;
- Formal risk workshop in December 2017 with range of participants to identify risks. The identified marine environment risks were re-examined and refined to a list of 53 marine risks in April and October 2019 which are assessed in Section 7;
- Detailed review of previous studies and relevant scientific literature to define the characteristics in impact pathways (existing conditions, see to Section 5);
- Identification of the parameters to define the proposed seawater discharge (flow rates, temperatures, residual chlorine concentration in discharges);
- Development of primary mitigation measures to minimise, to the extent practical, the impact of major risks (the mitigation measures are described in Section 7 and include a low velocity intake protected by a screen to reduce entrainment and high velocity discharge ports to increase initial mixing of the seawater discharge);
- Near-field modelling to predict the path and initial dilution of the discharge plumes within about 80 m of the FSRU under a range of tidal current and depth conditions (the model and model predictions are described in Section 6.0 and Section 7);
- Regional or far-field modelling using 3-D hydrodynamic model specially-adapted to represent the discharge and tidal conditions in Western Port, including the rise and fall of the tide, wetting and drying of mudflats, and the effects of winds and long period waves in Bass Strait (the model and model predictions are described in Section 6.0, with further output in Section 7);
- Development of a model to calculate the entrainment of plankton in seawater taken into the FSRU for the heat exchanger, ballast water, firefighting system, freshwater generation and other purposes) over various periods;
- Measuring tidal currents at three locations offshore from Crib Point to calibrate and check the predictions of the regional hydrodynamic model;
- Measuring seawater temperature at Crib Point to assess natural variations over averaging times from 1-hour to 24-hours, as well as the seasonal variation. The ambient variations in temperature are the basis for assessing acceptable and unacceptable variations in seawater temperature due to discharges from the FSRU;
- Measuring plankton composition and numbers at sites in Western Port to establish the natural populations, as an input to the assessment of the effects of entrainment on plankton (refer to Section 7);
- Assessing a wide range of potential risks to the marine environment of Western Port, including construction risks, entrainment risks, cooler seawater discharge risks, warm water discharge risks, chlorinated seawater risks, contamination risks (spills, marine pests), physical risks (scour, light), and biota risks (refer to Section 7);

- Assessing cumulative risks and pathways to effects on protected species (Section 8); and
- Assessing residual risk and defining an appropriate marine monitoring program (Section 8).

A separate underwater noise impact assessment has been carried out for the Project and is included in Annexure I to this report (Jasco, 2020). This underwater noise impact assessment is accompanied by an Underwater Acoustic Modelling Report at Annexure J to this report (Jasco, 2019).

4.7 Assumptions and Limitations

The main assumptions that underlie this assessment of marine biodiversity impacts are:

- The FSRU would be moored at Crib Point Jetty (Berth 2). The dimensions of the FSRU used in the hydrodynamic modelling are 300 m long by 50 m wide. It is understood that the dimensions of the actual FSRU may differ slightly (e.g. the width of a currently-expected vessel is 46 m) but small changes in the dimensions do not materially affect the marine impact assessment;
- The peak discharge rates associated with the regasification process (excluding ballast, fire testing and freshwater generation) are based on estimates supplied by AGL and listed in this impact assessment report (468,000 m^3/d for the open loop process and 187,000 m^3/d for the closed loop process);
- The assessment of intake and discharge effects is based on the assumption that the peak discharge applies for a month (in winter) and the average rate applies for the other months. The average intake and discharge rate from the FSRU in open loop production is two-thirds of the peak rate;
- The temperature of the seawater discharge with the open loop process is 7°C below ambient seawater;
- The temperature of the seawater discharge from the closed loop process is variable. For the purpose of modelling closed loop discharges, an estimate of 4 to 5°C above ambient seawater temperature was used;
- The concentration of residual chlorine oxidants for all seawater discharges other than ballast water does not exceed 0.1 mg/L. The concentration of residual chlorine oxidants for ballast water is approximately 0.021 mg/L;
- There are no contaminants other than residual chlorine (and a change in temperature) in the seawater discharges;
- The open loop seawater discharge will be released through six ports with a horizontal velocity exceeding 5 m/s;
- The intakes for seawater meet the design criteria defined above and are approximately at mid-depth on the sides of the FSRU with a horizontal velocity < 0.15 m/s;
- The near-field and regional hydrodynamic models provide reasonably accurate predictions of contaminant transport paths and dilution, and the rate of entrainment.

The main limitations for this assessment of marine impacts are:

- Plankton sampling periods in field programs cover the period December 2018 to December 2019, and depth-integrated individual zooplankton, phytoplankton and ichthyoplankton single samples collected at multiple sites throughout Lower North Arm at monthly intervals provide a reasonable representation of conditions in Lower North Arm for the environmental risk assessment;

- Seabed biota documentation is based on habitat categorisation and mapping along towed underwater video transects, descriptions of infauna community from existing information and supplemented with additional sampling of Crib Point Jetty in 2019;
- Unknown long-term environmental events or trends, may create significant stresses;
- The actual FSRU is very similar in operations and discharge characteristics to the assumptions for dimensions, intake and discharge conditions used for this assessment;
- Hydrodynamic modelling period is representative of the full range of conditions and neutrally buoyant particles are representative of plankton distribution; and
- Plankton entrainment (a lower trophic level) provides a reasonable indication of impacts on primary productivity and effects on higher trophic levels.

4.8 Stakeholder Engagement

A program of stakeholder and community engagement were undertaken to assist with Project development (refer to EES Chapter 26 *Stakeholder engagement*).

Specific stakeholder engagement undertaken as part of this impact assessment is summarised in Table 4-9.

Table 4-9. Stakeholder Engagement

Activity	When	Key issues discussed	Engagement outcome
Risk Workshop	14 Dec 2017	Risks	Risks
Public Information Meeting	27 Feb 2018	Community concerns	Community issues
Public Information Meeting	15 March 2018	Community concerns	Community issues
Public Information Meeting	27 March 2018	Community concerns	Community issues
Public Information Meeting	3 April 2018	Community concerns	Community issues
Public Information Meeting	28 July 2018	Community concerns	Community issues
Public Information Meeting	3 Sept 2018	Community concerns	Community issues
Public Information Meeting	7 Sept 2018	Community concerns	Community issues
Public Information Meeting	8 Sept 2018	Community concerns	Community issues
Public Information Meeting	13 Sept 2018	Community concerns	Community issues
Public Information Meeting	15 Sept 2018	Community concerns	Community issues
Public Information Meeting	25 Sept 2018	Community concerns	Community issues
Public Information Meeting	26 Feb 2019	Community concerns	Community issues
Public Information Meeting	2 March 2019	Community concerns	Community issues
Technical Reference Group (TRG) Meeting	12 March 2019	Modelling approach	Agency feedback

Activity	When	Key issues discussed	Engagement outcome
Public Information Meeting	24 Aug 2019	Community concerns	Community issues
Public Information Meeting	27 Aug 2019	Community concerns	Community issues
Public Information Meeting	28 Aug 2019	Community concerns	Community issues
Public Information Meeting	3 Sep 2019	Community concerns	Community issues
TRG Meeting	23 Oct 2019	Modelling results	Agency feedback
TRG Meeting	11 Feb 2020	Impact assessment results	Agency feedback

4.9 Independent Peer Review

An independent scientific review of the near-field and far-field hydrodynamic modelling reports was carried out by Dougal Greer of eCoast Marine Consulting and Research, New Zealand (see Annexure K). He has previously worked on modelling inputs from rivers and sediment transport in Western Port. The peer review assessed the CEE/HydroNumerics modelling studies focusing on the CEE reports for near-field modelling and the HydroNumerics report for far-field modelling.

The peer review concluded that, overall, the methodology and software used to model the effects of the plume in the near-field were appropriate for the purposes of this impact assessment. The processes of wind, sea level variability (tidal and non-tidal), temperature and salinity are all adequately represented in the regional model.

The conclusions drawn from the models on seawater temperature variations seem reasonable; the representation of chlorine in the model is sound; the methodology and results for residual chlorine levels seem reasonable; and the method of using different particle release zones is appropriate for assessing the potential impacts of the FSRU on larval populations.

Overall, the peer review concluded that "the methodology is sound" and the tools and methods used for the nearfield and regional modelling are appropriate and the results seem reasonable. The conclusions drawn as to the worst-case impact of the operation in terms of the plume are presented (the marine risk assessment technical report) and provide an accurate summary of the results presented in Hydronumerics (2020a).

GHD made an independent peer review of the Marine Environment Impact Assessment to determine whether it adequately addressed the EES scoping requirements (see Annexure L). The GHD review reached the following conclusions (GHD, March 2020):

- The marine ecology assessment methodology is appropriate for the assessment required and the conclusions presented can be reasonably drawn from the methods used.
- The underwater noise assessment methodology is appropriate for the assessment required and the conclusions presented can be reasonably drawn from the methods used (see Annexure I).
- The hydrodynamic modelling methodology adequately assesses the cooler seawater (from heat exchangers) and warmer seawater (from FW cooler) discharges on the seabed habitat for a number of scenarios. In particular, the assessment sensibly

identified the optimal solution for the discharge of open loop (cooler water) from the FSRU as reconfiguring the design for port (west) side discharge. The methodology provides reasonable estimates of the area extent in which the seabed criterion of ±0.5°C is exceeded (i.e. Table 6-5).

- The modelling methodology adequately assesses the chlorine discharges on the seabed habitat over a number of scenarios. The methodology provides reasonable estimates of the areal extent in which the seabed criterion of 6 µg/L is exceeded (i.e. Table 6-6).
- The modelling methodology adequately assesses the entrainment predictions of planktonic organisms in the water column into the FSRU sea chest over a number of scenarios with the caveat of further clarification of withdrawal envelope volumes provided in Table 6-8 (see below). The methodology appears to provide reasonable estimates of the expected percentage of entrainment of planktonic organisms within North Arm (i.e., Tables 6-9 and 6-10).

4.10 Linkage to Other Technical Reports

This marine biodiversity impact assessment should be read in conjunction with other relevant technical reports forming part of the EES. Impacts relating to terrestrial flora and fauna (including birds in the Ramsar intertidal zone) were considered in detail in EES Technical Report B: *Terrestrial and freshwater biodiversity impact assessment*.

Where relevant to the marine study, other technical reports are considered and referenced.

The following reports provide the details of the methods and results of field studies and hydrodynamic modelling. The reports listed below are provided as technical annexures to this assessment.

Location	**Reference**
Annexure A	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
Annexure B	CEE (2019a). Phytoplankton Technical Report – AGL Gas Import Jetty and Pipeline Project. Report for AGL.
Annexure C	CEE (2019b). Zooplankton Technical Report – AGL Gas Import Jetty and Pipeline Project. Report for AGL.
Annexure D	CEE (2019c). Benthic Habitats Technical Report - AGL Gas Import Jetty and Pipeline Project. Report for AGL.
Annexure E	CEE (2019d). Seawater Temperature Technical Report - AGL Gas Import Jetty and Pipeline Project. Report for AGL.
Annexure F	CEE (2019e). Threatened Ghost Shrimp Survey, Lower North Arm Western Port - AGL Gas Import Jetty and Pipeline Project. Report for AGL.

Annexure G	CEE (2019f). Ichthyoplankton Technical Report - AGL Gas Import Jetty and Pipeline Project. Report for AGL.
Annexure H	Hydronumerics (2019). Hydrodynamic Modelling Report - Crib Point Gas Import Facility. Technical report prepared for CEE Pty Ltd.
Annexure I	Jasco (2020). Underwater noise impact assessment – Floating Storage and Regasification Unit. Technical report prepared for AGL.
Annexure J	Jasco (2019). Underwater Acoustic Modelling. Technical Report prepared for AGL.
Annexure K	eCoast Marine Consulting and Research (2020) Western Port Modelling Review of Responses to Request for Further Information
Annexure L	GHD (2020) Independent Peer Review of AGL Gas Import Jetty Marine Environment Considerations

5.0 Existing Conditions

5.1 Introduction to Western Port

Western Port is a tidal embayment on the south coast of Victoria that surrounds Phillip Island in the south and French Island in the north (Figure 5-1). There are two entrances from Bass Strait:

- a large western entrance between Flinders on the Mornington Peninsula and Point Grant on Phillip Island
- a smaller and constricted eastern entrance between Phillip Island and San Remo.

The waters of Western Port cover an area of 754 km^2 at high tide and 523 km^2 at low tide. The area of mudflats exposed at low tide is 231 km^2.

The key physical features of Western Port are the deep tidal channels in the entrance, North Arm (along the west and north side of French Island), East Arm (along the north coast of Phillip Island and east coast of French Island) and the large areas of intertidal mudflats and sand bars.

The key hydrodynamic features of Western Port are the large tidal range in the bay, the corresponding large tidal prism (volume of water moving with each tide) and the strong tidal currents.

The key habitat features of Western Port are the saltmarsh, mangrove and seagrass habitats, subtidal sediment habitats, and the very small area of rocky reef habitat. The area north of a line between Pt Leo on the Mornington Peninsula and Cowes on Phillip Island is designated as the '*Western Port Ramsar site'*. The key historical and ongoing threats to saltmarsh, mangroves, unvegetated mudflats and seagrasses in Western Port are the result of economic development, economic activity and population growth in the catchment, and anthropogenic greenhouse gas emissions leading to a warmer climate with greater variability and extremes.

Western Port has a catchment size of 3,721 km^2 and an estimated population of 45,000 people in 2018/19 (Port Phillip and Westernport Catchment Authority, 2018/19). In the early 1850s the catchment around Koo Wee Rup was drained to convert the surrounding swampland to settlements and farmland. By 1897 the drainage works were completed including the channelization of the Bunyip River, Deep Creek and several other smaller drains.

This chapter provides a detailed description of existing conditions in Western Port as they relate to the proposed Project. The chapter covers the following aspects of the Western Port Environment:

- Bathymetry;
- Hydrodynamics;
- Water Quality;
- Benthic ecology;
- Plankton ecology;
- Fish ecology;
- Marine Mammals (seals) and Birds (penguins);
- Protected Matters;
- Introduced Marine Species; and

- Port Facilities and Urban Development.

5.1.1 Previous Studies

The first comprehensive study of the Western Port environment was the Western Port [Bay] Environment Study from 1973 to 1974 (Shapiro, 1975). The objective of the study was to document baseline conditions in Western Port prior to further urban and industrial development. The study included assessments of land use, geology, sediments, hydrodynamics, geochemistry, groundwater, biology and general ecology. A series of subject reports were published, as well as an overview report (Shapiro, 1975).

In 2009 the Port of Hastings Development Authority commissioned a review of existing information on the Western Port environment to inform feasibility studies for proposed expansion of the Port of Hastings. CEE reviewed reports and scientific studies from the Western Port Bay Environmental Study up to 2009, particularly the extensive research on changes to the Western Port ecosystem since the 1970s (CEE, 2009).

In 2011, EPA Victoria published a "*Western Port Condition Report*" that documented trends in water quality from 1984 to 2009 and assessed measured conditions against the objectives in the State Environment Protection Policy (Waters of Victoria) 2018.

Also, in 2011, Melbourne Water published a report *"Preliminary Assessment of Water Quality Requirements of Seagrasses in Western Port".* The study combined maps of seagrass distribution, measurements of water quality and numerical models of hydrodynamics, wave characteristics and sediment transport to assess patterns of variables and critical thresholds for seagrass. The modelling simulated 1974, 1998, 2009 and 2012. Highest nutrient concentrations were in the far north-west of Western Port at Watsons Inlet, where seagrass density is high. There was little change in nutrient concentrations from the 1970s to 2010.

In 2013, Cardno prepared a detailed list of previous Western Port study reports and available data for the Port of Hastings Development Authority. The list included information on bathymetry, sediments, suspended solids, geomorphology, tides, storm surge, currents and waves, together with recommendations for further work required to support port development (Cardno, 2013).

Melbourne Water, together with the Department of Sustainability and Environment and the Port Phillip and Westernport Catchment Management Authority, coordinated a review of the existing understanding of the Western Port environment in 2011. The first report *"Understanding the Western Port Environment"* was released in 2011. The review identified major threats to the ecosystem, and consolidated research needs and priorities. A second report discussing results of investigations undertaken between 2011 and 2017 was released in 2018 (Melbourne Water, 2018).

These major reviews as well as other previous studies and reports have been used in preparing this summary of existing conditions in Western Port, with a focus on North Arm, and matters relevant to the environmental assessment of the Project.

5.2 Bathymetry of Western Port

Western Port, viewed from above, forms a figure of eight, leaning to the right. French Island occupies the upper loop with Phillip Island occupying the lower loop (see Figure 5-1). The waters in Western Port are connected to those in Bass Strait by the wide western entrance, which contains a deep channel along the northwest coast of Phillip Island. This channel is mostly 10 to 15 m deep but reaches 40 m depth in places.

Middle Bank is a long sand bar that extends south from Sandy Point and separates the deep water of the main entrance channel from shallower water nearer the coast of the Mornington Peninsula (Flinders, Shoreham, Point Leo and Somers).

The western channel splits and divides to the north of Phillip Island (the 'Confluence Zone'). North Arm extends north past Hastings (Lower North Arm) and northeast around the coast of French Island (Upper North Arm). East Arm extends around the south and east of French Island (past Corinella).

The eastern entrance is much smaller and constricted due to the narrow channel where a bridge connects Phillip Island (Newhaven) to the mainland at San Remo.

In the north and north-east of Western Port, there is a large area of intertidal mudflats with a dendritic (branch-like) network of channels. Water from North Arm and East Arm flows to and from the mudflats via the dendritic channels on the flood and ebb tides respectively. The waters of North Arm and East Arm meet at the tidal divide, located between the north-east corner of French Island and the mainland near Land Lang. The path of the North Arm and East Arm channels, and the location of the 'Tidal Divide' are readily apparent in the bathymetric map in Figure 5-1.

Smaller areas of mudflat with or without dendritic channels occur throughout Western Port including at Hastings, Hanns Inlet, and on the south coast of French Island and northeast of Phillip Island. Mangroves and saltmarsh occur above mean sea level around much of Western Port's coastline, inshore from the mudflats. Along with seagrasses, mangroves and saltmarsh both protect the intertidal seabed by stabilising sediments.

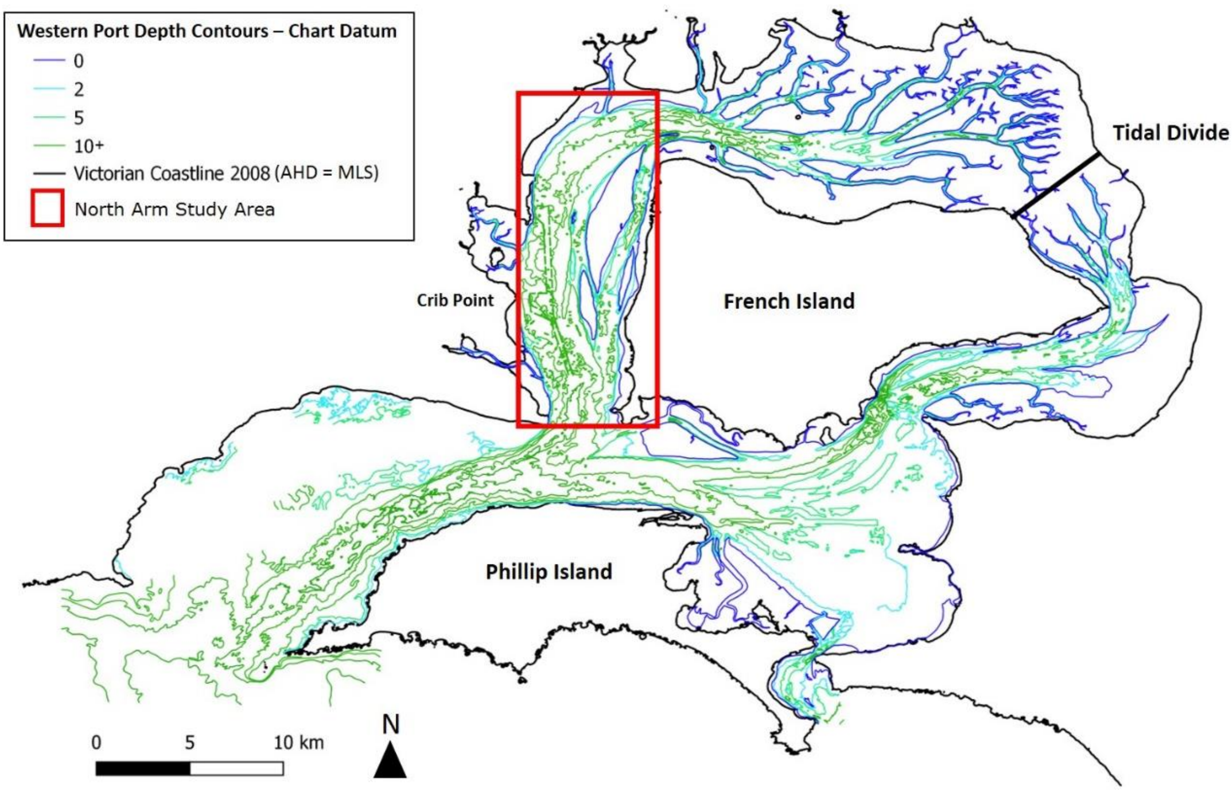


Figure 5-1. Western Port Bathymetry

Source: Victorian Spatial Data online (DELWP)

5.2.1 Bathymetry near Crib Point

Figure 5-2 shows the detailed bathymetry in Lower North Arm near Crib Point. There are two channels in this part of Lower North Arm:

- a deep, 2.5 km wide main channel immediately offshore from Crib Point
- a narrower and shallower channel between Middle Bank (a large sand bar) and French Island.

Parts of the main channel have been dredged to provide a minimum depth of 14 m so ships can access port facilities at Crib Point. Dredging has also been undertaken further north near Long Island Point Jetty and the BlueScope Steel Wharves.

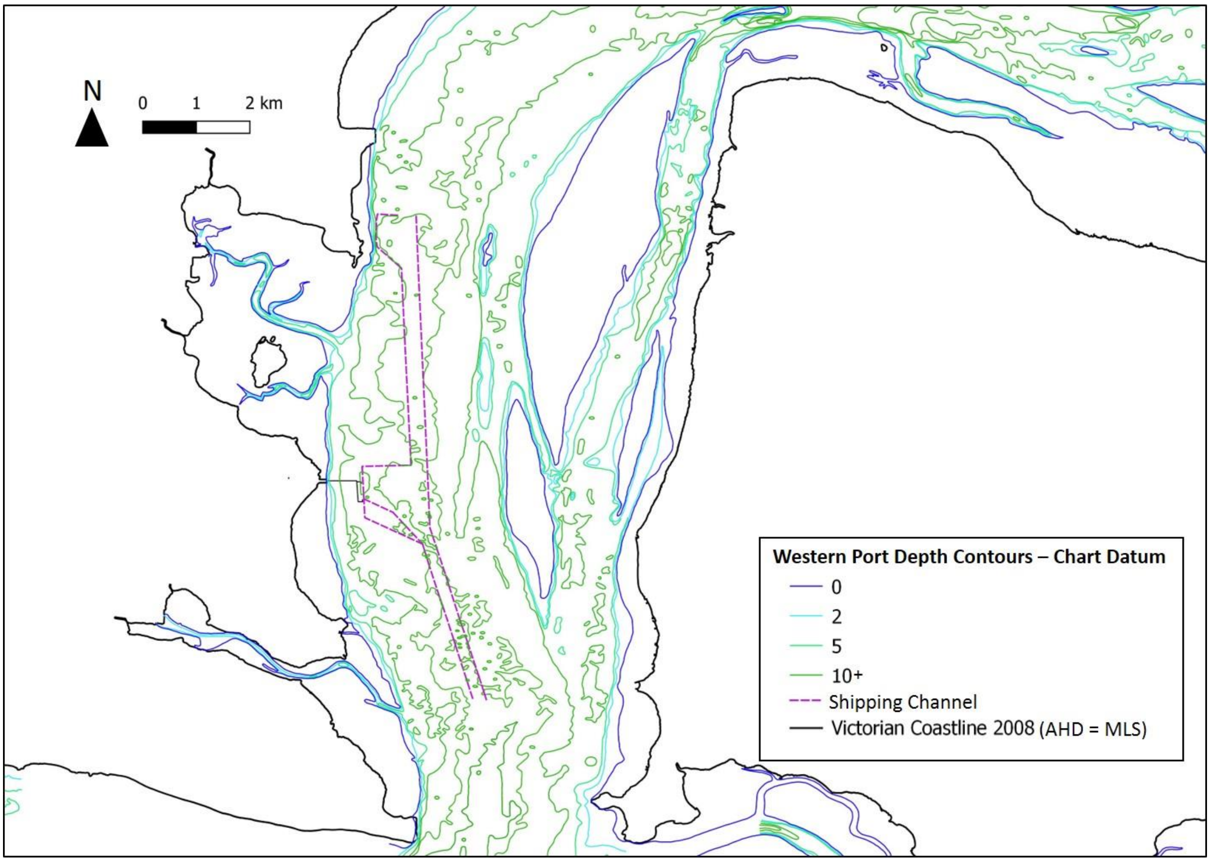


Figure 5-2. Bathymetry of Lower North Arm near Crib Point

Source: Victorian Spatial Database (DELWP)

There are intertidal mudflats on the west side of the channel to the north and south of Crib Point.

The topographical map in Figure 5-3 shows that the intertidal areas have very little relief (they are flat) while the deeper channels have relatively complex relief of sand waves and ripples. The dredged swing basin and berth pockets at Crib Point are clearly visible. Areas with underwater sand waves and sand dunes formed by the strong currents are also visible, as well as shoals and deeper holes in the channels.

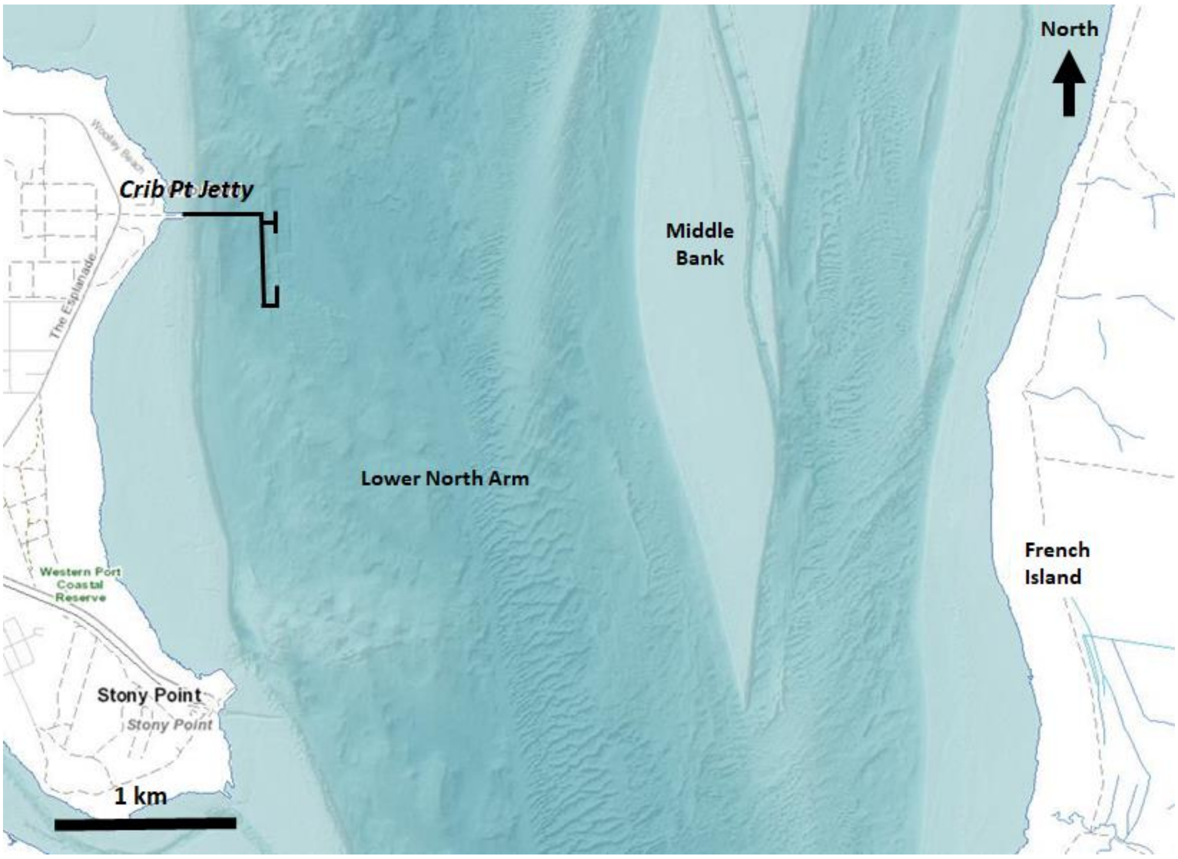


Figure 5-3. Seabed Relief of Lower North Arm near Crib Point

Source: NatureKit (DELWP)

5.3 Tides in Western Port

Tides are the major process driving water movement in Western Port with wind having little effect (Hinwood and Jones, 1979). Tides in Western Port are semidiurnal lunar tides, as in Bass Strait. Table 5-1 lists the tide levels for Western Port (Stony Point) from the Victorian Regional Tides Authority (2018).

Table 5-1. Western Port Tide Heights

<table>
<tr><th>Tide Level</th><th>Abbrev.</th><th>Height (m)</th><th>Spring Tide</th><th>Neap Tide</th></tr>
<tr><td>Highest Recorded Tide</td><td></td><td>2.1</td><td rowspan="2"></td><td rowspan="3"></td></tr>
<tr><td>Highest Astronomical Tide</td><td>HAT</td><td>1.7</td></tr>
<tr><td>Mean High Water Spring</td><td>MHWS</td><td>1.2</td><td rowspan="5">Spring range = 2.4 m</td></tr>
<tr><td>Mean High Water Neap</td><td>MHWN</td><td>0.7</td><td rowspan="3">Neap range = 1.3 m</td></tr>
<tr><td>Mean Sea Level (AHD)</td><td>MSL</td><td>0.0</td></tr>
<tr><td>Mean Low Water Neap</td><td>MLWN</td><td>-0.6</td></tr>
<tr><td>Mean Low Water Spring</td><td>MLWS</td><td>-1.2</td><td rowspan="3"></td></tr>
<tr><td>Lowest Astronomical Tide</td><td>LAT</td><td>-1.9</td><td rowspan="2"></td></tr>
<tr><td>Lowest Recorded Tide</td><td></td><td>-2.0</td></tr>
</table>

The tide ranges are 2.4 m for spring tides and 1.3 m for neap tides. This means there is a marked difference between spring and neap tide heights and current speeds.

According to data published in the Shapiro report (1975) and Melbourne Water tide measurements at Tooradin for 2011, the spring tidal range at Tooradin is approximately 2.6 m, which is larger than for Stony Point (2.4 m). This is due to the progressive reduction in the cross-sectional area of Western Port moving north – the tidal wave is compressed and increases in amplitude from south to north. Peak tide height at Tooradin occurs about 2 hours later than at Stony Point.

5.3.1 Sea Level Rise

From 1961 to 2003, the average rate of sea level rise at Stony Point is estimated to be 1.8 mm/yr (National Tide Centre, 2011). It is estimated that this trend has been continuous for the last century, implying a rise in sea level of about 180 mm over that period. From 1993 to 2011, the average rate of sea level rise was estimated to be 2.6 mm/yr (National Tide Centre, 2011) implying a further rise in sea level of about 70 mm over that period.

Predictions of future sea level in Western Port take account of future sea level rise and possible changes in wind conditions. The Marine and Coastal Policy (2020) recommends that planning should adopt a rise of not less than 800 mm by 2100. These forecasts imply significant changes will occur in mangrove and other intertidal communities in Western Port due to sea level rise. Further discussion on sea level rise is provided in EES Attachment IV *Climate change risk report*.

5.3.2 Monthly Variation in Sea Level

The movement of high and low atmospheric pressure systems and the passage of coastal trapped waves (also linked to weather systems) can cause variations in mean sea level in Western Port of +/- 120 mm for a week or so at a time. Such variations can lead to a large intrusion of Bass Strait water into the Bay (weekly increase in mean sea level) or a large flushing of Western Port water to Bass Strait (weekly decrease in mean sea level).

5.3.3 Tidal habitats

The large tidal range leaves large areas of intertidal mudflats exposed during each low tide, particularly in the north of Western Port. Table 5-2 lists the volumes and areas for the whole of Western Port and North Arm at high, mean and low tide. The bay contains 567 gigalitres (GL) (6 %) less water at low tide than at high tide. The water covered area at low tide is 231 km^2 (31 per cent) less than at high tide – approximately 30 per cent of the Western Port seabed is intertidal.

Table 5-2. Volume and Area of Western Port at Tidal Stages

Area	High Tide		Mean Tide		Low Tide	
	Volume (GL)	Area (km^2)	Volume (GL)	Area (km^2)	Volume (GL)	Area (km^2)
Western Port	9,654	754	9,613	717	9,087	523
Lower North Arm	1,019	114	839	101	696	69

Figure 5-4 shows the tidal areas of North Arm in more detail. The blue colour shows the area below low tide, the green area shows mean sea level (MSL) to low tide and the orange area represents high tide to MSL. At low tide, the water is confined to the subtidal channels (blue colour) and Middle Bank is exposed between the north and eastern channels (green colour). The intertidal mudflats in Watson Inlet, Hastings Bight and elsewhere around the coast are

also exposed. At the mean tide, the mudflats are covered with shallow water as is Middle Bank (green areas). The mangrove and saltmarsh habitats above mean sea level are only covered at high tide (orange areas).

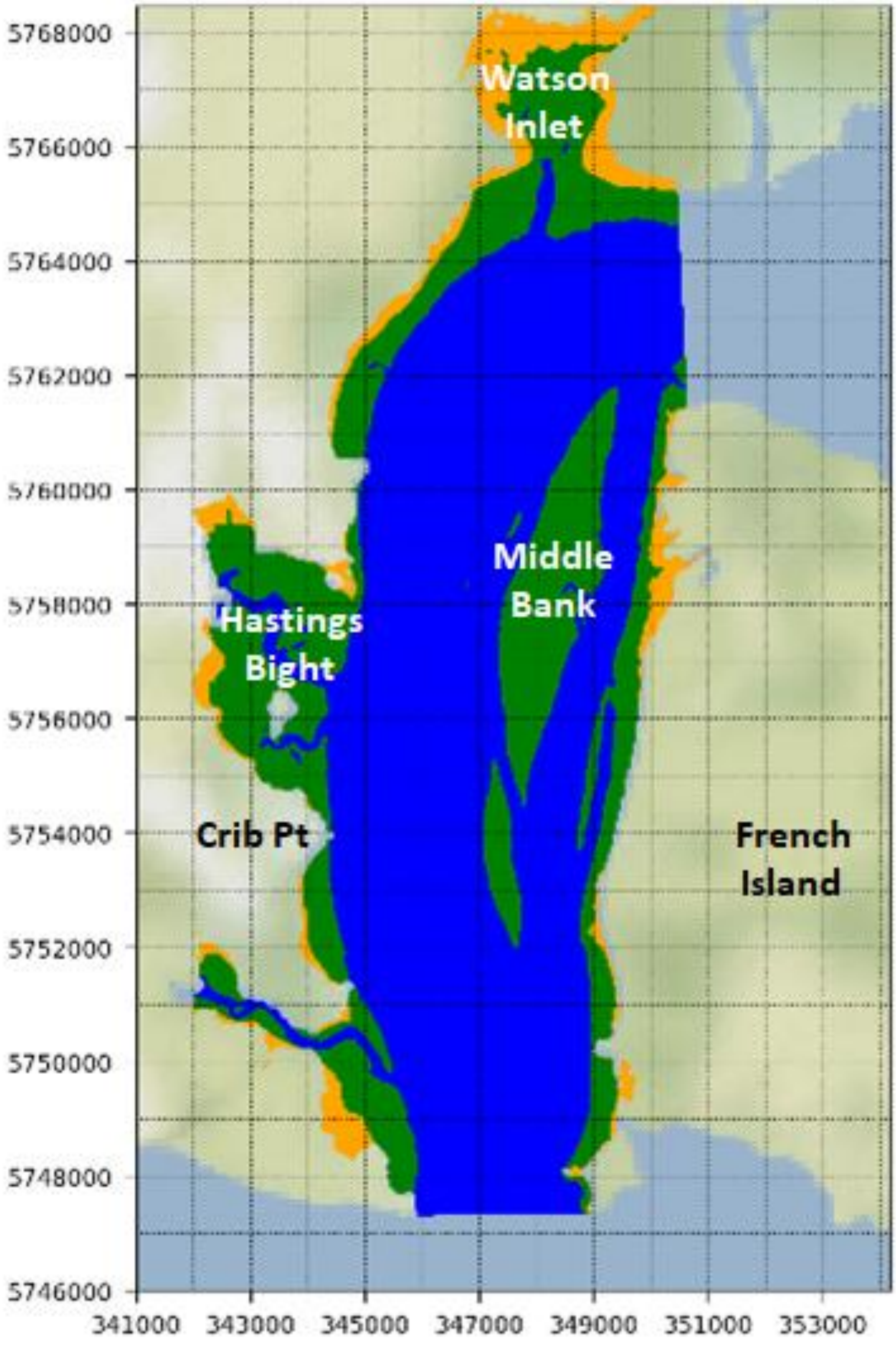


Figure 5-4. North Arm Tide Ranges

Eastings and Northings are GDA 94

Blue represents the area below low tide.

Green area represents mean sea level to low tide.

Orange area represents high tide to MSL (AHD).

5.4 Currents in Lower North Arm

Tides are the main factor that drive currents north and south through Lower North Arm, past Crib Point. There are other factors that influence currents including; wind, long period waves in Bass Strait, meteorological pressure and inflow of freshwater during floods. Currents have been measured at various times and recent data for North Arm is available from current meter deployments by Cardno in 2013 and CEE in 2019 (for this Project).

Cardno measured currents from December 2012 to January 2013 at 1-minute intervals at two sites in the main North Arm channel. The southern site was located between BlueScope and Long Island Point jetties at 15.5 m depth and the northern site was approximately 4 km northeast in the channel at 9.5 m depth. Average-depth current speed exceedances for these two sites are shown in Figure 5-5. The graph shows that the median current speed in North Arm is approximately 0.45 m/s at the north-west of French Island and around 0.5 m/s offshore from Hastings. This means that currents will be below 0.5 m/s for 50 % of the time at Hastings, with slightly lower speeds north-west of French Island.

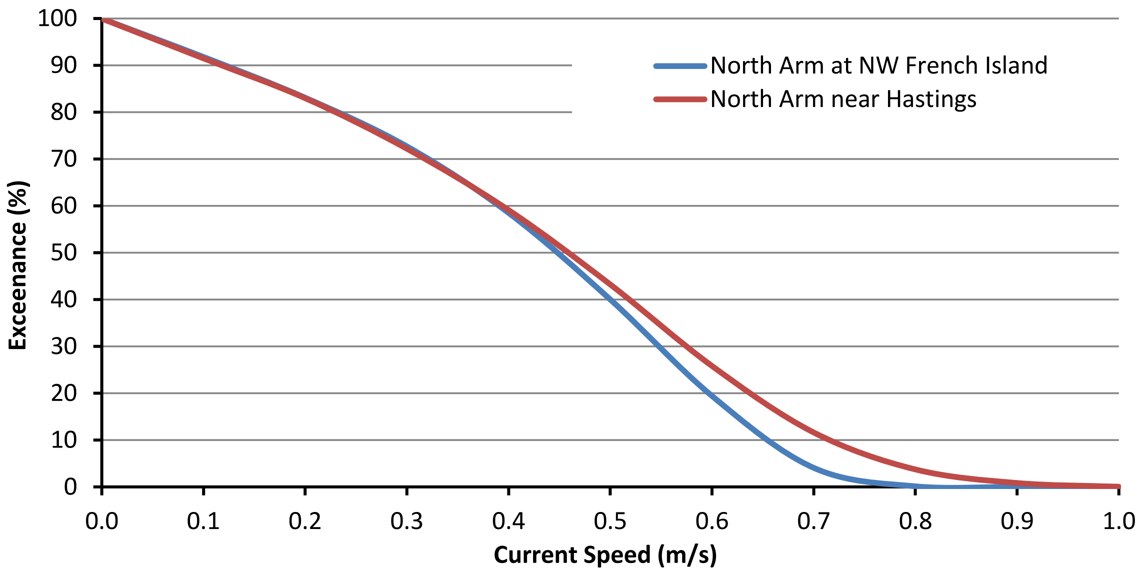


Figure 5-5. Distribution of Current Speeds in North Arm – from Cardno, 2013

5.4.1 Lower North Arm Currents near Crib Point

CEE measured currents at three sites across Lower North Arm from 19 March to 17 April 2019. The Acoustic Doppler Current Profilers were deployed:

- near the proposed FSRU location at Crib Point Jetty Berth 2 (ADCP #1)
- the east side of the main channel (ADCP #2); and
- in the channel east of Middle Bank (ADCP #3).

These current meters measured current speed and direction every 10 minutes at 1 m depth intervals during the deployment.

The ADCPs were deployed on the seabed facing up. The depth of measurements is upwards relative to the seabed.

Figure 5-6 provides a comparison of the 2019 measurements with the longer-term data set collected by Cardno (2013). Current speeds at 5 m above the seabed at each site were extracted and graphed to show the distribution of current speeds at each ADCP location.

Figure 5-6 shows that ADCP #1 (West) had the slowest currents and ADCP #2 (Centre) had the fastest currents. For 50 % of the time the currents were below:

- 0.4 m/s at ADCP #1
- 0.52 m/s at ADCP #2; and
- 0.47 m/s at ADCP #3.

Therefore, median current speeds measured in this deployment for the Project near Crib Point in 2019 (0.4 m/s to 0.52 m/s) were comparable to those measured by Cardno further north in 2012-13 (0.45-0.5 m/s).

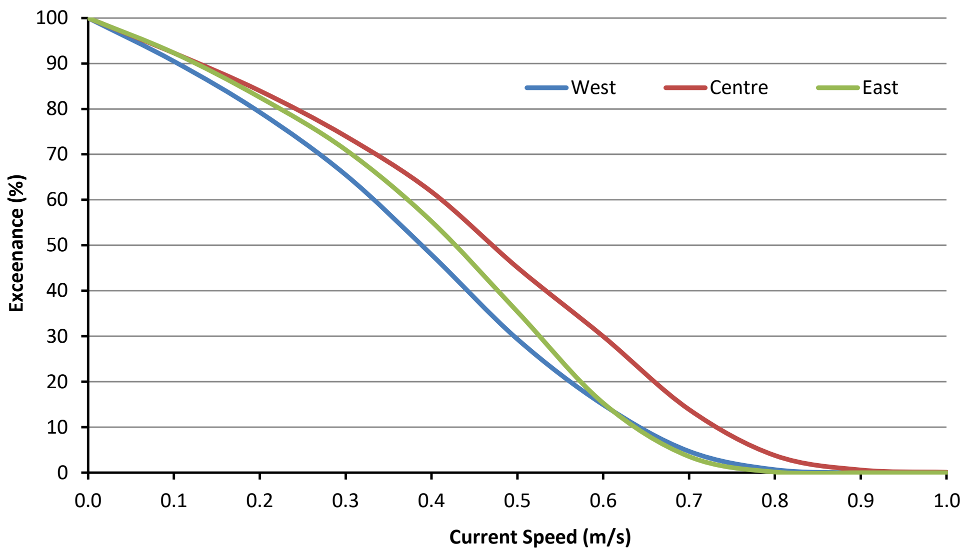


Figure 5-6. CEE (2019) Current Speed near Crib Point

The current meter records for 2019 are described below in terms of variations in current speeds from west to east at Crib Point, with tidal phase (ebb, flood) and tidal cycle (neap, spring).

Influence of tide phase and cycle

Figure 5-7 shows the north/south current speeds at ADCP#1 at Crib Point. The meter was located offshore from Berth 2 (the proposed location of the FSRU at Crib Point Jetty).

The positive values for current speed depict northward movement of water on a flood tide while the negative numbers depict southward movement of water on an ebb tide. The spring to neap to spring variation in tidal currents is evident in the graph. Peak flood tide current speeds during spring tides are a little over 0.6 m/s while, during neap tides, they are around 0.4 m/s. Ebb tides are somewhat stronger at this location, with spring tide peak currents of 0.8 m/s and neap tide peak currents of around 0.4 m/s. The net current at Crib Point over the month was in a southerly direction.

At low tide the currents are typically weak at around 0.05 m/s over a period of about 20 minutes. In reality, there is rarely a zero-current speed at high or low tide (CEE, 2018a) as the bathymetry near Crib Point creates lateral currents at high and low slack water within the main channel, so the current roses are elliptical (they include some east and westerly flows, and no periods of calm).

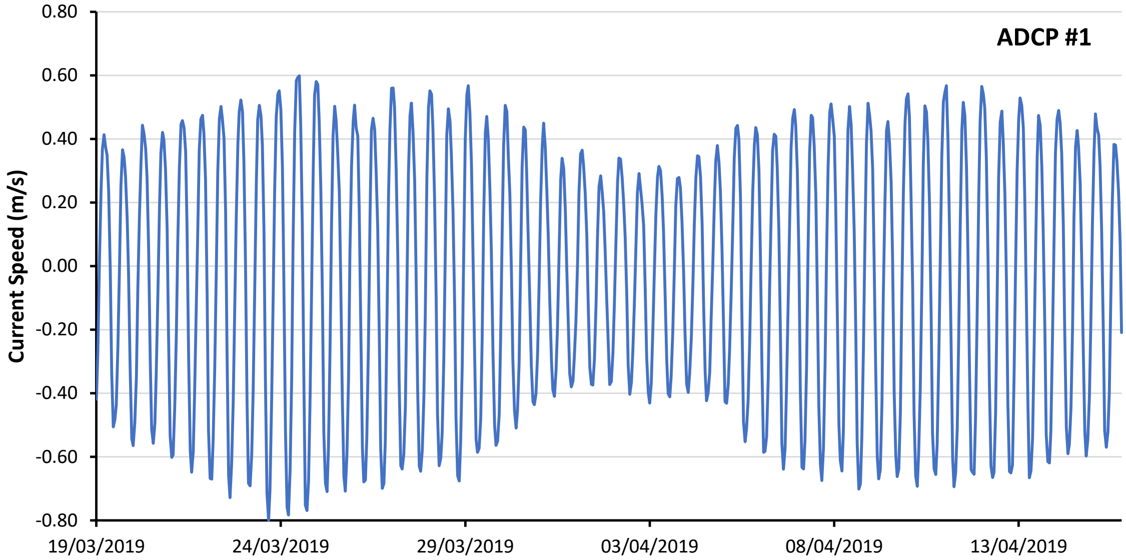


Figure 5-7. Mid-water Currents at Crib Point Jetty Berth 2

Influence of location and depth

Table 5-3 shows the distribution of mid-water (5 m above instrument) current speed and direction near Crib Point Jetty Berth 2 (ADCP #1). The table shows that currents flow due north 45 % of the time and due south 48 % of the time. Southerly currents were dominant at this location. Currents with an easterly or westerly component occur for less than 8 % of the time. Due east or west currents each occur less than 1 % of the time and are very weak (peak of 0.1 m/s). South flowing currents are faster (peak of 0.9 m/s) than north flowing currents (peak of 0.7 m/s). The most frequent current speed is approximately 0.5 m/s which occurred 12% of the time during north currents (flood) and 7 % of the time during south currents (ebb).

Table 5-3. Distribution of 5 m Current Speed and Direction at ADCP #1

Direction	Degrees	Per cent currents in range (speed in m/s)											Total (%)
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	
N	338 - 23	1.8	4.4	7.9	10.3	11.6	7.5	1.0					**44.6**
NE	23 - 68	0.5	0.2										**0.8**
E	68 - 113	0.6											**0.6**
SE	113 - 158	0.9	0.2										**1.2**
S	158 - 203	2.2	4.9	5.5	7.3	7.0	6.9	9.2	4.0	0.6			**47.7**
SW	203 - 248	1.2	0.1										**1.3**
W	248 - 293	0.7											**0.8**
NW	293 - 338	1.5	1.2	0.2									**2.9**
	Total	**9.5**	**11.2**	**13.8**	**17.6**	**18.6**	**14.4**	**10.2**	**4.0**	**0.6**			**100**
	Exceedance	100	90.5	79.3	65.5	48.0	29.4	14.9	4.7	0.6			

Table 5-4 shows the distribution of mid-water (5 m above instrument) current speed and direction on the east side of the main channel (ADCP #2). The table shows that currents flow due north around 49 % of the time and due south around 46 % of the time at this location. Peak north current speeds are 1 m/s and peak south currents are 1.1 m/s. There was slight north current dominance at this location. The most common current speed was 0.5 m/s which accounted for almost 17 % of the records. Currents with an easterly or westerly component occurred for just 6 % of the time and were weak.

Table 5-4. Distribution of 5 m Current Speed and Direction at ADCP #2

Direction	Degrees	Per cent currents in range (speed in m/s)											Total (%)
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	
N	338 - 23	1.9	3.4	4.9	6.6	8.9	8.9	8.6	4.2	1.2	0.1		48.5
NE	23 - 68	0.4	0.1										0.5
E	68 - 113	0.4											0.4
SE	113 - 158	0.7	0.5	0.1									1.4
S	158 - 203	1.9	3.6	4.7	5.5	7.7	6.2	7.4	6.0	2.0	0.4	0.1	45.5
SW	203 - 248	0.8	0.1										0.9
W	248 - 293	0.5											0.5
NW	293 - 338	1.1	0.7	0.3	0.1								2.2
	Total	7.7	8.3	10.0	12.2	16.7	15.2	16.1	10.1	3.2	0.5	0.1	**100**
	Exceedance	100	92.3	84.0	74.0	61.8	45.1	29.9	13.9	3.7	0.6	0.1	

Table 5-5 shows the distribution of mid-water (5 m above instrument) current speed and direction for the channel east of Middle Bank (ADCP #3). Due north currents occurred for 48 % of the time and south currents for 46 % of the time at this location. Peak north current speeds were 0.8 m/s while peak south currents were 0.9 m/s. There was slight north current dominance at this location. Currents with an easterly or westerly component occurred for less than 6 % of the time and were weak.

Table 5-5. Distribution of 5 m Current Speed and Direction at ADCP #3

Direction	Degrees	Per cent currents in range (speed in m/s)											Total (%)
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	
N	338 - 23	1.3	4.0	5.5	8.0	11.1	12.0	4.9	1.1				47.9
NE	23 - 68	0.4											0.4
E	68 - 113	0.2											0.2
SE	113 - 158	0.5	0.1										0.7
S	158 - 203	1.8	4.6	6.0	7.7	8.7	8.1	6.9	2.3	0.1			46.2
SW	203 - 248	1.3	0.3										1.6
W	248 - 293	0.8	0.2										1.0
NW	293 - 338	1.4	0.6										2.0
	Total	7.7	9.8	11.5	15.7	19.9	20.1	11.8	3.4	0.1			**100**
	Exceedance	100	92.3	82.5	71.0	55.3	35.4	15.3	3.6	0.1			

The records from the three current meters show that there is slightly more flow to the north on the east side of the main channel and in the channel east of Middle Bank, and more flow to the south at Crib Point Jetty Berth 2. The difference in currents from west to east indicate an overall anti-clockwise circulation of water within Lower North Arm. Overall, the current measurements show a net inflow in to North Arm in the east and a net outflow from North Arm in the west near Crib Point.

Table 5-6 shows depth related differences in current speed at ADCP #1 to #3. Current speeds are shown for the seabed (2 m above the instrument), mid-depth (5 m above the instrument) and the surface (9 m above the instrument). At Crib Point Jetty Berth 2 (ADCP #1) current speeds were slowest at the seabed (average 0.35 m/s) and increased towards the surface (average 0.41 m/s). The peak or 90th percentile speed at this location was over 0.79 m/s near the surface.

On the east side of main channel (ADCP #2) current speeds were also slowest at the seabed but faster than at the seabed near Crib Point Jetty (average of 0.4 m/s). Average current speeds at the surface were fastest, and faster than near Crib Point Jetty (average of 0.5 m/s). Peak current speeds on the east side of the main channel were over 0.8 m/s at the surface.

In the channel east of Middle Bank (ADCP #2) average current speeds at the seabed were the same as at Crib Point Jetty (average 0.35 m/s). Surface currents at this location were mid-way between those at Crib Point Jetty and the main channel (average 0.47 m/s). Peak current

speeds at the surface were also mid-way between Crib Point Jetty and the main channel with a 90th percentile of 0.72 m/s.

Interestingly, peak current speeds near the seabed were highest at Crib Point Jetty, with a 90th percentile of 0.73 m/s (compared to 0.64 m/s in the main channel and 0.55 m/s in the channel east of Middle Bank).

Table 5-6. Current speeds by depth at ADCP 1, 2 and 3

	West (CPJB2) ADCP #1			Mid-Channel ADCP #2			East-Channel ADCP #2		
Current speed in m/s	**Seabed**	**Mid-water**	**Surface**	**Seabed**	**Mid-water**	**Surface**	**Seabed**	**Mid-water**	**Surface**
Average	0.35	0.38	0.41	0.40	0.46	0.50	0.35	0.40	0.47
90%	0.73	0.78	0.79	0.64	0.73	0.80	0.55	0.63	0.72
70%	0.59	0.65	0.67	0.52	0.60	0.66	0.45	0.53	0.61
50%	0.44	0.50	0.55	0.41	0.47	0.52	0.36	0.43	0.50
10%	0.35	0.39	0.43	0.11	0.13	0.14	0.12	0.12	0.15

5.4.2 Net Transport in Western Port

The tidal dominance of water movements and exchange and the bathymetry of Western Port mean that there is little circulation of water around Western Port. Studies by Hinwood and Jones in 1979 showed that the tides in Bass Strait push and pull the seawater in Western Port back and forth, with a small net clockwise circulation around French Island that is estimated to be just 1% of the tidal volume (Hinwood and Jones, 1979).

Small, residual volumes circulating clockwise around French Island were also modelled recently by Cinque *et al* (2018). The residual circulation around French Island is driven by the larger volume of water moving up North Arm relative to East Arm, as well as prevailing westerly winds. Net flows can exist in the opposite direction to the main flow of the currents (particularly during easterly winds). The bathymetry in the northeast of the bay is consistent with this small residual circulation. The tidal divide is characterised by continuous, level mudflats and there is a wide disconnect between the dendritic channels in North Arm and East Arm (Figure 5-8).

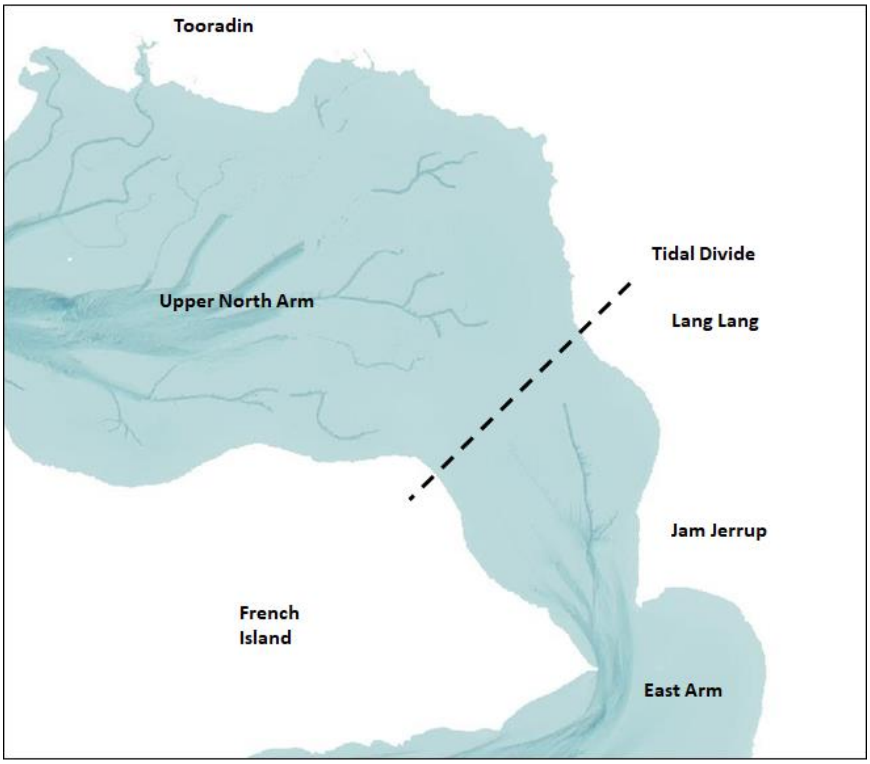


Figure 5-8. The Tidal Divide in Western Port

Source: NatureKit, DELWP

Half-tidal fluxes measured by Hinwood and Jones in 1979 at several cross sections across the bay show that the fluxes of water moving into and out of the bay are very similar (Figure 5-9). One of the measured sections during the study extended across the bay from Stony Point. There were two sets of measured data for the half-tide fluxes at the Stony Point section. The first measurement shows 380 x 10^6 m^3 of water flowed north past the cross section, while 375 x 10^6 m^3 of water flowed south.

The second measurement showed 391 x 10^6 m^3 of water flowed north and 420 x 10^6 m^3 flowed south. This would indicate that the movement of water during the ebb and flood tides is almost equal, with similar volumes of water moving in either direction, rather than circulating clockwise around the bay. Thus, the same water is moving back and forth in North Arm and is slowly being exchanged with Bass Strait water over a longer period.

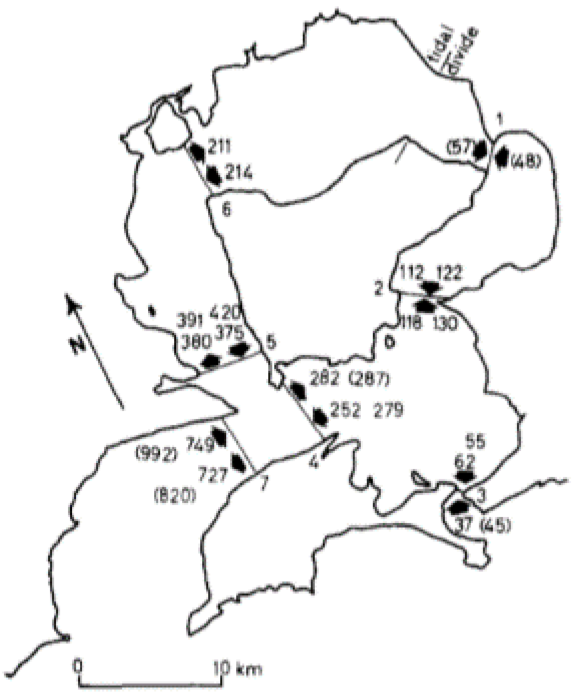


Figure 5-9. Half-Tidal Fluxes at Cross Sections

Source: Hinwood and Jones, 1979

CEE performed a similar study with the current data obtained from ADCP #1, #2 and #3. A cross section was established from the Crib Point Jetty to French Island along the path where the three current meters are positioned. The cross-section depth data was obtained from (DEPI Future Coasts, 2.5 m LADS) and Multibeam Data (2013). The total area of the cross section was separated into three separate sections with ADCP #1 representing the area nearest Crib Point, ADCP #2 representing the main channel and ADCP #3 representing the eastern channel (Figure 5-10).

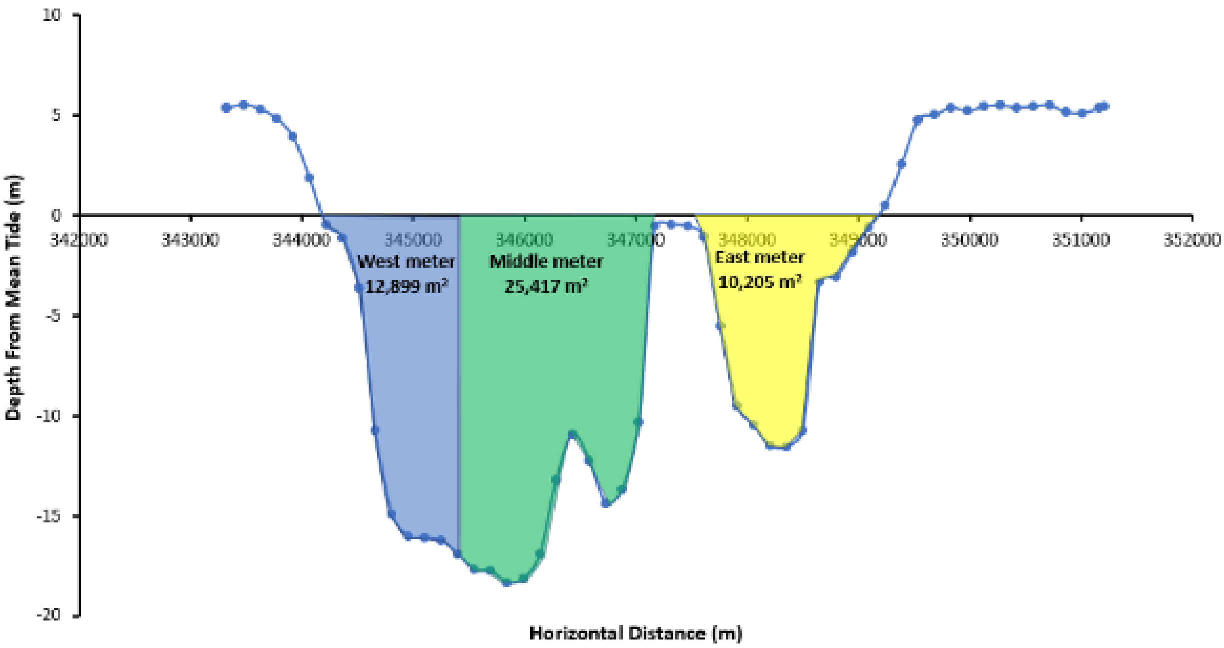


Figure 5-10. Crib Point Cross Section

The first ten days of current data from the meters was extracted and separated to represent water moving north from water moving south. The vectors were adjusted for the duration of tide cycles, summed and multiplied by the area to find:

- the total volume of water moving north and south at each meter
- the total flow north and south for all three sections; and
- the net water movement.

The results were then divided by 20 (20 tide cycles in 10 days) to obtain the half-tide cycle values.

These 2019 results can be compared to the 1979 study by (Hinwood and Jones, 1979). The results of calculations for the 2019 current data are shown in Table 5-7.

Table 5-7. Crib Point Flux Results

	Total Volume North	Total Volume South	Net Flow
West Meter	1,883,828,000	-2,298,001,000	-414,173,000
Middle Meter	5,075,546,000	-4,867,983,000	207,563,000
East Meter	1,854,572,000	-1,627,208,000	227,364,000
Total	8,813,946,000	-8,793,192,000	20,754,000
Half Tidal Flux	440,697,000	-439,660,000	1,037,000

The 2019 results show that there is a very similar volume of water moving north and south at each tide with only a very small net movement north over the section across North Arm. They also show that the net flow at Crib Point is south, whereas the movement at the middle and eastern meters is to the north. This finding matches the current speed patterns shown in Table

5-3, Table 5-4 and Table 5-5. The half-tidal fluxes show that the total volume of water moved per half tide is 441x10^6 m^3 north and 440x10^6 m^3 south (Figure 5-11). The 2019 results for Crib Point are very similar to the results of Hinwood and Jones (1979) for Stony Point (Figure 5-9).

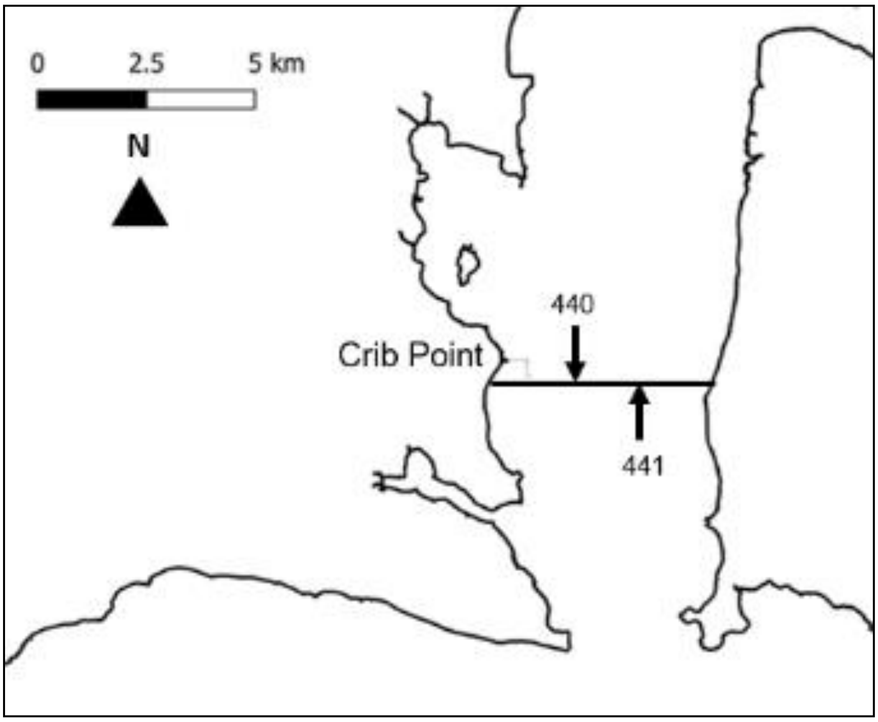


Figure 5-11. Crib Point Half-Tidal Fluxes (10^6 m^3), 2019

5.5 Western Port Water Quality

Water quality in Western Port is linked to that in Bass Strait owing to the regular tidal exchange, with the exception of nutrients and suspended solids (discussed below). No major rivers flow into Western Port. There is local freshwater input from small creeks on the Mornington Peninsula, as well as input from the Koo Wee Rup swamp (and foothills) though constructed drains forming the Bunyip River, Lang Lang River, Deep Creek and Toomuc Creek. Bass River enters the East Arm between Corinella and San Remo, draining an area of South Gippsland to the east of Western Port.

The entire Western Port catchment has an area of 3,500 km^2 and produces a freshwater input estimated to average 0.6 million m^3/d. In contrast, tidal water inflow averages about 1,200 million m^3/d. Thus, except at times of major floods in the catchment, freshwater input is very small in relation to tidal flows and Western Port generally has much the same salinity, temperature and nutrient concentrations as the oceanic waters in Bass Strait.

Water Quality in Western Port has been monitored regularly (approximately monthly) at three fixed locations by EPA Victoria for many years. EPA monitors one site at Hastings (Lower North Arm), one at Barrallier Island (Upper North Arm near north-west corner of French Island) and one at Corinella (East Arm). Water quality testing is used to monitor the potential influence of human activity on Western Port water quality. Several indicators of water quality are assessed against water quality objectives published in the State Environment Protection Policy (Waters) 2018. Monitoring data are presented in annual 'Report Cards' on water quality in Western Port and its Catchment.

5.5.1 Water Quality Index

The report card for Western Port (Yarra and Bay, 2020) includes five water quality indicators; turbidity, nutrients, algae, salinity and dissolved oxygen. These are each assessed on a scale from Very Poor to Very Good and are then combined to give Western Port an overall Water Quality Index (WQI) score.

The 2017-18 report card for Western Port gave an overall WQI score of good. Nutrients, algae and salinity indicators ranked as Very Good; while water clarity ranked as fair (Figure 5-12). Dissolved oxygen was not included in the report card for 2017-18 due to instrument problems, but in previous years had mostly ranked as 'Very Good'. The WQI for 2017-18 varied by region, with water quality in North Arm ranked as Very Good, while East Arm (Corinella) ranked as Poor (due to low water clarity). The WQI for Western Port has ranged from 'Good' to 'Very Good' since the year 2000, with no long-term trend. The WQI varies from year to year due to climatic conditions and rainfall variability.

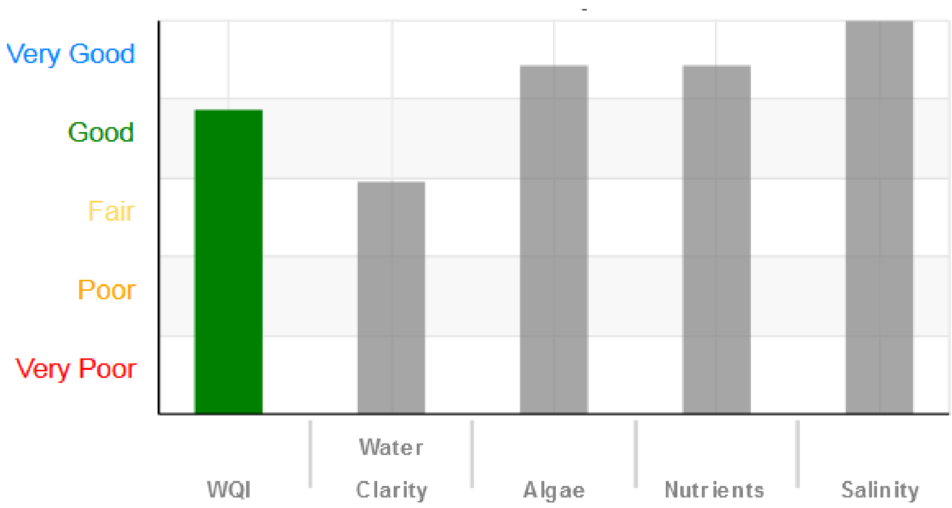


Figure 5-12. Western Port Water Quality Index in 2017-18

5.5.2 Salinity

Salinity in Western Port has a small range and a similar variation across seasons at each of the sites; although the variation at Corinella is greater than at Hastings and Barrallier Island. Salinity in North Arm ranges from 35 practical salinity unity (psu) in winter-spring to 37 psu in late summer. The increase in salinity in summer can be attributed to the local effect of evaporation from the shallow mudflats during the summer months. The more variable salinity in East Arm (Corinella) is due to freshwater inputs from rivers and streams around the northeast and east coast of Western Port in winter-spring and evaporation over the mudflats in summer.

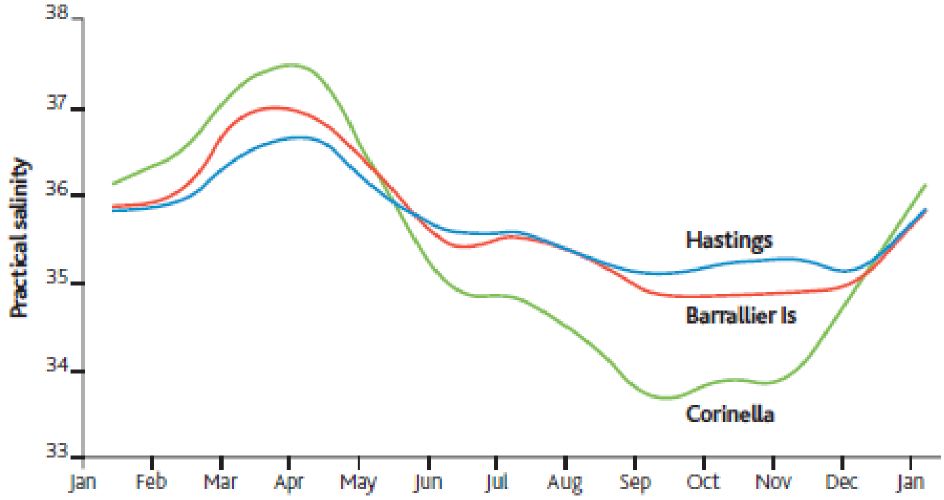


Figure 5-13. Western Port Water Quality- Salinity

5.5.3 Suspended Solids

Suspended solids are a major ecological factor in Western Port as they reduce water clarity and light availability in the water column. Suspended solids in Western Port are much higher than those in Bass Strait or Port Phillip due to resuspension of sediment from the mudflats and channels. Levels of total suspended solids in North Arm (Hastings and Barralier Island) are typically around 6-7 mg/L. These levels cause generally low water clarity (compared to the Western Entrance and Bass Strait for example). Much higher and more variable levels of suspended solids occur in East Arm (Corinella) due to erosion of the shoreline near Lang Lang by wind waves and resuspension of sediments from mudflats by wind waves and tidal currents.

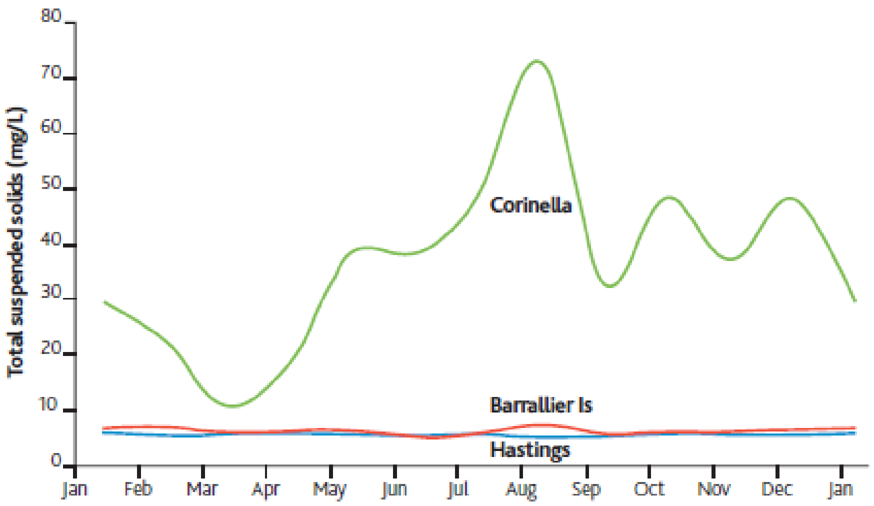


Figure 5-14. Western Port Water Quality – Suspended Solids

5.5.4 Dissolved Oxygen

Dissolved oxygen levels are generally high at over 90 per cent saturation (Figure 5-15). The water quality has generally been classed as 'good' (EPA, 2011) and levels of two key indicators, enterococci and E. coli, have been within state guideline limits for the bay (EPA, 2011).

Each year there are large variations in the dissolved oxygen. Dissolved oxygen has been decreasing throughout the bay over the last 20 years with a drop at Hastings and Corinella by approximately 6 % and a drop at Barrallier of approximately 8 %. Figure 5-15c shows the yearly variation at Barrallier Island. 2006 - 2009 shows less variation with more constant averages year to year.

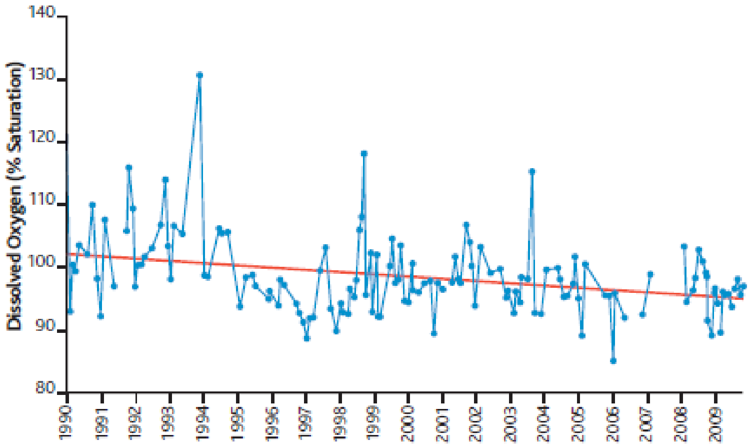


Figure 5-15. Western Port Water Quality – Dissolved Oxygen

Source: EPA Victoria, 2011

5.5.5 Nutrients

Nutrients inputs to Western Port from the catchment are relatively low due to the small freshwater inputs, especially compared to Port Phillip (Melbourne Water 2011, Shapiro 1975). The nutrient regime in Western Port is strongly linked to that in Bass Strait owing to the large tidal exchange.

The water quality index for Western Port shows that since the year 2000 nutrient concentrations have been classed as Good in four years and Very Good in 12 years (Yarra and Bay, 2020). Figure 5-16 shows the monthly pattern of total nitrogen concentrations at Hastings for the period 1984 to 2013 (EPA Victoria data). The plot shows that average total nitrogen at Hastings varies from a low of 0.12 mg/L in winter to a peak of 0.16 mg/L in late Summer – a relatively small annual range. Higher total nitrogen concentrations are measured near Lang Lang – around 0.25 mg/L in winter months.

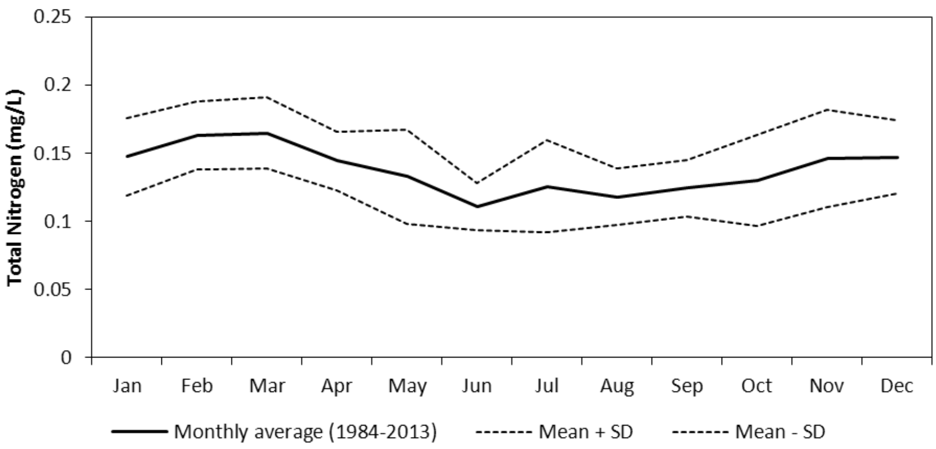


Figure 5-16. Monthly variation in dissolved inorganic nitrogen at Hastings

Source: EPA Victoria

5.5.6 Seawater Temperature

As with other water quality parameters, seawater temperature in Western Port is strongly linked to that of Bass Strait, though there is additional variation due to local effects. Additional heating and cooling occurs predominantly over the shallow mudflats due to seasonal air temperatures, winds, insolation and inundation and exposure of the mudflats. Figure 5-17 shows a maximum temperature of 21-22°C occurs in February and the minimum of 11-12°C occurs in July.

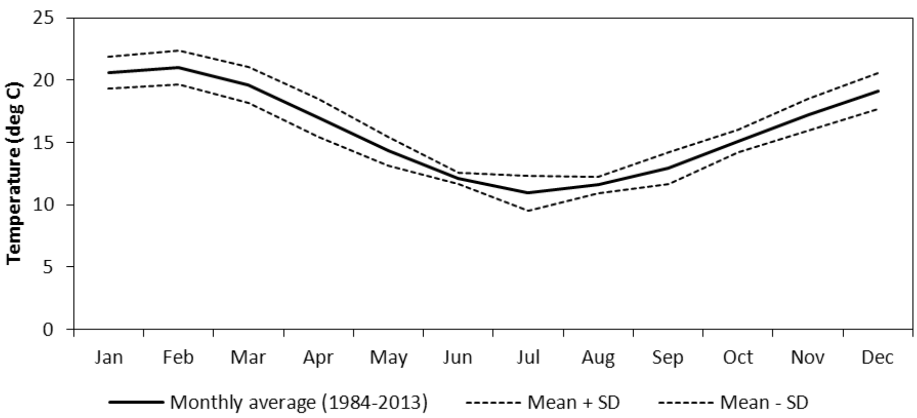


Figure 5-17. Monthly variation in temperature at Hastings

Source: EPA Victoria

Temperature Monitoring at Crib Point

A project-specific 12-month assessment of short-term and long-term natural variations in seawater temperature was conducted using temperature loggers deployed at Crib Point Jetty. Seawater temperature was measured every 15 minutes from January 2019 to January 2020. These data were used to determine the magnitude of seasonal, daily and hourly variation in temperature experienced by marine biota near Crib Point (and is indicative of conditions throughout Lower North Arm).

Figure 5-18 plots the daily average, maximum and minimum temperatures at Crib Point along with daylength over 2019. The graph shows that the water temperature maximum lagged longest daylength by approximately a month in summer, and minimum temperature lagged shortest daylength by approximately a month in winter 2019. The maximum average temperature in 2019 was 24°C, and the minimum average was around 11°C. This is similar to the longer-term records of EPA Victoria shown in Figure 5-17, though the 2019 summer maximum was above average, likely due to 2018-2019 being a warm year. The variation between daily maximum and minimum temperatures was highest in Summer and Winter at around 2°C and smaller in Autumn and Spring at around 1°C.

In mid-February 2019, there was a significant decrease in ambient temperature from a peak of 23°C to 20°C over just a few days. Towards the end of March, there was another sudden drop in water temperature from approximately 21°C to under 19°C in just over a day. Another large temperature variation was measured in December 2019-January 2020 (corresponding to the peak bushfire event in Victoria). These were the most significant changes in temperature recorded.

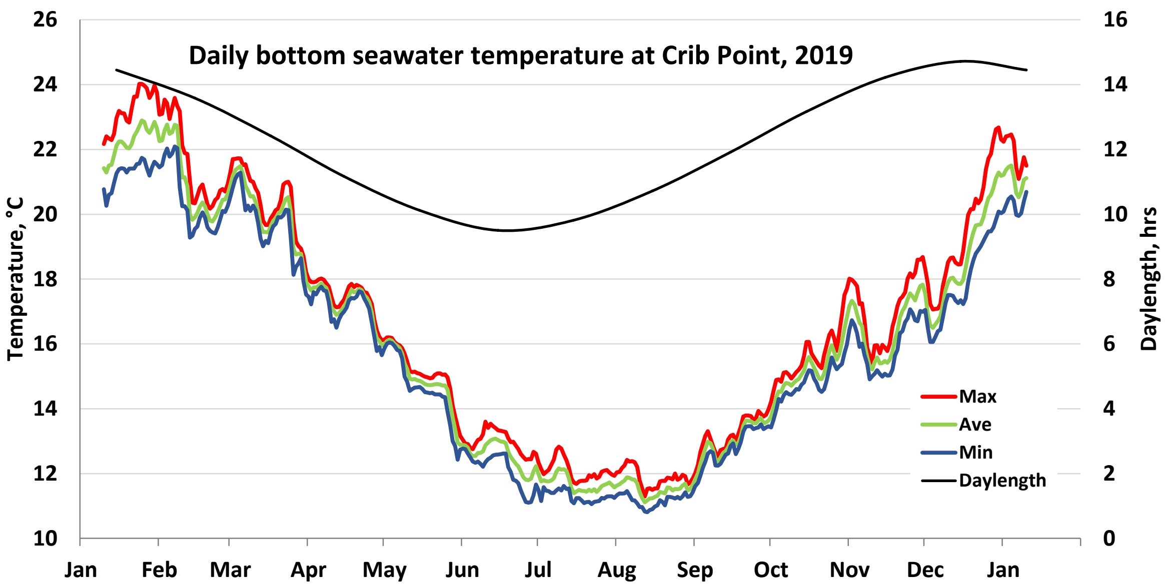


Figure 5-18. Daily Temperature at Seabed

The rapid declines in seawater temperature are due to storm fronts causing an influx of cooler Bass Strait water as well as cooling of shallow waters in Western Port. Through the Autumn months the water temperature showed gradual rises and falls in each month but had a declining trend down to a low of 12°C at the end of June. The temperature remained between 11°C and 12 °C during July and August and then increased steadily from September to November as atmospheric temperatures began to rise. After steady warming through spring, there was a sudden drop in temperature at the end of November, again associated with a large storm.

Figure 5-19 shows the daily variation in seawater temperature at Crib Point during the period of monitoring. The monitoring shows that marine biota at Crib Point (and Lower North Arm) naturally experience a 13°C seasonal variation in temperature, and a daily variation of up to 2°C on a daily basis (Summer and Winter).

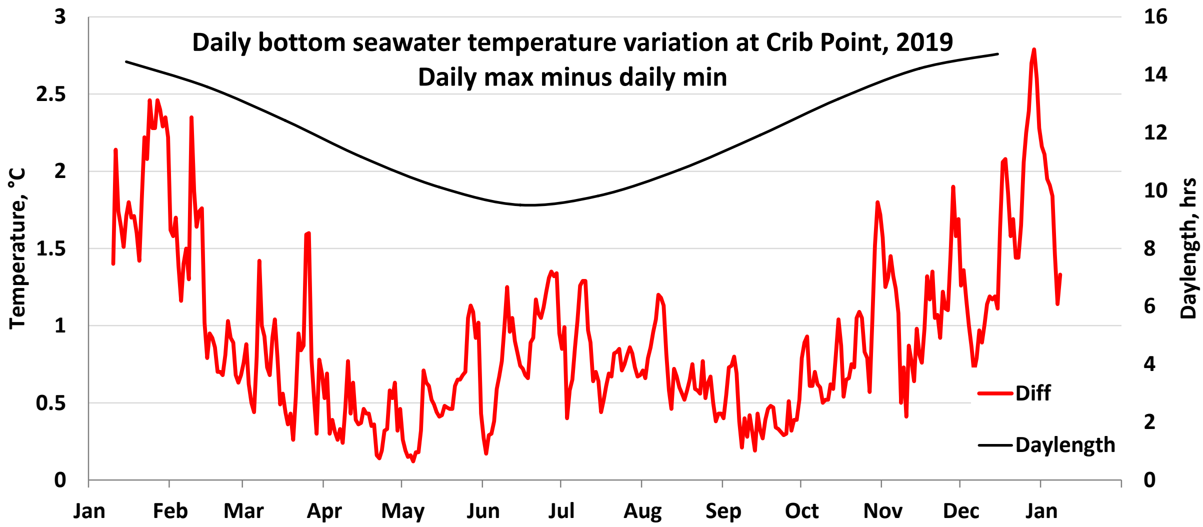


Figure 5-19. Daily Temperature Variation at Seabed

The figure also shows that the natural variation is smaller in the autumn and spring months and is higher in the summer and winter months. This is due to local processes such as the heating and cooling of mudflats during the flood and ebb tides. During summer the mudflats and shallow bay waters are heated by the sun and are warmer than the incoming water from Bass Strait resulting in a large temperature difference. In winter the mudflats and shallow waters are cooled resulting in Wester Port water being cooler than the water from Bass Strait.

The short-term variations in seawater temperature at the seabed at Crib Point are similar to the daily variations. There are significant levels of natural variation in seawater temperature around the vicinity of Crib Point throughout the year over an hour and larger variations over 6-hour and 12-hour periods.

Temperature Stratification with Depth

Figure 5-20 shows the depth profile of temperature at Crib Point Jetty for each month between December 2018 to July 2019. The temperature stratification was measured using a hydro profiler. The figure shows that there is little to no stratification through the water column in any month – temperature is consistent at all depths. The plot is consistent with the strong tidal currents causing regular mixing of the water column, meaning that the water column does not become stratified in any month or season.

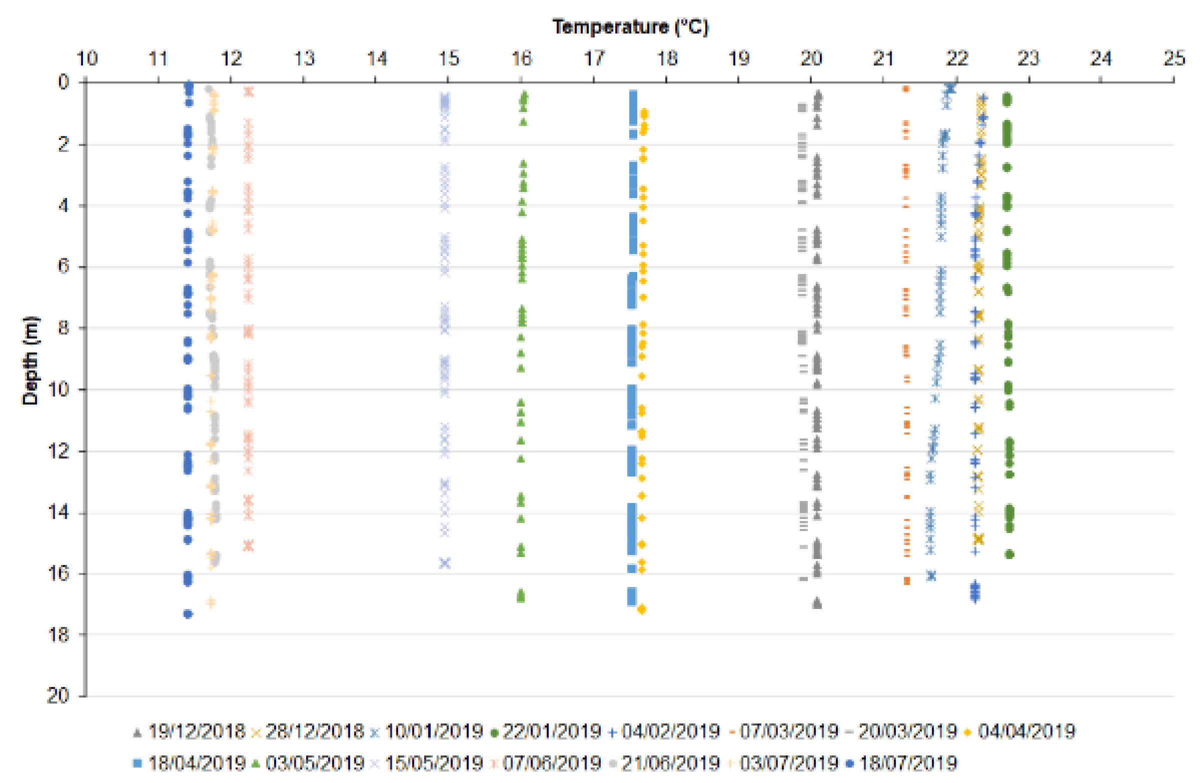


Figure 5-20. Temperature Stratification at Crib Point

Guideline Value for Temperature Assessment

Temperature can cause biological stress due to:

- impacts on the metabolism of biota
- the toxicity of contaminants
- levels of stressors such as pH and dissolved oxygen.

An appropriate method for establishing a guideline value for a water quality stressor is set out in SEPP (Waters) 2018 and ANZECC (2000). The Victorian SEPP (Waters) 2018 states that water quality guideline objectives can be established by calculating the 25th and/or 75th percentiles for reference sites using data collected at least monthly over a minimum of 12 months. ANZECC (2000) differs slightly in specifying the 20th and 80th percentile.

25th per centile, 50th per centile and 75th per centile temperature change values were calculated from the collected data for half tidal (6 hour), full tidal (12 hour) and 24-hour time periods. There is negligible increase between the 6-hour and 12-hour periods and only a small increase to the 24-hour period. The 1-hour variation was smaller than the 6-hour temperature changes. This confirms that the 6 to 12-hour temperature variations are most likely due to the solar heating and cooling of shallow water and exposed mudflats and thus, the mixing of water of different temperatures. The monitoring data shows that the marine biota in North Arm are accustomed to large seasonal and short-term variations in seawater temperature.

Table 5-8. Interquartile Range of Temperature Variation (calculated in December 2019)

Range Period	25th per centile	50th per centile	75th per centile	Interquartile range (25% - 75%)
6-hourly	0.34°C	0.55°C	0.83°C	0.5°C
12-hourly	0.34°C	0.55°C	0.83°C	0.5°C
24-hourly	0.46°C	0.67°C	0.96°C	0.5°C

One relevant guideline value to prevent temperature stress at Crib Point is the interquartile range calculated from the 2019 records discussed above. This was calculated for all data available in December 2019 (before the last month of measurements in the bushfire period, where seawater temperature was influenced by a temporary change in climatic conditions).

The derived guideline was 0.5°C. In this context, 0.5°C represents a short-term temperature variability that marine biota within the vicinity of Crib Point within Western Port are currently accustomed to.

The calculated guideline value provides a metric that:

- Is based on measured seawater variation at Crib Point over an eleven-month period;
- Represents temperature variation experienced by biota in the water column and on the seabed in the channel in the vicinity of Crib Point on 6, 12 and 24 hourly time-scales;
- Includes high and low variation either side of the mean annual temperature; and
- Provides a conservative basis for assessing the risk to marine biota from thermal differences resulting from FSRU discharges.

Figure 5-19 shows that there were large variations in seawater temperature in the final month of monitoring (December 2019 to January 2020). As a result, the 0.5ºC over the 11 months became 0.6ºC over 12 months.

The frequency distribution of 12-hour temperature changes over the year are shown in Figure 5-21 The variation over 12-hours exceeded 2ºC on a few days. However, it is considered that such changes are likely to result in stress on some marine biota.

For the assessment of changes in seawater temperature, two limits were used:

- A conservative guideline of 0.5ºC (represented by the red circle in Figure 5-21; and
- A maximum acceptable change of 0.8ºC based on the 75 per centile of the measured ranges (represented by the yellow circle in Figure 5-21).

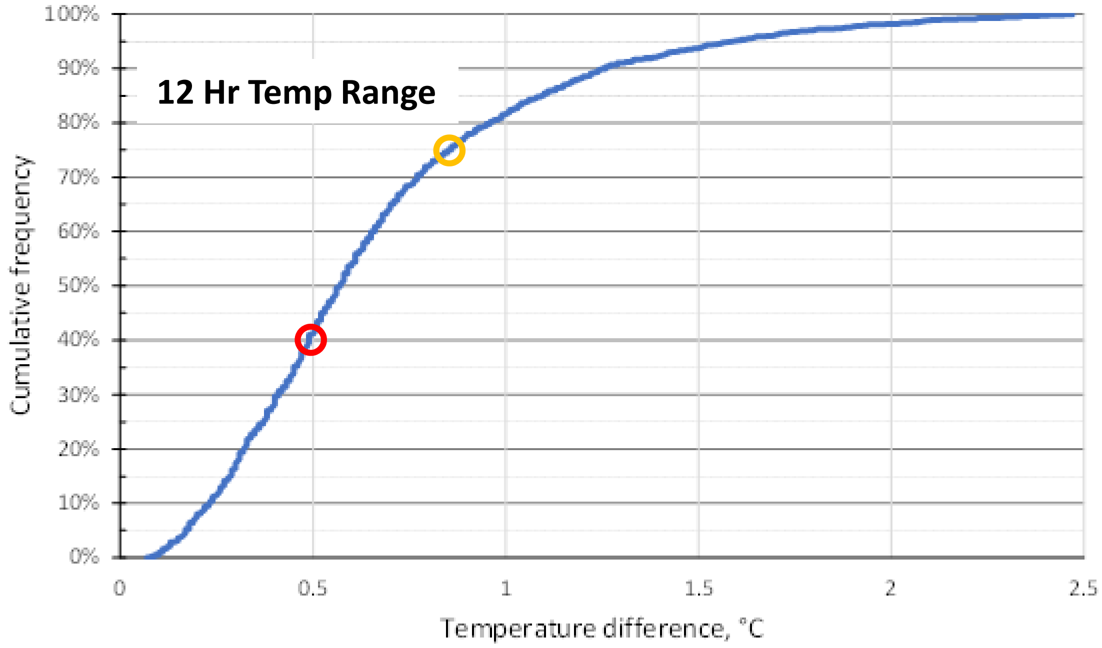


Figure 5-21. Cumulative Frequency of Temperature Difference

5.6 Benthic (Seabed) Habitats and Biodiversity

The proposed FSRU would be located at Berth 2 at Crib Point Jetty (shown in red on Figure 5-22). This berth is at the southern end of the Crib Point Jetty head. The jetty head from the northern mooring dolphin to the southern mooring dolphin is approximately 670 m long. Berth 1 is located at the north end of the jetty head and is currently used for unloading petroleum and distillate, which are stored in onshore tanks.

A large part of the shipping basin at Crib Point Jetty was dredged in the 1960s in preparation for the operation of tankers servicing the Crib Point oil refinery, which was decommissioned in the mid-1980s.

The seabed habitats in the vicinity of the jetty comprise soft seabed, with saltmarsh and mangrove communities in the upper intertidal area, patches of seagrass meadows in the intertidal and shallow subtidal areas, bare intertidal mudflats between the mangroves and seagrass and largely unvegetated seabed below the lower extent of the subtidal seagrasses (Figure 5-22).

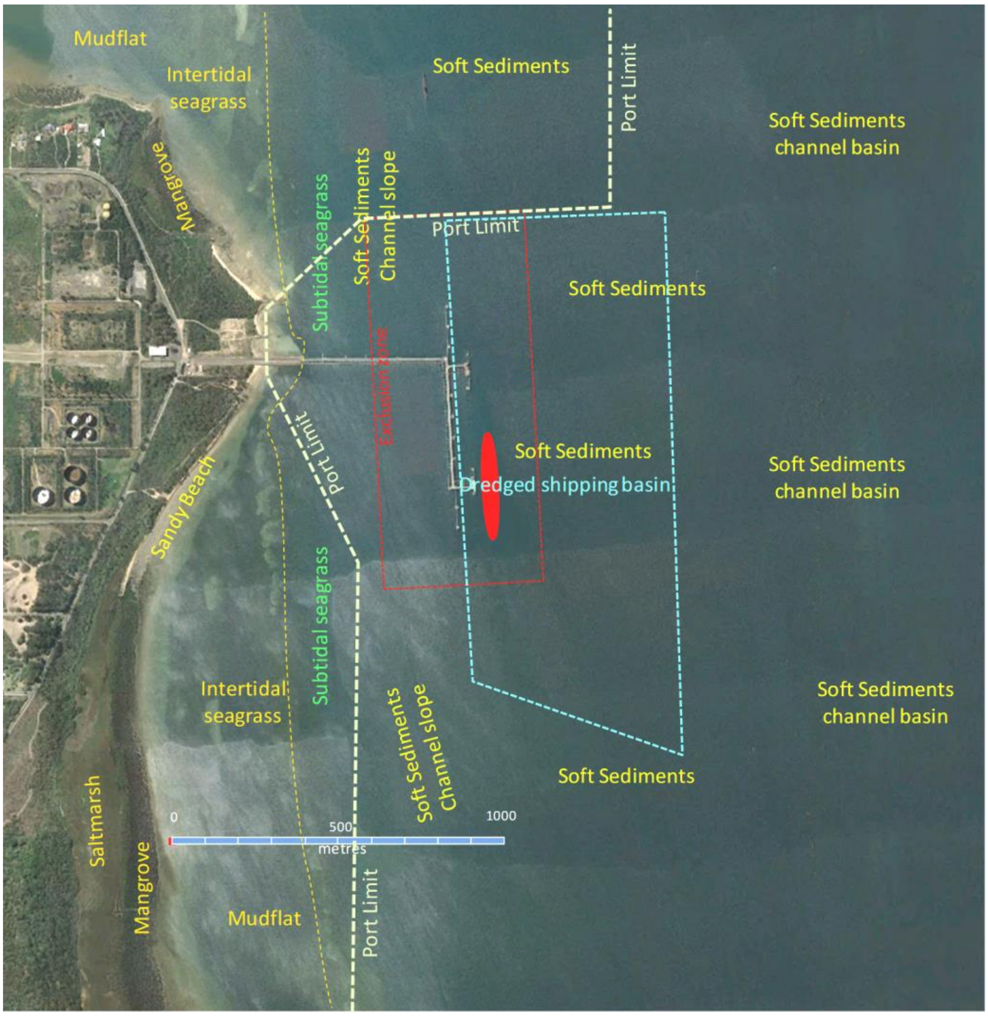


Figure 5-22. Marine benthic habitats at Crib Point

Source CEE 2018c

Benthic habitats are the product of:

- seabed composition and bathymetry
- hydrodynamics
- temperature
- light and nutrient regime
- biological conditions.

Seabed types in the marine environment typically include sediments, rock, and biogenic hard substrate and vary from intertidal to deep subtidal environments. Hydrodynamics are the product of bathymetry, tide and wind driven currents.

The light climate for benthic habitats is determined by latitude (solar exposure), water quality and depth (light attenuation). The temperature climate is determined by latitude with a significant influence from regional scale factors such as landmasses and ocean currents. The nutrient regime is determined by the nutrient inputs from riverine, aeolian and oceanic sources and nutrient cycling within the ecosystem. Biological conditions are influenced by benthic

habitat forming species such as seagrasses and some epifauna and infauna that modify sediment characteristics through bioturbation.

The seabed of Western Port is characterised by extensive intertidal mudflats intersected by deep channels. These are key to the ecological character of Western Port (Kellogg Brown and Root, 2010). Aerial photographs and sediment grab samples collected in the 1970s were used to map the distribution of sediment types and bedforms (Figure 5-23).

Sediments in the deeper channels of Lower North Arm are medium sand while the intertidal banks comprise fine sand, silt and clay (Figure 5-23). Coarse sand occurs in the deeper sections of channels in Upper North Arm, near Corinella and in the Western Entrance.

While soft sediments dominate the seabed, there is also a sparse or patchy distribution of unconsolidated hard substrates such as shell, rhodolith and other biogenic substrates.

Reef forms a very small proportion of benthic habitat in Western Port. Reef habitat in North Arm includes bedrock, boulder and cobble at Crawfish Rock and Eagle Rock and small isolated areas associated with headlands or rock outcrops. Larger areas of reef and cobble occur along the coast between Flinders and Somers, around Tortoise Head on French Island and along the north coast of Phillip Island.

Saltmarsh, mangrove, seagrass and unvegetated sediment are the major benthic habitats in Western Port. Maintenance of these habitats, along with the diverse range of benthic invertebrates and fish associated with each habitat are critical to the ecological character of the Western Port Ramsar site (Kellogg Brown and Root, 2010).

5.6.1 Existing Understanding of Benthic Habitats

The distribution of major marine benthic habitats and associated communities is compiled at a national level in GIS format at the Institute of Marine and Antarctic Studies (IMAS), University of Tasmania (Lucieer et al 2017). These data compiled between 2001 and 2016 together with water depth data (DELWP and VRCA) for Western Port were compiled into QGIS by CEE for this project and are shown in Figure 5-24.

Thematic data on marine values, features and coastal hazards in Western Port can be accessed at https://uat.mapshare.vic.gov.au/coastkit/.

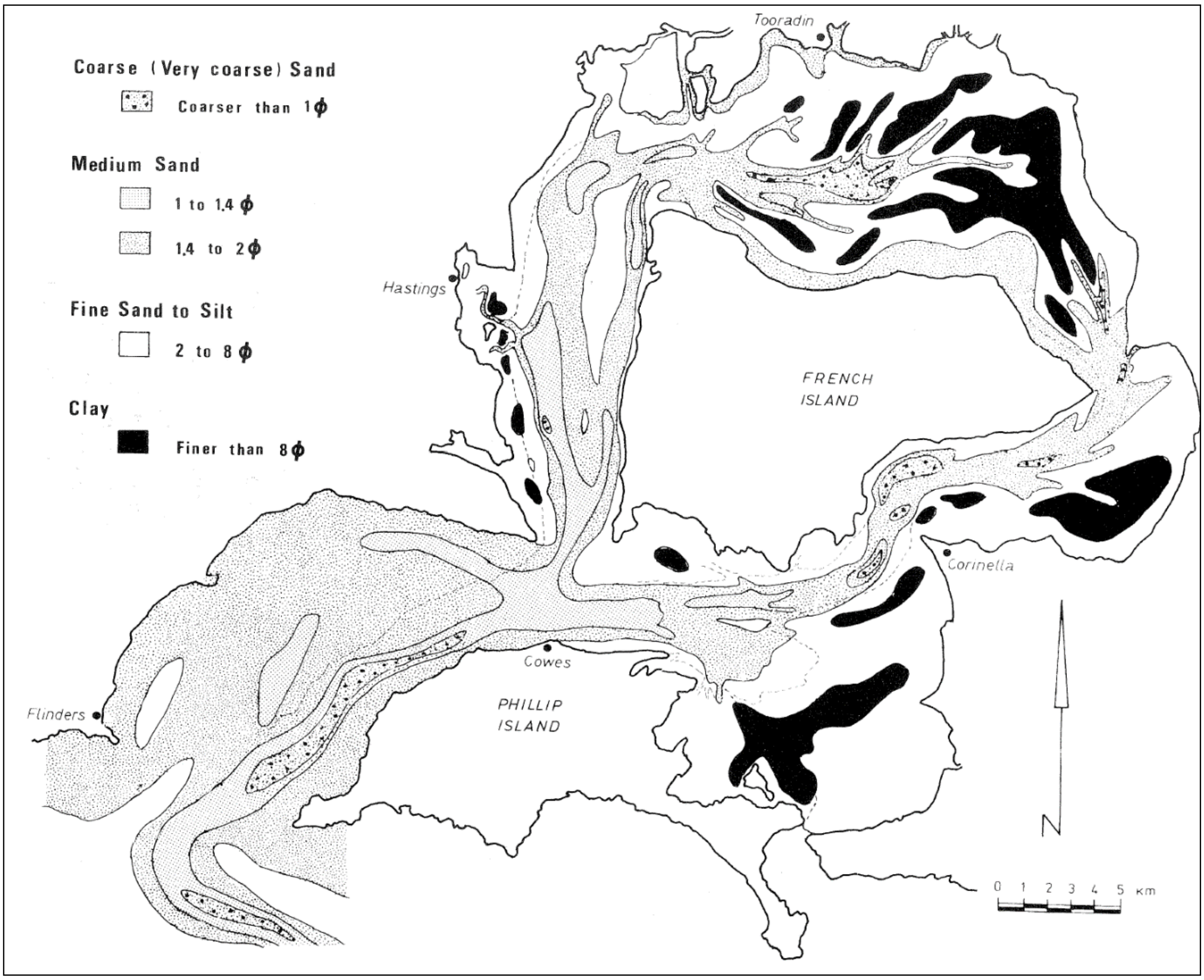


Figure 5-23. Western Port seabed sediments

Source: Marsden, Mallett and Donaldson 1979

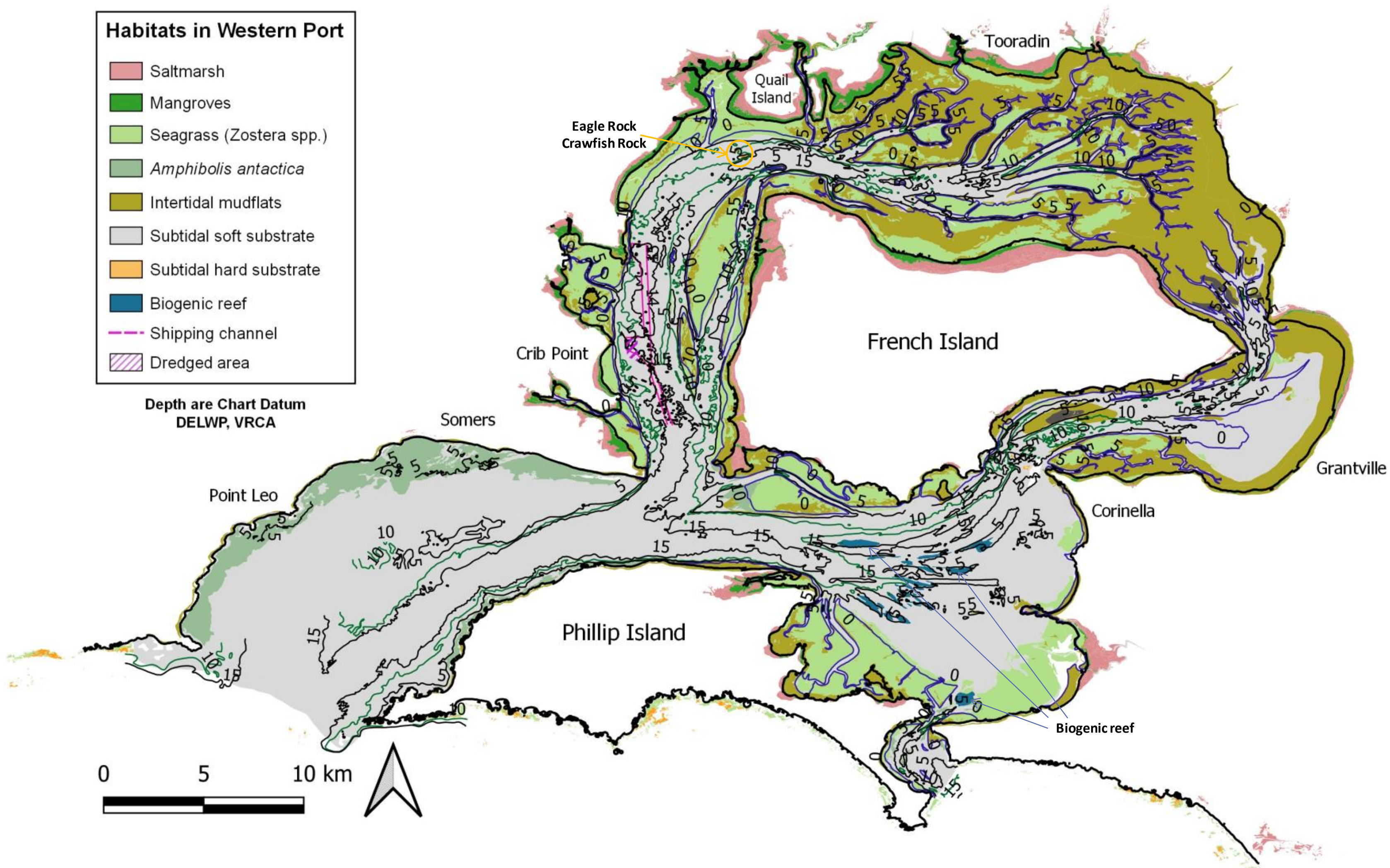


Figure 5-24. Benthic (seabed) Habitats in Western Port

Habitat Data Source: SeaMap Australia (Lucier *et al* 2017)

Almost 70 per cent, or 523 km^2 of the benthic habitat in Western Port is subtidal channel and basin (subtidal soft substrate) with sandy sediment being the dominant substrate. Around 40 per cent of seabed habitat in Lower North Arm is subtidal channel and basin (subtidal soft substrate), as shown in Figure 5-24. Subtidal habitats in Western Port include seagrass, mobile sand and mixed sediments of sand, shell and other biogenic substrates.

The remaining 30 per cent, or 231 km^2 of seabed in Western Port is intertidal and includes mangrove, mudflat and seagrass habitat. There is a further 11 km^2 of saltmarsh habitat inshore of mangroves above the mean high tide mark in Western Port (Boon, 2011). Around 60 per cent of seabed habitat in Lower North Arm is intertidal mangrove, mudflat and seagrass. Intertidal habitats are mostly broad, level, sand and mud flats. The distribution of intertidal seagrass, mangrove and saltmarsh habitat is relatively well described by a series of seagrass mapping studies (NSR 1974, Bulthuis 1984, Stephens 1995, Blake and Ball 2001, Boon *et al* 2011).

The sparseness of information on subtidal soft seabed benthic habitats was identified as a major knowledge gap during the referral stage and was reflected in the scoping requirement for the EES. Thus, towed video surveys and infauna sampling methods to develop a better understanding of the distribution and biodiversity of subtidal benthic habitats and biodiversity in the vicinity of Crib Point were undertaken as part of this assessment.

5.6.2 Saltmarsh and Mangroves

Saltmarsh and mangrove habitats occur along the west and north shorelines of North Arm, the west and north shoreline of French Island, the east side of Phillip Island and around the mouth of the Bass River (Figure 5-24). The wave and current exposure at Crib Point is too high for the establishment of saltmarsh and mangroves. The nearest saltmarsh and mangrove habitats to the proposed location of the FSRU are shown in (Figure 5-22) and occur:

- near the HMAS Otama Lookout approximately 1 km west-northwest from the proposed FSRU
- to the south of Woolley's Beach around 1 km west-southwest FSRU.

More extensive areas of saltmarsh and mangrove habitat occur in Hastings Bight to the north of Crib Point, and Hanns Inlet south of Crib Point.

Saltmarsh and mangrove habitats form two of the three important marine vegetation components (the other is seagrass) in the Western Port Ramsar site (DSE, 2003, Boon et al, 2011).

Saltmarsh occurs above mean high tide level in areas subject to intermittent tidal inundation or saline groundwater, usually between terrestrial vegetation and mangroves. Saltmarsh vegetation is generally less than 0.5 metres tall and consists primarily of salt-tolerant succulent herbs, low succulent shrubs, rushes and sedges.

Boon *et al* 2011 estimated that there is around 1,088 hectares of saltmarsh habitat around Western Port, comprising:

- Wet Saltmarsh Herbland (182 hectares);
- Wet Saltmarsh Shrubland (761 hectares);
- Coastal Tussock Saltmarsh (39 hectares);
- Coastal Dry Saltmarsh (8 hectares); and
- Coastal Aggregate Saltmarsh (98 hectares).

Saltmarsh provides habitat for many bird species. It is likely saltmarsh provides foraging opportunities for some marine fish species that move into saltmarsh from the mangrove and mudflat habitat offshore during periods of inundation (Boon et al, 2011). Saltmarsh can stabilise and accumulate sediment, and also colonises suitable new habitat created by changes in sea level or seabed level due to natural and anthropogenic processes (Boon *et al* 2011). The area of saltmarsh habitat at Western Port that existed around the time of European colonisation is estimated to have been reduced by around 15 per cent due to infilling and harbour construction activities at Hastings and Yaringa (Boon *et al* 2011). Saltmarsh that remains in these areas has also been damaged by vehicles (four-wheel drives and motorbikes, Boon et al, 2011).

A single species of mangrove, *Avicennia marina subsp*. a*ustralasica*, occurs within Western Port, which is near the southern-most extent for mangroves in the southern hemisphere. The latest estimates (Boon *et al* 2011) are that there are 1,800 hectares of mangroves around the shores of Western Port.

Mangroves can protect coastlines from erosion by wave action and may also expand seaward and landward where conditions are favourable. They provide habitat for a variety of terrestrial and aquatic fauna, although the functional links between organisms and these habitats in Western Port was identified as a research priority in the Melbourne Water review (2011).

Mangroves provide a substrate for the growth of algae and colonization by sessile invertebrates such as barnacles. The sediment within mangrove stands is habitat for benthic invertebrates, including gastropods, crustacea and polychaete worm. They also provide habitat structure for (mainly juvenile) fish, which are most abundant at the edge of mangrove habitat. The distribution of mangroves around Western Port appears to have been relatively stable since European colonisation, but their area has decreased in some areas and increased in others due to human activities (Dittman, 2011).

Mangrove habitat was lost to harvesting for production of Barralier ash in the 1840s, while other areas were removed through infilling (land claiming) for harbour and port facilities at Hastings and Long Island Point. Mangrove habitat has been lost or fragmented around boat ramps and drainage channels. On the other hand, mangrove habitat has expanded along channels constructed to drain the Koo-Wee-Rup swamp, and has also expanded seaward in some areas and landward into saltmarsh habitat in others (likely where land-subsidence has occurred).

5.6.3 Unvegetated Intertidal Mudflats

Unvegetated intertidal mudflats occur extensively in Western Port, particularly in the Upper North Arm and the Corinella segments. The nearest intertidal mudflats to the proposed FSRU and jetty facilities are approximately 500 m shoreward (west) of Berth 2 (Figure 5-22).

Data presented by Blake and Ball (2001) indicated that there was up to 168 km^2 of unvegetated intertidal mudflat in Western Port, or 22 per cent of the total seabed. Unvegetated intertidal mudflats occur between the seaward extent of mangroves (or the shoreline where mangroves are absent) and the landward extent of intertidal seagrass, as well as in between patches of intertidal seagrass below mean sea level. The area of unvegetated intertidal mudflat in Western Port increased significantly between 1973/74 and 1983/84 due to broadscale decline in intertidal seagrass cover, with only partial recovery documented to 2001 (Blake and Ball, 2001). The largest declines in intertidal seagrass, and the most limited recovery, have occurred in Upper North Arm and Corinella segments, which have shifted from predominantly intertidal seagrass to predominantly unvegetated mudflat habitat.

The intertidal mudflats support diverse and species rich assemblages of invertebrate infauna and epifauna. Benthic microalgae (microphytobenthos) contribute some primary production on unvegetated intertidal mudflats. The invertebrate fauna of intertidal unvegetated mudflats derive their food from detritus (such as seagrass and algae wrack), microphytobenthos and phytoplankton and zooplankton (at high tide).

Intertidal mudflats are important foraging areas for shorebirds and waders that feed on the infauna and epifauna, particularly at low tide. Fish and mobile invertebrates can forage over the intertidal flats at high tide, moving in from adjacent deeper habitat.

The structure of the invertebrate community in bare sediment habitats is variable at small and large spatial scales and relates to sediment particle sizes and depth/elevation. Infauna diversity tends to increase downslope (with inundation period) on intertidal flats (Edgar *et al* 1994).

The most numerous invertebrate fauna on unvegetated intertidal mudflats are polychaete worms and crustaceans. Grazing snails and burrowing clams (filter feeders) are also common and occasionally present in high numbers. Other invertebrate groups occur in low numbers.

Invertebrate diversity and abundance are generally lower in unvegetated areas compared to vegetated (seagrass) areas (Edgar *et al* 1994, Watson *et al* 1984).

The proportion of polychaete worms is higher in unvegetated areas than grassed areas, although capitellid worms are present in relatively high numbers in both vegetated and unvegetated areas (Edgar et al 1994, Watson et al 1984). Seagrass habitats are discussed in the next section. Unvegetated intertidal mudflats occur directly inshore from Crib Point Jetty, as well as along the shoreline to the north and south of Crib Point.

5.6.4 Intertidal and Subtidal Marine Seagrasses and Macroalgae

Benthic macrophytes such as seaweeds and seagrasses are important primary producers in coastal ecosystems and provide habitat for algal and invertebrate epiphytes, invertebrates and fish (particularly small or juvenile fish). Subtidal seagrasses in the North Arm do not currently extend much past 4 to 5 m depth in Lower North Arm due to the light attenuation in the typically turbid waters of Western Port and hydrodynamic factors (CEE 2009). The nearest seagrass habitat to the proposed FSRU and jetty facilities is approximately 450 m shoreward (west) of Berth 2.

Seagrasses are a key component of the marine environment of Western Port and one of three important vegetation components in the Western Port Ramsar site. They have important roles in primary production, provision of habitat and biogeochemical processes.

Seagrass Species and Distributions

Four species of seagrass occur in Western Port: *Zostera nigricaulis* (black-stemmed eel grass), *Zostera muelleri* (Mueller's eelgrass), *Amphibolis antarctica* (sea nymph), and *Halophila australis* (southern paddlegrass). Each species is characteristic of particular seabed characterisitics, light climate and wave exposure. The map in Figure 5-25 shows the extent of *Amphibolis* and *Zostera* spp. in 2001, based on aerial photography and extensive ground truthing (Blake and Ball, 2001) The map underestimates the extent of subtidal *Zostera* as it could not be distinguished in areas more than 2 m below low-tide due to low water clarity.

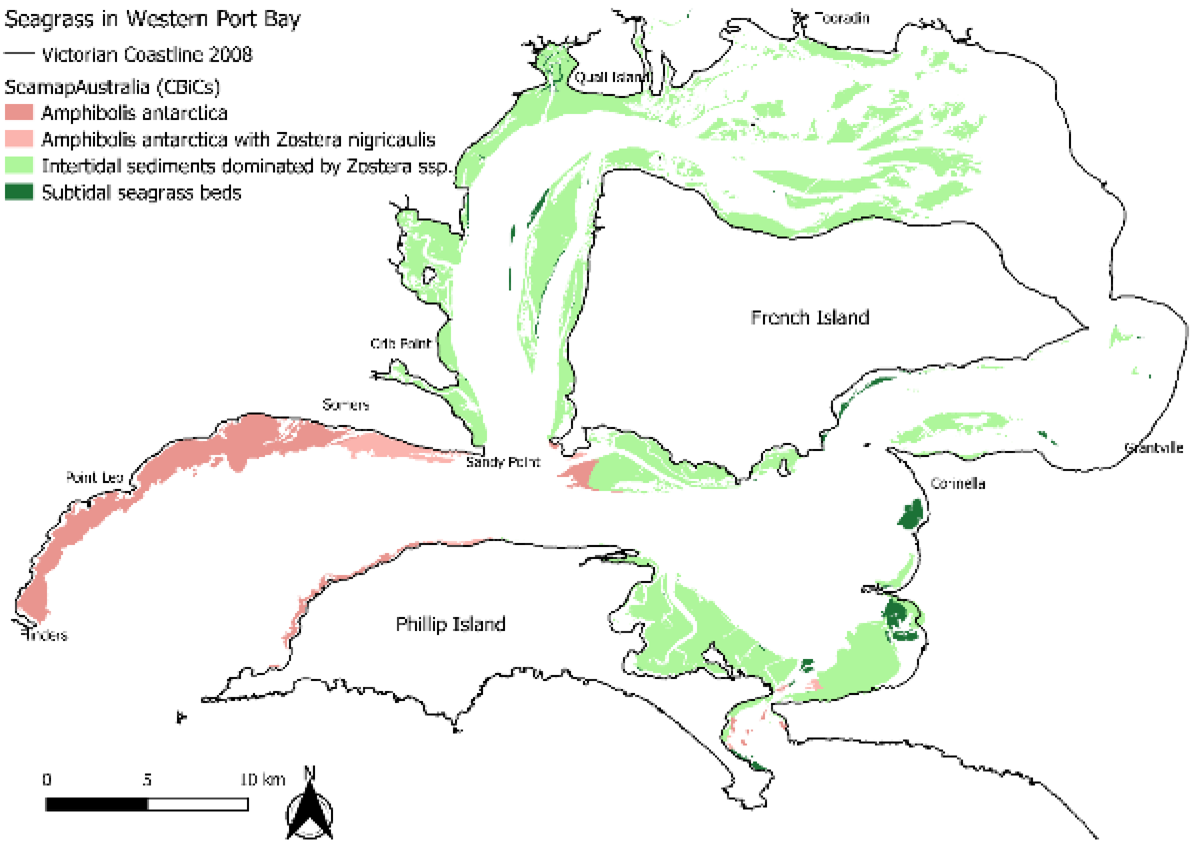


Figure 5-25. Map of seagrass species distributions in Western Port

Source: compiled from SeaMap Australia data, based on the work of Blake and Ball (2001)

Amphibolis antarctica (sea nymph) is found on areas of subtidal reef or rubble (hard substrate) with low to moderate swell exposure. In Western Port *Amphibolis* occurs on reef/rubble seabed to around 5 m depth in the Western Entrance and Confluence Zone. *Amphibolis antarctica* beds occur along the Mornington Peninsula coastline from Flinders to Sandy Point, around Tortoise Head on French Island, and along the northwest coast of Phillip Island from Cowes to Point Grant. In places *Amphibolis* occurs with *Zostera nigricaulis*, particularly between Somers and Sandy Point.

Zostera nigricaulis is the most widely distributed and abundant seagrass species in Western Port. It forms extensive beds in intertidal and shallow subtidal areas throughout Lower North Arm, Upper North Arm and East Arm. The extent of subtidal *Z. nigricaulis* has never been comprehensively mapped and this species is likely to cover a greater area in Western Port than currently estimated.

Figure 5-26. Seagrass banks draining at low tide, Hastings Bight June 2019

Zostera nigricaulis predominantly occurs on sandy or silty seabed with low or no swell or wave exposure. *Z. nigricaulis* is generally understood to be a subtidal species that cannot survive long periods out of the water. However, in Western Port it occurred extensively over intertidal mudflats (NSR 1974, Bulthuis 1981a, Bulthuis and Woelkerling 1983, Bulthuis et al 1984). It was the most abundant species of seagrass in Western Port in the 1970s (when it was known as *Heterozostera tasmanica*) accounting for 54 % of seagrass cover (Bulthuis, 1981) and remains the dominant species today. The wide, flat mudflats with thick cover of *Z. nigricaulis* combined with raised lips of 'overwash sands' around the periphery of mudflats (Marsden et al 1979, Bulthuis 1981a, Miles 1976) appeared to retain enough water on the mudflats during low tides to prevent the species drying out (Figure 5-26).

Zostera muelleri is characteristic of sandy or muddy seabed above low tide level – it rarely occurs in subtidal waters, where it is replaced by Z *nigricaulis*. *Zostera muelleri* can withstand some drying out during low tides. The area covered by *Zostera muelleri* in Western Port was estimated at 16% of the total extent of seagrass in Western Port in the 1970s (Bulthuis, 1982). Maps produced at the time showed it occupied areas in the upper intertidal on the east and west shorelines of north arm and upper north arm, and on middle spit, as well as in the Corinella segment (Bulthuis, 1981). Sparse *Z. muelleri* colonised some areas of intertidal mudflat previously occupied by *Z. nigricaulis* following its large-scale decline in the upper north arm (Stephens, 1995).

It is only possible to conclusively separate the identity of three *Zostera* species Z *muelleri*, Z *nigricaulis* and Z *tasmanica* by close examination. The depth distribution of Z *muelleri*, Z *nigricaulis* overlaps and they may be comingled, whereas Z *tasmanica* tends to occur in open, deeper water and does not generally overlap the depth range of the others. Hence, recent mapping work has not attempted to distinguish between *Z. muelleri* and *Z. nigricaulis* in aerial images used for mapping (Blake and Ball, 1999) ground-truthed surveys (French et al. 2014, Blake and Ball, 2001).

Halophila australis is characteristic of subtidal muddy or sandy seabed with little or no wave exposure, and lower light availability than areas occupied by *Z. nigricaulis*. *Halophila* is a small species that occurs interspersed beneath the *Z. nigricaulis* canopy near its lower depth limit, or forms sparse beds in deeper water than *Z. nigricaulis* (Blake and Ball, 2001). *Halophila* cannot be distinguished from aerial photography. Blake and Ball (2001) estimated that *Halophila* occupied at least 7.5 km^2 of Western Port habitat in 1999, mostly co-occuring with medium density or sparse *Z. nigricaulis*.

Historic Changes in Seagrass Distribution

Patches of seagrass decline in localised areas were reported in the 1970s (Stephens 1995), however broadscale seagrass decline was reported in 1982. Approximately 70 per cent of the area of intertidal seagrass in Western Port mapped in the early 1970s became bare muddy seabed between 1974 and 1984. Seagrasses area reached lowest documented level just within 2 years after the initial reports of broadscale decline.

Intertidal seagrass beds dominated by *Z. nigricaulis* experienced the greatest decline, from 136 km^2 in 1973/74 to 27 km^2 in 1983/84. Smaller reductions in the extent of *Z. muelleri* (intertidal) and *A. antarctica* (subtidal) were observed between 1973/4 and 1983/4 (Table 5-9).

The extent of seagrasses in Western Port was not reassessed until 1994 when an EPA mapping study again used aerial photography combined with ground truthing to map seagrass extent (Stephens, 1995). The study showed some recovery in the area covered by seagrass, from a minimum of 53 km^2 in 1983 to 93 km^2 in 1994 (Table 5-9). Stephens (1995) noted that

> "*the recovery documented is patchy, and in some limited areas* Z. muelleri *has colonised banks formally dominated by* [Z. nigricaulis]".

The areas where *Z. muelleri* had colonised areas that formerly had been dominated by *Z. nigricaulis* were mostly near Tooradin and Hastings. *Z. nigricaulis* recovery was noted in the centre of upper North Arm, particularly near channel margins, on middle Spit in the Lower North Arm and the Rhyll Segment.

Table 5-9. Areas (km^2) of seagrass recorded in Western Port

Year Mapped	Total vegetated area (including algae)	*Amphibolis^*	*Zostera**	Report
1973/74	250	20	142	NSR 1975
1983/84	72	13	53	Bulthuis *et al* 1984
1994	113	20	93	Stephens 1995
1999	154	22	107	Blake and Ball 2001

adapted from Walker, 2003
^Western Entrance seagrass (includes some *Zostera* habitat)
*total seagrass area minus Western Entrance (*Zostera* dominated habitat

Seagrasses were subsequently mapped in Western Port in 1999 (Blake and Ball, 2001), which documented further small increase in the cover of seagrasses (Table 5-9). The 1994 and 1999 aerial photograph series show an increase in cover of the intertidal mudflats with seagrass in the lower North Arm, upper North Arm and Rhyll segment.

Some recovery of seagrass cover occurred in other areas off the Bunyip River, where seagrass had been denuded prior to 1973. There was little or no recovery of seagrasses in the Corinella segment or near the tidal divide. By 1994 the area covered by *Amphibolis* in the western entrance was similar to that seen in 1973/74, and increased slightly in 1999.

Areas of seagrass in Western Port selected for monitoring between 2005 and 2007 included Woolley's Beach near Crib Point (Ball *et al* 2006, Ball *et al* 2010). The analysis showed a negligible increase in seagrass cover at these sites between 1999 and 2007.

The major loss of seagrass from Western Port in the late 1970s early 1980s was *Z. nigricaulis* from intertidal mudflats. Subtidal stands of *Z. nigricaulis* survived during the period (Bulthuis, 1984). Long-term data on the standing crop of *Z nigricaulis* at sites near the Lysaght Steel Wharf show biomass was relatively stable from 1973 to 1989 (MSE, 1989). Modelling by Holland *et al* (2013) showed that sufficient light was available for subtidal *Zostera* throughout 201Western Port in 1998. Studies of the lower limits of seagrass in Western Port showed that the lower limit of Z *nigricaulis* near the Bluff in the Lower North Arm in 2014 was similar to that documented in 1983 (Bulthuis 1983, CEE 2014) These findings indicate that sufficient light has remained available for this species in subtidal areas, even after increased turbidity due to loss of intertidal seagrass.

Causes of seagrass loss in Western Port

A number of factors acting synergistically are likely to have contributed to the observed decline in seagrass cover in Western Port. Modification of the catchment to develop agriculture, industry and housing (particularly drainage of the Koo Wee Rup swamp) contributed, by changing the nutrient and freshwater inputs. The seagrass losses are commonly attributed to increased sediment inputs from the channels used to drain Koo-Wee-Rup swamp to the north of Western Port.

There was localised seagrass loss in the order of 35 km^2 that was directly attributable to smothering by sediments in the north of Western Port (Wilk *et al* 1979, Stephens, 1995). There is also evidence for dredging and port construction contributing to some small-scale loss of seagrasses (Stephens, 1995). Commercial fishing activities, in particular shellfish (oyster) harvesting that was common in the late 1800s and early 1900s, and construction of the Cardinia Reservoir between 1970 and 1973 may have also have been a factor.

Ecological factors, in particular gradual increase in the level of mudflats due to accretion of sediments among the seagrass stems and roots, may also have been important. This process may have resulted in the mudflats becoming more exposed at low tides.

The rapid, broadscale decline in Western Port intertidal seagrasses in the early 1980s suggests that a large-scale, high-intensity event was a cause. Major climate events are increasingly being linked to catastrophic impacts on marine species around Australia. Marine heatwaves have caused large-scale dieback of habitat forming macrophytes on temperate reefs in Western Australia in 2011 (Wernberg and Smale 2012, Smale 2013, Wernberg *et al* 2016). Corals on the Great Barrier Reef and northwest Australian reefs were bleached by record ocean temperatures in 2016 and sections of the Great Barrier Reef bleached again in

2017 (AIMS, 2019). Drought, extreme heat and low sea level caused mass-scale dieback of mangroves in the Northern Territory in 2015-16 (Duke *et al* 2017).

In Victoria, warm and dry conditions with low nitrogen inputs during the Millenium drought have been linked to low *Z. nigricaulis* cover in Port Phillip while cooler and wetter years with higher nitrogen inputs correlated with increased *Z. nigricaulis* cover (Jenkins and Keough, 2015). This research shows that climatic shifts and cycles are a major influence on the abundance and extent of *Z. nigricaulis*.

The Victorian climate in the early 1980s was warm and dry. Extremely low rainfall and high heat through 1982 culminated in the catastrophic Ash Wednesday bush fires on 16 February 1983. High temperatures coupled with low sea levels would have caused extreme conditions and high desiccation stress on Western Port's extensive intertidal mud flats.

Very hot conditions occurred from January to March in 1981 to 1983. Temperature records for Moorabbin Airport (the nearest weather station with a long-term record) show:

- 15 days over 35°C, with 6 days in a row over 35°C in January 1981
- 13 days over 35°C, with several two to three-day periods over 35°C in 1982
- 12 days over 35°C, several two to three-day periods over 35°C in 1983

In contrast, 35°C was exceeded on only four days in 1980 and one day in 1984 (BoM Climate Data Online, 2019).

Spring low tides periodically occur during the middle of the day in the Victorian summer which, when combined with hot weather, cause desiccation stress in intertidal ecosystems (Keough 1998). High pressure systems cause lower sea levels on top of midday low tides. Hot, dry conditions in Victoria typically coincide with large, slow-moving high-pressure systems. Sea level records for Stony Point in Western Port and Point Lonsdale show that minimum sea levels in 1982 and 1983 were below the long-term average, particularly during the warmer months (CEE, 2019).

The climatic conditions in the early 1980s may have led to a marine heatwave in Western Port and is a possible cause of the catastrophic loss of seagrass from the intertidal mudflats. There is anecdotal evidence that fish kills ('ling') were noted in Western Port at about that time (Bennett 2004).

The pattern of seagrass loss experienced in the early 1980s is not directly consistent with increased sedimentation, as losses occurred both near and far from the areas impacted by sediment deposition and subtidal seagrasses do not appear to have been affected.

The loss of seagrass caused a major shift in the state of the Western Port ecosystem. Loss of seagrass cover from the intertidal mud flats exposed the fine sediments to erosion by waves and tidal currents, leading to resuspension of sediment, phosphorus and silicate (Bulthuis et al, 1984). Turbidity of Western Port waters increased markedly, reducing light availability, and turbidity remains high. While increased turbidity has not been shown to be the cause of the loss of intertidal seagrasses (Bulthuis 1983), the increased turbidity is a major factor in preventing re-establishment of seagrasses on the intertidal mudbanks in the upper north arm (Stephens 1995, Parry 2006, Holland *et al* 2013).

Simulations of water quality, hydrodynamics, waves and sediment transport for 1974, 1998 and 2009 confirmed that suspended solids concentrations in the northeast and east of Western Port are higher today than they were in 1974 (Holland et al, 2013). Holland *et al* 2013

showed that large areas of the northeast and east of Western Port remain unsuitable for intertidal seagrasses due to high suspended solids.

Seagrass Subtidal Depth Limits

The existing and historic distribution of subtidal seagrasses, in particular *Z. nigricaulis* and *Halophila australis,* is difficult to determine from aerial photography alone. Bulthuis (1984) reported that subtidal *Z. nigricaulis* seagrasses persisted in areas adjacent to areas where intertidal *Z. nigricaulis* was lost in the early 1980s and occurred down to 5.9 m below MSL near the Bluff in Lower North Arm (Bulthuis 1983). Turbidity influences underwater light availability, a key factor that determines the depth to which seagrass can grow (Bulthuis, 1983; Duarte 1991). It could reasonably be expected that the lower-depth limit of seagrass declined due to increased turbidity following the loss of intertidal seagrasses, however the presence of seagrasses to around 6 m depth near the Bluff in 2014 (CEE 2014) indicates the relationship may not be so simple. Other physical factors are also important however, such the interlinked factors of hydrodynamics, substrate type and bed-slope (Bulthuis 1983, CEE 2014).

Studies of seagrass in Western Port in 2014 (Table 5-10), recorded a maximum lower limit of seagrass (*Zostera nigricaulis*) in North Arm of 7.5 m MSL (6 m CD) where the seabed slope is gradual and current speeds relatively low. The lower depth limit at Long Island Point and Stony Point was just 1.5 m below MSL, and coincided with the upper edge of the relatively steep sided main channel through north arm, where current speeds are high. The lower depth limit of subtidal seagrasses in Western Port is therefore determined by a number of factors, not just light attenuation.

Table 5-10. Depth limits for *Zostera nigricaulis* around Western Port

Segment	Sites	Depth limits (metres below MSL)			Median light attenuation in Jan 2014 (Kd, m^{-1})
		Max	Min	Median	
Upper North Arm	11	-4.7	-1.7	-2.8	0.35
Lower North Arm	36	-7.5	-1.3	-4.7	0.36
Confluence Zone	4	-4.0	-1.6	-2.3	0.27
Rhyll	3	-2.9	-1.0	-1.3	0.37
Corinella	5	-2.9	-1.0	-1.3	0.34

Source: CEE (2014)

Ecological Role of Seagrass

Seagrasses are a primary producer in coastal embayments and estuaries contributing 33-38 per cent of primary production, along with macroalgae, benthic microalgae and phytoplankton (Mateo *et al* 2006). Few animals feed directly on seagrasses in Western Port, except for the Black Swan *(Cygnus atratus*), some fish (garfish) and some invertebrates (Watson et al 1984).

The carbon produced by seagrasses is largely refractory due to its high concentration of cellulose and lignin. The major role of seagrass is habitat formation and provision of organic debris which is an important source of nutrients and carbon for the microbial loop. Much of the primary production in seagrass habitats that makes its way into the food web is from the micro- and macroalgal epiphytes that live on seagrass stems and leaves. These are more commonly and easily digested by invertebrates and fish.

Seagrass habitats support a high density and diversity of invertebrate infauna (Edgar *et al* 1994) and epifauna (Hindell *et al* 2004) and are major contributors to food webs in Western

Port. Migratory birds forage over intertidal mudflats at low tide, feeding on invertebrates and fish. At high tide fish and invertebrates such as squid can move over intertidal seagrass beds to feed. The invertebrate and fish fauna and migratory birds are critical components of the Western Port Ramsar site ecological character (Kellogg Brown and Root, 2010).

Subtidal seagrasses provide habitat and foraging areas for mobile invertebrates and fish, particularly FFG Act and EPBC Act listed Syngnathid species (pipefish).

Seagrasses provide important nursery habitat for fish such as King George Whiting, adults of which are targeted by recreational anglers in Western Port. Other species that use seagrass and are targeted by recreational anglers include Blue Weed Whiting (*Haletta semifasciata*) and southern calamari (*Sepioteuthis australis*).

Seagrasses can help stabilise sediment beds, protecting sediments below their leaves from resuspension by waves and tidal currents, and accumulating fine sediments beneath the canopy of seagrass leaves (Marsden *et al* 1979). Other mechanisms of fine sediment accumulation in seagrass beds include filtering of particulates by the microbiota on the seagrass leaves and adherence of material directly on the leaves (Marba *et al* 2006). Maintaining existing bathymetry and sediment processes in Western Port are seen as critical to maintain the ecological character of the Ramsar site (Kellogg Brown and Root, 2010).

Seagrass at Crib Point

The nearest seagrass habitat to the proposed FSRU and jetty infrastructure are around 450 m inshore and comprise *Z. nigricaulis* and *H. australis* habitat in the subtidal and *Z. nigricaulis* and *Z. muelleri* habitat in the intertidal zones.

Surveys to inform this EES show that the lower depth limit of seagrass inshore of the Crib Point jetty is near 3.5 m depth (MSL) (Figure 5-32). This distribution of subtidal seagrass is consistent with seabed slopes and current speeds that are intermediate between The Bluff and Long Island Point/Stony Point. Extensive areas of intertidal and shallow subtidal seagrass extend from Crib Point throughout Hastings Bight to the north, and to the south towards Stony Point. Intertidal and shallow subtidal seagrass also occurs on Middle Bank, around 2 km east of the proposed FSRU. The seawater intake and discharge from the proposed FSRU at Crib Point Jetty would be approximately 450 m offshore from the lower limit of subtidal seagrasses at Woolleys Beach at Crib Point (Figure 5-32).

Macroalgae

Macroalgae occur to greater depths than seagrasses owing to their lower light requirements. Macroalgae in Lower North Arm mostly occur sparsely as drift or attached to shell or cobble (mostly red algae species). *Caulerpa cactoides* (green algae) can form dense patches on sediment within and around the edge of subtidal and intertidal seagrass beds. Macroalgae are most diverse and abundant on hard substrates, including Crawfish Rock and jetty piles (Bok et al 2018, Shepherd *et al* 2009). The lower-depth limit and diversity of seaweeds on Crawfish Rock reduced from 12-13 m depth and 138 species in the 1970s to 4-5 m depth in the 2000s and 66 per cent fewer species. This major environmental change was attributed to reduced water clarity following documented broad-scale loss of seagrasses from intertidal mudflats in Western Port during the early 1980s. The shallowing of the macroalgal zone at Crawfish Rock was accompanied by an expansion of the diverse invertebrate community of sponges, bryozoans, ascidians and hydroids into shallower water previously occupied by the macroalgae.

5.7 Subtidal Epifauna and Infauna

The physical features of the subtidal habitats in Western Port marine ecosystem have been described through studies on sediment composition (Blake et al 2013, Marsden et al 1979, Coleman et al 1978), bathymetry (Aust. Hydrographic Office, DELWP) and hydrodynamics (Harris et al 1979, Hinwood and Jones 1979, EPA 2011). Figure 5-23 shows that sediments in the deeper channels of North Arm comprise medium sand (Wentworth size class, Marsden et al 1979).

5.7.1 Epifauna

Epifauna are the animals that grow on or attached to the surface of the seabed. The characteristics and distribution of invertebrate biota are strongly influenced by seabed character, such as reefs, areas of rubble, banks and channels. The distribution of seabed character can be determined from a variety of methods including aerial photography, detailed bathymetry (multibeam), side scan and direct or indirect observation. It was noted in the Westernport Bay Environmental Study that "*In some areas, such as North Arm, features at a depth of some 16 m could be readily distinguished*" from aerial photographs taken in the early 1970s.

"*Sponge beds occupied at least 2 km of the 15 – 20 m channel off Hastings and were visible in the aerial photographs as a faint mottling"* (NSR 1974). As discussed in previous sections of this report, water clarity rapidly declined in the late 1970s and it is no longer possible to determine seabed features in water depths greater than approximately 5 m in North Arm.

The epifauna of the subtidal channels of Lower North Arm are characterised by sparsely distributed sessile and mobile invertebrates, and patches of seabed where invertebrate species are concentrated in high numbers or species-diverse 'clumps' that may be classified as biogenic reefs (CEE 2018, Edmunds and Flynn 2018, Flynn et al 2018, Harvey and Bird 2008).

Epibiota include a wide range of sponges, bryozoans, hydroids, ascidians, crustaceans and echinoderms (CEE 2009). There are a number of notable sessile epibenthic invertebrate species including the brachiopod *Magellania flavescens*, the 'living fossil' bivalve *Neotrigonia margaritacea*, tube-forming polychaete worm *Eunice* sp., sea-pen *Sarcoptilus grandis*, ascidian *Pyura dalbyi* and bryozoans *Celleporaria* and *Tryphyllozoan*. Mobile species include the sea urchins *Goniocidaris tubaria* and *Heliocidaris erythrogramma* and the seastars *Nectria ocellata, Tosia magnifica* and *Meridiastra gunnii* and the spider grab *Leptomithrax gaimardii*.

Smith *et al* 1974 described the sea pen *Sarcoptilus grandis* (previously *Sarcophyllum sp.*) as the most conspicuous epifauna of the channels in the 1970s, along with *Magellania* and *Pyura.* Crawfish Rock featured a large biomass of sponges, encrusting colonial ascidians, arborescent bryozoans (in particular *Bugula dentata*) and a range of hydroids. Smaller areas of hard substrate, including jetty piles, have similar species.

Sarcophyllum sp *Sarcoptilus grandis*

Figure 5-27. Seapens in Lower North Arm, 2009

Photos: J Watson 19 May 2009

Native flat oysters *Ostrea angasi* once formed extensive intertidal and subtidal beds in Western Port that formed the basis of a fishery from the mid-1880s to early 1900s (Bennett 2004, Ford and Hamer 2016). These oysters were initially collected by hand in the intertidal area and subsequently by small harvesters (dredges) by small fishing boats after the intertidal stocks were depleted (Bennett 2004). Intertidal oyster leases were established for a short period in Hastings Bight. As the subtidal stocks also became depleted, the fishers moved into habitat less favourable for dredging due to the amount of 'coral' that filled the dredges. It seems that fishers crushed the collected 'coral' before returning it to the bay to prevent it fouling their dredges (Bennett 2004).

'Coral' in the sense used by many fishermen in Victoria usually refers to large colonies of bryozoan (for example *Tryphyllozoan* and *Celleporaria*) or tube worm (Serpulisdae such as *Galeolaria*) rather than the reef building Scleractinians of the tropics or the local hard coral *Plesiastrea versipora*. The location of most oyster dredging is unclear, but most may have been in the southeast of the Bay. There is no oyster fishery in Western Port in the present day, but scattered oyster shells are visible on the seabed surface and are found in shell strata below the surface. Introduced oysters are present on the tidally exposed piles of some the shipping jetties in Lower North Arm.

Invertebrates such as bryozoans and sponges and certain coralline algae can form dense biologically-based habitats that may be described as biogenic beds or reefs. These habitats can establish on soft seabed and form diverse communities of invertebrates and fish, depending on the size and extent of the reef.

The broad-scale distribution of epibiota habitats in Western Port was mapped using towed underwater video by Department of Primary Industries Fisheries Research Branch (DPI) between 2009 and 2012 (Blake et al 2013) to fill priority data gaps in the development of a statewide marine habitat model. The survey produced maps of substrate type and major biota groups at select locations across Western Port and the data provide input to the statewide marine habitat database (Lucieer *et al* 2017).

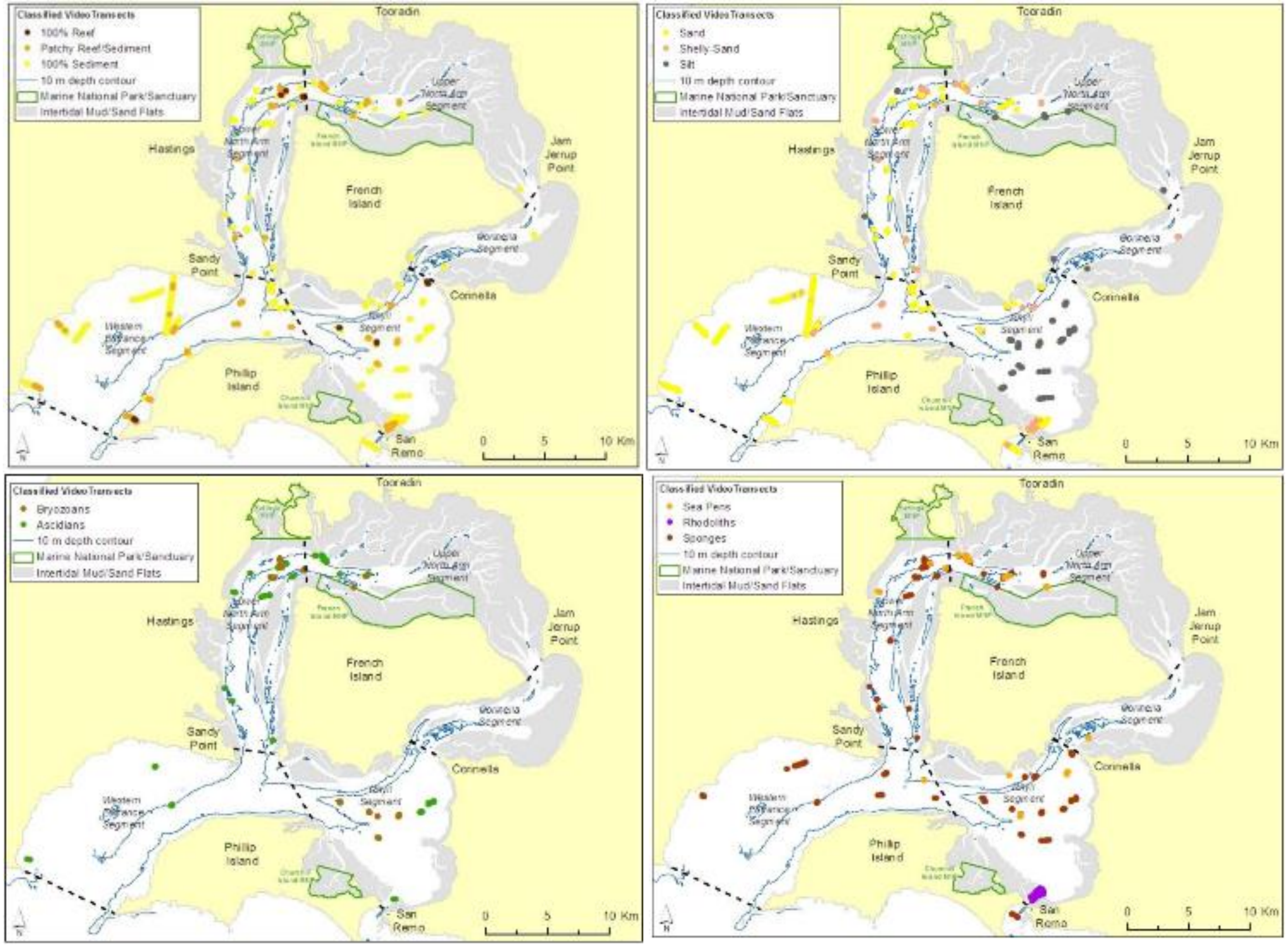


Figure 5-28. Broadscale seabed habitats and associated biota in Western Port

Source: Blake et al 2013

Examples of maps from the DPI study (Figure 5-28) show that the seabed at most sites in Lower North Arm was sediments, some sites comprised patchy reef (rubble) with sediment and rocky reef ("100% reef") only occurred in the far north of North Arm at the Crawfish Rock/Eagle Rock reef complex. Soft seabed sites in Lower North Arm were located in water depth less than 10 m. The site closest to Crib Point was <5 m deep as demonstrated by the presence of seagrass ('*Zostera*') and the green alga *Caulerpa*, which are restricted to water depth less than 5 m in this part of Lower North Arm. The soft seabed at sites in the deeper (>10 m) channel of Lower North Arm was classified as Sand or Shelley-Sand, as it was at most deeper sites in the Upper North Arm, Western Entrance, and Rhyll Segment.

Areas of rich bryozoan reef were subsequently identified in 5 m to 8 m water depth in the Rhyll Segment of Western Port in 2016 (Flynn et al 2018). Bryozoan reefs were found to comprise significant areas of individual mounds up to 6 m^2 and 2 m relief separated by relatively bare sediments.

The DPI study provides a good broadscale information on seabed habitat and associated biota for comparing with descriptions of smaller spatial scale area around Crib Point jetty that may be affected by the Project as described below.

Jetties

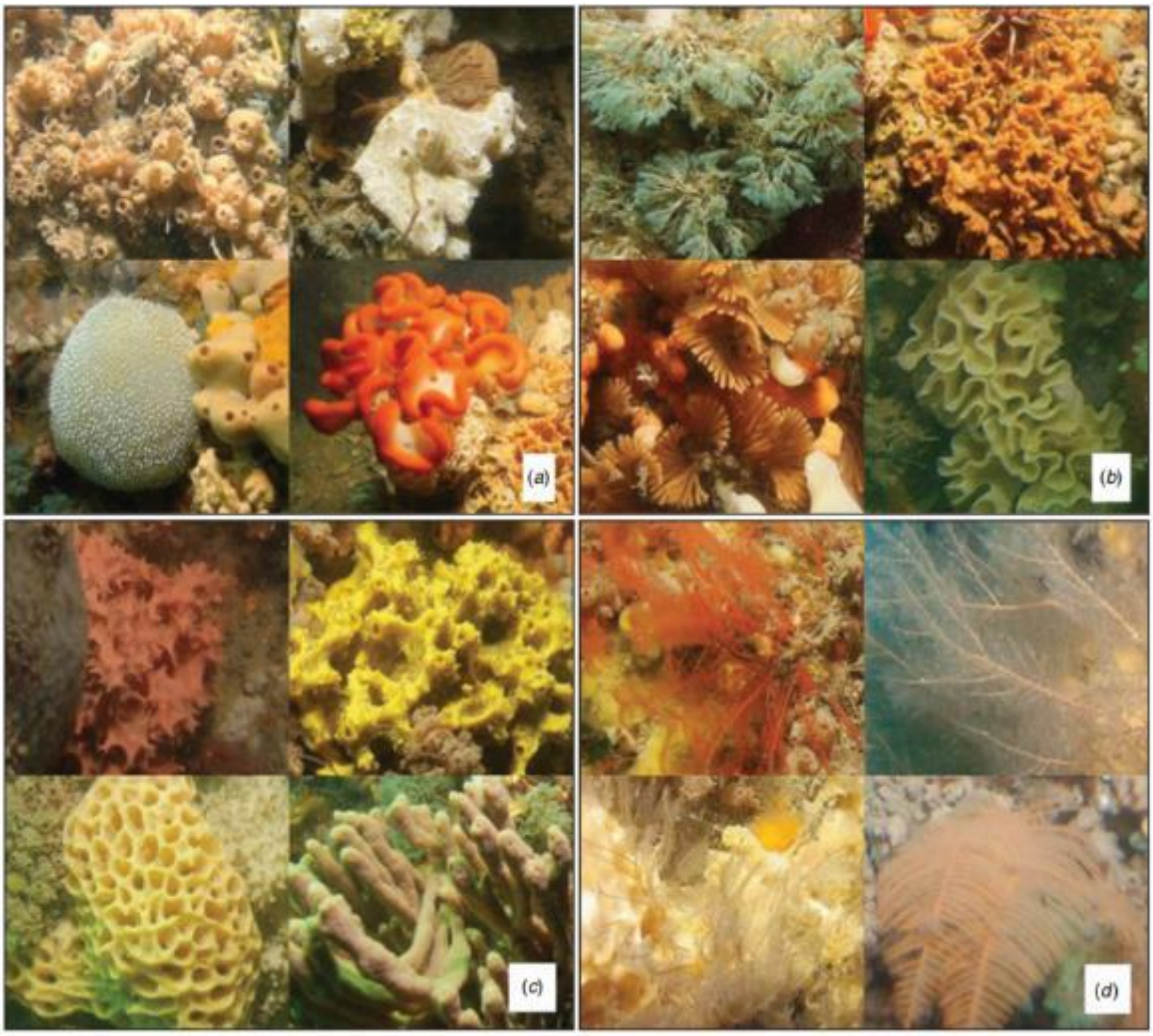
Shipping and boating jetties in the marine environment provide three-dimensional, hard substrate environments that may be absent from areas with predominantly flat, soft seabed, such as Lower North Arm of Western Port. These artificial structures provide stable, solid habitat for settlement and growth of a range of encrusting invertebrates and a three-dimensional habitat for sedentary mobile species of fish, mollusks and crustaceans in the water column, on the piles or on the seabed among the piles.

Shipping jetties in Lower North Arm are located at BlueScope and Long Island Point on the western side just north of Hastings, Crib Point on the western shore just south of Hastings Bight and Tankerton on French Island east-south-east of Stony Point.

Location	Jetty and berthing heads	Jetty length (from low water)
Stony Point	190 m, 55 m	65 m
Crib Point (central western shore)	400 m, 40 m, 40 m	410 m
Long Island Point (northern shore)	70 m and 110 m	100 m
Blue Scope (northern shore)	220 m, 80 m, 45 m	-
Tankerton	30 m	10 m

The jetty heads are piled and located at different distances from the low tide mark. The depth of water at the jetty heads, length of piles submerged and water current regime varies between the jetties. The decks of the jetty heads shade the water column beneath them, which also affects the nature of the biota growing on the piles in this artificial environment.

The 3 m length of jetty piles below the high tide mark are exposed each tidal cycle and are characterized by macroalgae and mobile and encrusting intertidal invertebrates, which include the introduced Pacific oyster *Crassostrea gigas*. The proportion of algae and its distribution below the lower intertidal area depends on the amount of light reaching the piles beneath the jetty. The encrusting invertebrates beneath the BlueScope, Long Island Point and Crib Point jetties were monitored over a five-year monitoring period by Esso Australia Pty Ltd (Bok et al 2017, Hall et al 2013).



Clockwise in each panel: (a) Ascidians: *Stolonica australis*, *Didemnidae* sp., *Sycozoa* sp., *Aplidium* sp.;(b) Bryozoans: *Bugulaserrata*,*Celleporariasp*., *Tryphyllozoonsp*., *Cabereasp*.(c)Sponges: Aplysilla sp.,Aplysillasp., cf. *Echinoclathriasp*, *Hollopsamma* sp.; and (d) Hydroids: *Halopteris* sp., *Nemertesea* sp., cf. *Sertularia* sp., cf. *Sertularia* sp.

Figure 5-29. Invertebrates on Lower North Arm jetty piles

The jetty piles were found to be encased in a diverse and colourful range of encrusting invertebrates including various species and forms of sponge, bryozoans and ascidians (Figure 5-29). These invertebrates provide habitat for a range of other animal groups and species including gobies, pipefish and other small fish species, molluscs, clams, seastars, sea urchins, worms and other crustaceans. Fish were generally closely associated with the structures and were not abundant in the general water column. The richness of the community was attributed to the strong tidal currents in the area. The encrusting biota were generally rapidly growth invertebrates that quickly colonise and overgrow artificial substrates in the marine environment.

The study found strong similarities between the three jetties in terms of community composition and variation in composition over the five years of the study. These similarities are related to the strong tidal currents in North Arm that can carry and mix the tiny larvae of these biota from one jetty to the next in a single peak spring tide. The seabed and associated water column communities were expected to show similar connectivity, with potential differences due mainly to the physical configuration of piles and water depth at each jetty.

5.7.2 Infauna

Infauna are the burrowing invertebrates found in the sediments below the surface of the seabed. They comprise a wide array of species and abundances from place to place depending on ambient environmental conditions. Typical infauna groups found at most coastal environments include burrowing worms, shrimps, crabs, brittle stars, clams, snails, urchins and burrowing species of other groups including fish.

Infauna across Western Port were sampled comprehensively during the 1973 to 74 Ministry for Conservation Western Port Bay study (Shapiro 1975). The infauna communities were found to be highly species rich and abundant (Coleman et al 1978). The fauna was dominated by polychaete worms (the most numerous group), various crustaceans (the most species rich group) and molluscs (clams and snails).

The 1973/74 sampling process recognised a range of physical factors that might influence infauna community structure and divided the Bay into eleven different strata, of which the channel of North Arm was one entire stratum (Figure 5-30). The spatially comprehensive sampling program found that the most abundant species were widely spread. The errant polychaete worm *Nepthys australiensis* was the second most common species collected and was distributed over 85 per cent of all stations sampled.

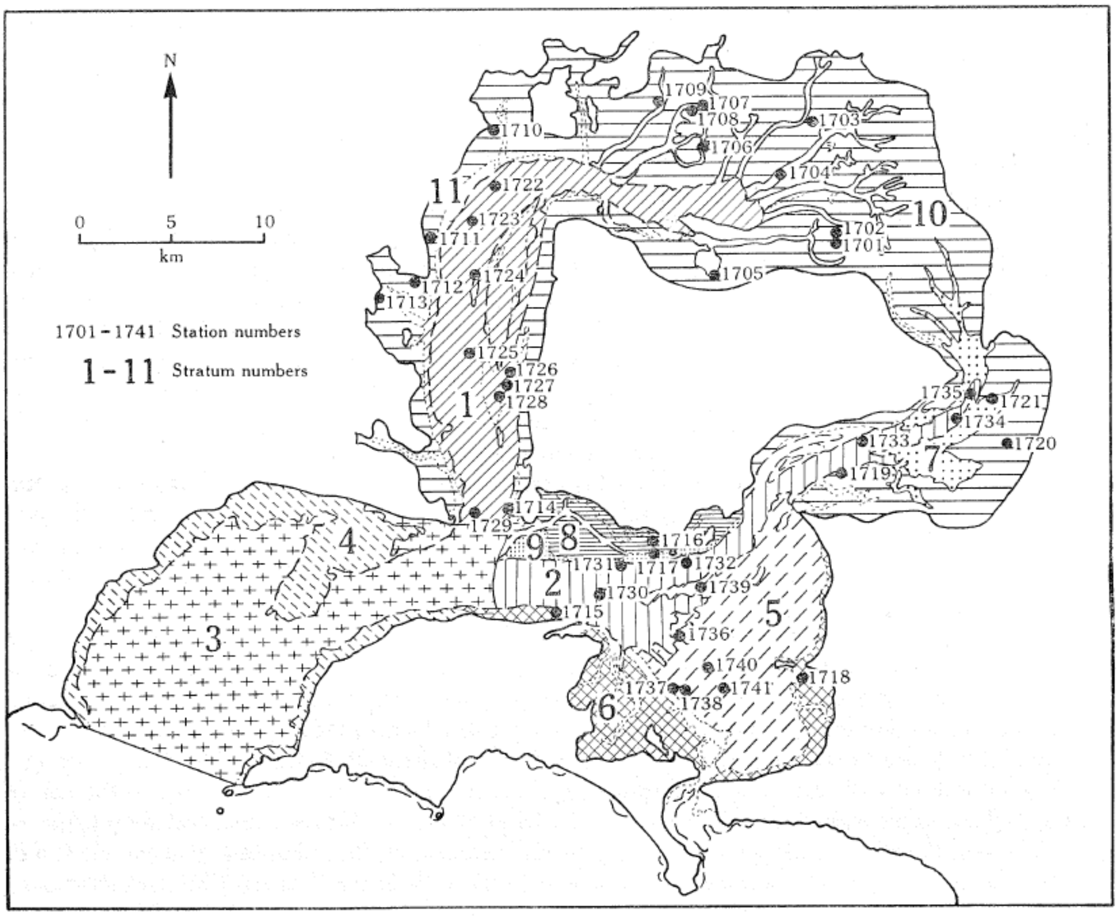


Figure 5-30. Infauna sampling strata and sites - Westernport Bay Environmental Study

Source: Coleman *et al* 1978

Affinity analysis of the infaunal data from the combined eleven different sampling strata divided the infaunal community into two general groups. The key environmental factor that separated the two groups was sediment character.

The two groups were termed:

1. clean medium sand assemblage – with average mean grain size of medium sand and a mud content <10 per cent, and
2. fine sand and mud assemblage – with mud contents greater than 20 per cent.

These two groups appear to be correlated with depth: the first group being found in predominantly deeper channels and the second, muddier group, being found along the margins of the Bay. The infauna of the Lower North Arm channel are part of the 'clean medium sand assemblage' along with channel and basin strata in the Corinella and Rhyll segments (Coleman et al 1978).

The clean medium sand assemblage was characterised by polychaete species *Scoloplos*, *Rhodine*, *Travisa*, clams *Neotrigonia margaritacea*, *Notocallista diemensis*, *Solen vaginoides* and *Venericardia bimaculata*, and crustaceans *Halicarcinus rostratus, Ampelisca, Cheiriphotis megachelis, Leptanthura diemensis* and *Paranchialina angusta*.

The fine sand and mud assemblage is characterised by the polychaete worms *Amaeana* and *Mediomastus* and bivalve molluscs *Tellina* and *Katelysia*.

Species diversity was marginally higher in the clean medium sand assemblage, although the difference was not statistically significant. In all strata, the order of taxonomic group abundance was polychaetes>crustaceans>molluscs, except for stratum 1 (North Arm channel) and stratum 6. Crustaceans were more numerous than polychaetes in North Arm channel.

The closest site to Crib Point Jetty in the 1973/74 sampling was #1725 shown in Figure 5-30 (Coleman et al 1978). The infauna assemblage from this site was given mention in the 1973/74 report. The assemblage at the site was found to have very low diversity (Shannon H') due to low species richness of polychaetes, crustaceans and molluscs and high abundance of one particular species – the crustacean species *Apseudes*. The "lack of species" at this site was attributed to its position in "a dredge area" and possible lack of colonisation since the last dredging. The survey (late 1973 - early1974) would have been almost 10 years after dredging. The location of the site (#1725 in Figure 5-30) seems to be outside the area of the shipping basin at Crib Point. Hence, the reason for the low diversity at this site in "a dredge area" is not clear.

Subsequently, infaunal production in the shallow channels (5 m) was higher than bare mudflat areas, but generally lower than intertidal seagrass areas (Edgar *et al.* 1994). There is no information on the productivity of the deeper channels. Monitoring of infauna communities near the steel wharf north of Long Island Point (BlueScope) by Marine Science and Ecology (MSE 1990, MSE 2009) found the infauna community was dominated by polychaete worms and crustaceans, with molluscs, echinoderms and all other groups each comprising less than 10 per cent of the infauna by abundance.

5.7.3 Subtidal Seabed Habitat Investigations at Crib Point

Context

As discussed in Section 1.0 of this report, the primary potential effects of the project on the benthic marine environment of Western Port would be due to the extent and magnitude of water temperature change and chlorine (as CPO) concentration from the discharge from the FSRU.

Modelling of the initial operation during the referral-stage of the project identified the benefits of a multiport discharge compared to the initially proposed single or dual point discharges of cooler seawater (CEE 2018a). A six-port discharge was chosen for the development proposal. Referral-stage modelling conservatively estimated that the water temperature difference of the six-port option would only be detectable to approximately 240 m from the diffuser and at depths greater than 12.5 m within this area at all stages of the tide (CEE 2018a). Chlorine concentrations (CPO) would be reduced to conservatively determined safe concentrations at that time within 200 m upstream and downstream and 60 m east and west of the point of discharge (CEE 2018b).

Subsequent more detailed modelling, reviews and investigations described in Chapter 6 indicates these referral-stage estimated areas above guideline values were responsibly conservative overestimates.

As shown above, previous seabed and epibiota mapping (Blake et al 2013) and infauna characterisation (Coleman et al 1978) provide broadscale information on seabed habitat and associated biota in Lower North Arm. Habitats or ecological assemblages that may be considered unusual for Western Port have been identified at Crawfish and Eagle Rock and Marine Protected Areas are located in the north of North Arm (Yaringa and French Island MNPs) and southeast of Rhyll on Phillip Island (Churchill island MNP).

Field investigations were carried out to characterise benthic habitats and associated communities at and adjacent to Crib Point Jetty. The purpose of these investigations was to determine the presence of benthic habitat that might be considered unusual or under-represented in North Arm. The investigation methods, described in Section 4.2, CEE technical report 2019c and below, provided information on the distribution of habitat and key biota as the basis for discussion of the implications of the project modelling described in subsequent sections and potentially more detailed (e.g. statistically-based) investigations and design of baseline and operational monitoring programs.

Epibiota communities were characterised using towed video techniques and infauna were characterised from grab samples of sediments to:

1. Document the benthic habitats and benthic assemblages that occur in the proximity of Crib Point Jetty envelope of potential effect based on referral-stage modelling
2. Compare benthic habitats and benthic assemblages those in the marine neighbourhood of Crib Point Jetty with that documented elsewhere in Lower North Arm

Habitat and epibiota

Habitats and associated biota were mapped at the Crib Point area using similar towed underwater video field methods as DPI (Blake et al 2013). The positions of the towed underwater video transects are shown in Figure 5-31, with higher resolution of the Crib Point area in Figure 5-32. A total of 20 combined habitat/biota categories were developed by examining the series of still photos taken during the video tows (Table 5-11). Seventeen of the

categories are sandy seabed habitats with variable quantities of shell, visible epibiota and/or evidence or presumed presence of infauna. Three categories describe habitats with rocky substrate or biogenic hard substrate.

Twenty different habitat classes and a wide range of species were identified from the towed video records. Table 5-12 shows the species (or other taxonomic categories) used to assess species distribution and diversity. The presence or absence of categories were determined from still frames at approximately 15 second intervals for each transect was plotted for the combined habitat/biota categories (Figure 5-31 and Figure 5-32), and the per centage of biota records for each tow tabulated (Table 5-13).

Table 5-11. Key to Benthic Habitat/biota Categories in Lower North Arm

Based on SeaMap Australia classification system (Lucieer *et al* 2017)

- Sand dominated by seagrass (Intertidal)
- Sand dominated by seagrass (Subtidal)
- Sand with seagrass and macroalgae
- Sand with seagrass and benthic invertebrates
- Sand dominated by macroalgae
- Sand/shell with benthic invertebrates and macroalgae
- Sand/shell with benthic invertebrates, infauna and macroalgae
- Sand with infauna and macroalgae
- Sand dominated by benthic invertebrates
- Sand/shell dominated by benthic invertebrates
- Sand with benthic invertebrates and infauna
- Sand/shell with benthic invertebrates and infauna
- Sand/shell with benthic invertebrates
- Sand with infauna
- Sand/shell with infauna
- Sand
- Sand/shell
- Reef with benthic invertebrates and macroalgae
- Patchy biogenic reef (mixed invertebrates)
- Reef with benthic invertebrates

Dredged area

Bathymetry (m, Chart datum)

- 0
- 2
- 5
- 10
- 12.8 (Shipping channel)
- 14.3 (Shipping channel)
- 15

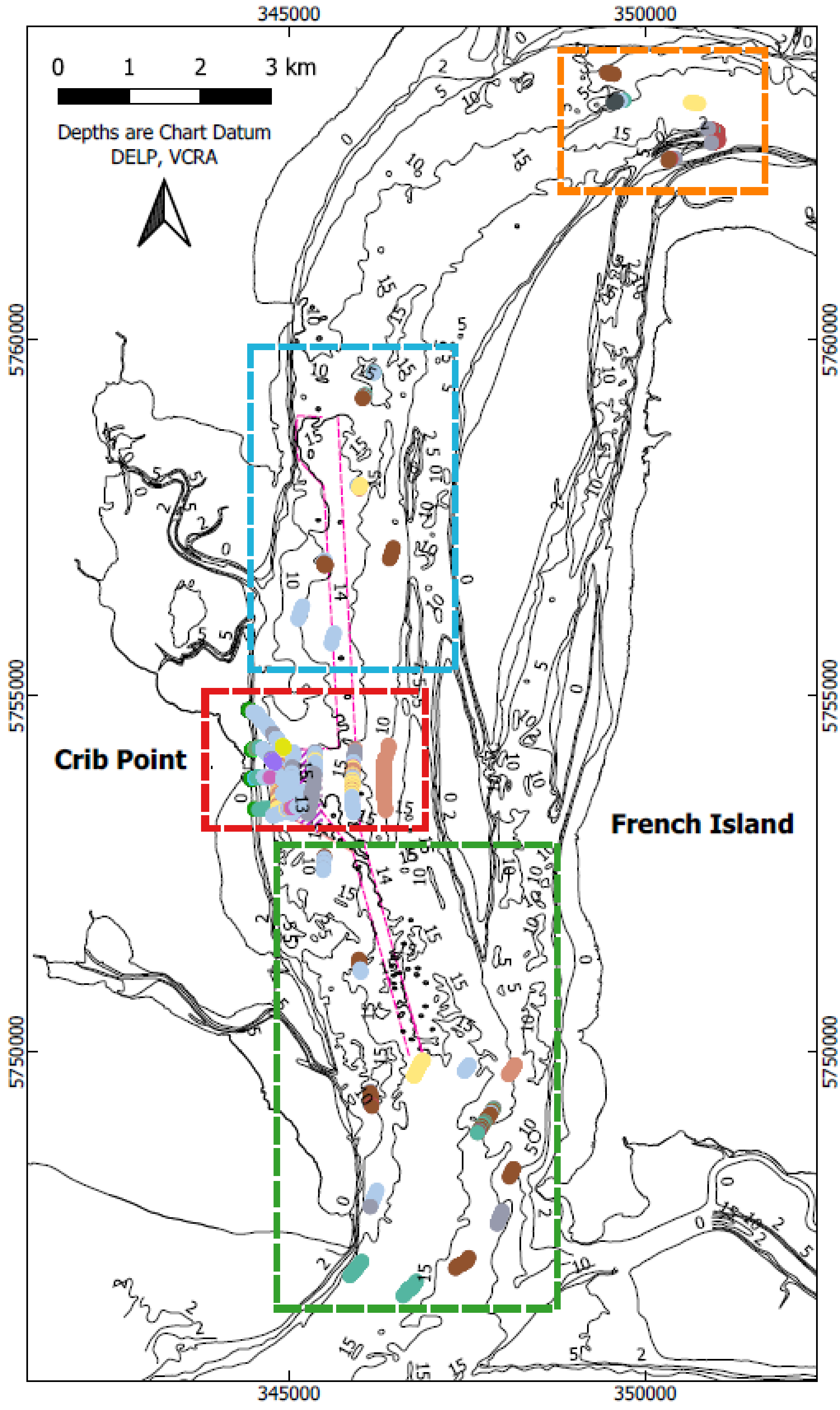


Figure 5-31. Benthic Habitats in Lower North Arm

(Refer to Table 5-11 for Legend)

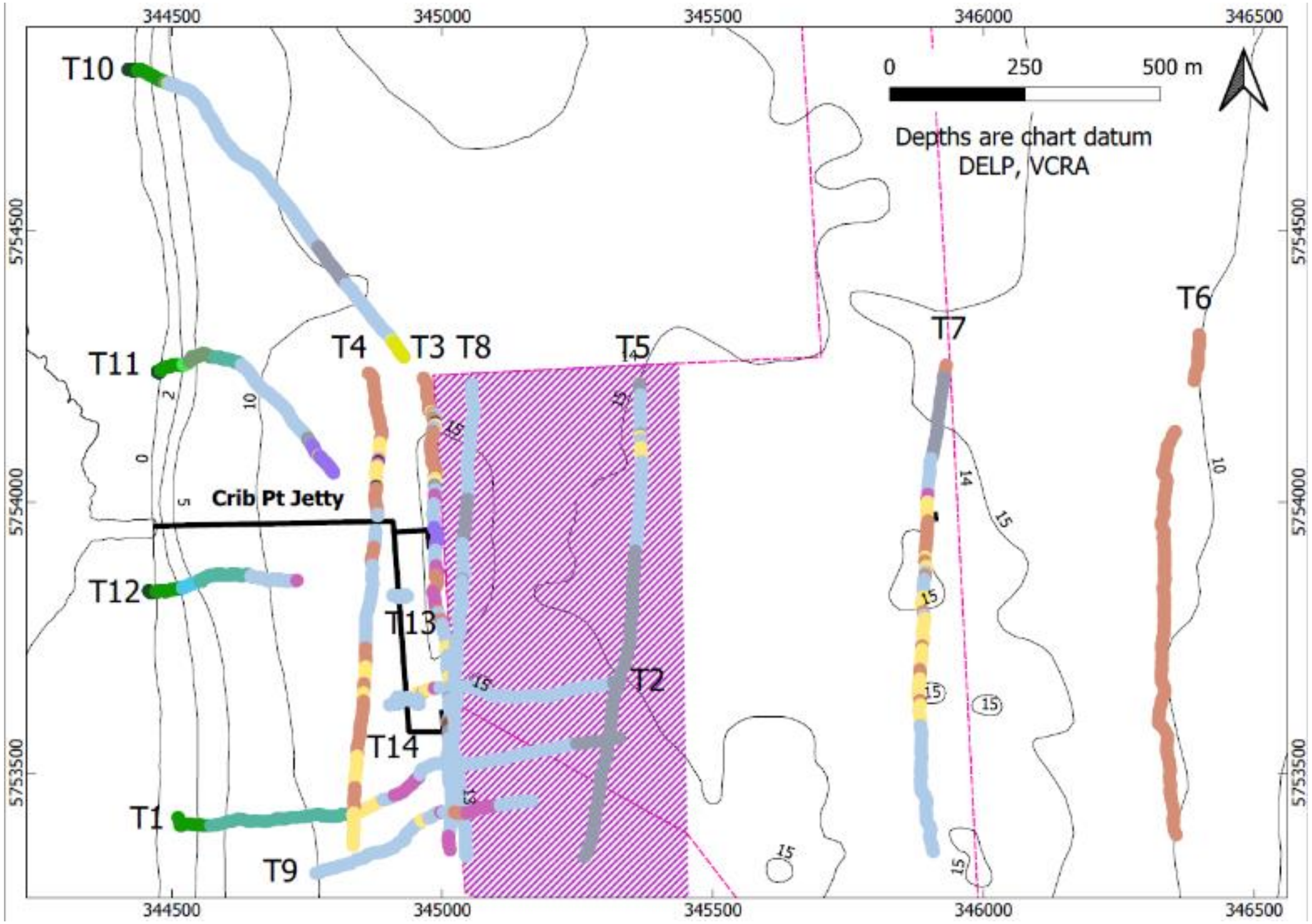


Figure 5-32. Benthic habitats near Crib Point

(Refer to Refer to Table 5-11 for Legend)

The survey found that benthic habitats at the Lower North Arm locations were similar to those mapped previously. Most locations were characterised by sand or sand/shell (DPI=shelly sand). However, the transect images showed finer levels of variation in surface texture and biological association than the generally reported categories (Blake et al 2013) and added further context to interpretation of habitats classified on the basis of grain size analysis from grab samples (Coleman et al 1978).

The most common subtidal benthic habitat type in Lower North Arm was sand/shell sediment with epibenthic invertebrates and infauna (34 per cent of benthic habitat on average). The next most common habitat types were sand/shell sediment with epibenthic invertebrates and macroalgae (leaving some space for infauna, 20 per cent of benthic habitat on average) and sand/shell sediment with epibenthic invertebrates, macroalgae and infauna (this habitat had more sparse epibiota leaving space for infauna, and accounted for 10 per cent of benthic habitat on average). Sand/shell sediment dominated by benthic invertebrates (leaving little space for infauna) accounted for 9 per cent of benthic habitat. Sand and sand/shell sediment with infauna (lacking epibiota) accounted for 8 and 9 per cent of benthic habitat respectively.

Reef habitat is found in the Upper North Arm by Crawfish Rock and Eagle Rock (Figure 5-24). Reef habitat with epibenthic invertebrates and/or macroalgae accounted for 5 per cent of the benthic habitat surveyed, and occurred on three transects at Crawfish and Eagle Rock, one transect north of Crib Point, one transect south of Crib Pt and two transects near Crib Pt (Figure 5-31). The only transects where reef habitat comprised 25 per cent of benthic habitat or more were at Crawfish and Eagle Rock and transect 24 between Hastings and LIP.

Epibenthic invertebrates with hard exoskeletons such as bivalves and bryozoans and rhodoliths formed by coralline red algae can form ‘biogenic reef’ habitats. Species that form biogenic hard substrate reefs are known to occur throughout Western Port. Documentation of areas of biogenic reef formed by rhodoliths and bryozoans in the Rhyll segment of Western Port in recent years has generated interest in whether these habitats occur more widely in Western Port. The Rhyll segment is characterised by generally shallower depths and lower current speeds than Lower North Arm. The towed video transects in Lower North Arm did not detect any substantial areas of biogenic hard substrate habitat. Small patches of habitat (one to a few square metres in size) that could be considered biogenic reef were common, and occurred throughout Lower North Arm. It is considered that the strong water currents prevent formation of large areas of biogenic hard substrate habitat in Lower North Arm.

The transects near Crib Point in Figure 5-32 show that a wide range of benthic habitat types were present. The map also shows the boundaries of port zones and the maintained depths within them. Seabed adjacent to Crib Point Jetty Berths 1 and 2 along with seabed in the swing basin to the east of Crib Point Jetty has been dredged and is deeper than adjacent natural seabed levels. Around 350,000 m^3 of seabed material has been removed from this area in past dredging campaigns.

Habitats with a significant cover of seagrass and macroalgae near Crib Point are confined to shallow depths and show clear zonation, from dense seagrass cover (sand dominated by seagrass) on intertidal and shallow subtidal seabed to sparse seagrass and macroalgae between 2 m and 6 m depth (CD). The most common subtidal habitats near Crib Pt are sand/shell and sandy sediment with epibenthic invertebrates and infauna, or sediment dominated by epibenthic invertebrates. These habitat types accounted for an average of 64 per cent of benthic habitat along each transect, of which 52 per cent was sand/shell with epibenthic invertebrates and infauna. These habitats were widely distributed around Crib Point below depths of 4-5 metres. These habitats are highly heterogeneous at small scales due to

variable density and composition of epibenthic invertebrates (and infauna, see sections below).

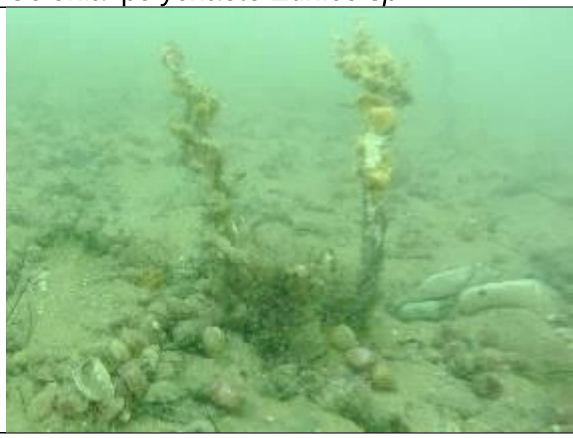
Epibenthic fauna in Lower North Arm	
Lamp-shell *Magelania flavescens*	Slate pencil urchin *Goniocidaris turbaria*
	
Sea-pen *Sarcoptyllus grandis*	Colonial polychaete *Eunice sp*
	
Doughboy scallop *Mimachlamys asperimma*	Bryozoans *Triphyllozoan* and *Celleporaria*
	

Figure 5-33. Images of epibenthic fauna in Lower North Arm

The next most common habitat was sand and sand/shell sediment with infauna (i.e. sediment bare of epibiota). This habitat accounted for an average 20 per cent of benthic habitat along each transect near Crib Pt. This habitat was found patchily inshore and offshore from Crib Pt Jetty (particularly to the north of Berth 1, transects T4 and T3) and in the centre of the main

North Arm Channel (T7) and was the dominant seabed type on the east side of the channel (T6).

Hard substrate habitat around Crib Pt was only present as isolated rocks or boulders with associated habitat of less than 1 m^2 and was considered a negligible proportion of the benthic habitat.

Hard substrate was surveyed at Crawfish Rock and Eagle Rock in the far north of Lower North Arm (Figure 5-31). The transects demonstrated the very small amount of hard substrate present even in this part of Lower North Arm. Hard substrate habitat was localised to Crawfish Rock and Eagle Rock, both of which are surrounded by soft-substrate habitat. The reef habitat at Crawfish Rock supported both epibenthic invertebrates and macroalgae, while reef habitat at Eagle Rock lacked macroalgae. Currents in this part of Lower North Arm are quite strong owing to the constricted bathymetry created by Crawfish and Eagle Rock. The transect in channel habitat (T18) where currents are strong had no epibiota, while the habitat on flat seabed outside the main channel (T21, T23) did support epibiota.

Transects were surveyed around north of Crib Pt between Hastings Bight and Long Island Point as shown in Figure 5-31. The transects show that the most common habitats were sand/shell with benthic invertebrates and infauna (40 per cent) and sand/shell with benthic invertebrates and macroalgae (32 per cent). These habitats are all widely distributed in Lower North Arm, including around Crib Pt.

Transects surveyed south of Crib Pt between Stony Point and Sandy Point (Confluence Zone rock as shown in Figure 5-31 showed that the most common habitats were sand/shell with benthic invertebrates and macroalgae (33 per cent), sand/shell with benthic invertebrates and infauna (23 per cent) and sand/shell with benthic invertebrates, infauna and macroalgae (18 per cent). Macroalgae were more common on transects to the south of Crib Pt, particularly around Tea Tree Point on French Island and in the deep channel where North Arm meets the Confluence Zone. It is thought that the higher water clarity in this area, and higher abundance of shell material (possibly due to winnowing by the stronger currents) provide better habitat for macroalgae.

The maps and habitat classification discussed above show epibenthic invertebrates and infauna are the major biota associated with subtidal benthic habitats in Western Port. Key epifauna include the brachiopod (lamp-shell) *Magellania flavescens,* doughboy scallop *Mimachlamys asperimma*, colonial tube forming polychaete worm *Eunice sp.*, clump-forming ascidian *Pyura dalbyi,* bryozoan (lace corals) *Celleporaria* and *Triphyllozoan spp.*, slate pencil urchin *Goniocidaris turbaria* (as well as other sea urchin and seastar species). *Eunice, Pyura* and Bryozoan species all form biogenic substrate colonised by a range of other sessile and mobile invertebrates and fish. Images of these species are shown in Figure 5-33.

Table 5-12. Species and categories used in presence / absence analysis

Group	Taxon/Category	Group	Taxon/Category
Benthic Microalgae	Benthic microalgae	Spoon Worms (Echiura)	Echiuran (general)
Brown Algae	General	Crustaceans	Shrimp burrow
	Ecklonia radiata		Crustacean (general)
Red Algae	Drift	Bivalves, Gastropods Nudibranchs (Molluscs)	*Mimachlamys asperrima*
	Seagrass epiphyte		*Pecten fumatus*
	Frondose		*Ostrea angasi*
	Encrusting Coralline		Gastropod (general)
	Rohodolith		*Ceratosoma amoenum*
Green Algae	*Caulerpa cactoides*	Brachiopods	*Magellania flavescens*
	Caulerpa trifaria	Lace Corals (Bryozoa)	Phidoloporidae (cf. *Triphyllozoon*)
	Caulerpa scalpelliformis		*Celleporaria* spp.
	General		*Bugula* sp.
Seagrasses	*Halophila australis*		*Orthoscuticella ventricosa*
	Zostera nigricaulis	Sea Urchins, Seastars (Echinoderms)	Sea urchin (general)
Sponges (Porifera)	General		*Heliocidaris erythrogramma*
	Tethya sp.		*Goniocidaris tubaria*
	Holopsamma sp.		*Tosia australis*
Soft corals, hydroids, anemones (Cnidaria)	*Sarcoptilus grandis*		Seastar (general)
	Alcyonacea (soft coral)		*Nectria* sp.
	Ralpharia sp.		*Meridiastra gunnii*
	Hydroid (general)	Sea squirts (Ascidiacea)	Ascidian (Solitary)
	Pink anemone		Ascidian (Colonial)
	Anthonoe sp.		*Stolonica australis*
Worms (Polychaeta)	*Eunice* sp. (colony)		*Pyura dalbyi*
Worms (Polychaeta)	Tubeworm (general)		*Sycozoa* sp.
	Fanworm (general)		*Pyura australis*

Table 5-13 shows the percentage of images on each transect (site) where key benthic groups were present. The table uses a colour scale, with darker green shading indicating a species was present in a higher proportion of images.

Table 5-13. Proportion of benthic biota groups on Lower North Arm video tows

Taxon/ Category	Brown Algae	Red Algae	Green Algae	Seagrass	Sponges	Cnidaria	S. grandis	Eunice sp.	M. asperimma	M. flavescens	Bryozoans	Celleporaria spp.	Echinoderms	G. tubaria	Ascidians	P. dalbyi
Crib Point (18 Dec 2018)																
Tow-01	1	35	1	14	41	10	0	1	6	24	4	4	7	6	5	1
Tow-02	0	40	0	0	44	4	0	0	13	46	13	13	27	21	4	0
Tow-03	0	19	0	0	27	18	2	0	4	38	5	3	23	23	0	0
Tow-04	0	3	0	0	7	2	0	2	2	5	2	2	3	3	5	0
Tow-05	0	45	0	0	29	6	0	9	12	76	3	2	11	10	9	0
Tow-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tow-07	0	16	0	0	14	2	0	30	1	4	1	1	5	5	9	7
Tow-08	0	22	0	0	28	10	0	0	9	35	13	12	12	9	7	2
Tow-09	0	9	0	0	24	7	0	2	5	3	2	2	17	16	12	10
South of Crib Point (19 Dec 2018)																
Tow-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tow-02	0	50	0	0	50	31	0	63	0	13	31	13	38	13	38	31
Tow-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tow-04	0	94	0	0	59	6	0	9	3	31	59	31	22	13	50	38
Tow-05	9	100	0	0	55	9	0	0	0	0	0	0	18	18	9	0
Tow-06	0	44	0	0	89	0	0	17	0	0	11	11	50	0	94	94
Tow-07	0	67	0	0	57	0	0	81	0	0	67	48	14	0	67	62
Tow-08	0	6	0	0	88	0	0	100	0	0	38	31	25	13	44	44
Tow-09	0	13	0	0	94	0	0	50	0	0	19	19	6	0	81	81

0
1-10
11-30
31-70
70-90
90-100

Tow-10	0	30	4	0	96	4	0	57	0	0	26	26	70	17	30	30
Tow-11	0	100	0	0	96	0	0	43	4	4	26	26	39	4	13	4
Tow-12	0	82	0	0	41	0	0	53	0	35	0	0	0	0	41	35
Tow-13	0	53	0	0	42	0	0	32	5	32	5	5	21	16	11	5
North of Crib Point (19 Dec 2018)																
Tow-14	0	0	0	0	11	0	0	94	0	0	6	6	0	0	0	0
Tow-15	0	0	0	0	19	0	0	50	6	6	0	0	0	0	0	0
Tow-16	0	86	0	0	93	0	0	36	0	0	0	0	21	21	57	57
Tow-17	0	5	0	0	24	0	0	10	0	0	5	5	24	19	0	0
Tow-24	0	43	0	0	71	0	0	0	0	14	14	14	14	14	57	43
Tow-25	0	39	0	0	100	17	0	61	0	0	11	6	44	44	56	56
Tow-26	0	75	0	0	69	0	0	56	6	50	31	25	75	75	31	25
Crawfish and Eagle Rocks (19 Dec 2018)																
Tow-18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tow-19	14	45	17	0	79	3	0	0	0	0	31	3	24	0	14	0
Tow-20	26	63	11	0	95	32	0	0	0	0	63	0	0	0	42	0
Tow-21	0	0	0	0	21	0	0	0	0	0	0	0	7	0	0	0
Tow-22	0	38	0	0	84	16	0	0	0	3	50	28	28	16	44	19
Tow-23	0	57	0	0	43	0	0	14	0	0	7	7	7	7	36	36
All	1	31	1	1	39	6	0	16	4	19	12	8	16	11	17	12

^Data shown are the proportion of images where species was present

(Green Shading Represents Abundance)

Magellania flavescens (Brachiopod - Lamp-shell) was present in high numbers to the east of Crib Point Jetty with transect T5 showing the highest coverage (76%) and highest density (Table 5-13 and Figure 5-34) along with T3 and T8. *M. flavescens* occurred in dense patches at the disused Berth 2, but in lower abundance than the frequently used Berth 1 (T3 and T8).

These data as well as data in MSE (2009) show that the modified shipping basin and berth habitats in Lower North Arm support high abundances of *M. flavescens.* In contrast, *M. flavescens* was present in low to moderate density at only 9 out of 26 reference transects to

the north and south of Crib Pt and around Crawfish Rock/Eagle Rock. It was mostly absent on far eastern transects near Crib Point (T6 and T7, Figure 5-34) and less abundant to the west of Crib Pt Jetty (Table 5-13).

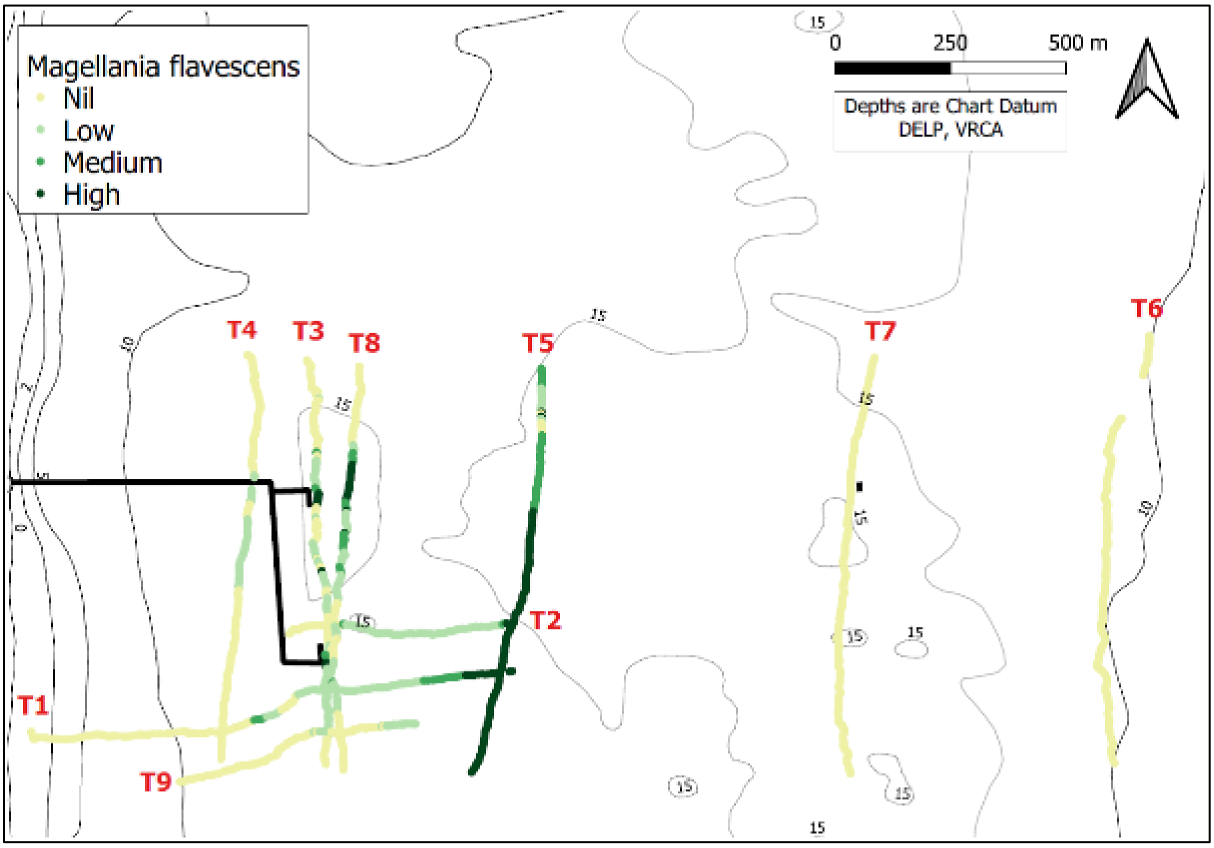


Figure 5-34. *Magellania flavescens* (Lamp-shell) density near Crib Point Jetty.

Mimachlamys asperrima (Doughboy scallop) was found on almost 90% of transects near Crib Point, and in between 1 and 13% of images analysed. In reference areas (North and South of Crib Pt, Crawfish Rock and Eagle Rock) the doughboy scallop was less abundant and only present on 5 out of 26 transects (Table 5-13). At Crib Point Jetty Doughboy scallops were sparsely and patchily distributed on transects up to 300 m away from the jetty. No scallops were found on the two eastern most transects and the north-south transect west of the jetty. For a comprehensive presence/absence map for transects near Crib Point and North Arm, see Figure 15, Annexure D.

Slate Pencil urchins (*Goniocidaris turbaria*) were found at various locations near Crib Point, with the highest abundances at two transects adjacent to the jetty. No Pencil urchins were found on the easternmost transect and sites west of the jetty nearer to shore. This species was present at reference transects throughout North Arm with the highest numbers in the zone north of Crib Pt (Table 5-13).

Tubes of polychaete worms of a Eunice sp. were occasionally found at most transects near Crib Pt Jetty (Table 5-13). However, this species was predominantly found in zones north and south of Crib Pt Jetty with occurrences at 16 out of 20 transects and coverage between 50 and 100% for most transects (Table 5-13). *Eunice* was characteristic of deeper sandy channel habitat where it forms important biogenic habitat – the tubes provide substrate for the attachment of sessile sponges and colonial ascidians.

Bryozoan species were identified at all except the easternmost transect near Crib Pt Jetty. Among the species identified were *Celleporaria*, *Triphyllozoon* and *Orthoscuticella* spp. Bryozoan species were well represented throughout North Arm with between 5 and 67% of images containing bryozoans.

The clump-forming ascidian (sea squirt) *Pyura dalbyi* occurred on some of the transects near Crib Point, but was most common on transects to the south and north of Crib Point where it attains high densities in places. *Pyura dalbyi* was noted as one of the more common epifauna in Smith *et al* (1979).

The Sea Pen *Sarcoptyllus grandis was* identified in only a few images on just a few transects near Crib Pt, but not on any other transects. This was surprising as *Sarcoptyllus grandis* was noted for its wide distribution and abundance in assessments by Smith *et al* (1979) and MSE (2009).

Echinoderms including the seastars *Tosia sp*, and *Nectria* sp. and the sea urchin *Heliocidaris erythrogramma* were widely distributed and common in 2018 and 2019. These species were also common in the 1970s (Smith *et al* 1979). The sea start *Meridiastra gunnii* was common on one transect in the south of Lower North Arm, where drift algae (it's main food source) was also common.

Subtidal Infauna Survey

Infauna were sampled at 29 sites in Lower North Arm (Figure 5-35, Figure 5-36) using a weighted ponar grab to document the distribution and characteristics of infauna in the Crib Point area and elsewhere in the main channel including sites sampled in the Westernport Bay Environmental Study (Coleman et al 1978): Ref-N3, Ref-N4, Ref-S4, Ref-N5 and Ref-E2.

Table 5-14 shows the abundance of the three main infauna classes and seabed categories found at 29 sites in Lower North Arm, Western Port.

Polychaetes ("bristle worms") were the most abundant class (mean abundance per site: 392/grab), closely followed by crustaceans (385/grab). 64 molluscs per grab were present at each site on average. Only ~7 individuals per grab were associated with other classes or phyla including Echinodermata, Chordata, Cnidaria and Nemertea. All three main classes were found at all sites throughout North Arm, except Ref-S3 where no molluscs were present. The dominance of the infauna by polychaetes and crustaceans is consistent with the findings of Coleman *et al* (1975) and MSE (1990).

Infauna were abundant in the Berth 2 area (876 – 2200/grab) while reference sites were least inhabited by infauna (32-764/grab). The infauna density generally correlated with the visually estimated level of bioturbation, except at E10a where high numbers of infauna (1833/grab) were documented but levels of bioturbation were rated as 'Low'. This site showed a unique distribution of the main infauna classes with relatively low numbers of polychaetes (133/grab) and high numbers of crustaceans (1658/grab), mainly amphipods of the family Corophiidae. Corophiid amphipods are not known for forming large, easily visible burrows, which likely explains the discrepancy between visually estimated and actual infauna density at E10a.

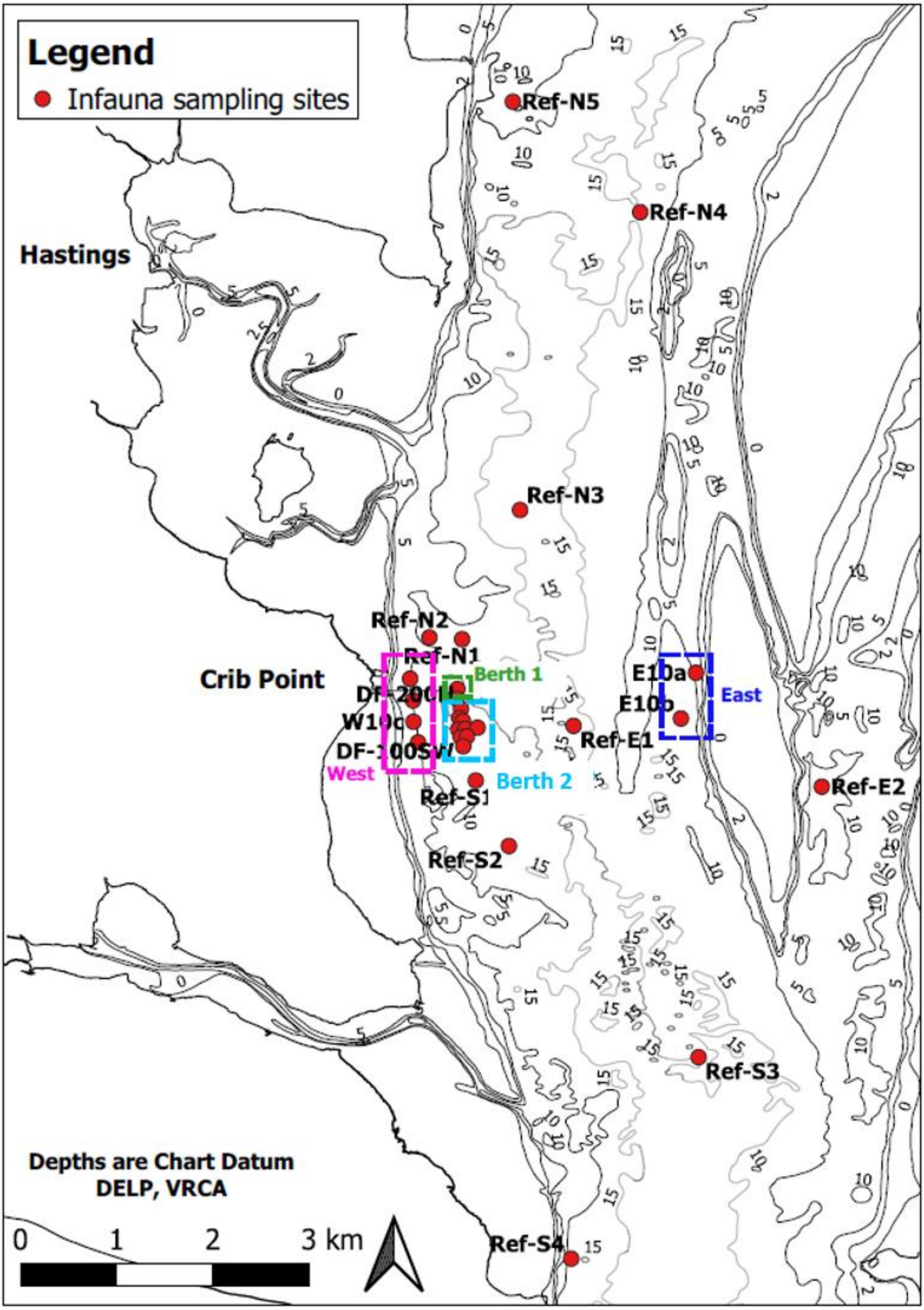


Figure 5-35. Infauna sampling sites in Lower North Arm

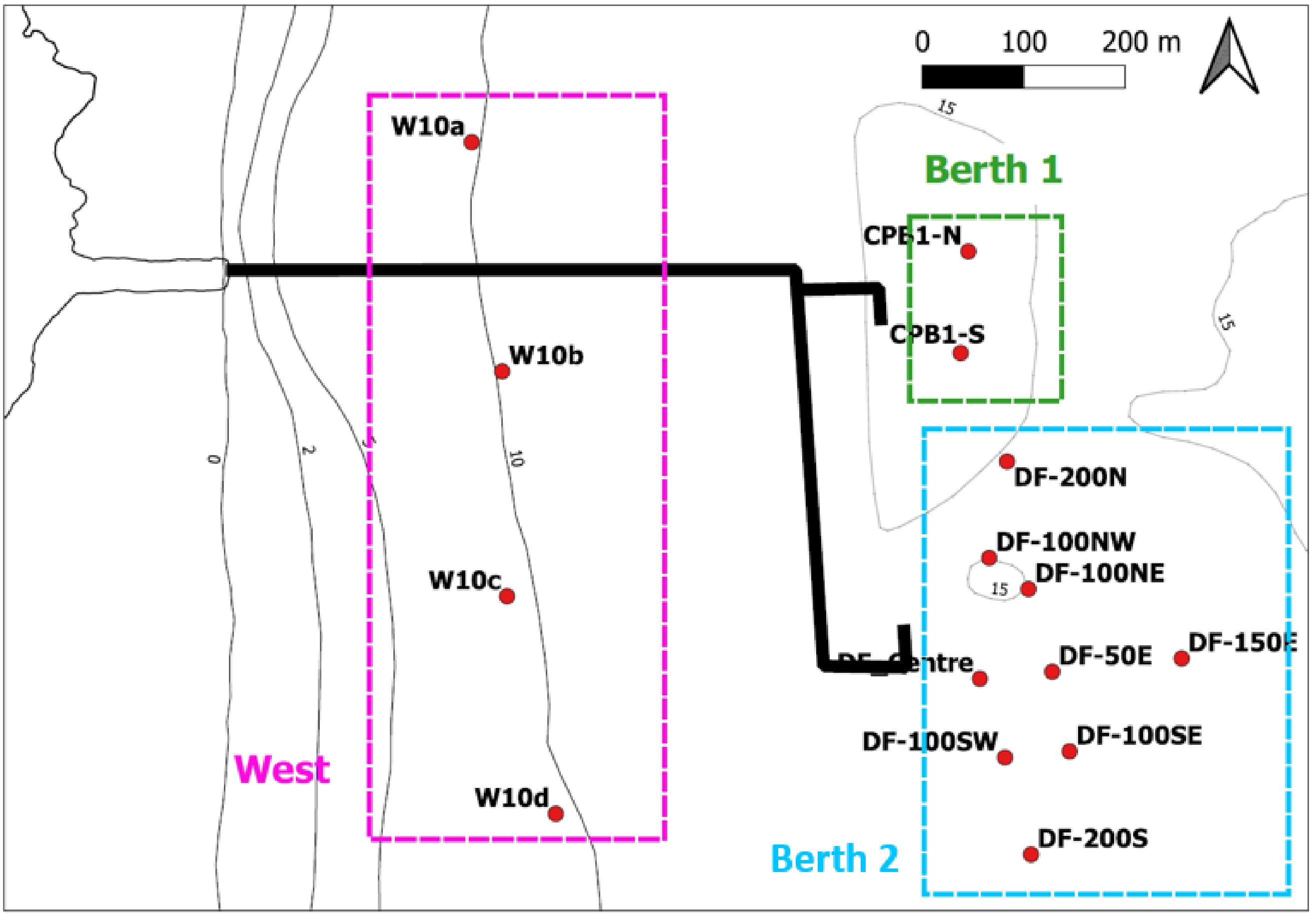


Figure 5-36. Infauna sampling sites near Crib Point Jetty

Table 5-14. Abundance of major infauna groups and seabed characteristics

Site details		Infauna (number per grab)					Seabed characteristics			
Site	Depth (m)	Polychaete	Crustacean	Mollusc	Other	Total	Sediment	Shell	Bioturbation	Benthic invertebrates
W10a	10	256	276	92	20	644	Fine sand	N/A	N/A	N/A
W10b	10	370	625	115	30	1140	Fine sand	N/A	N/A	N/A
W10c	10	300	348	36	4	688	Fine sand	N/A	N/A	N/A
W10d	10	218	238	26	6	488	Fine sand	Low	Medium	Medium
CPB1-N	16	362	341	48	10	761	Fine sand	Medium	Medium	Low
CPB1-S	16	568	392	44	12	1016	Fine sand	Medium	Medium	Low
DF-200N*	14	688	1356	148	8	2200	Fine sand	Medium	High	Low
DF100NW*	14	770	327	206	18	1321				
DF100NE*	14	556	328	84	0	968				
DF-CENTRE*	14	652	508	60	8	1228				
DF-50E*	14	520	304	48	4	876				
DF-150E*	14	697	394	91	0	1182				
DF-100SW*	13	768	800	148	4	1720				
DF-100SE*	13	764	467	79	30	1340				
DF200S*	13	700	384	88	12	1184				
E10a**	10	133	1658	43	0	1833	Medium sand	Medium	Low	Medium
Ref-N1**	12	53	63	34	7	156	Medium sand	Medium	Nil	Nil
Ref-N2**	12	258	44	54	12	368	Fine sand	Medium	Medium	Medium
Ref-N4**	13	5	21	5	2	32	Medium sand	Nil	Nil	Low
Ref-N5**	12	110	158	46	2	316	Medium sand	Low	Low	Low

Ref-E1**	14	258	36	3	0	297	Medium sand	Nil	Low	Nil
Ref-E2**	11	30	44	26	2	102	Medium sand	Nil	Low	Nil
Ref-S1**	11	424	297	30	12	764	Fine sand	Low	Medium	High
Ref-S2**	12	332	120	36	8	496	Medium sand	Medium	Low	Nil
Ref-S3**	13	6	85	0	0	91	N/A	N/A	N/A	N/A
Mean		**392**	**385**	**64**	**7**	**848**				

* For these sites, seabed categories were inferred from habitat video tows east of Crib Point J

Table 5-15 summarises numbers and mean densities of the thirteen most abundant infauna families and higher taxonomic orders (>1% of total) at the five site groupings 'West', 'Berth1', 'Berth 2', 'East' and 'Reference'. This survey found infauna from 109 families (Table 5-15). The number of infauna at each site grouping ranged from 13 to 25, with generally more infauna found at Berth 2 (1163/grab) and 'East' (1709/grab) than at 'West' (552/grab), 'Berth1' (777/grab) and 'Reference' (219/grab) sites.

The majority of infauna were crustaceans of the family Corophiidae, although their high total numbers were due to particularly high densities found at only one site E10a ('East').

The second and third most abundant groups were Ampharetidae (terebellid polychaetes, (840/grab) and small shrimp-like crustaceans of the order Tanaidacea (657/grab). Among molluscs, Veneridae ("Venus clams") were highest in numbers (137/grab). Polychaetes of the families Chaetopteridae, Lumbrineridae and Opheliidae, and the crustacean Ampheliscidae ranged between 107 and 189 individuals per grab.

Most groups were found at all sites, except Chaetopteridae and Eunicidae which were absent from the 'East' site.

Table 5-15. Abundance of the 13 infauna families comprising 1 % of infauna by zone

Zone	West	Berth 1	Berth 2	East	Reference	Total	% of Total
Number of sites	4	2	9	1	9	25	-
Number of families	33	38	32	32	20	109	-
Total infauna*	552	777	1163	1709	219	4421	100
Polychaeta (>1%)							
Ampharetidae*	83	267	430	3	57	840	19
Capitellidae*	21	4	20	9	8	61	1
Chaetopteridae*	2	66	19	0	21	107	2
Eunicidae*	24	6	8	0	2	40	1
Lumbrineridae*	35	53	74	12	16	189	4
Opheliidae*	15	44	40	33	36	168	4
Terebellidae*	25	5	15	15	3	63	1
Crustacea (>1%)							
Ampheliscidae*	55	24	32	61	2	174	4
Corophiidae*	126	41	124	1494	39	1824	41
Phoxocephalidae*	15	13	40	18	7	92	2
Tanaidacea*	101	222	280	39	15	657	15
Mollusca (>1%)							
Calyptraeidae*	32	9	19	6	2	69	2
Veneridae*	20	25	62	18	12	137	3
Other (96 families)*	188	111	172	124	72	667	15

Figure 5-37 shows the distribution and abundance of the top-ten infauna families. Sites in the 'West', 'Berth 1' and 'Berth 2' zones at Crib Point had similar infauna community composition. Abundance was higher at Berth 2 than to the west and at Berth 1. Berth 2 is characterised by greater depth (dredged), lower current speeds and winnowing (such as by shipping at Berth 1) and more shell, silt and epibiota than adjacent seabed so may be favourable for abundant infauna community.

Ampharetidae (polychaete worms) were the largest group at most sites within the development footprint zone, while Tanaidacea (crustaceans) were present at all sites in moderate to very

high abundance. Corophiidae (amphipod crustaceans) dominated at the west sites, all of which were around 10 m deep, and comprised almost 90 per cent of the infauna at E10a.

Reference sites mostly showed low abundance of the top-ten infauna families and great variability. These sites were largely in channel habitats where currents tend to be higher and sediments are likely to be more frequently mobilised. The infauna assemblages at Ref S1 and Ref S2 were the most similar to those at Crib Pt Jetty sites – both these sites were within 1 km of the jetty and in similar habitat adjacent to, but not in the main channel.

Figure 5-38 shows the Shannon H' index for the infauna assemblage at each site. This index is commonly used as a measure of biodiversity: it provides an index of the evenness of species abundances (dominance or lack thereof by one or a few species):

$$\text{Shannon Index (H)} = -\sum_{i=1}^{n} p_i \ (\ln p_i)$$

Where p is the number of individuals in species 'i' divided by the total number of individuals found. Higher values of the index indicate higher species diversity.

Figure 5-38 shows that most sties had a Shannon H value of between 2 and 3 (moderate to high diversity), while a few sites had values between 1 and 2 (lower diversity). There were no clear habitat or location related patterns in diversity.

One of the interesting species that is characteristic of Western Port benthic ecosystem is the bivalve *Neotrigonia margaritacea* (Melbourne Water, 2011). *Neotrigonia* was identified at 7 sites in abundances from 1 to 7 per grab (average 2). Two *Neotrigonia* were identified in samples from Crib Point Berth 2 (development footprint) and on from Berth 1. The area clearly supports this species but does not appear to have high abundances of *Neotrigonia*.

Western Port is a known location for two FFG Act listed ghost shrimp species: The Western Port ghost shrimp *Eucalliax tooradin* (known from just a few intertidal and shallow subtidal mudflat sites) and small-gilled ghost shrimp *Michelea microphylla* (known from just one deep subtidal site near Hastings). Both these species are from the crustacean family Callianassidae. Callianassidae accounted for less than 1 per cent of the infauna collected and all specimens were the common species *Trypaea australiensis.* Six *Trypaea australiensis* were collected at Ref-E2, the same area where large numbers were identified during targeted surveys for *Michelea microphylla* (CEE, 2019e), and where large numbers of burrows were visible on the seabed. No *Michelea* or *Eucalliax* were collected in subtidal sediment grabs.

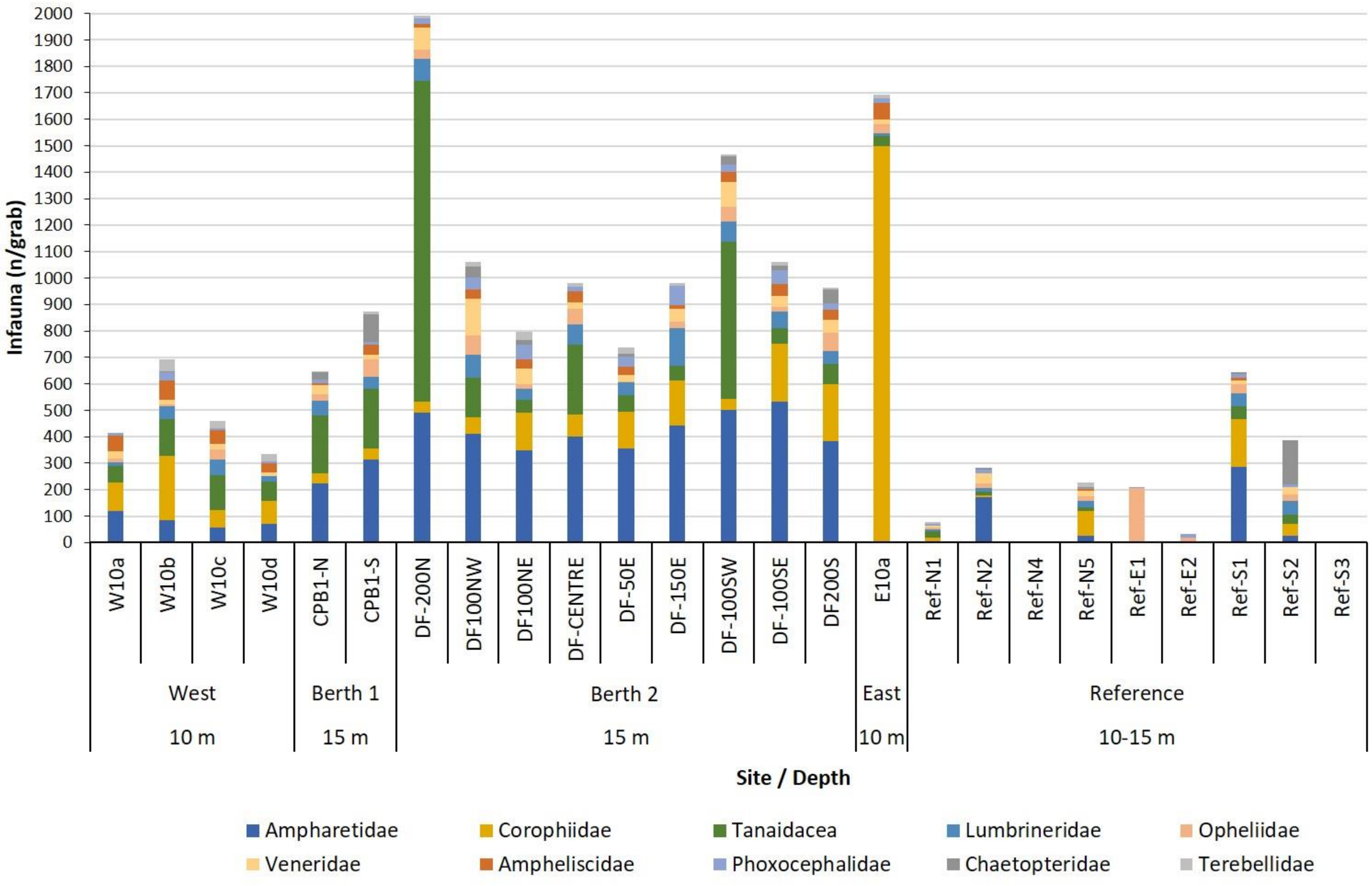


Figure 5-37. Ten most abundant infauna families at sites in Lower North Arm

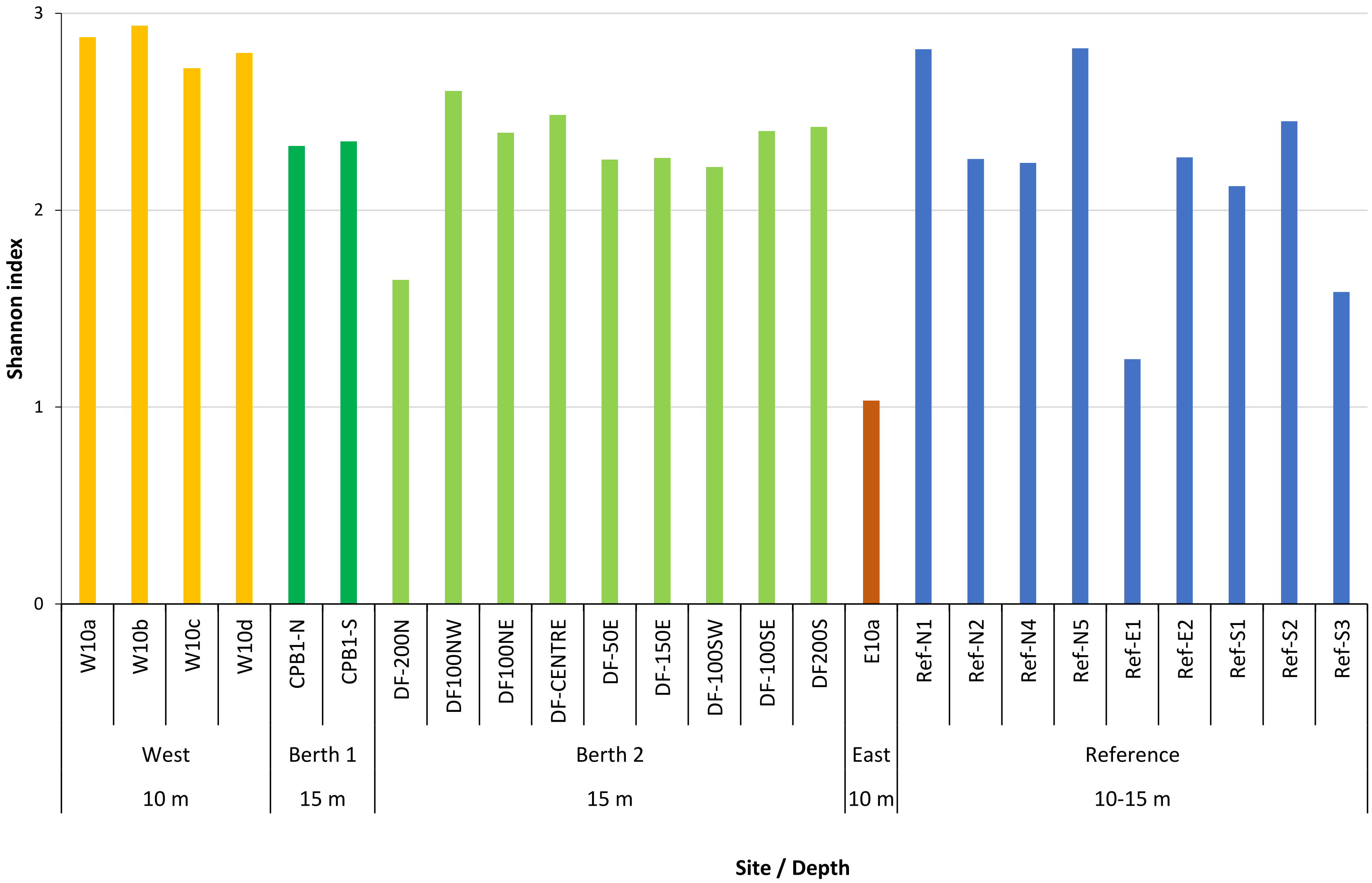


Figure 5-38. Infauna Species Diversity in Lower North Arm (Shannon H')

Data from previous surveys of infauna in Lower North Arm are available from MSE (1990) and Coleman *et al* (1978). Data from the 2019 survey (CEE) and monitoring by MSE near the steel wharves from the 1970s to 1980s are shown in Table 5-16. The table shows that the infauna communities were very similar, dominated by polychaete worms (annelida) and crustaceans, while molluscs, echinoderms and other taxa were present in minor abundances.

Table 5-16. Comparison of CEE (2019) data with MSE (1990) infauna data

Study	Annelida	Crustacea	Mollusca	Echinoderm	Other
% of total (CEE 2019)	46.7	45.8	7.6	0.2	0.8
% of total (MSE 1990)	40	45	10	2	3

Table 5-17 compares infauna data from Lower North Arm 2019 (CEE 2019) to infauna data from all over Western Port in the 1970s (Coleman *et al* 1978). Data are shown by family, the taxonomic unit level used in 2019, with the species identified from each family by Coleman *et al* 1978 listed. The data show a moderate degree of similarity in the infauna communities, with many taxa common to each survey with similar ranks in abundance. The dominant taxa in both surveys were polychaete worms, in particular Ampharetidae (*Isolda* sp. in Coleman *et al*) and Capitellidae (*Mediomastus* sp in Coleman *et al*). Ampharetidae was by far the most abundant polychaete in 2019, while Coleman *et al* 1978 found a more evenly distributed polychaete assemblage.

The Molluscs were also similar, though Veneridae dominated in 2019 and Tellinidae in 1978. *Neotrigonia margaritaceae* had similar abundance in 2019 as it had in the 1970s at around 3 per cent. The crustaceans were dominated by Tanaidacea and Corophiidae in both surveys.

Table 5-17. Comparison of infauna communities documented in 2019 and 1970s

Order/ Subclass	Family	% of all infauna by class	% of all infauna (Coleman 1978)	Species (Coleman 1978)
Annelids (Polychaete worms)				
Errantia	Nereididae	0.2	3.4	*Platynereis* sp.
Errantia	Nephtyidae	1.1	13.1	*Nephtys australiensis*
Errantia	Eunicidae	2.1	3.2	*Eunice* sp.
Errantia	Dorvilleidae	< 1	2.2	*Dorvillea* sp.
Sedentaria	Capitellidae	3.6	16.9	*Mediomastus* sp.
Sedentaria	Ampharetidae	52.6	12.3	*Isolda* sp.
Sedentaria	Orbiniidae	< 1		*Scoplos* sp.
Sedentaria	Terebellidae	3.5		*Amaeana* sp.
Molluscs (Gastropods and Bivalves)				
Gastropoda	Calyptraeidae	21.5	5.6	*Sigapatella calyptraeformis*
Bivalvia	Nuculidae	< 1	6.3	*Pronucula concentrica*
Bivalvia	Trigoniidae	2.5	3.1	*Neotrigonia margaritacea*
Bivalvia	Lasaeidae	< 1	17.1	*Lepton frenchiensis, Mysella donaciformis*
Bivalvia	Veneridae	50.1	16.2	*Notocallista diemenesis, Katelysia rhytiphora*
Bivalvia	Tellinidae	< 1	42.8	*Tellina deltoidalis, Tellina mariae*
Crustaceans				
Tanaidacea	Leptocheliidae	15	3.4	*Leptochelia* sp.
Isopoda	Leptanthuridae	17.4	0.7	*Leptanthura diemenensis*
Amphipoda	Aoridae/Corophiidae	< 1	3.8	Lembos sp. 4
Amphipoda	Amaryllididae	< 1	2.4	*Amaryllis macrophtalmus*
Amphipoda	Eusiridae	< 1	1.5	*Tethygenia* sp.
Amphipoda	?	< 1	1.4	*Marea mastersi*
Decapoda	Crangonidae	< 1	1	*Pontophilus intermedius*
Decapoda	Palaemonidae	< 1	1	*Macrobrachium intermedium*
Decapoda	Hymenosomatidae	< 1	1.9	*Halicarcinus ovatus*
Brachyura	Litocheiridae	< 1	1.6	*Litocheira bispinosa*

5.8 Plankton in Western Port

Plankton are the small and microscopic plants and animals that live in the water column. Plankton comprise holoplankton and meroplankton:

- Holoplankton are the plants and animals that spend their entire life cycle drifting in the water column. Holoplankton in western port includes: phytoplankton, which are the microscopic plants that photosynthesise and once of the key sources of primary production and food for small animals in Western Port; and, many zooplankton species, 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.

  Some 'holoplanktonic' phytoplankton and zooplankton can produces spores, eggs or resting stages that can survive in the sediments for years or decades
- Meroplankton spend only part of their life-cycle as plankton. In Western Port the meroplankton includes the planktonic phases of a wide range of fish, invertebrates and macroalgae that live on the mudflats, in the seagrass beds and in the channels of the various segments of Western Port. Meroplankton mostly comprise the drifting eggs, spores, seeds, propagules and larvae of larger plants or animals. This group of plankton is highly diverse with a range of different length planktonic phases from minutes to hours, days and weeks.

Plankton play an important role in marine ecosystems. The phytoplankton are the primary producers that use nutrients, carbon dioxide and the energy of the sun to create biomass. Phytoplankton are food for the small filter feeding or grazing invertebrates in the water column (zooplankton) or on the seabed (benthic invertebrates).

The small invertebrates that feed on the phytoplankton may also feed on drifting organic particles, marine bacteria or other plankton in the water column. They become food for larger invertebrates and filter feeding fish in the water column or on the seabed. These are a food source for larger invertebrates, fish, birds and mammals that inhabit Western Port. Hence, the plankton community links the benthic communities of the mudflats and channels.

Most plankton are weak swimmers and are carried horizontally by ambient water currents. Some plankton move vertically through the water column in response to time of day, this in known as diurnal migration. Others maintain themselves at a certain depth range in waters that are stratified by temperature or salinity layers. Still others may be associated with certain seabed habitats, such as seagrass or mudflats in shallow water and have strategies to maintain their position on, in or close to those habitats.

The geographic differences in the combination of physical, chemical and biological character of Western Port were recognised by interdisciplinary marine scientists during the Western Port study of the 1970s (Harris et al 1979, Hinwood, Marsden 1979) who partitioned Western Port into the arms, zones and segments shown in Figure 5-39 These areas remain relevant to environmental understanding and discussion of a range of environmental matters including planktonic communities.

The strong tidal water currents in the deeper main channels at Crib Point and throughout most of Western Port result in thorough mixing of the water column and the planktonic biota it contains, and the plankton in the mixed water column are transported back and forth for kilometres along the channels over each tide.

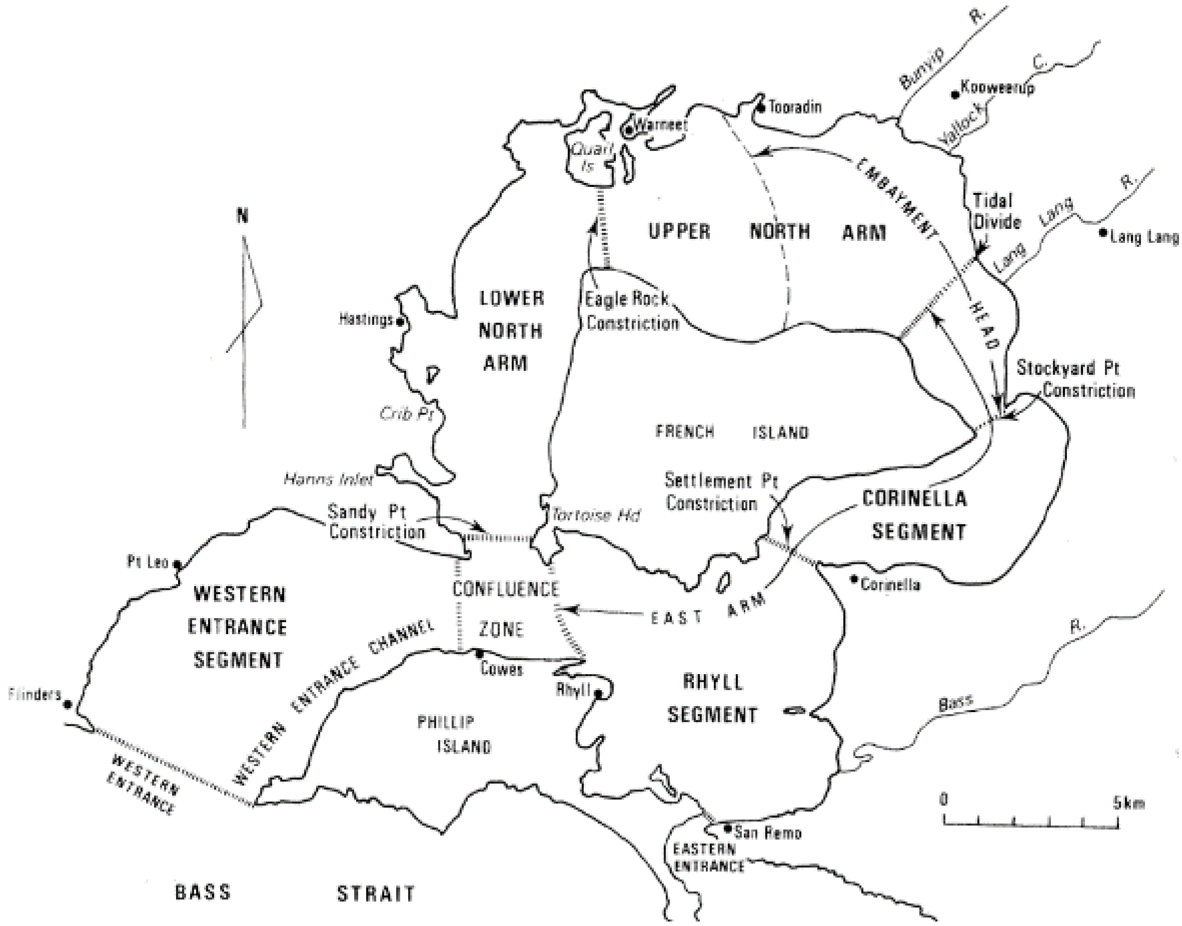


Figure 5-39. Environmental zone and features of Western Port

Source: Harris et al 1979, Marsden 1979

Wave action on the shallow intertidal mudflats and seagrass detritus from the extensive intertidal and subtidal seagrass beds results in relatively high amounts of suspended sediments and organic detritus in the water column in northern and eastern Western Port. Suspended material is highest in the shallow waters of the tidal divide in the northeast of the Western Port. Suspended material reduces through North Arm and Corinella and to very low concentrations at the Western Entrance near Flinders and Cape Grant as it mixes with the clear oceanic waters of Bass Strait. These factors influence the nature of the plankton communities throughout Western Port including those in North Arm.

5.8.1 Background to plankton in Western Port

Zooplankton were studied in Western Port in 1971-72 (Macreadie 1972), 1973-74 (Arnott 1974 and Min Con 1975) and 1982 -84 (Kimmerer and McKinnon various). Phytoplankton were also studied during the 1973-74 Ministry for Conservation Western Port Study (Min Con 1975). Fish eggs and larvae have been surveyed episodically and usually associated with the southern part of the bay and the shallow and intertidal habitats (Acevedo et al 2010, Edgar and Shaw 1995, Hoedt and Dimmlich 1995, Robertson 1978; Robertson and Howard 1978).

There have been no documentative studies of phytoplankton or zooplankton in North Arm since 1974. Studies of zooplankton in the 1980s focussed on the Corinella Rhyll and Western

Entrance Segments, and although some samples were collected in North Arm, the results were not reported.

In recognition of the gap in information on plankton communities in North Arm and the potential effects of the operation of the FSRU at Crib Point (including the potential effects of entrainment on the planktonic community of North Arm), a comprehensive program to sample plankton in North Arm was recommended and developed during the referral process in 2018.

The monthly phytoplankton, chlorophyll-a, zooplankton and fish eggs and larvae (ichthyoplankton) sampling program was initiated in December 2018.

5.8.2 Plankton Studies in 2019

Context

As discussed in Section 1.0 of this report, the primary potential effects of the project on the Western Port planktonic community will be due to entrainment of seawater through a heat exchanger on the FSRU to assist the regasification process. Referral-stage initial modelling (CEE 2018d) determined that the proportion of passive plankton entrained would depend on volume of water entrained, life-cycle duration, distance from the intake and planktonic seasonality and distribution.

An intake configuration was recommended that would reduce the potential for entrainment of plankton within approximately 2 m of the surface and 3 m of the seabed. It was recommended that hydrodynamic modelling and an integrated program of field measurements and entrainment modelling be developed to provide accurate predictions of entrainment proportion. A plankton and larval sampling program to provide information on spatial and temporal variations in plankton populations in Lower North Arm was also recommended.

The combined fit-for-purpose hydrodynamic, entrainment, phytoplankton, zooplankton and ichthyoplankton information would provide strong multiple lines of evidence for assessment of potential effects of entrainment and identify potential further mitigation measures.

Plankton study design

The plankton studies design was based on the 1982 to 1984 zooplankton investigations of Western Port and Port Phillip discussed previously (Kimmerer and McKinnon 1985, 1987a, b, c), which provide spatial and temporal information on zooplankton in East Arm and the Western Entrance. Methods are summarised in Section 4.2 and in greater detail in CEE technical reports CEE 2019a, b f) All plankton sampling used depth integrated samples to sample the same depth band of the water column that would be drawn into the FSRU heat exchange intakes. This was consistent with the 1980s sampling program (Kimmerer and McKinnon 1987a), which used single samples at multiple sites over a 24-month period. Fish larval phytoplankton sampling were designed to provide spatial and temporal information comparable to the zooplankton data.

Zooplankton and ichthyoplankton samples were collected monthly from December 2018 to December 2019 to provide seasonal replicates at sampling sites. Samples were collected using standard methods at seven sites in summer, autumn and winter and eight in spring. Sampling sites were dispersed along a longitudinal and lateral axis in Lower North Arm, day of month sample collection was randomised subject to weather suitability (3- to 6-week window), and the position of sampling was randomised by non-synchronisation with tide times (mean tidal excursion between 5 and 6 km at approximately 6-hour intervals).

In addition to the monthly sampling, zooplankton and phytoplankton samples were collected at the Berth 2 site during downloading of the water temperature logger (Section 5.5.6), which occurred at intervals approximately half-way between monthly plankton surveys. These data are not included in this report, so that monthly data for all sites is consistent but was used to further verify the assessment findings.

The location of monthly sampling sites is shown in Figure 5-40. Sites were distributed along:

- a north-south axis from the confluence zone in the south to the north of lower north arm; and
- a west-east axis with sites distributed between the 10 m depth contours to the west and east of Crib Point Jetty.

The north-south axis sites were designed to document spatial variability along the tidal gradient in Lower North Arm: waters in the south of Lower North Arm are exchanged with Bass Strait water on a shorter time-scale than those in the north of Lower North Arm.

The east-west sites document spatial variability between waters on the 10 m contour east (CPE10) and west (CPW10) of Crib Point that may be influenced by shallow subtidal and intertidal benthic habitats. The Crib Point Berth 2 site is at the location of the proposed FSRU where entrainment will occur and is adjacent to the jetty habitat created by the jetty piles. CPC1 represents mid-channel habitat. Phytoplankton samples were collected only at sites along the north-south axis and at Berth 2.

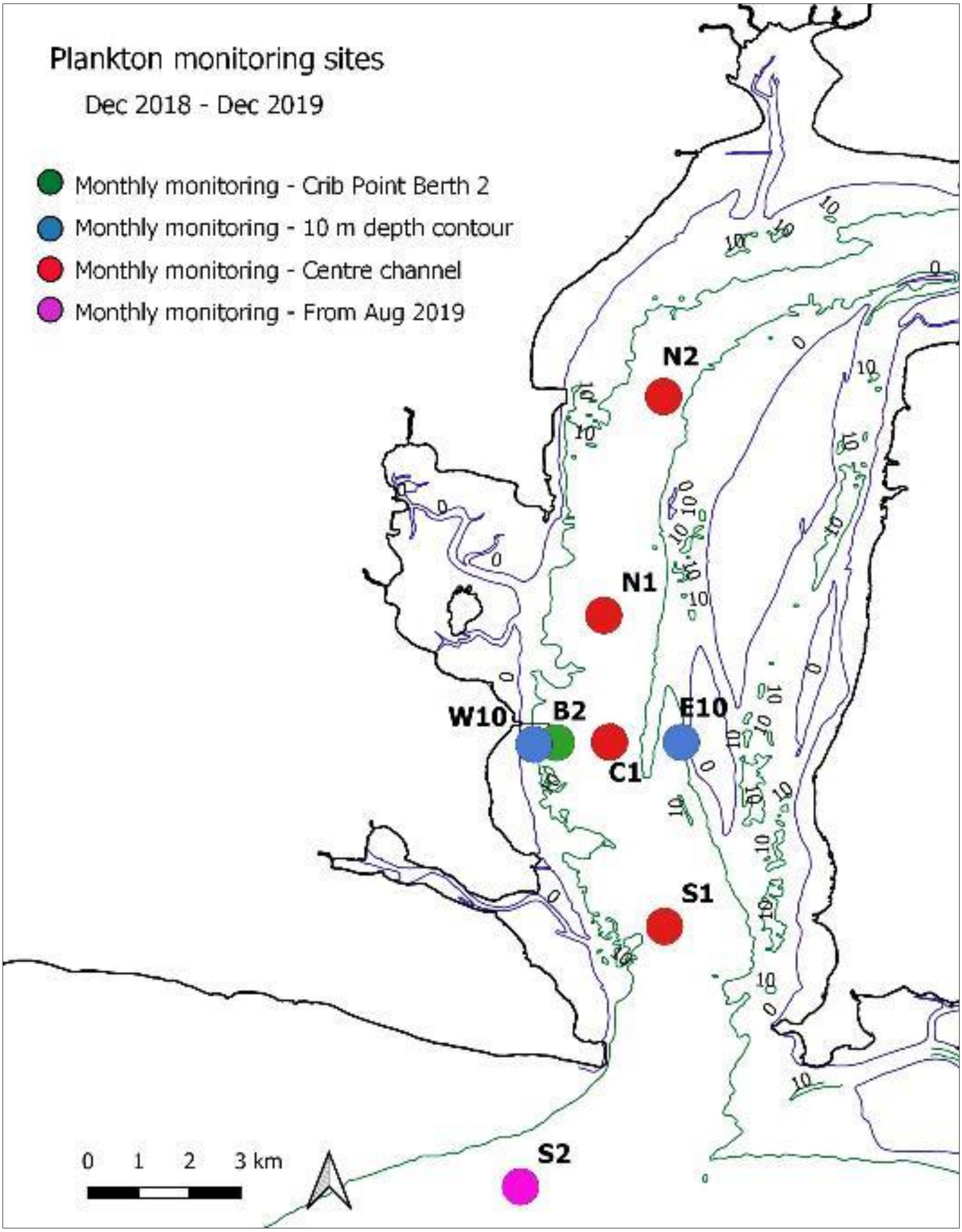


Figure 5-40. Plankton sampling sites used in regular monitoring

Table 5-18. Plankton sampling summary, December 2018 to December 2019.

Monthly Survey	Date	S2	S1	B2	W10	E10	C1	N1	N2
Survey 1	11/12/2018		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 2	10/01/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 3	4,11/02/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 4	07/03/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 5	04/04/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 6	03/05/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 7	07/06/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 8	03/07/2019		z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 9	02/08/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 10	03/09/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 11	1/10/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 12	30/10/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Survey 13	11/12/2019	z,i,p	z,i,p	z,i,p	z,i	z,i	z,i,p	z,i,p	z,i,p
Total number of surveys		5	13	13	13	13	13	13	13

z = zooplankton, i = ichthyoplankton, p = phytoplankton

5.8.3 Phytoplankton

The phytoplankton of Western Port includes species that are:

- autotrophic (obtain all their energy from photosynthesis)
- heterotrophic (obtain all their energy from ingesting organic matter, bacteria or other small phytoplankton); and
- mixotrophic (obtain energy from both photosynthesis and heterotrophy).

Phytoplankton are an important part of the food web. Autotrophic phytoplankton absorb nutrients and provide a food source for both zooplankton and heterotrophic and mixotrophic phytoplankton. The mixotrophic and heterotrophic phytoplankton are also a very important part of the trophic web, having a key role in the 'microbial loop' that recycles nutrients within the water column, as well as being a major food source for zooplankton (Suthers et al 2019).

Almost all phytoplankton have limited ability to move through the water column, although some are more suited to calm conditions (e.g. flagellates) and others are suited to turbulent conditions (e.g. diatoms). In either case, the strong tidal currents in the main channels of Western Port are sufficiently turbulent to prevent stratification of the water column or layering of phytoplankton over the water column.

General characteristics of Phytoplankton in Western Port

The phytoplankton in Western Port can be broadly divided into:

- diatoms (Bacillariophyceae)

- dinoflagellates (Dinophyceae); and
- other flagellates.

'Other flagellates' includes the phytoplankton classes Chrysophyceae, Prymnesiophyceae, Raphidophyceae, Dictyochophyceae, Cryptophyceae, Prasinophyceae and Euglenoidea.

The most diverse group were the diatoms with 76 species, followed by the dinoflagellates with 35 taxa. The remaining groups were each represented by between 1 and 7 taxa.

Flagellates can move through the water (at a very small scale) using their flagella for propulsion, planktonic diatoms tend to be non-motile, while benthic diatoms may be able to move across surfaces and through sediment.

A summary of the phytoplankton comprising 1 per cent or more of the total number collected over the sampling program is shown in Table 5-19. 19 phytoplankton taxa accounted for 85 per cent of the total phytoplankton numbers. The remaining 15 per cent of phytoplankton is distributed between the remaining 129 identified taxa. The top four taxa were all planktonic diatoms, and all of these are small (5-20 µm) species that form chains (often 200-300 µm long). There were two other common planktonic diatoms and one benthic diatom. The remainder of the list are flagellates: two dinoflagellate species, three cryptophytes, two prymnesiophytes, two prasinophytes, and one euglenoid. The diatoms are autotrophs, while flagellates included auto, hetero and mixotrophic species.

Table 5-19. Phytoplankton species comprising ≥1 % of population 2019

Class	Species	% total
Diatom (planktonic)	*Skeletonema costatum*	10.7
Diatom (planktonic)	*Asterionellopsis glacialis*	9.0
Diatom (planktonic)	*Thalassiosira cf. mala*	8.0
Diatom (planktonic)	*Chaetoceros spp.*	7.1
Dinoflagellate	*Gymnodinium spp.*	6.0
Cryptophyte	*Plagioselmis prolonga*	5.9
Cryptophyte	*Hemiselmis spp.*	5.8
Diatom (benthic/planktonic)	*Cylindrotheca closterium*	5.2
Prymnesiophyte	*Chrysochromulina spp.*	4.6
Prasinophyte	*Pyramimonas spp.*	4.2
Chrysophytes	*Ochromonas spp.*	4.1
Prymnesiophyte	*Emiliania huxleyi*	3.7
Diatom (benthic)	*Nitzschia spp.*	1.8
Euglenophyta	*Eutreptiella spp.*	1.8
Prasinophyte	*Nephroselmis pyriformis*	1.7
Cryptophyte	*Teleaulax acuta*	1.5
Dinoflagellate	*Heterocapsa rotundata*	1.4
Diatom (planktonic)	*Bacteriastrum spp.*	1.3
Diatom (planktonic)	*Dactyliosolen fragilissimus*	1.1

Most of the species observed in this study are considered cosmopolitan and are widespread in coastal waters of south east Australia (Brett et al 2019, Hallegraeff et al 2010). Any potentially toxic species collected were at densities below aquaculture alert levels.

The phytoplankton community was dominated by small cell-size diatoms and flagellates, with larger celled diatoms occurring sporadically. This is typical of a low-nutrient ecosystem where internal generation and recycling of nutrients is important and population turnover is rapid. This is consistent with the relatively low nutrient input to Western Port from the catchment or exchange with the waters of Bass Strait, which are classified as oligotrophic (low nutrient content).

Table 5-20 summarises monthly results of the monitoring program and shows phytoplankton abundance (cells/litre) by taxonomic class and month. Table 5-20 is colour coded to show the

abundance of different classes relative to the range of abundances over the monitoring program. The maximum abundance for any class of phytoplankton was 420,000 cells/litre, while the minimum was 42 cells/litre. The median was 24,000 cells/litre.

Table 5-20 shows that the dominant group of phytoplankton in each survey were the diatoms (Baccillariophyceae). Diatoms comprised 54 per cent of the phytoplankton on average and 78 taxa have been identified. Diatoms are autotrophic (photosynthetic) and have golden-brown photosynthetic pigments. The diatoms comprised both planktonic (49 per cent of the total) and benthic species (6 per cent).

The next most abundant group of phytoplankton were Cryptophytes (Cryptophyceae). Cryptophytes comprised 14 per cent of the phytoplankton over the course of the monitoring program and 7 taxa have been identified. They are predominantly autotrophic and may be red, brown, blue or green in colour depending on the accessory pigments in their chloroplasts.

Prymnesiophytes (Prymnesiophyceae) and Dinoflagellates (Dinophyceae) each comprised 9 per cent of the phytoplankton. Seven prymnesiophyte taxa and 38 dinoflagellate taxa have been identified. The dinoflagellates included both autotrophic and heterotrophic species. Most of the prymnesiophytes were *Chrysocromulina* sp. which is a mixotrophic species.

Prasinophytes (Prasinophyceae) comprised 7 per cent of the phytoplankton with 6 taxa identified. Prasinophytes are mostly autotrophic and are green algae (having green pigments). Chrysophytes (Chrysophyceae) comprised 5 per cent of the phytoplankton with 4 taxa identified. The Chrysophytes include both autotrophic and mixotrophic species. Euglenophytes (Euglenophyceae) comprised 2 per cent of the phytoplankton with just 1 taxon identified (*Eutreptiella* spp), a green-pigmented mixotrophic species. The remaining phytoplankton classes each comprised less than 0.5 per cent of the phytoplankton by number in each month since December 2018.

Table 5-20. Summary of phytoplankton concentrations (number per litre) by month

	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Total	
n (samples)	6	6	5	6	6	6	6	6	6	6	6	6	6	65	
Phytoplankton	4.2.E+05	3.4.E+05	3.2.E+05	3.6.E+05	3.3.E+05	3.6.E+05	4.7.E+05	4.9.E+05	5.8.E+05	6.1.E+05	3.1.E+05	3.3.E+05	2.6.E+05	5.2.E+06	
Chlorophyll-a (µg/L)	0.61		0.90	0.75	1.00	0.85	0.45	0.80	0.92	1.60	0.54	1.61	0.60	0.89	
Taxa	6	6	5	6	6	6	6	6	6	6	6	6	6	77	
Diatoms (78)	2.3E+05	1.6E+05	1.6E+05	2.1E+05	1.4E+05	2.1E+05	2.4E+05	2.6E+05	3.3E+05	4.2E+05	1.7E+05	1.5E+05	1.4E+05	2.8.E+06	54
Cryptophytes (7)	4.7E+04	4.6E+04	4.7E+04	4.4E+04	6.1E+04	4.8E+04	9.2E+04	7.1E+04	9.3E+04	7.2E+04	4.3E+04	5.5E+04	2.4E+04	7.4.E+05	14
Prymnesiophytes (7)	4.6E+04	4.0E+04	3.7E+04	3.2E+04	3.3E+04	2.8E+04	3.5E+04	4.4E+04	4.4E+04	3.8E+04	3.0E+04	3.4E+04	2.3E+04	4.6.E+05	9
Dinoflagellates (38)	4.2E+04	4.2E+04	4.1E+04	2.9E+04	3.9E+04	2.4E+04	3.9E+04	4.6E+04	4.8E+04	2.7E+04	1.8E+04	3.4E+04	3.5E+04	4.6.E+05	9
Prasinophytes (marine) (6)	3.3E+04	2.2E+04	2.0E+04	2.4E+04	2.9E+04	3.0E+04	4.1E+04	2.6E+04	3.6E+04	1.8E+04	2.3E+04	2.5E+04	1.3E+04	3.4.E+05	7
Chrysophytes (4)	1.8E+04	1.6E+04	1.2E+04	1.3E+04	1.4E+04	1.4E+04	1.7E+04	3.2E+04	2.3E+04	2.7E+04	1.1E+04	1.6E+04	2.5E+04	2.4.E+05	5
Euglenophyta (1)	9.4E+03	5.5E+03	4.2E+03	7.7E+03	6.5E+03	9.3E+03	8.0E+03	8.1E+03	6.0E+03	7.7E+03	9.0E+03	5.7E+03	4.0E+03	9.1.E+04	2
Dictyochophytes (3)	5.8E+02	6.7E+02	1.2E+03	1.0E+03	2.1E+03	4.2E+02	5.3E+03	7.5E+02	4.8E+03		3.8E+03	3.0E+03	8.3E+01	2.4.E+04	0.5
Raphidophytes (2)				9.2E+02	8.3E+02	3.3E+02		2.5E+02			8.3E+01	8.3E+01		2.5.E+03	0.05
Ciliate (1)	4.2E+01			8.3E+01	8.3E+01	8.3E+01	8.3E+01			2.5E+02	4.2E+02	3.3E+02		1.4.E+03	0.03
Chlorophytes (1)					1.3E+03									1.3.E+03	0.03
Cyanoprokaryota (4)										1.3E+03				1.3.E+03	0.02
Other (1)					8.3E+01	3.3E+02	4.2E+02							8.3.E+02	0.02

<25th per centile (< 4700 cells/litre)	25th-50th per centile (4,700 to 23,800 cells/litre)
50th-75th per centile (23,800 to 42,000 cells litre)	>75th per centile (> 42,000 cells/litre)

Figure 5-41. Chain forming diatom

Figure 5-42 shows that most of the month to month variability is due to changes in the abundance of the top four planktonic diatom species: *Skeletonema*, *Asterionellopsis*, *Thalassiosira* and *Chaetoceros*. These four species comprised 35 % of the total phytoplankton on average. All are small, chain-forming species. Their small cell size allows for efficient nutrient uptake and makes them resistant to mechanical damage in the strong mixing conditions. Chain formation and spines on *Chaetoceros* cells control sinking rates, thereby helping these phytoplankton remain suspended in the water column. Changes in the abundance of the other species are small relative to the diatoms.

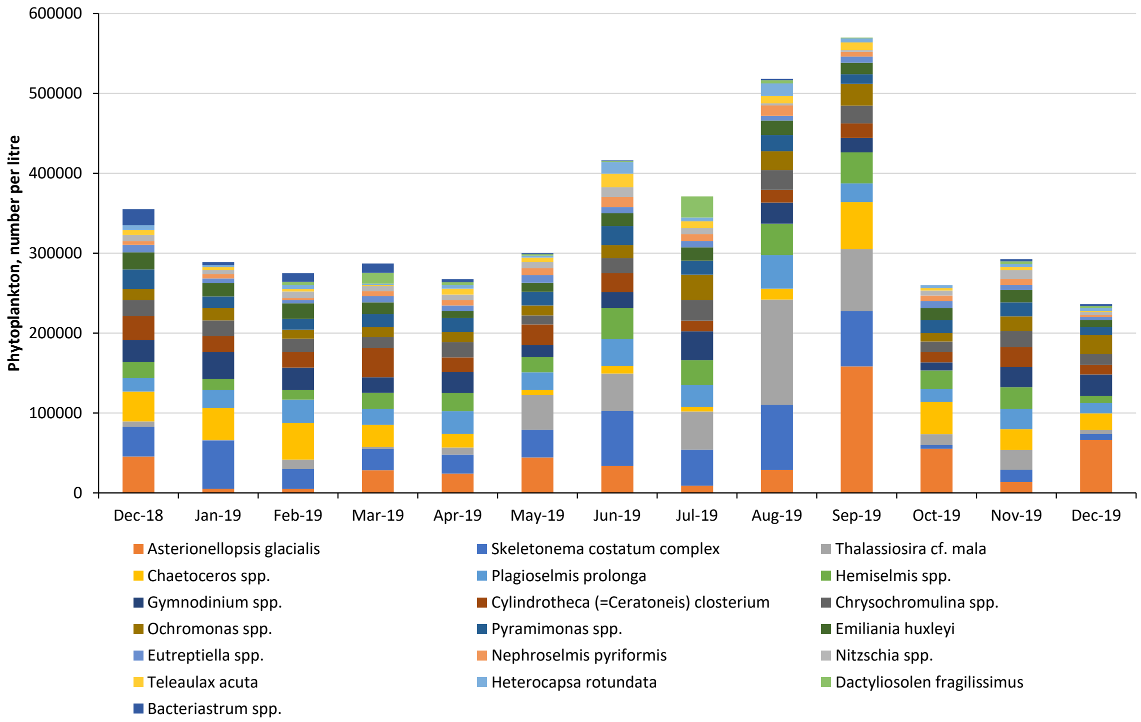


Figure 5-42. Average abundance of species > 1 % of total phytoplankton

Phytoplankton biomass (Chlorophyll-a)

Figure 5-43 compares monthly phytoplankton numbers to measured chlorophyll-a concentration, a measure of phytoplankton biomass, as well as solar exposure and rainfall for the preceding month. Average chlorophyll-a concentrations in Lower North Arm show minor correlation with observed patterns in average phytoplankton numbers over the period. Chlorophyll-a concentrations and phytoplankton numbers were stable from December 2018 to May 2019. Chlorophyll-a concentrations fell to their lowest in June 2019, despite there being relatively high phytoplankton numbers. Chlorophyll-a concentrations increased steadily after the winter solstice to September 2019, consistent with a possible ‘spring bloom’ in phytoplankton biomass. However, both phytoplankton abundance and biomass decreased in October probably due to grazing by zooplankton that increased in abundance over this month (see Section 0). While phytoplankton numbers remained relatively low over November and December, chlorophyll-a rose and fell. The relationship between phytoplankton numbers and chlorophyll-a can vary due to a range of factors including down-regulating chlorophyll-a levels during low-light, nutrient availability or different taxonomic compositions of the phytoplankton populations that have different pigment ratios and content. A varying relationship between chlorophyll-a and phytoplankton count is common in natural systems.

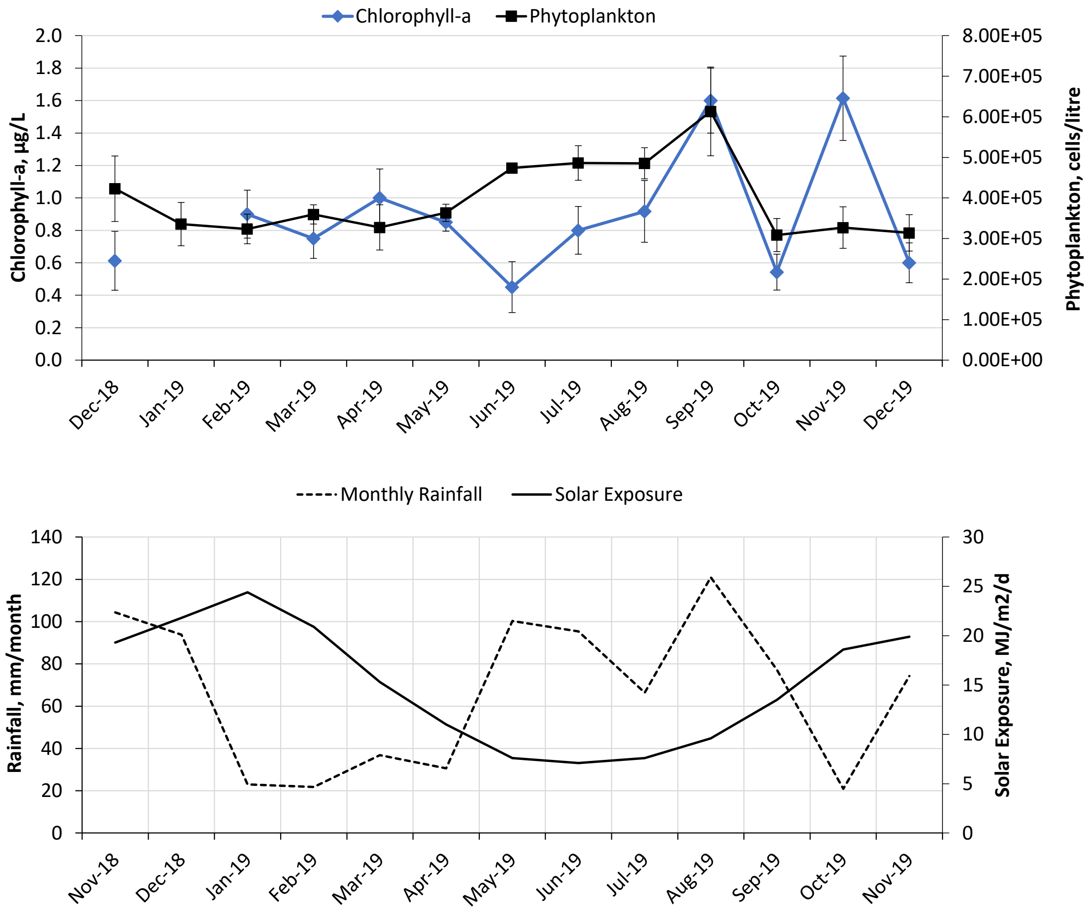
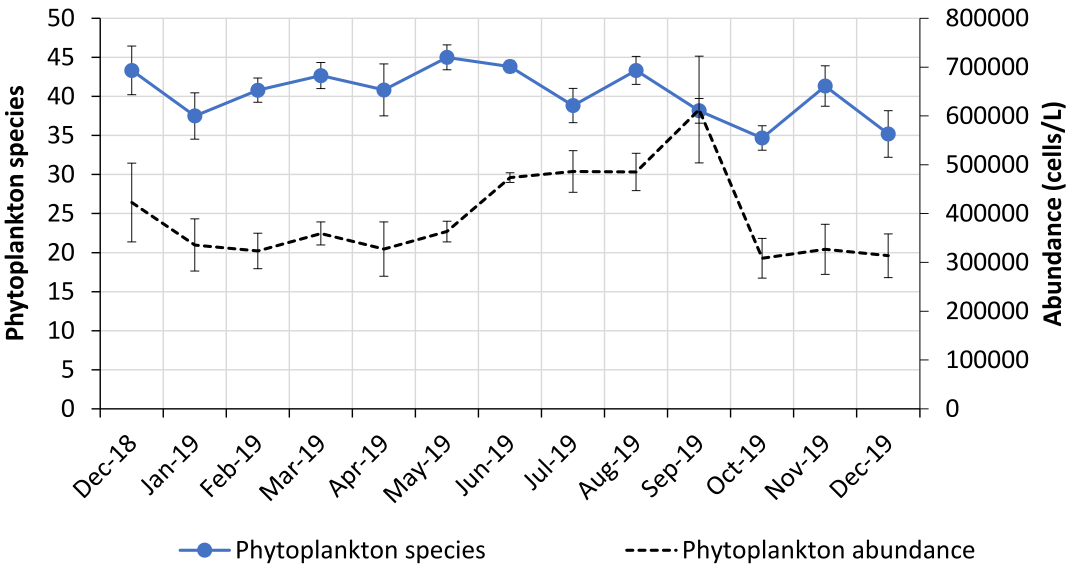


Figure 5-43. Monthly average chlorophyll-a and phytoplankton, Dec-2018 to Dec-2019

Phytoplankton species richness

Figure 5-44 shows the average number of phytoplankton species per sample in each month, and average phytoplankton abundance. Figure 5-45 shows data for individual sites along with average total phytoplankton abundance. The average number of taxa per sample ranged from 35 to 45. The highest number of taxa was recorded in May 2019, and the lowest in October and December 2019. There is no clear seasonal trend in the average number of taxa. The maximum change in the number of species between surveys is 19 per cent, and overall variation is only 22 per cent. Increases and decreases in the number of phytoplankton species generally matched increases and decreases in phytoplankton abundance from December 2018 to May 2019, but there is poor correlation from June to December 2019.

Figure 5-45 also shows that there were no consistent differences in the number of species per site and Crib Point Berth 2 had a similar number of phytoplankton species to all other sites.



Error bars show ± SEM

Figure 5-44. Monthly average phytoplankton species per sample, Dec-2018 to Dec-2019

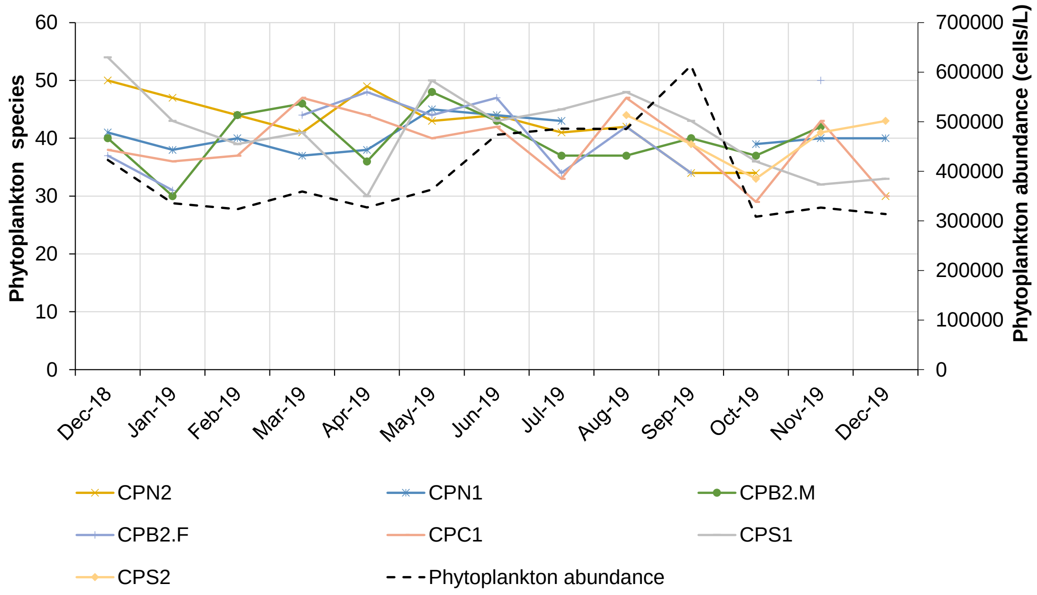
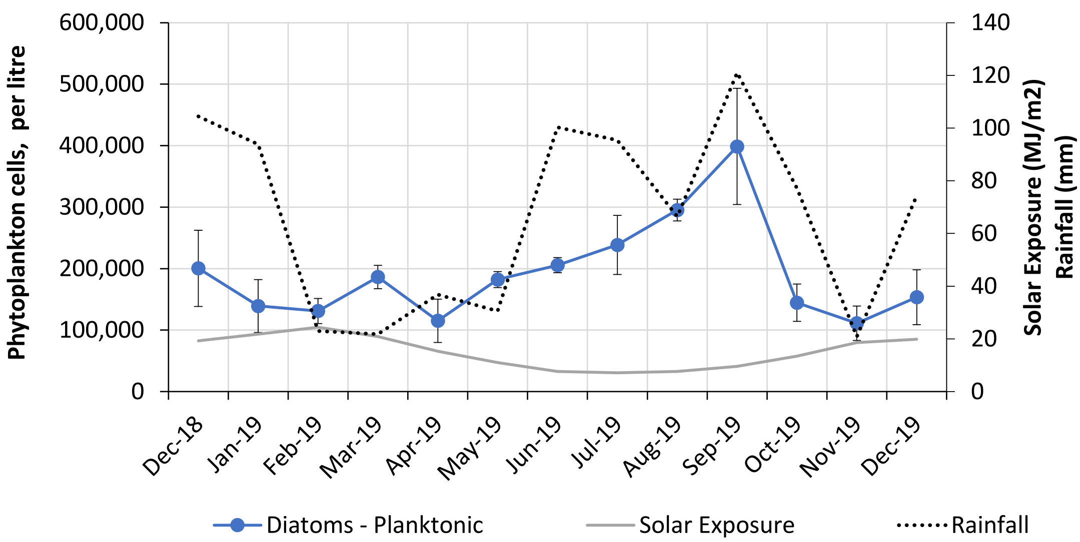


Figure 5-45. Phytoplankton species by site and month

Planktonic Diatoms

Planktonic diatoms comprised 49 per cent of the phytoplankton in North Arm. Figure 5-46 shows the average abundance of planktonic diatoms in each survey since December 2019. Patterns match those for all phytoplankton – variation in planktonic diatoms appears to account for most of the variation in the phytoplankton community. The abundance of planktonic diatoms was relatively stable from December to June 2019, ranging between 115,000 cells/litre and 200,000 cells/litre. As daylength began to increase in July the abundance of planktonic diatoms showed a steady increase until September 2019 when there were around 400,000 cells/litre. Numbers fell by more than 60 per cent in October however, likely due to predation by copepods and decreased rainfall.



Error bars show ± SEM

Figure 5-46. Average planktonic diatoms per sample, Dec-2018 to Dec-2019

Other phytoplankton classes

Figure 5-47 shows abundance of the other major classes of phytoplankton. These were all around half as abundant as the planktonic diatoms. Several classes show a peak in abundance in winter, after the winter solstice in June when solar exposure begins to increase.

Cryptophyte abundance (14.5 per cent of total phytoplankton) was relatively stable from December 2018 to May 2019 between 45,000 cells/litre and 60,000 cells/litre, before increasing to over 90,000 cells/litre in June 2019. Cryptophyte numbers remained high until September 2019 when they decreased to a little over 40,000 cells/litre in October 2019. Numbers of Chrysophytes were around 65,000 cells/litre in December 2018 but steadily decreased to around 40,000 cells/litre in May 2019. Their numbers increased to a peak in July 2019 of 75,000 cells/litre.

Numbers of Dinoflagellates and Prymnesiophytes showed a minor peak in late winter 2019, as well as a marked decrease in abundance in October 2019.

Abundances of benthic diatoms (around 10 per cent of the phytoplankton), Prasinophytes and Euglenophytes show little variability and no seasonal trend.

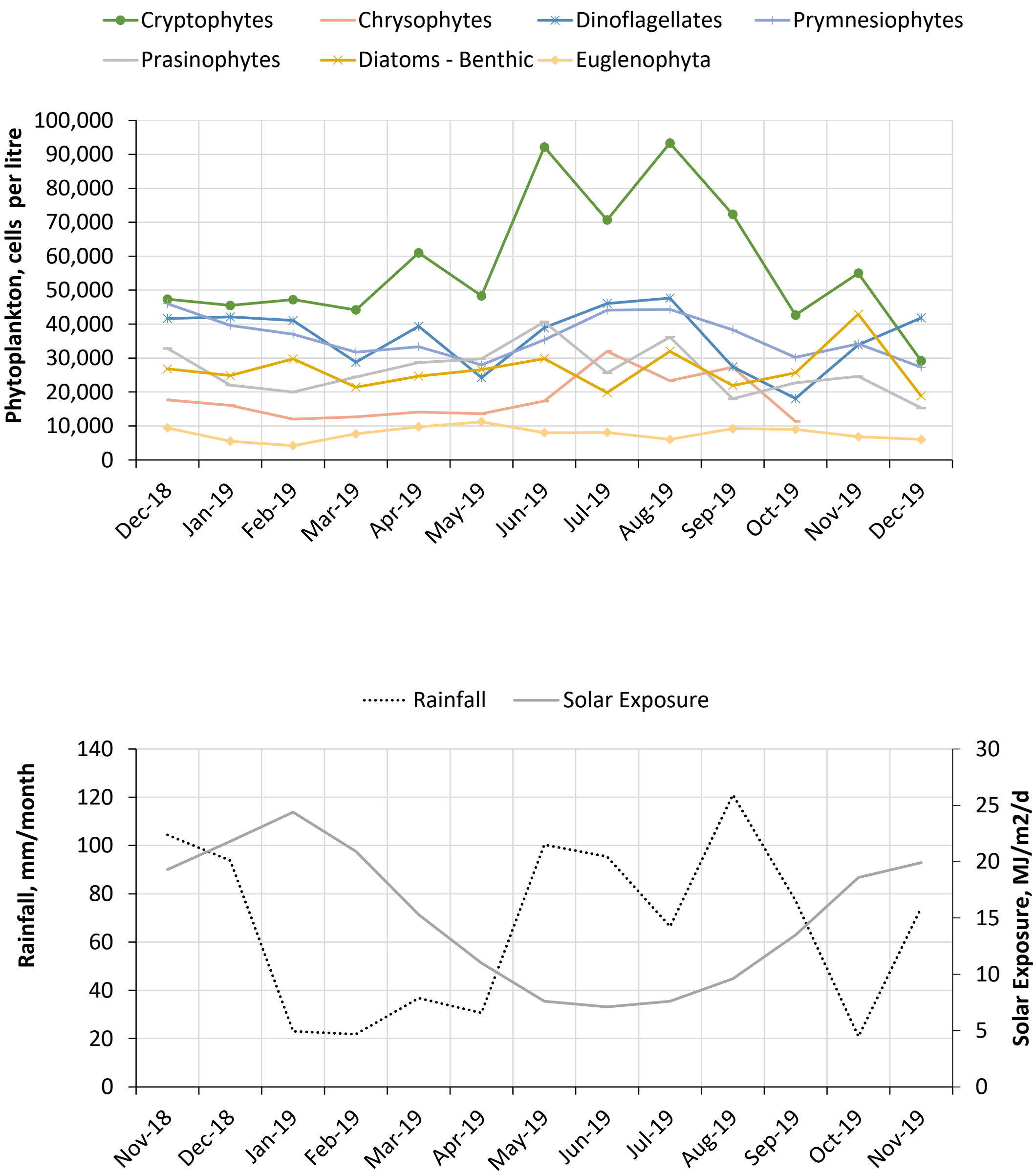


Figure 5-47. Average abundance of major classes, Dec-2018 to Dec-2019 (top) Rainfall and solar exposure (bottom)

Phytoplankton - General spatial patterns in Lower North Arm

The figures that follow illustrate spatial patterns in the phytoplankton in Lower North Arm. The distances shown are the distance from Bass Strait measured from a line between West Head and Point Grant along the centre of the channel. As three surveys during the 'spring bloom' from August to October were completed at site CPS2 in the confluence zone, data for site CPS2 is left out of some charts. Data for all sites during August to October are plotted separately where appropriate. Data for the monthly (11 surveys) and fortnightly (9 surveys) at Crib Point Berth 2 are plotted separately.

Figure 5-48 shows that phytoplankton concentrations are typically higher in the north of Lower North Arm (CPN2 averages 480,000 cells/litre) than the south (CPS1 averages 380,000 cells/litre). Crib Point Berth 2 shows intermediate phytoplankton abundance.

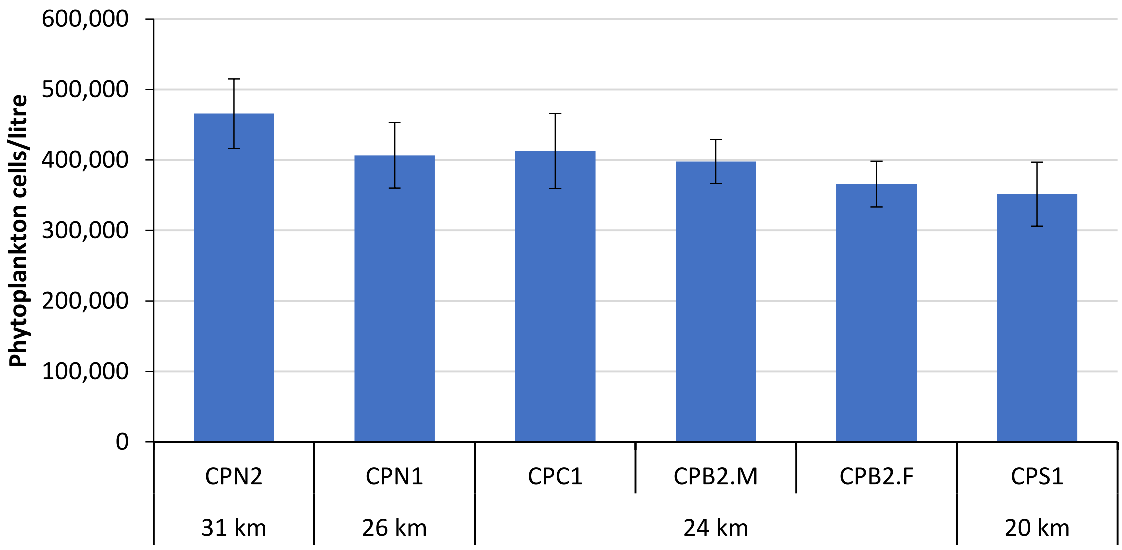


Figure 5-48. Average total phytoplankton abundance by site

Error bars show ± SEM

Figure 5-49 shows average total phytoplankton abundance for the three months when site CPS2 in the confluence zone has been sampled (CPN1 was only sampled once in this period). There is a large amount of spatial variability (between sites) but temporal variability (within sites) is also high. Overall, there is no clear spatial pattern. Phytoplankton abundance at CPS2 was similar to other sites.

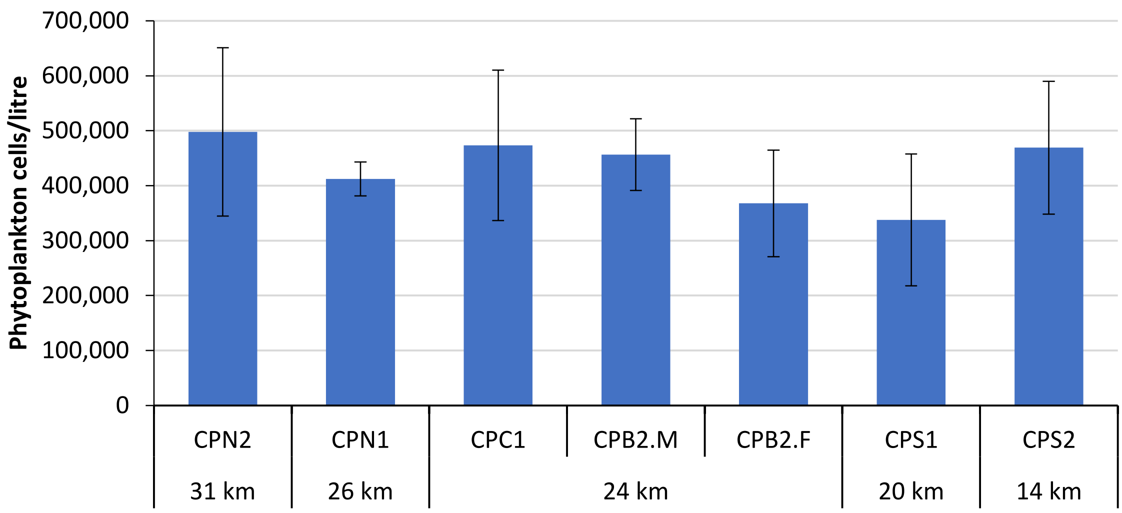


Figure 5-49. Average total phytoplankton by site (August to December 2019)

Error bars show ± SEM

Figure 5-50 shows the spatial variation in average phytoplankton biomass estimated by chlorophyll-a concentrations. Average Chlorophyll-a varied from 0.8 µg/L at CPC1 to 1.05 µg/L at CPS1. Based on these data, the middle of lower north arm has lower phytoplankton biomass than its extreme north and south, however error bars indicate there are no statistically significant differences between sites.

The annual range in phytoplankton biomass values is similar to that for southern Port Phillip sites reported in the 1990s (Beardall *et al* 1996).

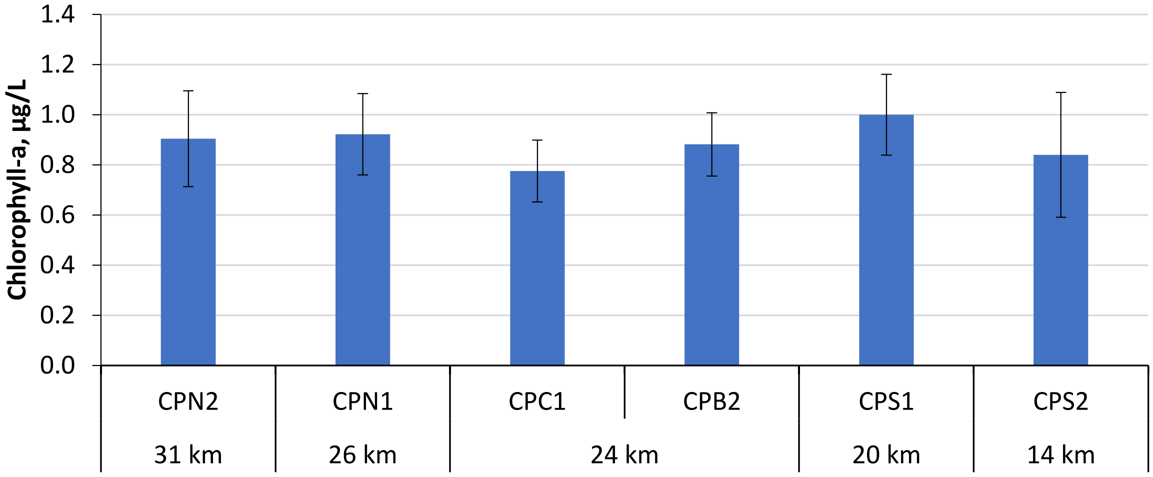


Figure 5-50. Average chlorophyll-a concentrations, Dec-2018 to Dec-2019

Error bars show ± SEM

Figure 5-51 shows that there is no consistent difference the number of species between sites in the north and south of lower north arm. There are typically between 38 and 43 species per sample at each site (40 per sample at Crib Point Berth 2). Figure 5-45 showed that species numbers at each site were similar at all times of the year.

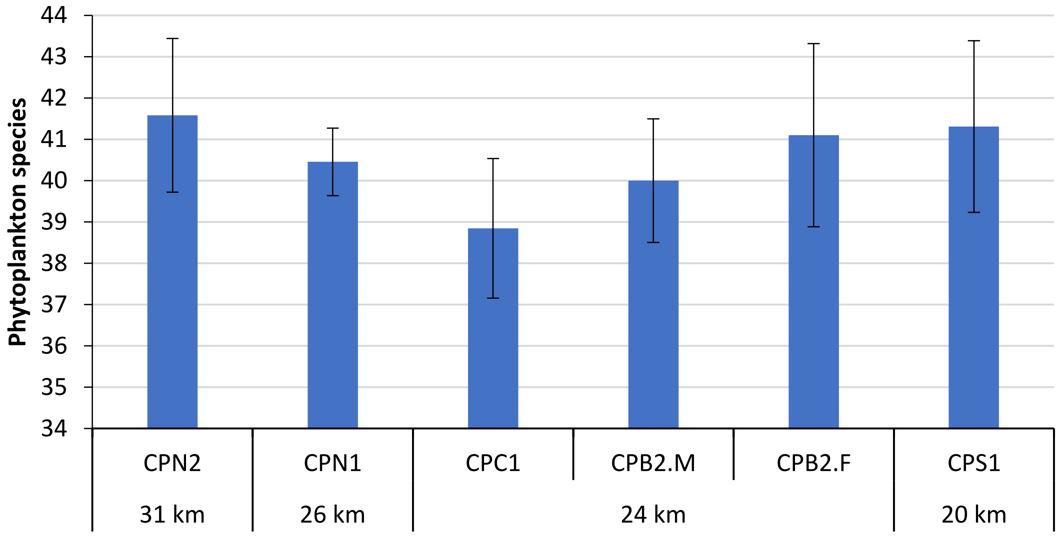


Figure 5-51. Average phytoplankton species per site

Error bars show ± SEM

Figure 5-52 shows that for surveys including site CPS2 in the confluence zone there is no spatial pattern in the number of species per site. This sampling period during the 'spring bloom' did however have a slightly lower average number of species than for all surveys.

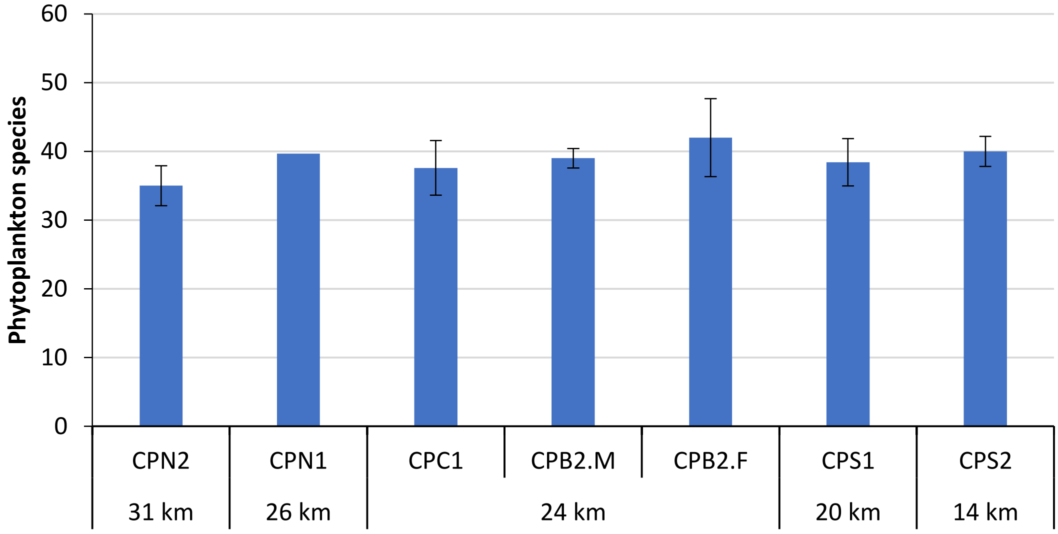


Figure 5-52. Average phytoplankton species per site (August to December 2019)

Error bars show ± SEM

Phytoplankton: Diatoms

Figure 5-53 shows the abundance of the diatoms, the dominant group of phytoplankton. The figure plots planktonic (49 % of the phytoplankton) and benthic diatoms (6 % of the phytoplankton) separately. Planktonic diatoms were more abundant at CPN2 than sites near Crib Point Jetty and CPS1 in most surveys. Benthic diatoms were also more abundant in the north of lower north arm than the south, consistent with the large areas of mudflats in the north. The longer residence times of water in the north of lower north arm may support higher diatom abundance through recycling of nutrients within the plankton.

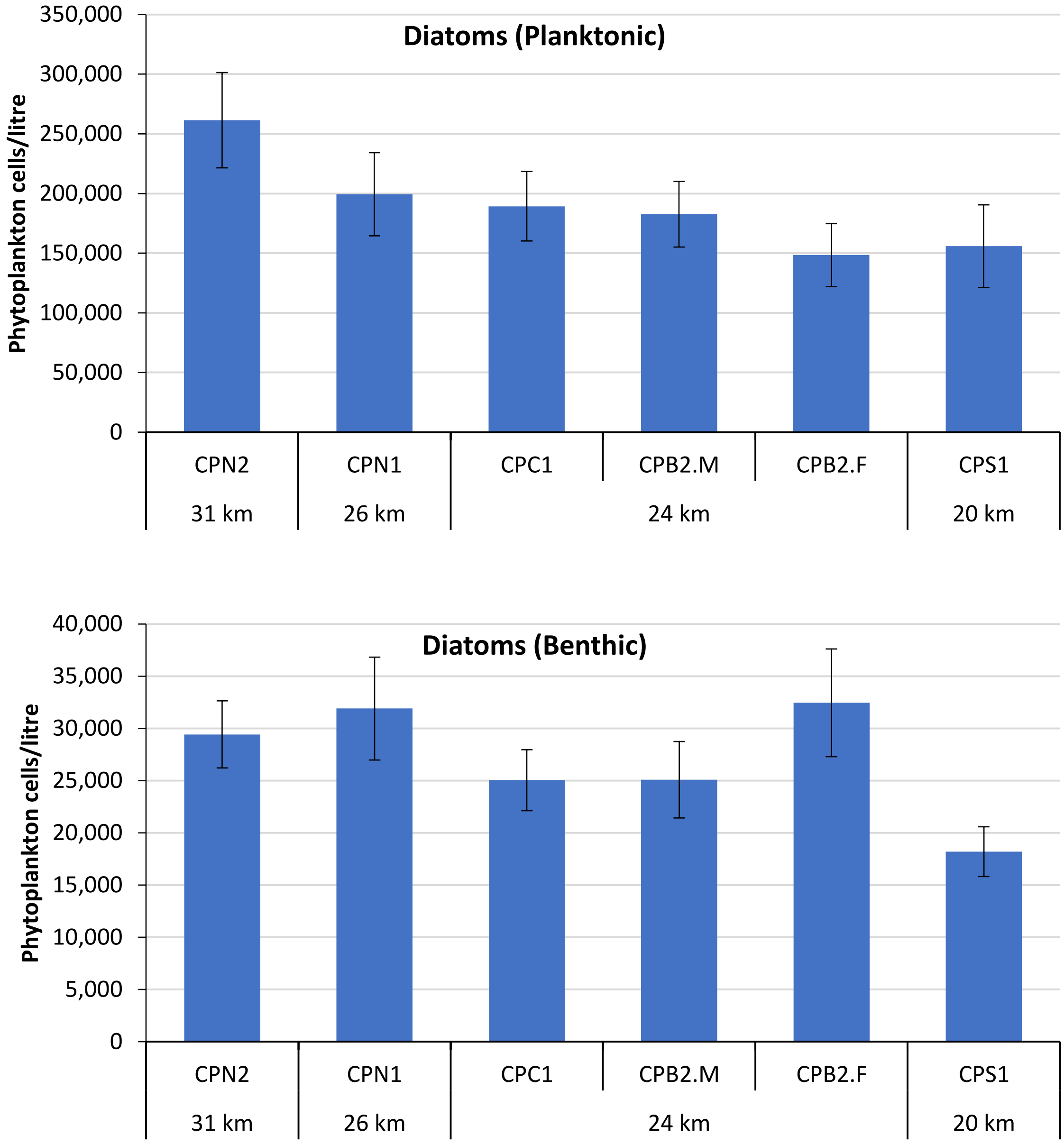


Figure 5-53. Planktonic and benthic diatom abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Phytoplankton: Cryptophytes

Figure 5-54 shows there were no differences in Cryptophyte abundance from the north to the south of lower north arm and that abundances at Crib Point Berth 2 are similar to those elsewhere. Cryptophyte abundance at CPS2 in the confluence zone for the August-October 2019 surveys were similar to those in lower north arm.

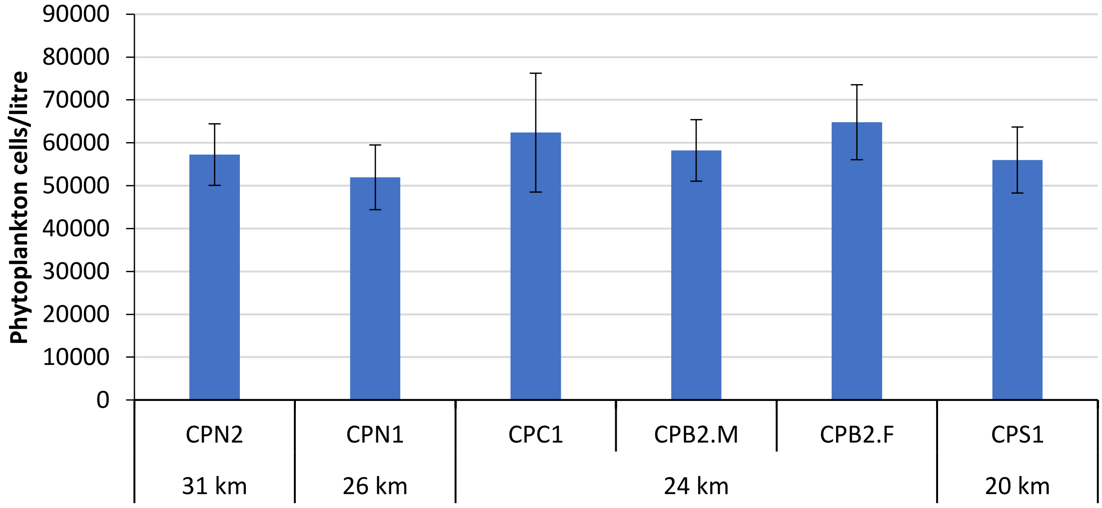


Figure 5-54. Cryptophyte abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Phytoplankton: Dinoflagellates

Figure 5-55 shows that Dinoflagellates were more abundant in the south of lower north arm (around Crib Point and CPS1) than the sites further north (CPN1 and CPN2). For months when CPS2 was included in monitoring dinoflagellate abundances at CPS2 were similar to the south of lower north arm.

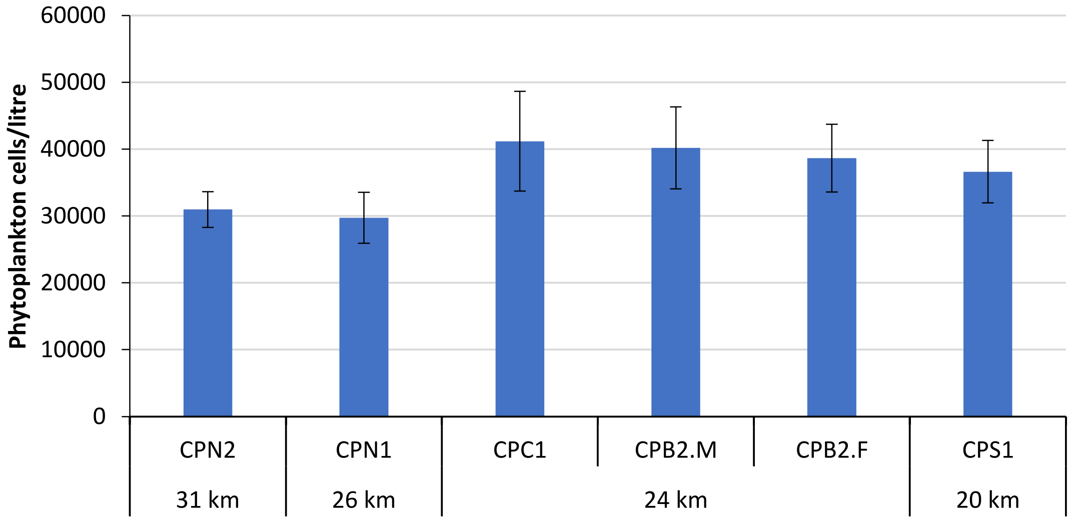


Figure 5-55. Dinoflagellate abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Phytoplankton: Prymnesiophytes

Figure 5-56 shows there is no pattern for higher or lower Prymnesiophyte abundance relating to location in lower north arm. The fortnightly surveys at Crib Point Berth 2 have found lower Prymnesiophyte abundance than monthly surveys at other sites. The smaller number of samples (n=9) analysed for this site may have influenced this result.

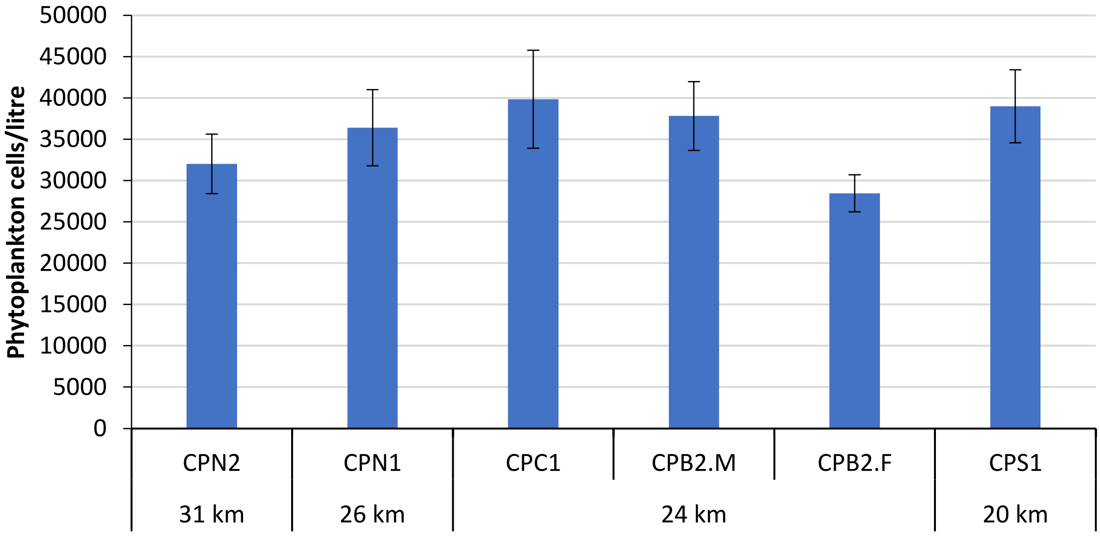


Figure 5-56. Prymnesiophyte abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Phytoplankton: Prasinophytes

Figure 5-57 shows that there tend to be higher abundances of Prasinophytes in the north of lower north arm (32,000 cells/litre) than the south (23,000 cells/litre) and that numbers Crib Pt Berth 2 are consistent with this pattern.

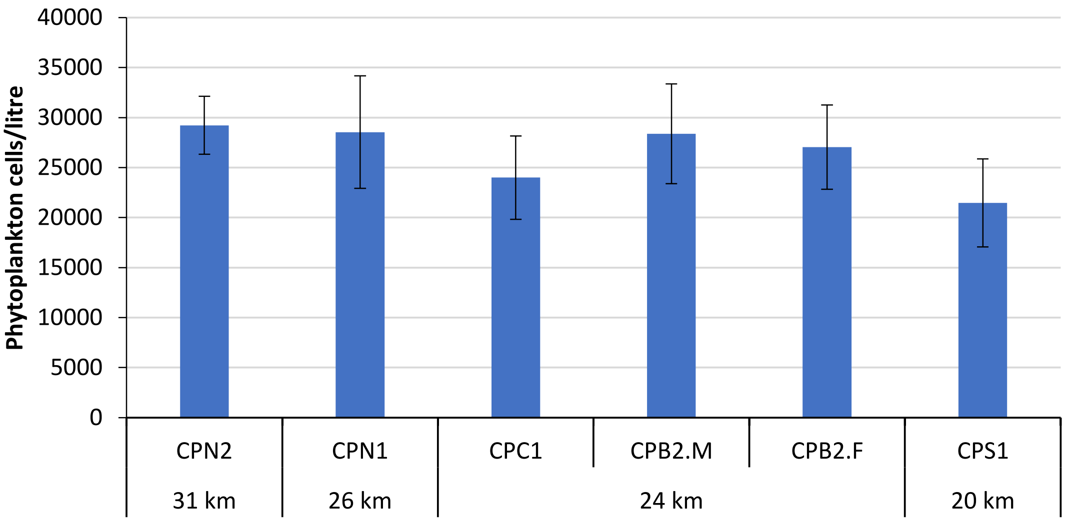


Figure 5-57. Prasinophyte abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Phytoplankton: Chrysophytes

Figure 5-58 shows that patterns in Chrysophyte abundance are similar to those of dinoflagellates, with lower and less variable numbers in the north than the south of lower north arm. Numbers at Crib Point Berth 2 are consistent with this pattern, numbers were higher at CPC1, but with a large error.

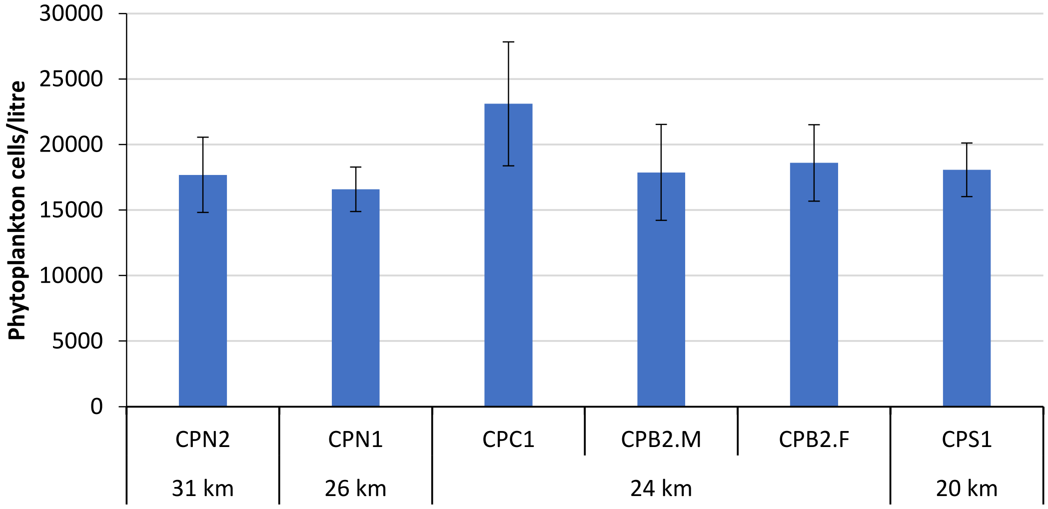


Figure 5-58. Chrysophyte abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Phytoplankton: Euglenoids

Figure 5-59 shows that there was no spatial pattern in the abundance of Euglenoids and variability was similar at all sites.

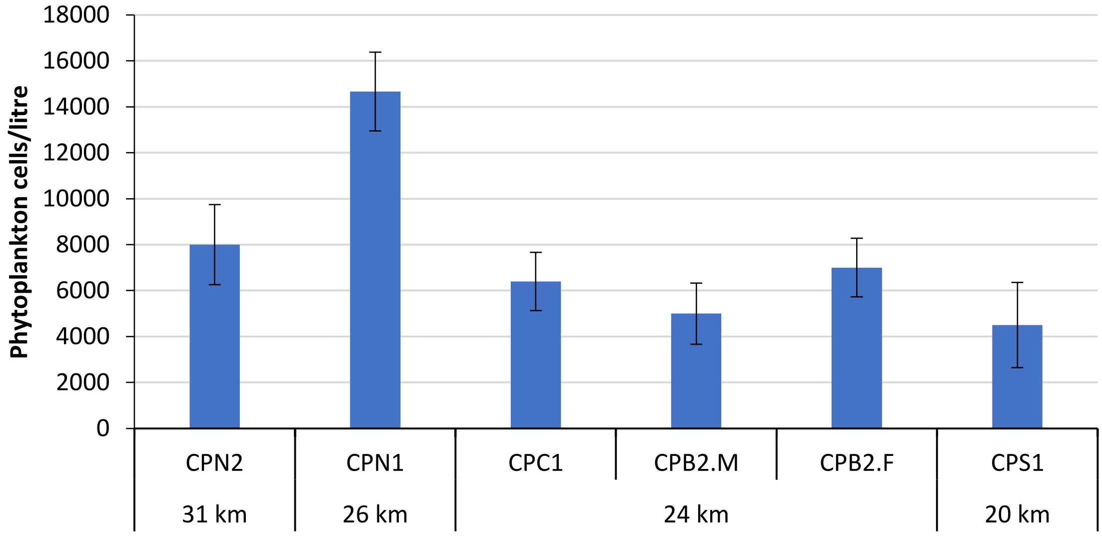


Figure 5-59. Euglenophyte abundance by site, Dec-2018 to Dec-2019

Error bars show ± SEM

Comparison with 1970s Western Port Study

Phytoplankton were sampled over 15 months from June 1973 to September 1974 for the Westernport Bay Environmental Study (Min. Con. 1975). The 1973-74 study collected phytoplankton samples using surface tows, whereas the 2018-19 sampling has collected depth-integrated samples over the water column. The 1973-74 study identified diatom and dinoflagellate species and assessed abundance qualitatively (rare, occasional, common, abundant). Qualitative abundance of one species, *Ditylum brightwellii* was reported for each survey and site on a scale of 1 to 3 (present, common, abundant).

Table 5-21 lists the species that were classified as 'abundant' or 'common' during the study. All are diatom species and includes planktonic and benthic species. The table includes data on the abundance of these or similar species in the 2018-19 study. The four most abundant diatom taxa in 2018-19 were also common or abundant in the 1973-74 study. Only two of the taxa shown from the 1973-74 have not been identified in the 2018-19 study, but in both cases, closely related species have been.

Figure 5-60 compares numbers of the planktonic diatom *Ditylum brightwellii* in the 1973-74 and 2018-19 studies. Both studies show substantial variability over the year, but no clear seasonal trend. The 2018-19 study found two clear peaks in *Ditylum* abundance in March and September, but no predicting factor has been identified.

Allowing for the different sampling strategy and analysis method, the data show that the phytoplankton community in the 1970s was similar to that documented over the past year.

Table 5-21. Abundant and common phytoplankton identified in the 1973-74 study

1973-74 Westernport Bay Environmental Study			This study (2018-19)		
Species	**Habitat**	**Abundance**	**Rank**	**% total**	**Species (if different)**
Chaetoceros spp.	Planktonic	Abundant	4	7.1	
Ditylum brightwellii	Planktonic	Abundant	21	0.7	
Asterionella japonica	Planktonic	Common	2	9	Asterionella glacialis
Biddulphia pulchella	Planktonic	Common	>100	<1	
Biddulphia sinensis	Planktonic	Common	>100	<1	
Climacosphenia moniligera	Benthic	Common	24	0.6	
Gyrosigma spp.	Benthic	Common	na	na	relative of Pleurosigma
Melosira sulcata	Benthic	Common	>50	<1	Melosira spp.
Nitzschia closterium	Planktonic	Common	13	1.8	Nitzshia spp.
Pleurosigma spp.	Benthic	Common	29	0.5	
Rhizoselenia setigera	Benthic	Common	55	<1	Rhizoselenia spp. = 1.8 %

Rhizoselenia shrubolei	Planktonic	Common	na	na	
Skeletonema costatum	Planktonic	Common	1	10.7	
Thalassiosira rotula	Planktonic	Common	3	8	Thalassiosira c.f. mala

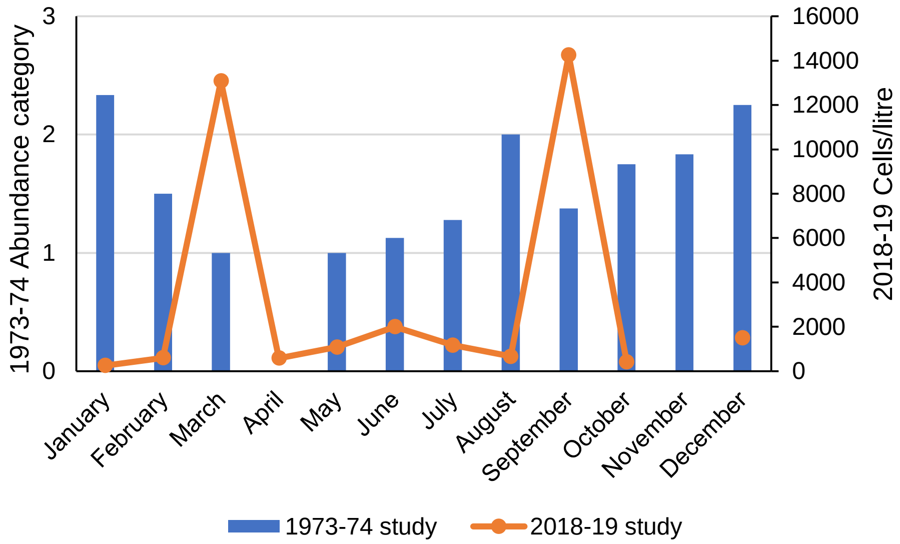


Figure 5-60. *Ditylum brightwellii* abundance in 1973-74 and 2018-19

Phytoplankton Summary and Discussion

This study has documented the biodiversity characteristics and identified key temporal and spatial patterns and likely limiting factors for phytoplankton in Lower North Arm, Western Port. The phytoplankton are characterised by small cell sizes, relatively low population variability (cell numbers) and low biomass (chlorophyll-a concentrations). The phytoplankton community is dominated by small chain forming diatoms and a range of small flagellates that are suited to the low light, low nutrients and high turbulence in Western Port. There are typically relatively large numbers of benthic diatoms in the plankton, as well as suspended solids, owing to the strong mixing and tidal currents. Phytoplankton abundance, biomass and diversity showed relatively little variability over the year and there were no 'blooms' characterised by order-of-magnitude increases in abundance or biomass.

The study has documented 148 phytoplankton taxa (species or higher taxonomic classification) that occur in lower north arm. Nineteen of these species account for 85 per cent of the phytoplankton by number. Diatoms accounted for 55 per cent of the phytoplankton, 14.5 per cent were cryptophytes (flagellates), 8.9 per cent were prymnesiophytes (flagellates), 8.6 per cent were dinoflagellates and 6.5 per cent were prasinophytes (green algae). The community includes autotrophs (all the diatoms, and many of the flagellates), heterotrophs and mixotrophs (some of the flagellates). Most of the species are cosmopolitan and widespread in southern Australia. The dominant species were similar to those in Western Port in the 1970s, and in Port Phillip in the 1990s.

The study detected spatial gradients in the abundance of some groups of phytoplankton: diatoms tend to be more abundant in the north of the study area, while flagellates tend to be more abundant in the south. There were no consistent differences in the number of species at

each site. The phytoplankton community at Crib Point Berth 2 showed no differences to other sites other than those expected given the documented spatial gradients.

A study of broadscale variation in phytoplankton communities found similarities between lower North Arm, the Western Entrance and Confluence Zone and East Arm. The community in the broad, shallow and quiescent waters of the Rhyll segment was different.

Solar exposure (light), rainfall (nutrient input) and zooplankton abundance are important predictors of phytoplankton abundance and productivity over the year. Grazing by zooplankton (mostly copepods) appears to put substantial downward pressure on phytoplankton abundance such that most excess phytoplankton production is consumed and that their populations remain relatively stable over time. Nutrient inputs from rainfall in the catchment also are strongly linked to phytoplankton abundance.

Temporal patterns in long-term average biomass estimates (EPA data) show similarities to Port Phillip with maxima in late autumn and minima in spring. Biomass does not show the ‘spring bloom’ of phytoplankton that can occur in temperate marine environments in response to increased light and nutrient availability after winter. This is likely due to the masking effect of intense zooplankton grazing. Zooplankton quickly proliferated after the winter solstice when light availability allows increased phytoplankton productivity (see below). This study detected a short-lived peak in phytoplankton abundance in September, followed by a rapid decrease in October.

5.8.4 Zooplankton

Zooplankton are found in almost all water bodies, both freshwater and marine, and throughout the major ocean realms. Zooplankton are critical to the functioning of marine food webs due to their large numbers and vital ecosystem roles. One of their vital roles is as grazers of the primary producers in food webs, forming the key pathways for energy transfer from phytoplankton to higher trophic levels such as fish, marine mammals and seabirds. Zooplankton are also crucial components of the biological carbon pump, as their grazing supports remineralisation of nutrients in surface waters and their products (carcasses, moults, faecal pellets) transfer carbon to the sediments, where they can be sequestered over geological time-scales. Over millennia carbon from plankton accumulates to become oil and natural gas deposits.

Representatives of most marine phyla are found in the zooplankton, with some spending their entire life cycle in the plankton (holoplankton) and others spending part of their life cycle (meroplankton). Examples of holoplankton are common crustaceans such as copepods, euphausiids (krill) and cladocerans (water fleas), and gelatinous species like jellyfish. Meroplankton represent those animals that often have a planktonic larval phase before settling to the seabed as adults (e.g. echinoderms, bryozoans, crabs) or grow into free-swimming nekton (e.g. fish, prawns). Zooplankton are mostly small, measuring millimetres or centimetres.

Because of their weak swimming ability zooplankton are dependent on currents for their dispersal and geographical movement, making them vulnerable to the effects of warming seawater temperatures and other environmental changes. Zooplankton are poikilotherms so their physiology is dependent on their environmental conditions, particularly water temperature.

Diurnal vertical migration is a behaviour common to many zooplankton species, where they ascend to surface waters at night and live deeper in the water during daylight hours. By feeding in the surface waters at night the organisms can avoid visual predators, predominantly planktivorous fish. The ability of zooplankton to overcome washout from tidal embayments by tidally timed vertical migrations was investigated in Western Port (Kimmerer and McKinnon 1987b). Analysis demonstrated inconsistency between species and vertical changes in centre of population mass were small in relation to the actual water depth and corresponding differences in current velocities.

Previous Zooplankton Studies in Western Port

A range of studies have documented the plankton community in Western Port. Zooplankton were studied in Western Port in 1971-72 (Macreadie 1972), 1973-74 (Arnott 1974 and Min Con 1975) and 1982 - 84 (Kimmerer and McKinnon 1985, 1987a, b, c). The 1970s programs included sites in Lower North Arm and the Western Entrance, with the 1980s program focussing on a group of ‘central’ stations in the north of the Rhyll Segment and southwest of the Corinella Segment and the Western Entrance of western Port, as well as Port Phillip. All studies found that although all species found in Western Port were distributed throughout to Bass Strait and Port Phillip and that all communities were dominated by copepods; the proportions of the key species were substantially different in eastern and north-eastern Western Port. The key difference between inner Western Port and Bass Strait and Port Phillip was the numerical and ecological dominance of the zooplankton community by a pair of *Acartia* species: A *fancetti* and A *tranteri (*McKinnon et al 1992). The two species are very difficult to separate taxonomically and appear to occupy the same ecological position

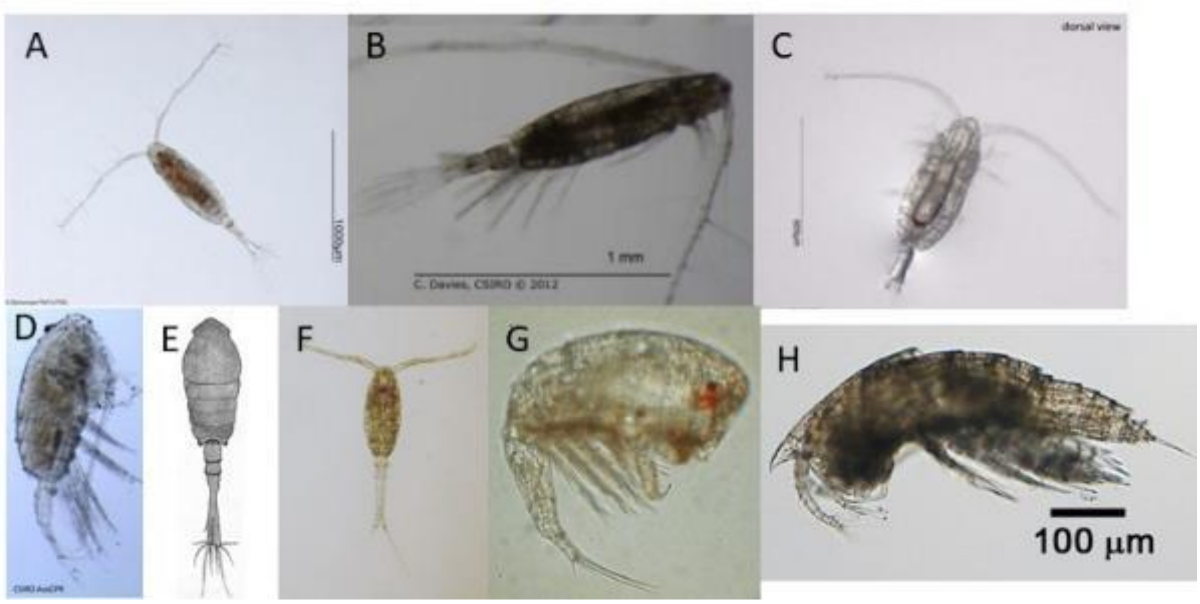
(Swadling 2019), so they are treated throughout the EES as a single entity, *Acartia spp*. The copepod *Paracalanus indicus* was more numerous than *Acartia spp* in Port Phillip and Bass Strait.

Groups other than copepods generally occurred in lower numbers; for example, cladocerans were only represented by a few records of *Podon*, viz. *P. intermedius* and *P. polyphemoides* (Kimmerer and McKinnon 1985). Gastropods represented as high as 25% of the total, while crab larvae reached 4% of the total (Macreadie 1972). The water column above the seagrass-covered mudflats at Crib Point were common habitat for crab zoea and larvae of callianassid and carid shrimps (Robertson and Howard 1978), and larvae of the barnacle *Elminius covertus* were observed near Rhyll, on the northwestern edge of Phillip Island (Satumanatpan and Keough 2001). Planktonic carnivores occurred in low numbers. These included the copepod *Tortanus barbatus*, chaetognaths, ctenophores and medusae (Kimmerer and McKinnon 1985). The jellyfish *Catostylus mosaicus* was sampled in Western Port and Port Phillip in April and May 1998 (Hudson and Walker 1998).

Zooplankton Studies in Western Port in 2019

The zooplankton sampling methods are described previously. Zooplankton samples were sorted to the lowest practical taxonomic level and counted at the Institute of Marine and Antarctic Science, University of Tasmania.

More than 40 taxa of zooplankton were recorded in samples from the Lower North Arm sites over the 13-month sampling period from December 2018 to December 2019 (Table 5-22). The mean density of zooplankton was 2895 individuals per m^3 and a mean monthly number of taxa of 24. More than 80% of the zooplankton collected were represented by seven species of copepod. Images of some key copepod species are shown in Figure 5-61. Copepods are typically the most abundant zooplankton in the sea, and are a key trophic link in planktonic and pelagic food webs (Kimmerer and McKinnon 1990).



A Acartia sp.; B. *Acartia danae*; C. *Paracalanus indicus*; D. *Bestiolina similis*; E. *Tortanus barbatus*; F. *Oithona* sp.; G. *Oncaea* sp.; H. *Euterpina acutifrons*

Figure 5-61. Examples of copepods collected from Western Port

Photos: AUSCPR, Swadling 2019

Table 5-22 summarises groups and taxa that contributed to the mean sample density by more than 1%. All species of zooplankton identified were common to marine waters in South-eastern Australia including Bass Strait and Port Phillip.

Table 5-22. Taxa comprising more than 1% of total zooplankton, n/m³

Taxon	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Mean	% of the Mean
Acartia spp. (C)	586	947	734	469	219	243	1532	1180	2430	2918	4752	4426	1850	1714	59
Noctiluca scintillans (O)	14	125	63	0	0	0	0	0	0	0	11	1079	2668	305	11
Paracalanus indicus (C)	23	89	60	83	165	148	253	570	280	93	82	6	15	144	5
Small gastropod (M)	110	833	429	193	72	35	0	0	0	0	0	0	0	129	4
Euterpina acutifrons (C)	2	6	2	0	0	0	156	6	178	673	368	60	4	112	4
Pseudodiaptomus cornutus (C)	0	79	124	35	2	4	172	64	100	289	157	226	107	105	4
Bestiolina similis (C)	0	0	0	338	81	23	62	21	90	113	0	0	0	56	2
Decapod larva (O)	30	27	83	39	5	6	19	0	0	7	5	10	319	42	1
Crab zoea (O)	22	33	90	20	4	11	0	4	1	127	15	23	42	30	1
Other (¬30 taxa)	139	234	205	343	226	126	696	221	108	522	382	45	388	280	10
All Zooplankton	927	2366	1799	1519	774	586	2889	2066	3186	4484	5772	5875	5393	2895	100
Number of taxa	24	30	30	33	23	22	19	25	18	22	30	15	19	24	

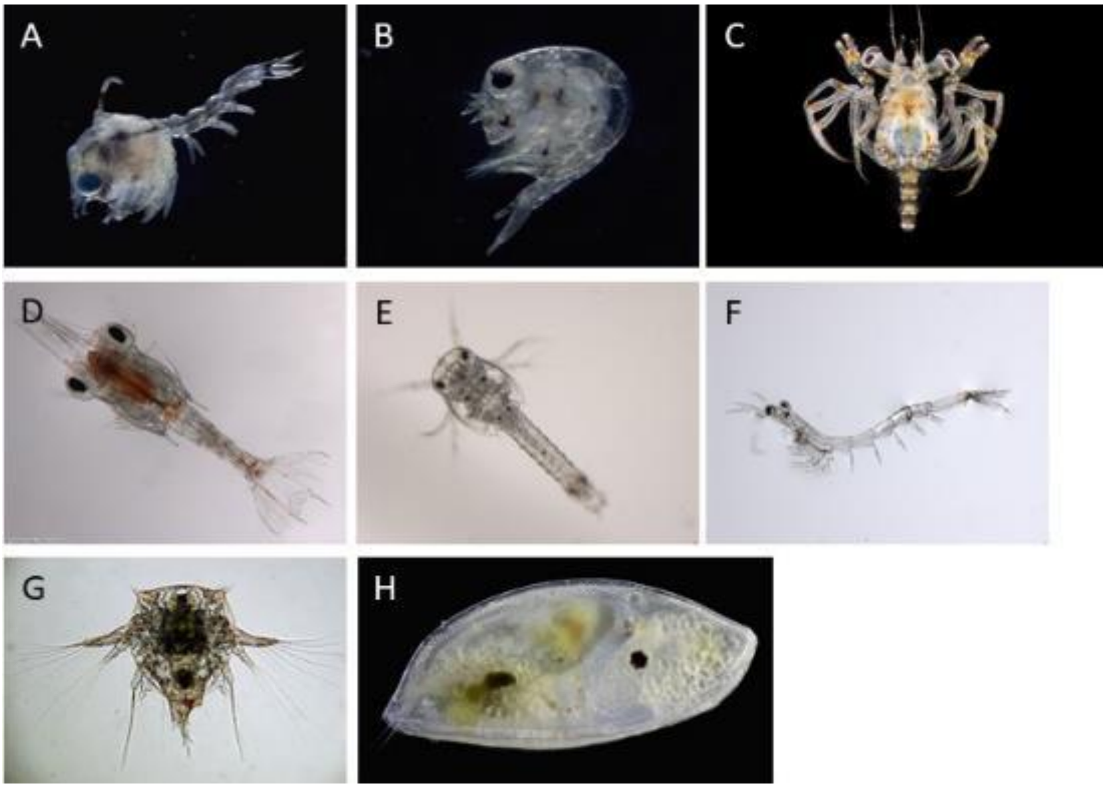
Colour	Plankton descriptor	Colour	Plankton descriptor	Letter code ()	
	Holoplankton species		Present in samples, n/m³	C	Copepods
	Meroplankton		Not present in samples	M	Molluscs
	Benthic biota			O	Other
	Mixed				

More than 60 per cent of the individual plankton collected over the sampling period were the copepod *Acartia* spp which was present in all samples in all surveys. The copepod *Paracalanus indicus* was the only other taxon collected in all months of the monitoring period. It was the second-most abundant taxon, but its numbers represented only 6% of the total zooplankton collected. Copepods *Euterpina acutifrons* and *Pseudodiaptomus cornutus* each represented almost 5% of the total zooplankton.

Copepods are small crustaceans, usually 0.5 to 3 mm in length, with a teardrop-shaped body and a pair of antennae. Marine copepods have high tolerance to salinity and temperature variations and are found in all depths and biogeographical zones of the marine environment.

Copepods spend their entire life cycle as plankton and are thus referred to as holoplankton. Copepod life history from the egg stage includes six, small nauplius stages and five larger copepodite stages before reaching the large reproductive adult stage. Nauplius and early copepodite stages are small and pass through most mesoplankton nets, but may represent more than 90 per cent of the total copepod population when abundances are highest. Hence, the total population numbers of copepod species during peak months (October through March) may be up to 10 times higher than indicated by the number of adults shown in this report.

Spatial and temporal patterns of the most abundant mesozooplankton taxa and groups are described in the following sections. Other zooplankton included larvae of polychaete worms, crustacean larvae (Figure 5-62) and planktonic or larval molluscs. Groups abundance under <1% but consistently over a period of the year included copepods such as *Corycaeus speciosus* (Jul-Nov), *Gladioferens* spp. (Mar-Nov), *Oncacea* spp. (Mar-Nov), *Microsetella norvegica* (Jun-Sep), *Temora* sp. (all year round) and *Oithona* spp. (all year round) as well as *Oikopleura* spp. and salps (Tunicata, salps and sea-squirts), barnacle nauplii and cyprids (larval stages), and sea jellies (Cnidaria).



. A. Crab zoea; B. Crab zoea; C. Crab megalopa; D. Larval shrimp; E. Euphausiid larva; F. *Lucifer Hannseni*; G. Barnacle nauplius; H. Barnacle cyprid.

Figure 5-62. Examples of crustacean larvae in Western Port

Monthly pattern of zooplankton abundance in North Arm

All major zooplankton community categories in North Arm over the sampling period showed strong seasonal patterns (Figure 5-63). The monthly pattern in total number of zooplankton mostly followed the monthly abundance of copepods except for January 2019 when small snails were present in the sampled water column and November and December 2019 when the heterotrophic diatom *Noctiluca scintillans* was abundant.

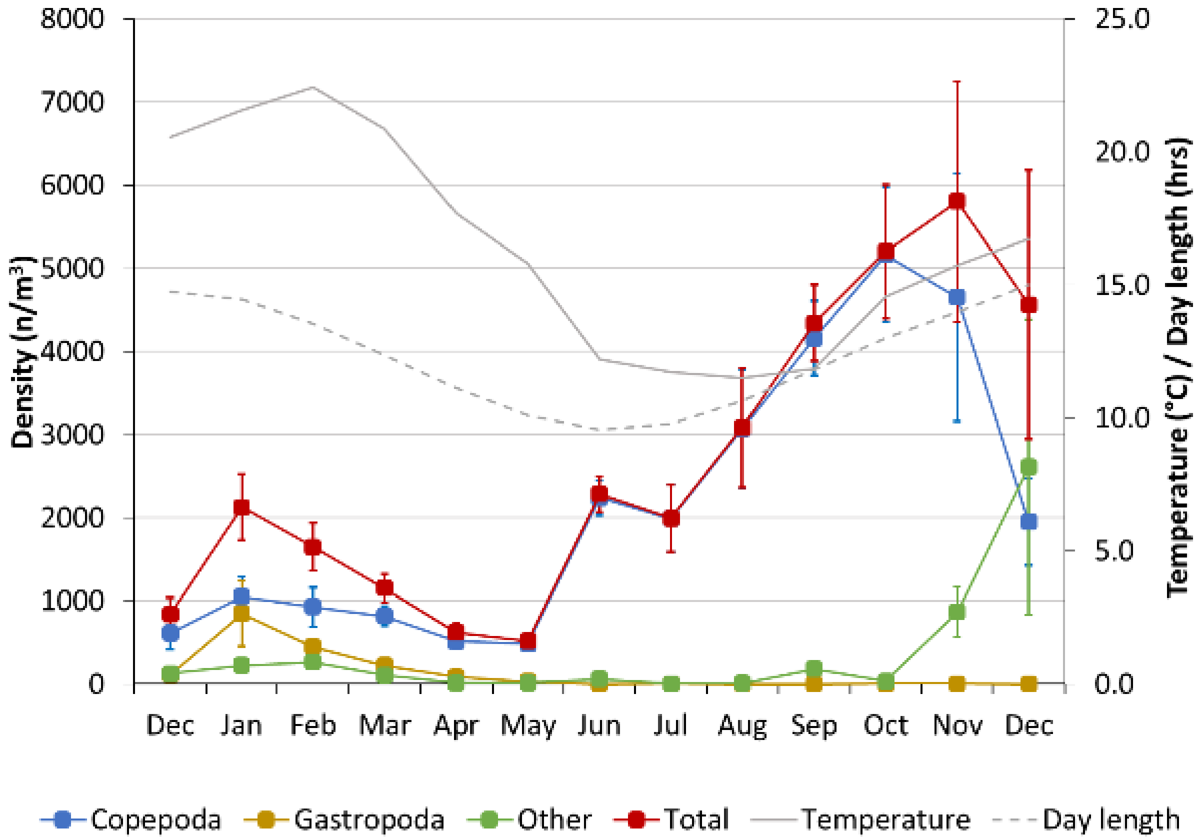


Figure 5-63. Monthly average abundance of key zooplankton categories

Only two taxa were present in detectable numbers in all months of the year and they were both copepods: *Acartia spp* (see previous explanation of this combination) and *Paracalanus indicus*. The monthly abundance of adults of *Acartia spp* and *P indicus* is shown in Figure 5-64.

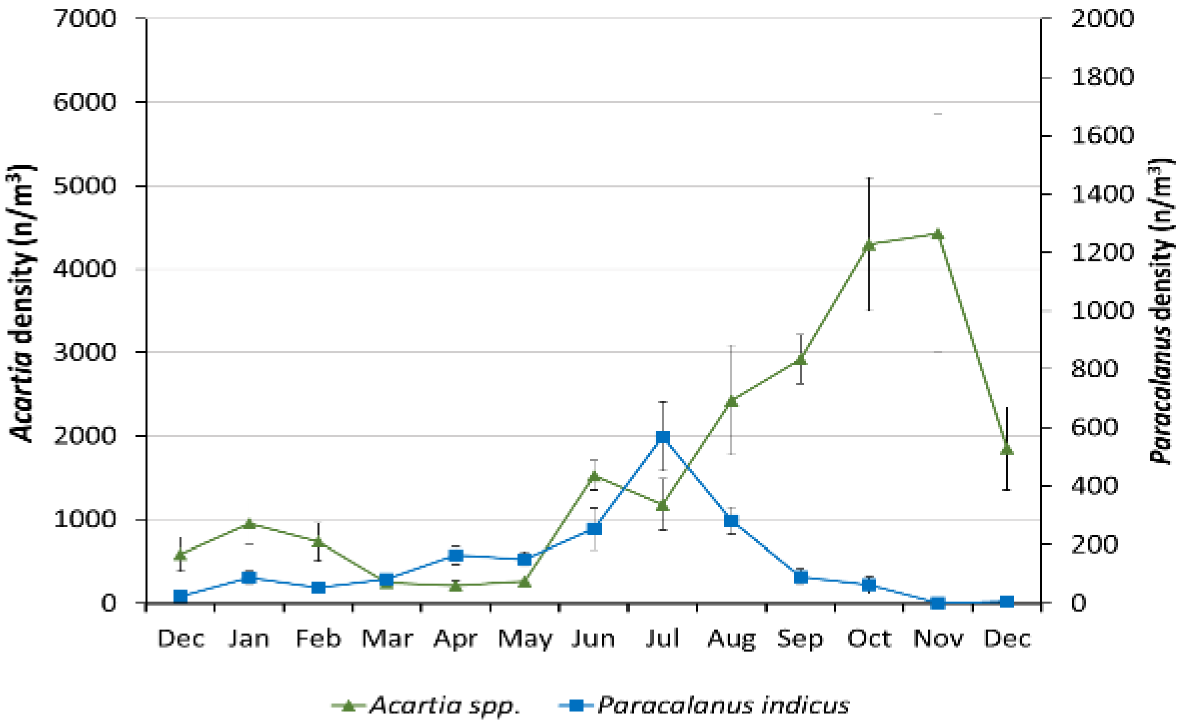


Figure 5-64. Abundance of *Acartia* and *P indicus* in Lower North Arm, 2018-19

(adults, mean ± SE from monthly samples at North Arm sites)

The figure of abundance shows the number of *adult* copepods caught in the mesoplankton net. However, as discussed previously, the total number of copepods in the plankton community comprises both adults and the smaller larval stages. The ratio of larvae to adults in copepods is typically low during low-growing periods that generally correspond with the lower end of the natural temperature range, but copepod larval abundance may be an order of magnitude more abundant than adults during peak growing conditions in warmer months (Hirst and Kiorboe 2002, Kimmerer and McKinnon 1987b).

Acartia spp adults were the numerically dominant zooplankton group over the entire year in Lower North Arm. They were more than four times more abundant than the next most numerous zooplankton species, *P indicus*, most of the year (Figure 5-64). *Acartia spp* are omnivorous and feed on phytoplankton, smaller zooplankton including the larvae of *P indicus*, and organic detritus. It is known to cannibalise its own larvae during times of low food supply (Kimmerer and McKinnon 1985) and is well-adapted to marine environments with high suspended solids loads such as those in Western Port (Kimmerer and McKinnon 1985, Swadling 2019).

Figure 5-64 shows that *Acartia spp* adult abundance was lowest over the first summer and autumn period, and was most stable over March to May. Mean numbers of adults increased in June corresponding to the shortest day, which is months before water temperature begins to increase in September. This increase may represent size growth of the smaller juveniles into individuals large enough to be caught in the standard mesoplankton net. Adult numbers continued to increase to peak in November 2019, when numbers were more than five times greater that the abundance in December 2018. Abundance fell by a factor of more than two in December 2019 to an abundance of fell approximately twice that of the previous December. This is an indication of the interannual variation together with variation in the monthly

abundance and pattern that can be expected in natural short-lived populations such as zooplankton and phytoplankton as discussed in the next section below.

Paracalanus indicus is a suspension feeder that grazes on phytoplankton. The high load of suspended sediments in North Arm are less favourable than clearer waters such as Bass Strait or Port Phillip, where it is proportionately more abundant than *Acartia spp*. *P indicus* abundance showed a similar pattern to *Acartia spp* of low abundance over the December to March period, with slight increase apparent in April and May. The increase became more apparent in June and population abundance of *P indicus* peaked in July. The population abundance of *P indicus* declined from July as the abundance of *Acartia* increased at a rapid rate. This is consistent with the ecological interaction of predation on *P indicus* by *Acartia spp*.

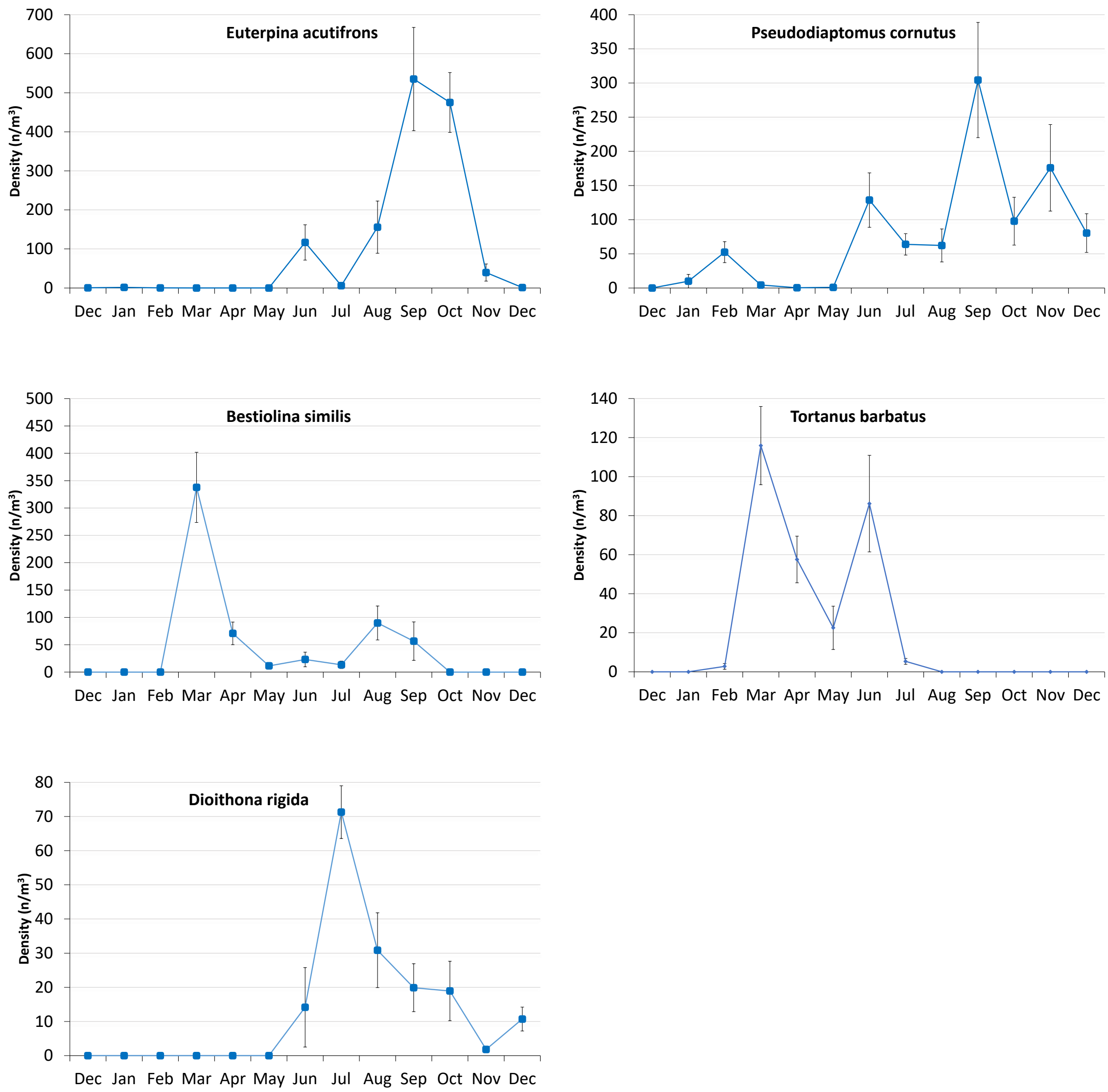


Figure 5-65. Abundance of other common copepods in Lower North Arm, 2018 -19

(mean ± SE from monthly samples at North Arm sites)

Food is the factor limiting *Acartia* population growth in Western Port (Kimmerer and McKinnon), whereas predation by *Acartia* appears to be a key limiting factor on the *P indicus*

population in North Arm as demonstrated by Figure 5-64 and documented by others (Kimmerer and McKinnon 1987, Swadling 2019).

Figure 5-65 shows that all other species of common copepod present in the zooplankton community are found in low or undetectable numbers for a large part of the year. They demonstrate rapid growth from low or undetectable numbers to maximum numbers within one or two months. The timing of peak abundances of these zooplankton is distinct and varies between species.

The larvae of polychaete worms (polychaete larvae) and crabs (crab zoea) were present in two distinct pulses (Figure 5-66). These larvae originate from worms and crabs associated with the seabed. Examination of the site data for the polychaete larvae and crab zoea showed that they were evenly distributed between most sites, with no obvious pattern of higher abundance along the north south or east-west axis of the site layout. The short duration of the polychaete larval peaks indicates that these larvae settled back to the seabed within one month of being released. The broader base either side of the peak in the crab zoea abundance indicates a gradual release over summer peaking in February, while the rapid increase in September indicates a single period of release. Both peaks show a gradual decline indicating a longer larval duration with a combination of settlement and flushing reducing the larvae over one to two months.

The dinoflagellate *Noctiluca scintillans* is a common but episodic (seasonal) coastal species with high concentrations commonly occurring in summer throughout south-eastern Australia. Examination of the *Noctiluca scintillans* North Arm site data showed a clear spatial gradient from highest concentration in the southern sites to very low concentrations and zero presence at the northern sites. Its presence in North Arm is therefore attributed to mixing from a larger Bass Strait population.

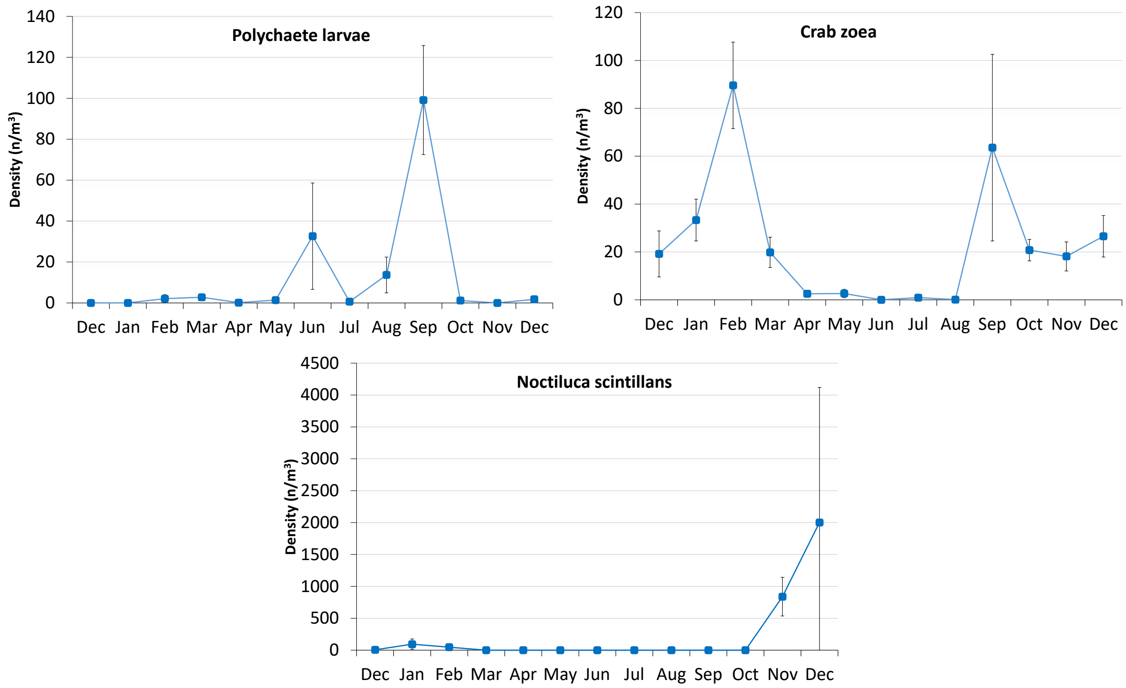


Figure 5-66. Abundance of benthic species larvae and dinoflagellates in Lower North Arm, 2018-19

(mean ± SE from monthly samples at North Arm sites)

In summary:

- The December 2018 to December 2019 sampling program has shown variation in population abundances over a twelve-month period that correspond with seasonal patterns in biological and ecological processes.
- The pattern in the two numerically dominant species (and one other common copepod) corresponded with initiation of population increase in the month of minimum daylength (July) rather than water temperature increase (September).
- The ecological interaction between increase in population abundance of the dominant species *Acartia* in the North Arm, suppressed and reduced the population of the second most common zooplankton community member *P indicus*. This interaction was previously observed in East Arm and explained as predation on *P indicus* by Acartia (Kimmerer and McKinnon 1987).

Comparison of* Acartia *seasonality in Western Port with previous studies

As discussed above, zooplankton of the East Arm of Western Port was sampled comprehensively in 1982 to 1983 (Kimmerer and McKinnon 1985, 1987, 1989). Their reports focused on the same dominant species documented in this study, *Acartia spp*. It is apparent that the numerical dominance of this species and its individual ecological importance in the North Arm and East Arm plankton community make it a keystone species.

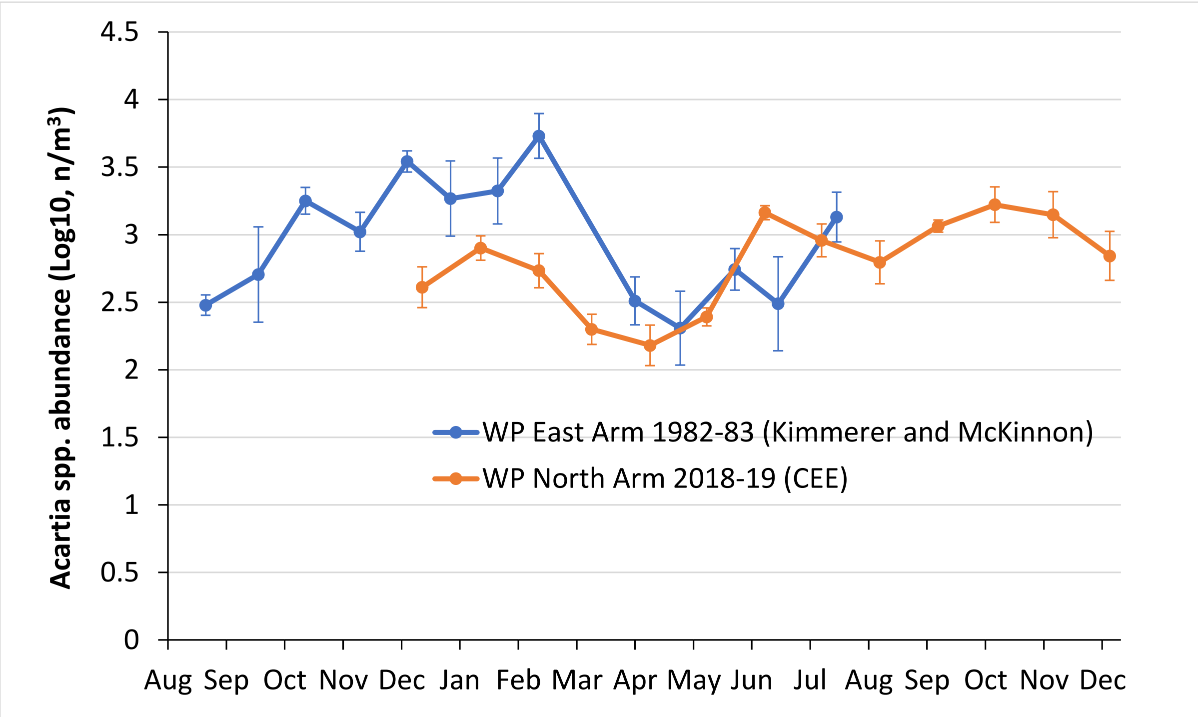


Figure 5-67. *Acartia* abundance in East Arm (1982-83), and Lower North Arm (2018-19)

(1982-83 mean and SE were published as $Log_{10.}$ 2018-19 data transformed similarly)

The monthly mean *Acartia spp* concentrations of the 1982-83 East Arm program and the 2018-19 North Arm program are shown in Figure 5-67. The two sets of data show notably similar patterns of variation and abundance for independently collected data that are 38 years apart

and from ‘separate’ segments of Western Port. The key features of comparison of the data sets are:

- The two data sets show annual peak abundance in summer and annual low in autumn.
- Both data sets show very similar measured abundances, particularly from mid-autumn to mid-winter.
- Both sets show the obvious commencement of the annual population increase from April to July
- The January to March 1983 abundances were substantially higher than the January to March 2019 abundances, however the trajectory of the August to November data was very similar for both years indicating that *Acartia spp* abundance over the 2018/19 summer was low compared to 82/83 and possibly 2019/20.
- The 1982-83 data show greater variance as demonstrated by the wider SE bars in the 1982-83 compared to the 2018-19 data. This is probably due to wider spatial separation of the1982-83 sampling sites, which included a site close to the confluence zone (see next section).
- There is strong similarity and likely to be connectivity between the zooplankton populations in North Arm and East Arm, with possibly higher summer density of populations in the East Arm environment.

The data for this keystone species of the plankton community in Western Port are an important indication of the seasonal and interannual variations that are natural and expected in Western Port due to their reliance on a range of primary natural factors (temperature, rainfall, wind, turbidity and large scale climate patterns that affect hydrodynamics and seawater characteristics) and the range of ecological interactions that also vary accordingly from year to year (Black et al 2016, Kimmerer and McKinnon 1985, Morrongiello and Jenkins 2016).

Spatial distribution of zooplankton

The distribution of each of the major plankton for each survey was initially screened from species/site/monthly abundance plots to inform the general nature of spatial distributions over the 13 monthly surveys. Examples of zooplankton species abundance/location/month charts used in the screening process are shown in (Figure 5-68).

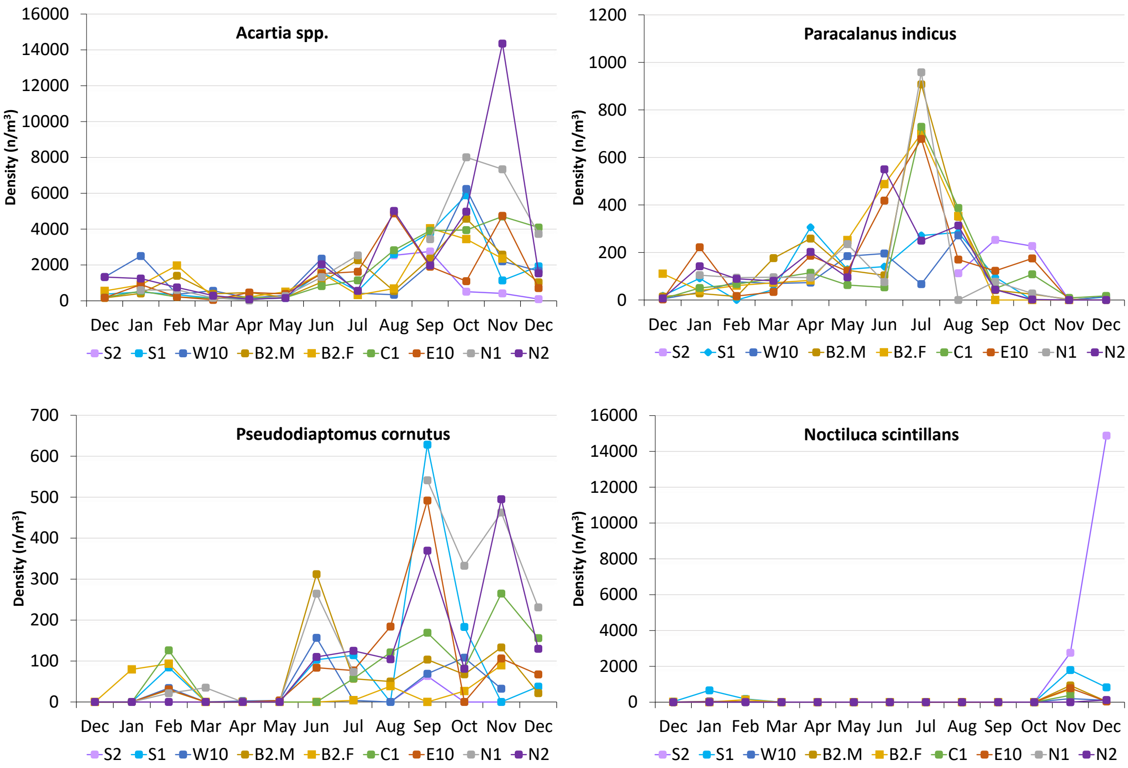


Figure 5-68. Examples of spatial patterns in monthly data

Plots of mean seasonal abundance for total and common taxa at monthly sampling sites are shown in Figure 5-69 which shows a general pattern of high abundance of spring seasonal abundance from high abundance to low abundance from north to south down the central sampling sites. There is no obvious pattern during the other seasons when total abundances are lower.

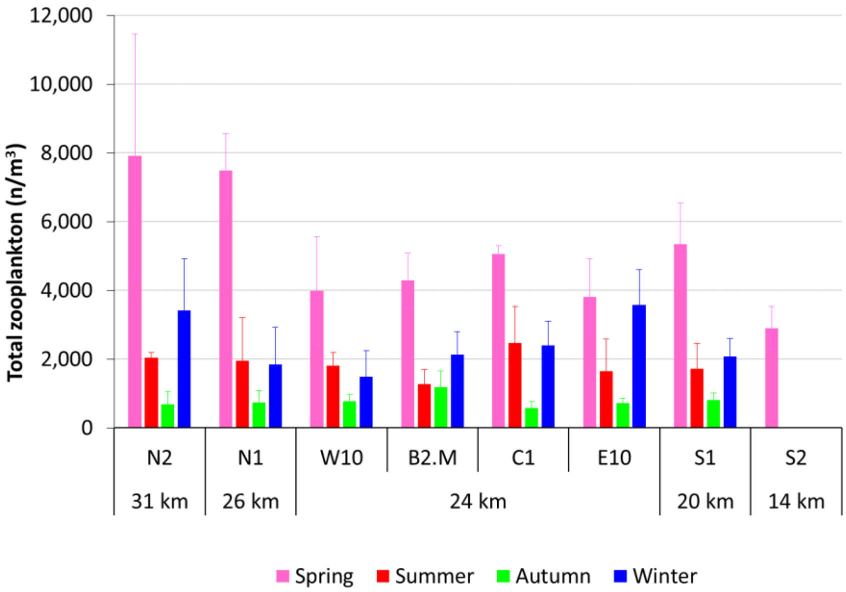


Figure 5-69. Seasonal abundance of total zooplankton per site (Dec-2018 to Dec-2019)

**Distances from Bass Strait. S2 data for spring only*

As discussed previously *Acartia spp* is numerically dominant and a keystone taxon of the plankton community in North Arm. The seasonal abundances for Acartia along the north south Lower North Arm channel and west-east axes of the channel at Crib Point are shown in Figure 5-70, Figure 5-71, respectively.

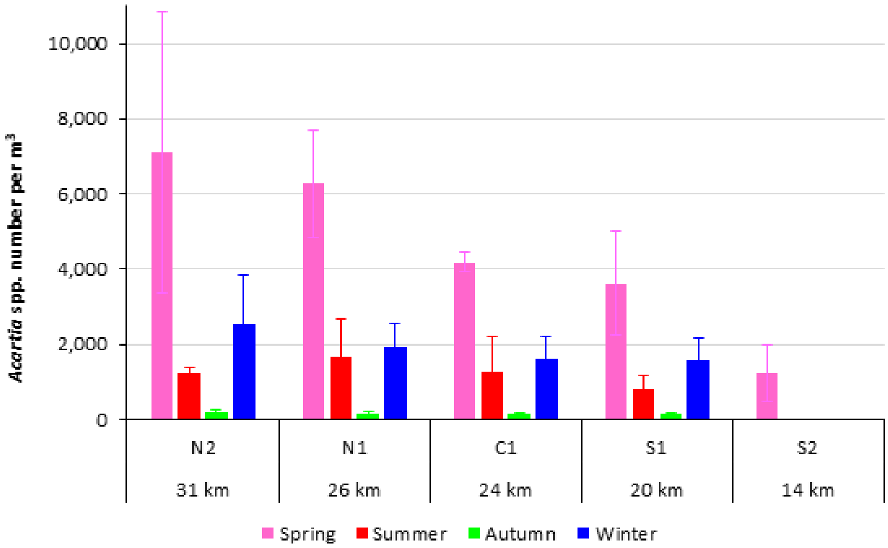


Figure 5-70. Seasonal distribution of Acartia spp along north-south sites

**Distances from Bass Strait. S2 data for spring only*

Figure 5-70 shows a strong north to south gradient *Acartia spp* abundance in spring from sequentially highest abundance at Site N2 in the far north of Lower North Arm to lowest abundance at Site S2 from north to south down the central sampling sites. The relatively high variance at N2 in spring was the result of the very high abundance of *Acartia spp* at this site in November 2019 (Figure 5-68).The north to south pattern is less obvious in summer and winter, which may be in part due to shifts in proportion of adults to larvae over the year as discussed previously.

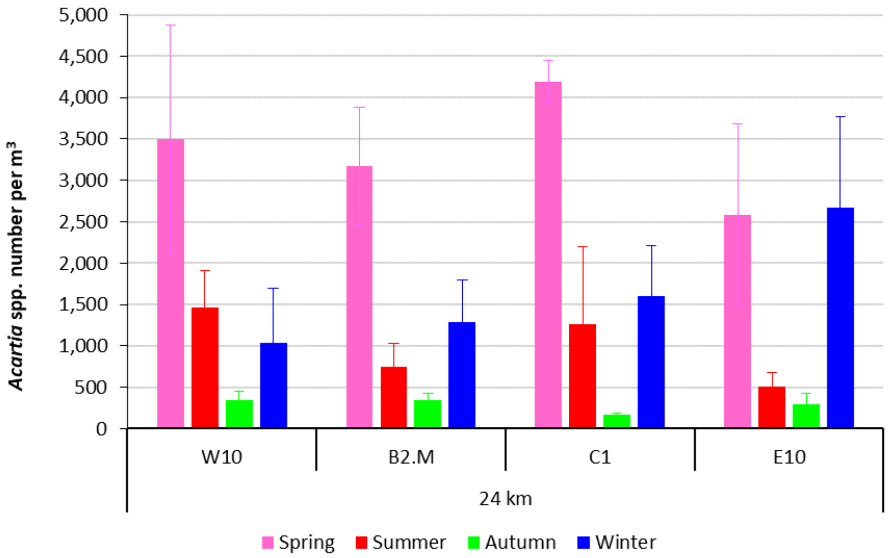


Figure 5-71. Seasonal distribution of Acartia spp along west-east sites

Figure 5-71 shows that possible gradients in abundance of *Acartia spp* in the shorter distance across the channel are less obvious than the long north south axis. There is some evidence of a gradient of increase from west to east in winter, but this is not apparent in other seasons.

The seasonal abundances for *P indicus* along the north-south Lower North Arm channel and west-east axes of the channel at Crib Point are shown in Figure 5-72 and Figure 5-73, respectively. Populations of *Paracalanus* were highest in winter, but there was no consistent gradient along the north south axis (Site S2 was not sampled in winter). Abundance along the west-east axis in winter was lowest at W10, but higher abundances at the other east-west sits were considerably more variable, so there was no obvious gradient in abundance across the channel. *Paracalanus* abundance was low at all sites in Lower North Arm in spring (when *Acartia spp* populations were highest), except for a relatively high concentration for spring at site S2, which was located in Western Entrance and had the lowest *Acartia spp* concentration. The was no consistent gradient on either axis in summer or autumn.

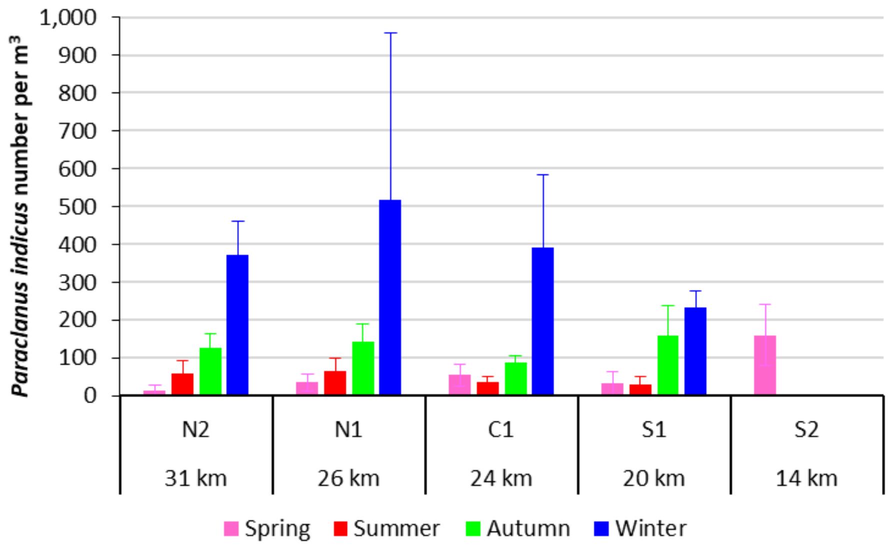


Figure 5-72. Seasonal distribution of Paracalanus indicus along north-south sites

**Distances from Bass Strait. S2 data for spring only*

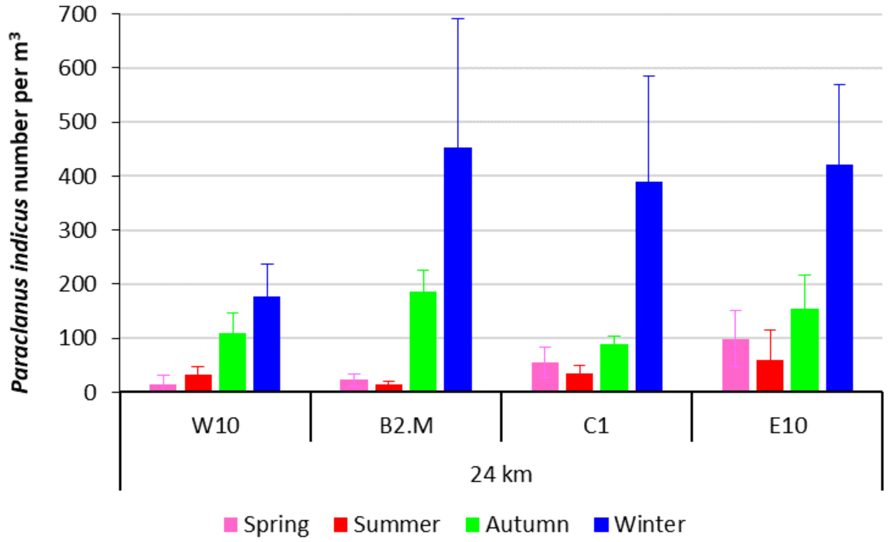


Figure 5-73 Seasonal distribution of Paracalanus indicus along west-east sites

Seasonal abundance at the sites is shown for a range of zooplankton community taxa in Figure 5-74. The figure further demonstrates the strong seasonality of all these taxa. There are no obvious, strong north-south or east-west gradients in the seasonal abundance data of these taxa in the Lower North Sites. As noted previously, the dinoflagellate *Noctiluca scintillans* showed clearly highest concentration at site S2 and its presence in North Arm is attributed to mixing from a larger Bass Strait population.

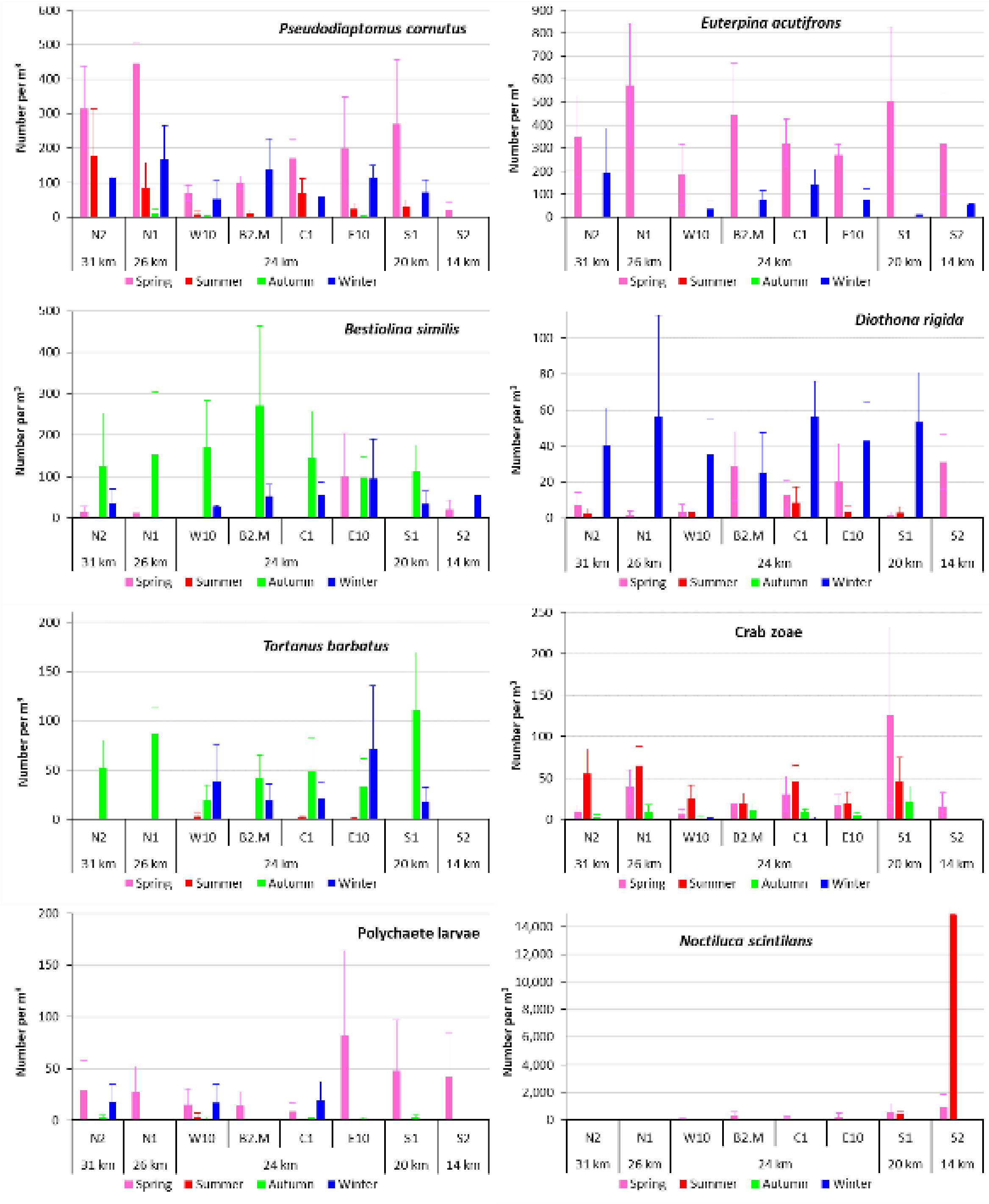


Figure 5-74 Seasonal distribution of other taxa at sampling sites

Comparison of zooplankton communities North Arm, East Arm and Port Phillip

Table 5-23 ranks the abundance of the six most numerous zooplankton species collected in Western Port in different studies:

- Lower North Arm by CEE in 2019 for this EES
- East Arm by Kimmerer and McKinnon in 1982-83 and
- Port Phillip by Kimmerer and McKinnon in 1982-83

Table 5-23. Species abundance rank in 2018-19 and 1982-83

Zooplankton species*	Western Port		Port Phillip
	CEE 2019	K&Mc 1983	K&Mc 1983
*Acartia sp***	1	1	5
Paracalanus indicus	2	3	1
*Euterpina acutifrons***	3	2	6
*Pseudodiaptomus cornutus***	4	4	Present
*Bestiola similis***	5	6	Present
Tortanus barbatus **	6	Present	3
Oikopleaura dioica	Present	5	2
*Lucifer Hannseni***	Present	Present	4

*excludes larvae, diatoms and benthic species

**nominated as bay residents Kimmerer and McKinnon 1985

The table shows that the composition of the zooplankton community sampled by CEE in North Arm in 2019 was very similar to the composition of the zooplankton community sampled 37 years earlier in East Arm in 1982-83 (Kimmerer and McKinnon 1985), with the abundance rank of the six most numerous zooplankton species collected being very similar.

- *Acartia* numerically dominated all North Arm sites during all surveys during the 2018-19 program and dominated all East Arm sites during the 1982-83 program.
- *Acartia* and *Paracalanus* were the only species present during all 2018-19 surveys.
- *Euterpina acutifrons* was the third most abundant zooplankton species present in the 2018-19 program, but was strongly seasonal and absent or in very low abundance in 6 of the 13 surveys.
- Five of the six most abundant zooplankton species present in the 2018-19 surveys were classified as “Bay residents” by Kimmerer and McKinnon (1985).
- The abundance rank of the key species in the zooplankton communities during the 1980s program differed substantially between Western Port and Port Phillip. These differences indicate substantially different environmental conditions in Western Port compared to Port Phillip as discussed previously.

Discussion of Zooplankton community in Lower North Arm, Western Port

It is apparent from the EES zooplankton investigations, monitoring program and comparison with previous studies that the zooplankton population in Lower North Arm is very similar to that in lower East Arm. The results of two independent studies 37 years apart in each area show remarkable similarities in major species abundance in the two areas of Western Port.

The characteristic North Arm and East Arm community in Western Port has lower diversity and a different species mix from Port Phillip and Bass Strait. The difference between Western Port

and Port Phillip/Bass Strait communities is due to tidal current turbulence, low nutrient input and high concentrations of suspended sediment in Western Port.

Despite the changes in seagrass extent in northern Western Port, the key characteristics of the North Arm zooplankton community in 2019 are similar to those reported in 1972. The zooplankton community in Lower North Arm seems to be resilient to changes over the past 46 years at least.

Both studies found that a single genus dominated the zooplankton community. *Acartia* is well-adapted to living and feeding in bays with high particulate content, dominates the zooplankton community in Western Port. Not only did *Acartia* numerically dominate the zooplankton community, it also directly preyed on juveniles of next most abundant species (*Paracalanus indicus*) during spring. The earlier studies in East Arm noted that food was the limiting resource for zooplankton during the peak growing season. Cannibalism by *Acartia* adults on their own larvae may be responsible for up to 2% of the mortality of their larvae during the peak growing season (CSIRO, 2019).

The two studies also show clear parallels or overlap in the annual pattern of variation in abundance of the keystone zooplankton indicator, *Acartia*, from the 1982-83 data and the 2019 data. The population growing season commences at about the time of the shortest day, which is approximately two months prior to the commencement of water temperature increased.

Both studies showed distinct gradients from high abundance at sites furthest from Bass Strait to lowest concentrations at sites closest to Bass Strait. The gradients correspond with dilution of the resident upper Western Port zooplankton populations along the mixing gradient with the less productive Bass Strait waters.

Kimmerer et al (2014) stated in relation to advection, washout or 'flushing' of embayment zooplankton populations to wider coastal waters that the "*Imperative for population maintenance is to maintain abundance in the core region*". The pattern of distribution shown in the EES monitoring program and particularly the October 2019 investigation is consistent with the waters of northern and eastern Western Port from about Site N1 in North Arm possibly through the Tidal Divide to site P2 in the East Arm representing the core or self-sustaining population region for the zooplankton in Western Port. The observed patterns in the lower North Arm and East Arm of population abundance decreasing along the flushing gradients are consistent with the concept that the core population "reseeds regions where advection has reduced abundance" (Kimmerer *et al* 2014). In the case of North Arm, the core population of Upper North Arm appears to reseed regions lower North Arm south of Long island Point to Bass Strait, where the mixing gradient reduces abundances of bay resident populations.

It appears, therefore, that the Upper North Arm resident holo-zooplankton population therefore reseeds the Lower North Arm at all times of the year. The reproductive rate varies over the year but must exceed the flushing rate for the population to be maintained. The reproductive rate of *Acartia spp* has been estimated as high as 12 eggs /female/day and adults comprise about 7 % of the population. Mortality rate of adults are approximately 6% d^{-1} and early nauplii, 16 %/d (Kimmerer and McKinnon 1985). For East Arm populations of *Acartia spp*, Kimmerer and McKinnon (1985) concluded that "Thus, a loss rate of 0.8%/day (due to wash out) is not large".

5.8.5 Spatial Tie-in Survey – Phytoplankton and Zooplankton

A single survey to inform a comparison of the 1982 to 1984 and the 2019 EES investigations was completed in October 2019. The survey collected single samples of zooplankton and phytoplankton at regular sampling sites from both programs in a single day. Sites P1 to P5 are in the same locations as those used by Kimmerer and McKinnon (1985), the others are the longitudinal axis sites from the 2019 monthly EES sampling program.

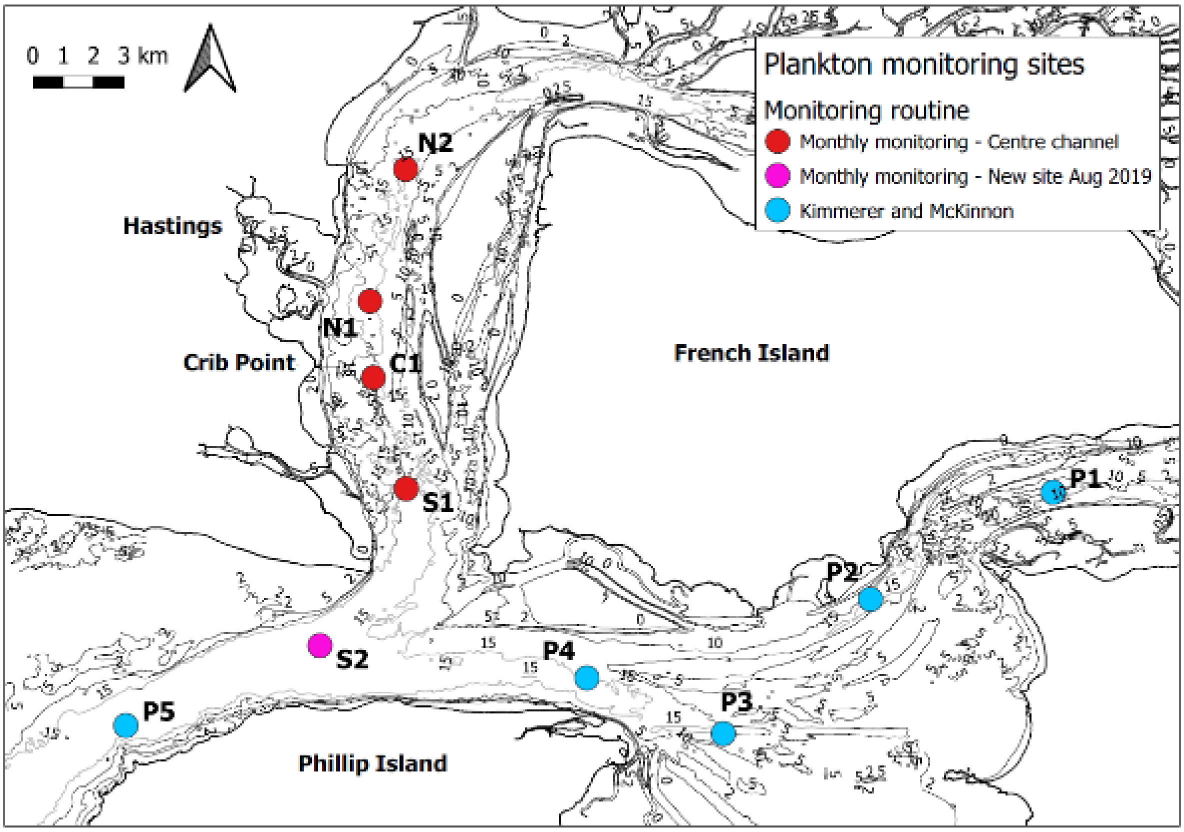


Figure 5-75. Spatial tie-in survey, October 2019

Phytoplankton

The spatial tie-in survey of October 2019 documented phytoplankton abundance and diversity at 10 sites in the Western Entrance and Confluence Zone (P5 and CPS2) the Lower North Arm (CPS1 to CPN2) and in the Rhyll (P4, P3) and East Arm (P2, P1) segments.

Figure 5-76 shows the abundance of the key phytoplankton classes. Diatoms were the most abundant class (25 %), followed by Cryptophytes (21 %), Prymnesiophytes (20 %), Dinoflagellates (17 %) and Chrysophytes (11 %). Other classes accounted for 5 % of the phytoplankton or less. This shows a quite different community structure to the average for December 2018 to October 2019 when diatoms comprised 55 per cent of the phytoplankton. Even when the sites in the Rhyll and East Arm segments are excluded, there were many more flagellates in the October broad scale study than the average for the year. Furthermore, diatoms accounted for over 55 per cent of the phytoplankton in the October monthly survey two weeks prior. Evidently there was a shift in the phytoplankton community over the September to October period. Grazing pressure from zooplankton was the highest for the

monitoring period at this time (see below) and there was a corresponding decrease in overall phytoplankton abundance and biomass.

Phytoplankton abundances varied markedly over the study area from around 100,000 cells/L to over 500,000 cells/L. Abundances were lowest in the confluence zone, south of lower north arm and at site P2 in east arm. Abundances were very high in the Rhyll segment owing to high numbers of flagellates including Cryptophytes, Prymnesiophtes, Dinoflagelates and Chrysophytes. Higher numbers were also present in the north of Lower North Arm and site P1 in East Arm.

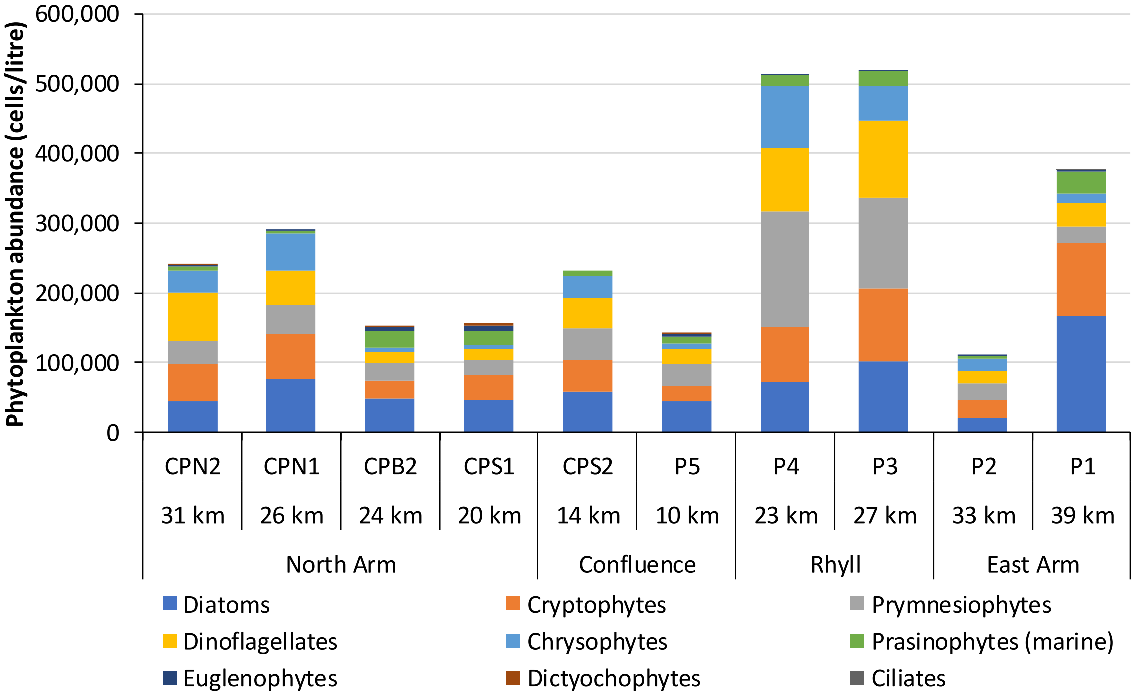


Figure 5-76. Broadscale patterns in of key phytoplankton classes, Oct-2019

Zooplankton

Copepods numerically dominated all samples. The abundances of the three most common species at all sites during the survey, A*cartia*, *Pseudodiaptomus* and *Euterpina*, are shown in Figure 5-77. The figure shows

- The clear effects of the flushing gradient from the Western Entrance through the confluence zone (sties P5 and S2) and into North Arm (S1 to N2) and East Arm (P4 to P1) as Bass Strait water with low populations of zooplankton penetrates both Arms during the regular process of tidal mixing and exchange.
- Highest concentrations *Acartia* and *Euterpina* occur at the upper sites in both Arms, which appear to represent the core regions for these Bay-resident populations.
- The densities of the zooplankton populations decrease by dilution with Bass Strait water along the mixing gradient from the core region towards Bass Strait.

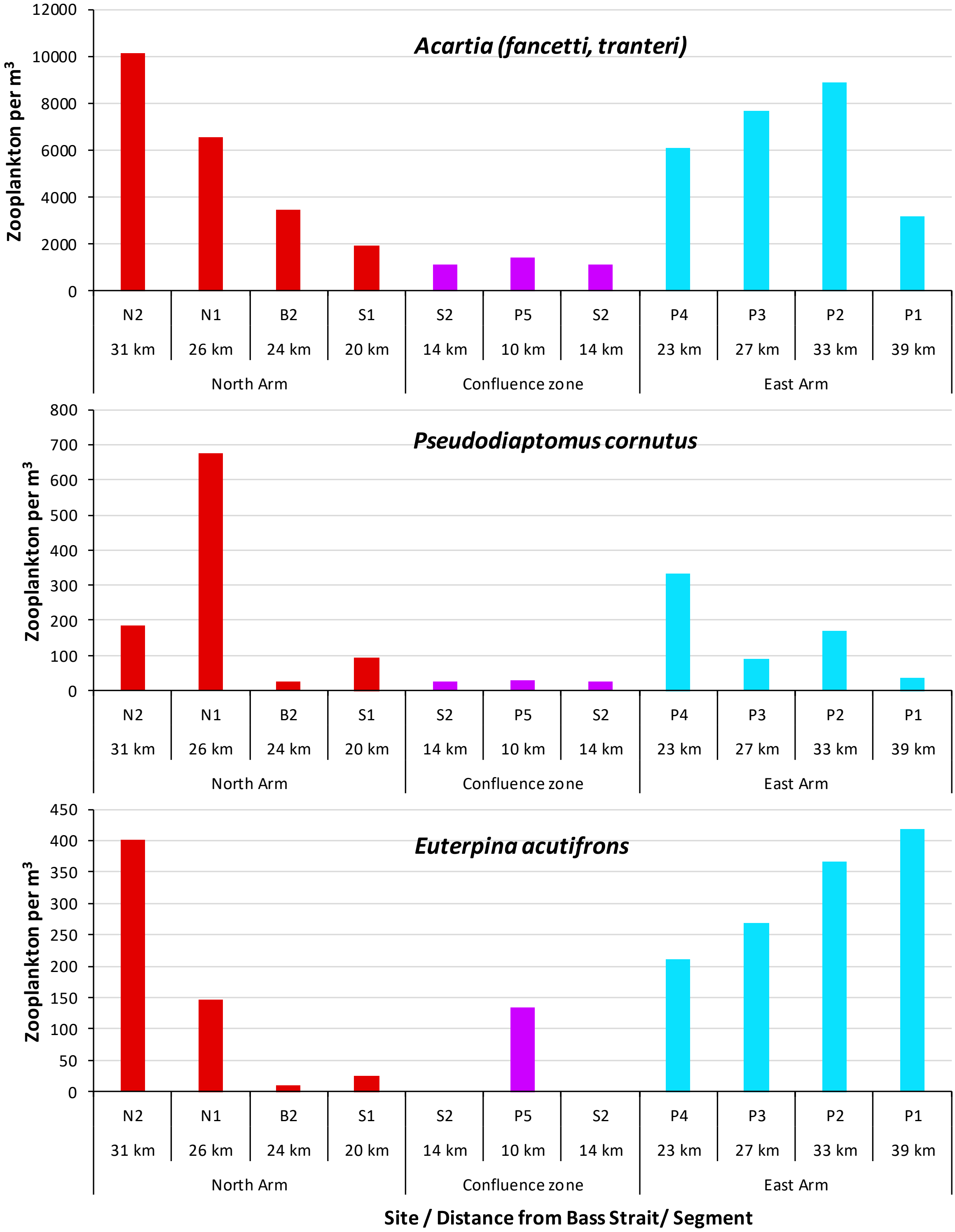


Figure 5-77. Dominant copepod abundances North and East Arm, October 2019

5.8.6 Ichthyoplankton

The marine environment of Western Port is characterised by a range of habitats, including seagrass, mangroves, algae and reefs, that support a rich and diverse fish fauna. Species from these diverse habitats release their eggs and larvae into the water column where they mix and are dispersed by currents until they reach the early juvenile stage. The egg and larval stage in marine fish (ichthyoplankton) is characterised by high mortality rates, and the early stages are important in determining levels of recruitment and abundance of the population (Houde 2008). Spatial and temporal variability in Western Port ichthyoplankton communities are the product of life history (spawning location, spawning period, larval period), mortality (mainly predation), and dispersal related to the wind driven hydrodynamics in Bass Strait and tide dominated hydrodynamics in Western Port.

Ichthyoplankton were sampled by CEE at the plankton monitoring sites (see above) monthly between December 2018 and December 2019. Methods are described in CEE 2019. Over 100 fish larvae samples were collected over the course of the monitoring program, each sample collected around 300 m^3 of seawater. Fish larval samples were coarse-sorted at CEE and sent to the Australian Museum for further enumeration and identification by specialist taxonomists. Data for all surveys were compiled and provided to Prof G Jenkins at the University of Melbourne for reporting. Prof Jenkins provided a report on the ichthyoplankton characteristics of the sampling program (Jenkins 2019, appended), which provides the basis for this section of the report.

Table 5-24. Monthly larval total numbers summary

Group	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Fish larvae^	2458	739	265	75	55	22	22	11	18	247	411	799	2023	550
Fish eggs	488	124	11	60	14	25	33	145	928	879	586	582	461	334
Cephalopods	283	237	189	59	56	22	7	5	4	4	12	152	198	95

^includes some post-larvae

Monthly average across sites

Fish larvae and paralarvae were most abundant at the start of the survey in summer, declining by two orders of magnitude by late autumn and winter before increasing again in spring (Table 5-24). The seasonal pattern of fish eggs was similar to larvae but abundances were highest in late winter and spring than summer. Abundances of cephalopod paralarvae (squid) were highest at the start of the survey in summer (December 2018) and thereafter declined to low levels in winter-spring.

Fish larvae came from 28 fish families, dominated by the Gobiidae (gobies) and to a lesser extent by the Syngnathidae (seahorses and pipefish) and Tetrarogidae (scorpionfish and cobblers). Cephalopods were dominated by adults of one small species, the pygmy squid, *Xipholeptos notoides*, together with a few individual larvae of the southern dumpling squid, *Euprymna tasmanica* and Luminous Bay Squid *Uroteuthis (Aestuariolus) noctiluca*.

Among the dominant larval fish families, gobies were most abundant in summer and to a lesser extent spring, reflecting the seasonal pattern of total larvae due to their dominance. This seasonal pattern was also shown by the Gobiesocidae (clingfish).

Other families, including the Syngnathidae, Aracanidae (boxfishes, cow fishes), Monacanthidae (leatherjackets), Apogonidae (cardinal fish) and Tetraodontidae (toadfish) had highest abundances at the start of the survey in summer before declining to low levels for the remainder of the survey. In contrast, the Tetrarogidae and Tripterygiidae (triplefins) were most abundant towards the end of the survey in spring.

Larvae of two goby species were identified, *Afurcagobius tamarensis* and *Gobiopterus semivestitus*, and the genus Nesogobius was also identified, together with 9 distinguishable but unknown "types" of larval goby. The Pale Mangrove Goby or flatback goby, *Mugilogobius platynotus*, is listed under the Victorian FFG Act (as *Mugilogobius paludus)*. Larvae of *M. platynotus* cannot be separated from larvae of other similar goby species based on current knowledge. Larval fish from three goby families that have larvae similar to *M. platynotus* were identified as 'potentially of conservation interest'.

The entire pipefish-seahorse (syngnathid) family is listed under CITES, IUCN Red List (some) and the Victorian Fisheries Act. Syngnathids are included under these various conservation lists due to potentially excessive collection of some species in some regions for 'traditional' medicine and aquarium trade. Syngnathids are not listed as threatened under the EPBC Act, but are listed as marine species for consideration in Commonwealth waters, which does not apply to this project. The syngnathids identified were dominated by the pipefish, *Stigmatopora* sp. (pipefish), while seahorses, *Hippocampus* sp., were also present.

The family Retropinnidae (smelt and grayling) includes the Australian Grayling which is listed under the EPBC Act, IUCN Red List and FFG Act, as well as the smelts that are not conservation listed. One retropinnid larva was identified from site B2 in September 2019.

Larval fish from ten families were potentially of recreational and commercial fishing interest. Six families included species that are targeted by recreational fishers. The flatheads (Platycephalidae) occurred in summer but were most abundant in October at the end of the survey. Specimens were collected along the length of the Lower North Arm but were most common at S1 and S2 (in the Confluence Zone).

Larvae of the Shortfin Pike (Sphyraenidae) were collected in December from sites B2, E10 and S1. Barracouta (*Thrysites atun*) larvae were collected in winter-spring between N1 and S2. A small number of right-eye flounder (Rhombosoleidae**)** larvae were collected from May to October, most commonly along the east-west transect opposite Crib Point. A small number of garfish (Hemiramphidae) larvae were collected in February from sites N1 and N2.

One post-larval King George Whiting (Sillaginidae) specimen was collected in October from site E10. This individual, like all King George Whiting in Western Port, Port Phillip and Corner Inlet, had begun life as a larva in South Australia and drifted more than 500 km before entering Western Port. Even in spawning areas in South Australia, larval densities during spawning period are less than 2 larvae per net tow (Rogers *et al* 2019). In Port Phillip, post-larvae are found in highest abundance in nearshore shallow waters (Jenkins et al 1999). This is consistent with King George Whiting larval habitat preference for vegetated seabed. Hence it is not surprising that only one King George Whiting larva collected 500 km from its parental spawning area and that it was at a site near to shore adjacent to seagrass beds.

Other families included larvae of species that are taken as bycatch in the recreational and commercial fishery (i.e. not targeted but likely to be kept if caught). These included the genus *Meuschenia* in the Monacanthids (e.g. Sixspine leatherjacket, *Meuschenia freyceneti*) and potentially the grass whiting, *Halleta semifasciata* in the odacids, together with some species of wrasse (Labridae) (Table 5-20). A few larvae came from families with species more commonly caught in the offshore commercial fishery, including ling (*Genypterus sp.*) and cod (Moridae).

Larvae of two species that are key elements of the food chain for larger pelagic fish and seabirds were also collected. Larvae of the Australian Anchovy, *Engraulis australis*, were collected in February, May and September. Larvae of the Australian Sardine, *Sardinops sagax*, were collected in summer and also in October, along the length of the Lower North Arm and including the Confluence Zone.

The seasonal spatial distribution of fish eggs and larval fish are is shown in Figure 5-78 and Figure 5-79, respectively. The figures show that fish eggs over the December 2018 to October 2019 period became abundant in winter and persisted through spring, with low numbers in summer and autumn. Larval numbers demonstrate an increasing number of larvae initially in spring and greatest number in summer and very low numbers in autumn and winter. This is the natural sequence of eggs being laid by adults in winter and spring, which develop into larvae late in spring and persist into summer. Most larvae have grown to juveniles or adults by summer, leaving a juvenile and adult population of sedentary species in North Arm over autumn and winter. Fish eggs tended to be more abundant at the northern and southern sites (in spring), as well as at E10.

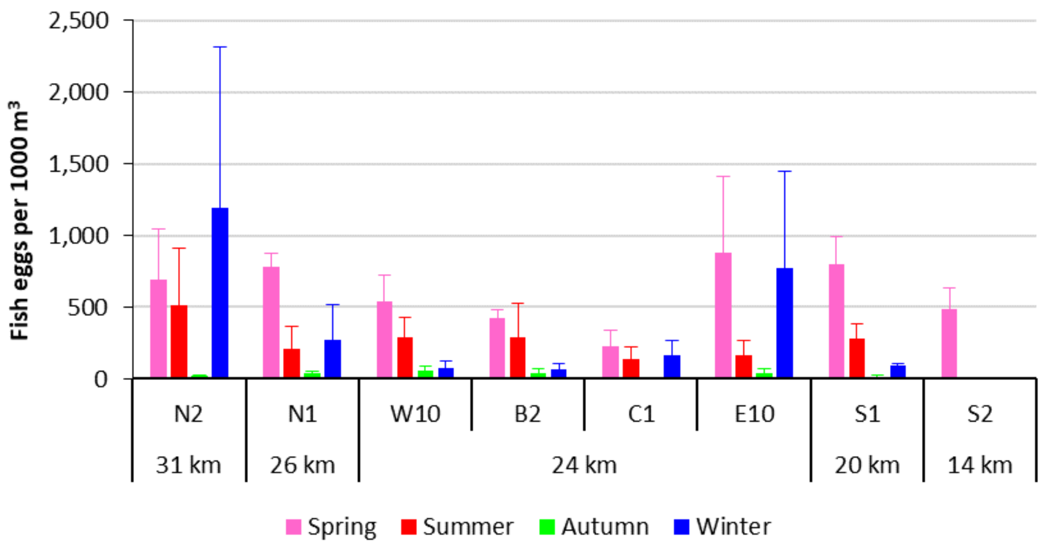


Figure 5-78. Seasonal abundance of fish eggs

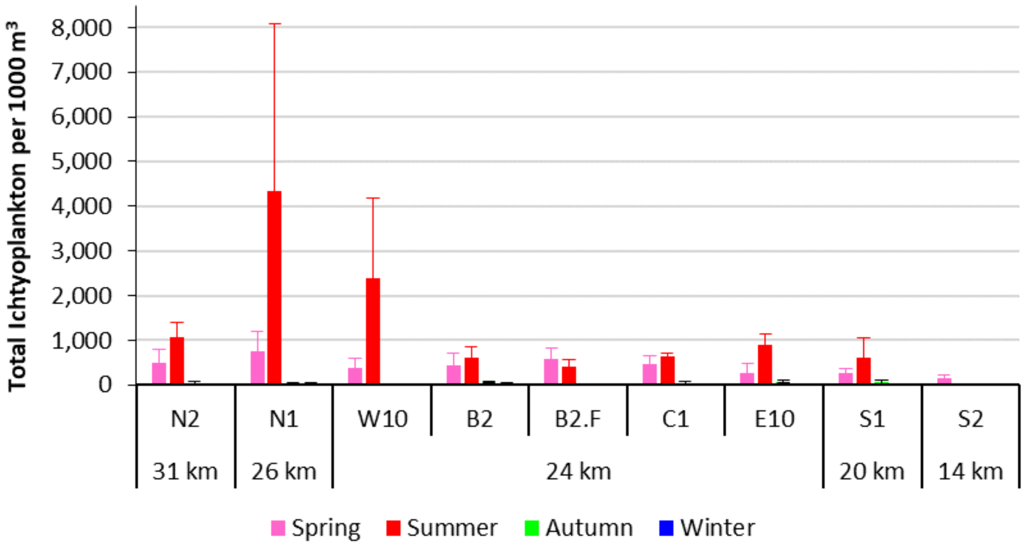


Figure 5-79. Seasonal abundance of total fish larvae

The average number of fish families represented as larvae per site (Figure 5-80) shows a similar seasonal pattern to eggs and larvae, with highest number of species in the larvae in spring and summer and lowest number of species in winter. The distribution of species number was relatively even across the North Arm sites.

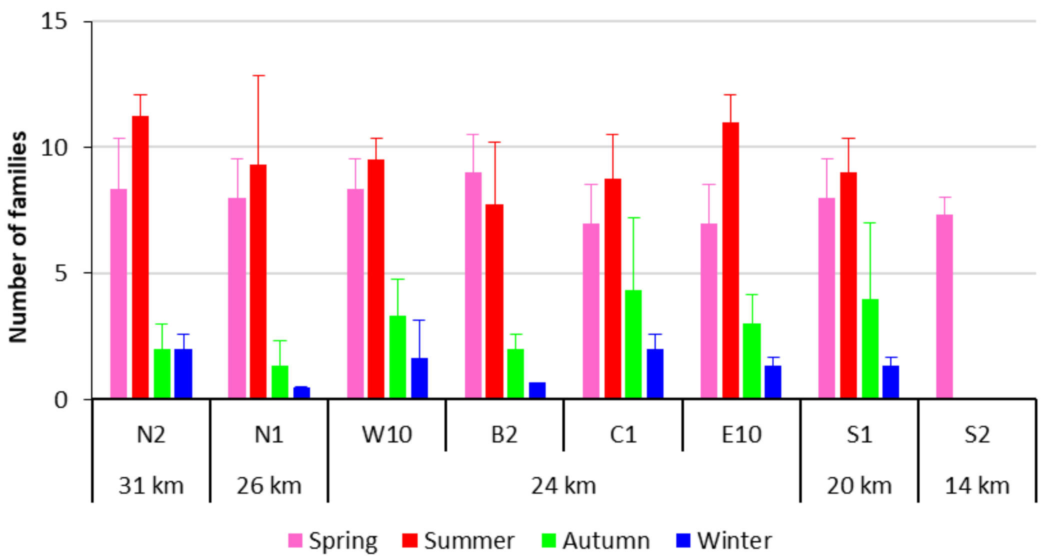


Figure 5-80. Number of fish families at monitoring sites

The seasonal abundance distribution of common larvae is shown in the charts below and demonstrates three general patterns:

- Peak abundance in spring: demonstrated strongly by cobblers and triple fin (Figure 5-82 and Figure 5-83);
- Peak abundance in summer: demonstrated strongly by boxfish and cardinal fish; and
- Peak abundance in summer with lower abundance into autumn: demonstrated by gobies, squid, leatherjackets and toad fish (Figure 5-86, Figure 5-87 and Figure 5-85).

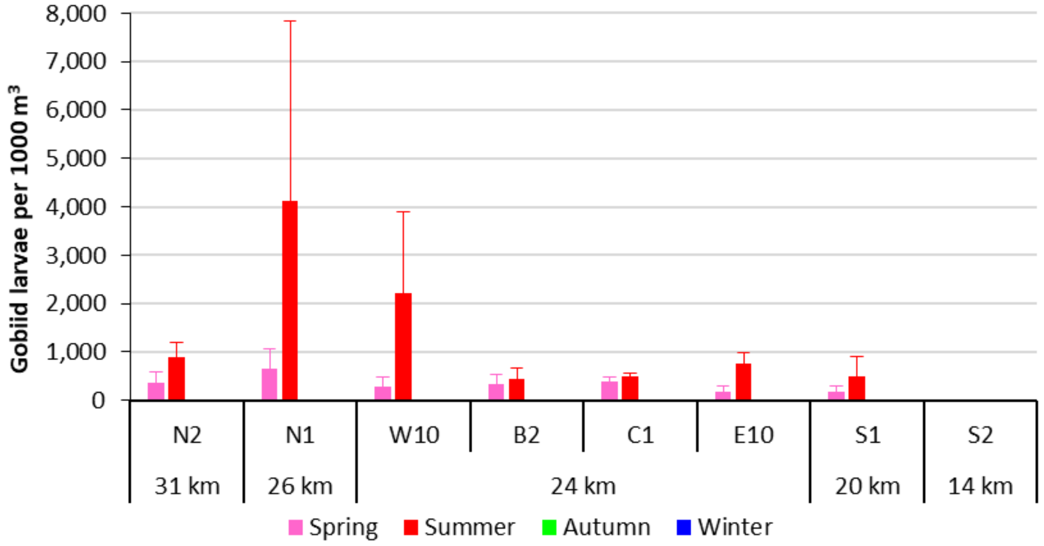


Figure 5-81. Seasonal abundance of gobies

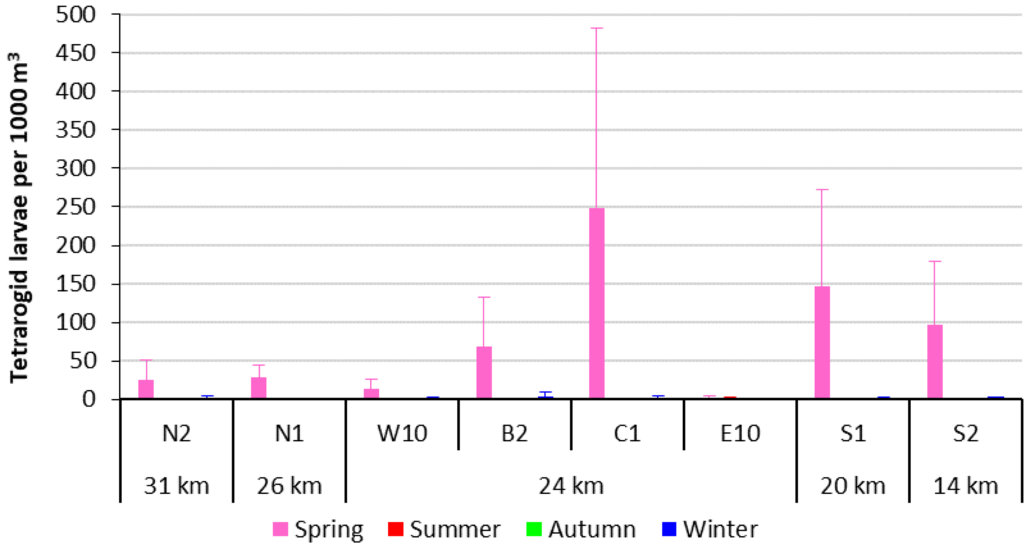


Figure 5-82. Seasonal abundance of cobblers

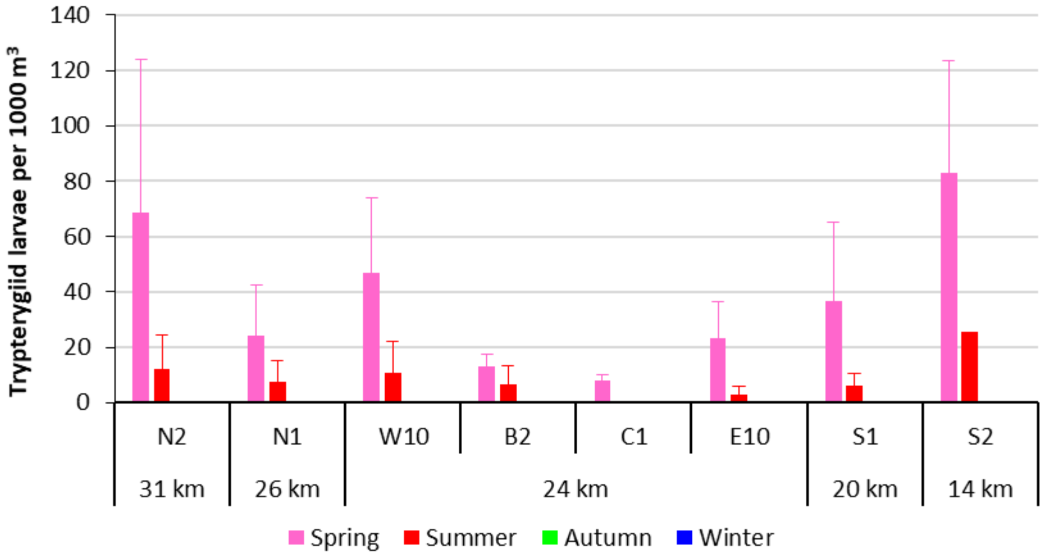


Figure 5-83. Seasonal abundance of triple fin

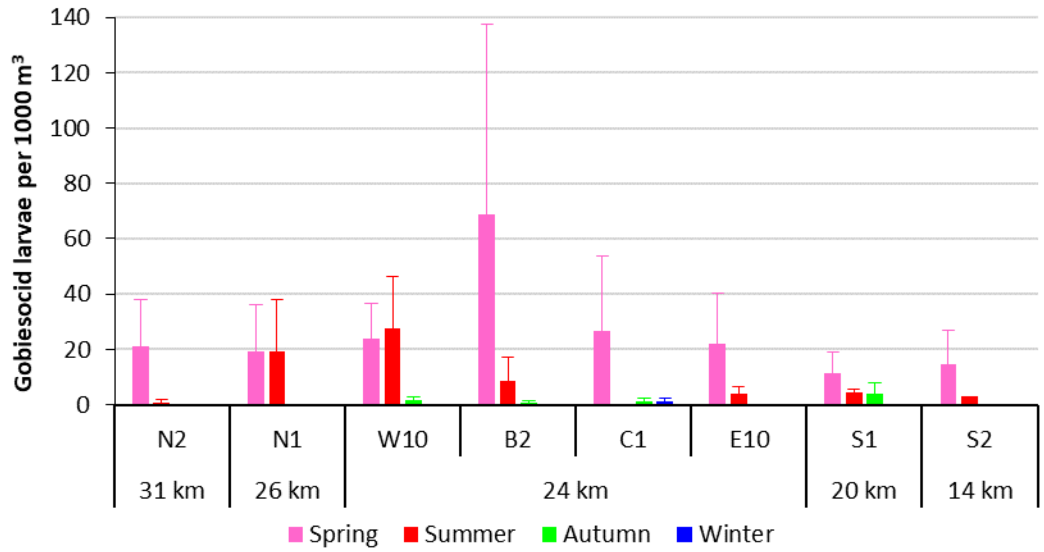


Figure 5-84. Seasonal abundance of clingfish

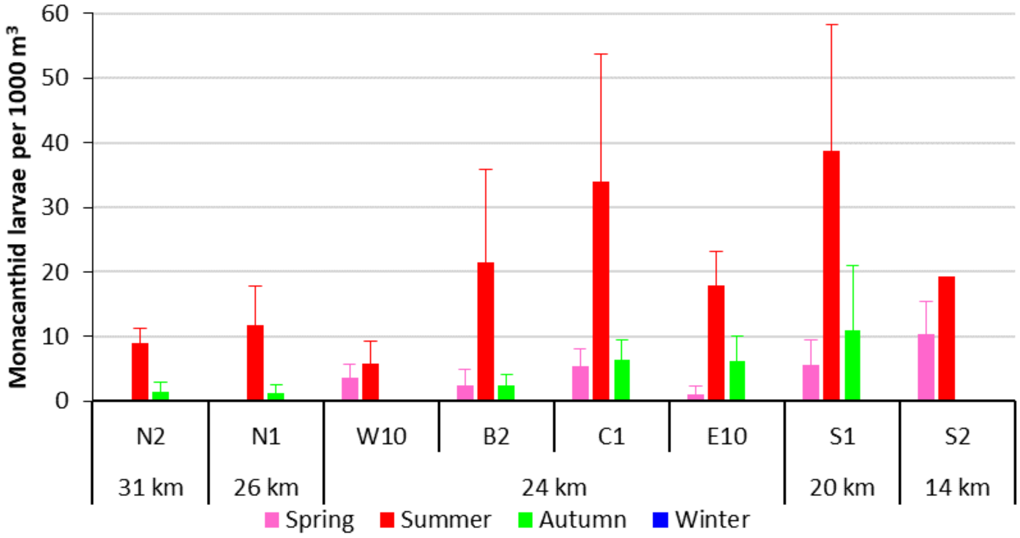


Figure 5-85. Seasonal abundance of leatherjackets

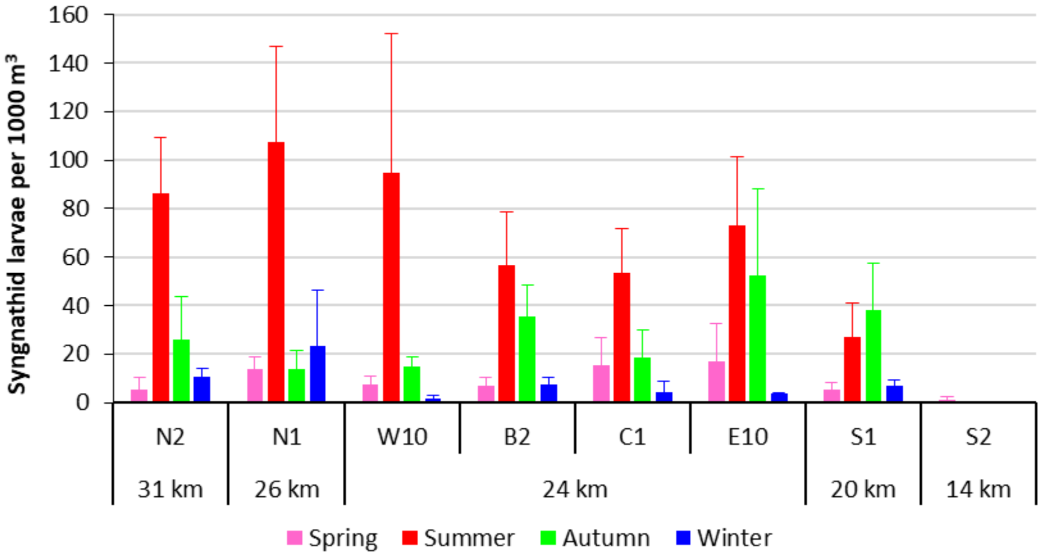


Figure 5-86. Seasonal abundance of pipefish

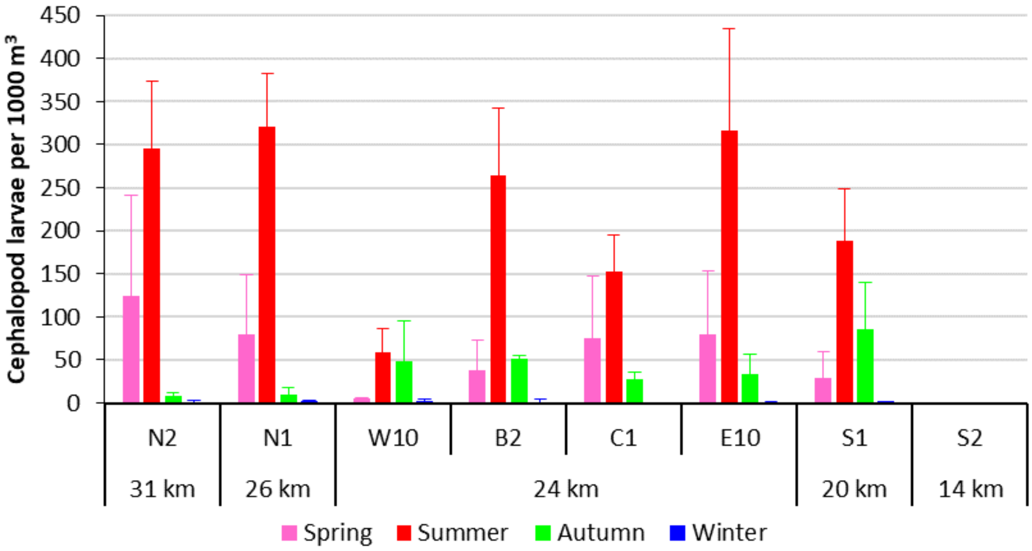


Figure 5-87. Seasonal abundance of squid

The data show that:

- Numbers of total larvae and the dominant gobiidae larvae were relatively even across sites apart from the influence of very large numbers of goby larvae collected from site W10 in December;
- The spatial distribution of cephalopod larvae was relatively even across sites with the exception of lower abundances at W10;
- The spatial distribution of Syngnathid larvae was relatively even with a tendency towards higher abundances at N1 and W10 and lower abundances at S1. Syngnathid larvae on the east-west axis sites were slightly more abundant at W10 and E10 than B2 and C1;
- Tetrarogid larvae, on the other hand, showed strong spatial variability, with most larvae coming from sites C1 and the southern sites;
- Aracanid larvae were relatively evenly distributed amongst sites with the exception of low abundances at N1;
- Monacanthid larvae tended to show higher abundances towards the south, with highest abundance at S1;
- Tripterygiid larvae, like Tetrarogid larvae, showed strong spatial variability, with most larvae collected from the southern sites;
- Spatial variability was also apparent for gobiesocid larvae that were mainly collected from W10 and S2 (in spring;
- Apogonid larvae that were mainly collected at the northern sites;
- Tetraodontid larvae that were mainly collected from sites N2.5, and C1 and E10 in summer; and
- Engraulid larvae were mainly collected on the east-west transect opposite Crib Point as well as at S1.

The abundance of fish larvae in the Lower North Arm was strongly seasonal, with highest abundances in spring and summer and low abundance in autumn and winter. This pattern was largely a reflection of the seasonal pattern of abundance of the two dominant larval fish families, the gobies and the syngnathids, as well as a number of less abundant families. The seasonal abundance of fish eggs showed a different pattern, with highest abundances in late

winter – early spring. This difference between seasonal patterns of abundance for larvae and eggs reflects the life histories of the dominant families.

The gobies lay benthic eggs and larvae hatch and enter the water column, while in the syngnathids the males brood the eggs before larvae are released into the water column. Both these strategies differ from the most common reproductive strategy for marine fish, spawning of pelagic eggs into the water column that hatch into pelagic larvae. The most abundant family that spawns into the water column was the Tetrarogidae, represented by a single species, the cobbler *Gymnapistes marmoratus*. Larvae of this species were most abundant in October and the observed peak in egg abundance in August and September is attributed due to the spawning of this species.

The dominant families represented as larvae in the Lower North Arm showed consistencies but also marked differences to that seen in Port Phillip. Like the current study, the dominant larvae in Port Phillip were the gobies (Jenkins 1986; Neira and Sporcic 2002). This likely reflects the high abundance and species diversity of these small benthic fish, as well as their ubiquitous habitat use (Jenkins 2019). Unlike the current study, the co-dominant or second most abundant larvae in Port Phillip were Australian Anchovy larvae, compared with 10th most abundant family in the lower North Arm. This reflects the fact that significant anchovy spawning occurs in the north of Port Phillip (Jenkins and Hatton 2007), while in contrast eggs and larvae of anchovy mostly occurred in southern Western Port and the adjacent coastal waters of Bass Strait (Hoedt and Dimmlich 1995). Larvae of the cobbler were abundant in both the Lower North Arm and in Port Phillip in late winter – spring (Jenkins 1986; Neira and Sporcic 2002).

The major difference in the fish community represented as larvae in the current study compared with previous studies in Port Phillip (Jenkins 1986; Neira and Sporcic 2002) was the dominance of families of seagrass associated fish represented as larvae in the Lower North Arm, including the Syngnathidae, Tetrarogidae, Monacanthidae, Gobiesocidae, Apogonidae, Tetraodontidae, and Odacidae. In contrast, only the Tetrarogidae, Monacanthidae and Odacidae were ranked highly in larval abundance in Port Phillip (Jenkins 1986; Neira and Sporcic 2002). Larvae of one family of seagrass associated fish, the weedfish (Clinidae) was more common in Port Phillip (Neira and Sporcic 2002) than Lower North Arm.

Previous ichthyoplankton sampling in southern Western Port was conducted at sites north of Phillip Island, in the Rhyll Basin and inside the Eastern Entrance (Acevedo *et al.* 2010; Kent *et al.* 2013). Like the Lower North Arm, gobies were also the most abundant larvae, but there were other marked differences. The second most abundant larvae in southern Western Port were the triplefins (Tripterygiidae) (Acevedo *et al.* 2010; Kent *et al.* 2013) which were common but more lowly ranked in Lower North Arm. Tripterygiid larvae in the current study were most abundant at the southern sites, consistent with a higher abundance of the family in southern Western Port, possibility reflecting the larger amount of reef habitat this group is primarily associated with. Abundances of other families also reflected the proximity of sites to Bass Strait in the earlier study, with a relatively higher abundance anchovy larvae, and a relatively lower abundance of syngnathid larvae (Acevedo *et al.* 2010; Kent *et al.* 2013).

Conclusion to plankton

The data presented above on the plankton community in Lower North Arm and Western Port generally provide an important indication that the seasonal and interannual variations in short lived populations and recruitment of longer-lived species are natural and expected in Western Port and all bay environments. This is due to their reliance on a range of primary natural factors (temperature, rainfall, wind, turbidity and large scale climate patterns that affect

hydrodynamics and seawater characteristics) and the range of ecological interactions that also vary accordingly from year to year (Black et al 2016, Kimmerer and McKinnon 1985, Morrongiello and Jenkins 2016). This information provides an important multiple trophic perspective on the plankton community of Western Port relevant to the discussion of entrainment effects later in this report.

5.9 Western Port for Fish and Fishing

Western Port supports a rich and diverse fish fauna due to its many and varied habitats (Jenkins et al. 2015). Many of these habitats occur in the Lower North Arm (Figure 5-24). Fish in Western Port include species of ecological, conservation and fishing importance. This section examines those species that are of ecological and fishing importance.

The characteristics of fish communities in Western Port was reviewed and described by Prof Greg Jenkins from the University of Melbourne (Melbourne Water 2011). Prof. Jenkins provided greater detail related to Lower North Arm fish communities in a review for CEE in 2018. The following descriptions are taken from his report (Jenkins 2018). Fish of conservation importance are discussed in Section 5.11.2.

5.9.1 Fish Communities in Lower North Arm

Fish Species in Pelagic Habitat

The fish community in the pelagic environment of Western Port includes the small clupeoid fish, such as Australian Anchovy and Australian Sardine, that are key elements of the food chain to larger fish and birds. Hoedt et al. (1995) surveyed clupeoid fish by examining stomach contents of Australian Salmon caught in the Lower North Arm and the Western Entrance segment. Australian Anchovy and Australian Sardine were the dominant species in most samples and Sandy Sprat were occasionally common. Adult clupeoids were found to be temporary inhabitants in Western Port, migrating into the bay between October and December and leaving between February and June (Hoedt et al. 1995). Juvenile Australian Anchovy and Australian Sardine were common in samples between February and April, indicating that Western Port serves as a nursery area for both species (Hoedt et al. 1995).

Eggs and larvae of Australian Anchovy and Australian Sardine were sampled in the Lower North Arm as part of a broader sampling program (Hoedt and Dimmlich 1995). Anchovy eggs and larvae were common in the Lower North Arm from December to March while Sardine eggs and larvae were rare (Hoedt and Dimmlich 1995). Anchovy eggs and larvae were distributed both inside Western Port and offshore, while Sardine eggs and larvae mainly occurred offshore or near the western entrance (Hoedt and Dimmlich 1995). Recent ichthyoplankton sampling in the Lower North Arm from December 2018 to December 2019 has recorded the presence of Sardine larvae from December to February, and Anchovy larvae in February and May (S. Chidgey, unpublished data).

Fish from various habitats inhabit the pelagic environment in the larval stage. Ichthyoplankton sampling in the eastern entrance and Rhyll Segment of Western Port found that larval abundances were strongly seasonal, with a peak around December and a minimum around June (Kent et al. 2013). The species composition was dominated by larvae of small, benthic species, such as the gobies (*Gobiidae*) and the triplefins (*Tripterygiidae*) (Kent et al. 2013). Seasonal occurrence of larvae included Australian Anchovy in summer, goby larvae in spring and summer, triplefin larvae in spring – early summer, clingfish and shore eel (*Gobiesocidae*) larvae and Tasmanian Blenny *Parablennius tasmanianus* larvae in spring (Acevedo et al. 2010).

Recent ichthyoplankton sampling in the Lower North Arm from December 2018 to December 2019 has found a similar seasonal pattern of larval fish abundance (S. Chidgey, unpublished data). Peak abundance occurred at the start of sampling in December, and this declined to a low level by March (refer to Annexure G). This pattern largely reflected the pattern for goby larvae that were the dominant group, but other abundant groups such as the pipefish (*Syngnathidae*), leatherjackets (*Monacanthidae*), boxfish (*Aracanidae*) and toadfish *(Tetraodontidae*) also showed this pattern (S. Chidgey, unpublished data). Juveniles and adults of these latter groups are primarily associated with seagrass (see next section).

Fish Species in Seagrass Habitat

A detailed study of fish in seagrass habitat was carried out at Crib Point in the mid-1970s as part of the Western Port Bay Environmental Study (Robertson 1978). The sampling was conducted on an intertidal mudflat where meadows of seagrass *Zostera nigricaulis* were covered with pooled water at low tide but beds of *Z. muelleri* and unvegetated areas were exposed (Robertson 1978). Samples were collected with either a large or small beach seine net (Robertson 1978).

The dominant fish species were either residents — including the Southern Longfin Goby, *Favonigobius lateralis*, Bridled Goby, *Arenigobius bifrenatus*, Common Weedfish, *Heteroclinus perspicillatus*, Cobbler *Gymnapistes marmoratus* and juvenile Greenback Flounder *Rhombosolea tapirina* — or tidal transients — including Silver Fish, *Leptatherina presbyteroides*, Smallmouth Hardyhead, *Atherinosoma microstoma*, Pikehead Hardyhead, *Kestratherina esox*, and Smooth Toadfish, *Tetractenos glaber* (Robertson 1978, 1980).

King George Whiting and Yellow-eye Mullet were resident as young juveniles but tidal transient as older (> 6 months) juveniles (Robertson 1980). Juvenile Western and Eastern Australian Salmon were also tidal transients (Robertson 1978). Permanent residents and Smooth Toadfish were more active at night, while hardyheads, Yelloweye Mullet and King George Whiting were more active during the day (Robertson 1980).

Deeper (~4 m) sub-tidal seagrass, *Zostera nigricaulis*, were sampled between Hastings and Yaringa in autumn with a mini otter-trawl (Jenkins et al. 2015). The dominant fish species in terms of abundance was the Spotted Pipefish, *Stigmatopora argus*, while the Grass Whiting, *Haletta semifasciata*, Little Weed Whiting, *Neoodax balteatus*, and the leatherjacket, *Acanthaluteres sp*., were also important (Jenkins et al. 2015). Species of potential fishing importance included the Rock Flathead and the Sixspine Leatherjacket, *Meuschenia freycineti*. Differences in the dominant species reported in the studies of Robertson (1978, 1980) and Jenkins et al. (2015) largely reflects the difference in depth sampled, as depth has been shown to strongly-affect fish species composition in central Victorian seagrass habitats (Jenkins et al. 1997b; Hutchinson et al. 2014).

Subtidal Seagrass beds were sampled with a fine-mesh seine net at three sites in the Lower North, three in the Upper North Arm, and one in the Rhyll Segment in winter (Hindell et al. 2004). The beds of *Zostera nigricaulis* were near the edge of channels in the shallow subtidal zone (Hindell et al. 2004). Most fish were small (< 10 cm) sedentary species such as gobies and pipefish (Hindell et al. 2004). The Widebody Pipefish, *Stigmatopora nigra*, was the most abundant species, while other common species included the Spotted Pipefish, *Stigmatopora argus* and the Halfbridled Goby, *Arenigobius frenatus*. Five species of potential fishing importance were collected — King George Whiting, Sixspine Leatherjacket, Australian Anchovy, Grass Whiting and Southern Calamari — and many of these fish were juveniles (Hindell et al. 2004).

Subtidal seagrass, unvegetated and channel habitat was sampled with seine and gill nets at sites in the Upper North Arm and the Rhyll Segment (Edgar and Shaw 1995a). The pattern of fish abundance, and to a lesser extent fish production, was strongly seasonal, with highest levels in summer and a consistent decline through autumn and winter (Edgar and Shaw 1995a). This variation was more pronounced in seagrass than in unvegetated habitats (Edgar and Shaw 1995a) and was consistent with higher seagrass biomass, and higher invertebrate production over summer (Edgar et al. 1994).

Fish Species in Mangrove Habitat

Hindell and Jenkins (2005) sampled the mangrove forest and along the seaward edge of the forest at Jacks Beach, between Crib Point and Hastings, between October and January. They found that the mangrove forest was dominated by gobiids and juvenile atherinnids, but the edge and mudflat were characterised by juvenile King George Whiting, Smooth Toadfish, and different goby species (Hindell and Jenkins 2005). Fish abundance was highest in the mangroves, whereas species richness was highest at the mangrove edge (Hindell and Jenkins 2005). The Pale Mangrove Goby was recorded in the mangroves and may be a resident species.

Fish in mangrove habitats were sampled in the Lower North Arm with fyke nets from November to May (Raadik and Hindell 2008). Common species included Smooth Toadfish, Yelloweye Mullet, Eastern Bluespot Goby, *Pseudogobius sp*., Glass Goby, *Gobiopterus semivestitus*, Halfbridled goby, Smallmouth Hardyhead, and Oyster Blenny, *Omobranchus anolius* (Raadik and Hindell 2008). As mentioned above, the Lower North Arm was also the area where most Pale Mangrove Goby were collected within Western Port in this survey (Raadik and Hindell 2008).

A survey of fish in mangroves was undertaken using pop nets at three sites each in the Lower North Arm, Upper North Arm and Rhyll Segment between May and September (Hindell et al. 2004). Samples were taken from within the forest and at the edge of the forest in the pneumatophore zone at each site (Hindell et al. 2004). As found previously, gobies were the most common fish in mangroves, with six species represented (Hindell et al. 2004). Smooth Toadfish, Prickly Toadfish, *Contusus brevicaudus*, and Pikehead Hardyhead, *Kestratherina esox*, were also collected, and Sandy Sprat was very abundant at one site (Hindell et al. 2004). Patterns of zonation were not as clear as in previous studies, possibly because previous studies used inconsistent sampling methods between zones, or the fact that sampling was undertaken in winter rather than summer (Hindell et al. 2004).

A broad-scale study of fish assemblages was conducted seasonally in both mangrove and intertidal mudflat habitat at sites located in the Lower North Arm, Upper North Arm and the Rhyll Segment, as well as Corner Inlet (Hindell and Jenkins 2004). Samples were collected with a beach seine, fyke nets, and gill nets. The number of species collected was slightly higher in unvegetated mudflat habitat (39 versus 37), but 70% of the individual fish were collected in mangrove habitat (Hindell and Jenkins 2004). Most species were found in both habitats, and five species were found only in mangrove and six species only on mudflats (Hindell and Jenkins 2004). Unlike tropical mangrove systems, very few species were resident within mangroves (Hindell and Jenkins 2004).

Mangroves were characterised by greater numbers of small and juvenile fish compared to unvegetated mudflats, but there was little difference in the abundances of older juvenile and adult fish (Hindell and Jenkins 2004), a similar pattern to that found in seagrass (Edgar and Shaw 1995a). As in seagrass (based on seine net sampling), fish abundance and species

richness in mangroves in Western Port tended to be lowest in winter (Hindell and Jenkins 2004).

Fish Species in Unvegetated Sediment Habitat

The fish assemblage on unvegetated mud flats at Jacks Beach, between Crib Point and Hastings was sampled with pop and seine nets between October and January (Hindell and Jenkins 2005). Fish species collected included three species of goby, Smooth Toadfish, and juveniles of two species of importance to fishing, King George Whiting and Greenback Flounder.

Sampling of subtidal channels and embayment plains with a mini otter-trawl was undertaken as part of a PhD thesis on the biology of Red Cod, *Pseudophycis bachus* (Kemp 2010). Species that occurred frequently in samples from the Lower North Arm included ornate cowfish, *Aracana ornate*, Spiky Globefish *Diodon nicthemerus*, red mullet, *Upeneichthys vlamingii*, and species of flathead, flounder and stingray.

In their study of mangroves and unvegetated mudflats in Western Port and Corner Inlet, Hindell and Jenkins (2004) found that Yelloweye Mullet, Smooth Toadfish, Silver Fish, and Southern Longfin Goby were common species on intertidal mudflat habitat. Apart from Yelloweye Mullet, juveniles of other species important to fishing included Greenback Flounder, Longsnout Flounder, *Ammotretis rostratus*, and King George Whiting (Hindell and Jenkins 2004).

In addition to seagrass, Edgar and Shaw (1995a) sampled unvegetated intertidal mudflat and subtidal channel habitat in the Upper North Arm and the Rhyll Segment. Species characteristic of unvegetated intertidal mudflats were the Eastern Bluespot Goby, the Tamar Goby *Afurcagobius tamarensis*, Greenback Flounder and Longsnout Flounder (Edgar and Shaw 1995a). Juvenile Rock Flathead were also found on unvegetated mudflat areas (Edgar and Shaw 1995a). Sand Flathead were common in both unvegetated mudflat and channel habitat, while species of stingaree *Urolophus spp*. were most common in channel habitat (Edgar and Shaw 1995a). Elephant Fish were caught in both mudflat and channel habitat, but were most abundant at a silty-substrate site within the Rhyll Segment (Edgar and Shaw 1995a).

Fish Species in Reef Habitat

The North Arm has patches of biogenic reef habitat formed by sedentary, filter feeding invertebrates such as bryozoans, sponges and ascidians in deep channels with strong tidal currents (Blake et al. 2012, P. Hamer, Pers. Comm.). Sampling for fish species associated with these habitats is difficult using typical methods such as nets (due to snagging) and underwater video (due to poor visibility) (Jenkins et al. 2013). These habitats are likely to be important for species that prefer deeper-water reef habitat such as Snapper and Gummy Shark (Jenkins and Conron 2015). Seabed video surveys for the EES (Section 5.7.3) indicate that biogenic reef habitat is absent from the areas surveyed in the Crib Point shipping basin and jetty region generally.

Feeding and Diet

For fish sampled on the intertidal and shallow subtidal seagrass flats at Crib Point, nine of the eleven dominant species were carnivores that fed predominantly on benthic crustaceans (Robertson 1984). For King George Whiting, Greenback Flounder, Longfin Goby and the Smallmouth Hardyhead, polychaetes also made a significant contribution to their diets (Robertson 1984). There was a marked ontogenetic dietary change for Yelloweye Mullet, from mainly insects, copepods and other crustaceans in the first year to an herbivorous diet when

older (Robertson 1984). The bridled goby also consumed mainly algae and some detritus (Robertson 1984).

Predation by fish appeared to be a major factor in determining the distribution and abundance of benthic invertebrates on the intertidal mudflats at Crib Point where seagrass standing crops were low, but were less important in dense stands of seagrass (Robertson 1984). The Smooth Toadfish was the dominant predator mudflats, accounting for 77% of the benthic invertebrates consumed by fish (Robertson 1984). Fish species on the seagrass flats at Crib Point had little dietary overlap (Robertson 1980). An exception was Smooth Toadfish and juvenile King George Whiting, which both fed predominantly on Ghost Shrimps, *Callianassa australiensis* over summer and early autumn (Robertson 1980).

The diet of most fish species from intertidal and shallow subtidal seagrass and unvegetated habitat in the Upper North Arm and Rhyll Segment was also dominated by benthic crustaceans (Edgar and Shaw 1995b). The next largest group, including pipefish, hardyheads and clupeoids, ate mainly planktonic crustaceans (Edgar and Shaw 1995b). Another significant group of species, including Yelloweye Mullet, leatherjackets and gobies, ate algae, sessile animals and seagrass (Edgar and Shaw 1995b). Fish predators were primarily pelagic fish (e.g. Australian salmon and Tailor, *Pomatomus saltator*) feeding on small schooling fish, and Rock and Sand Flathead feeding on small demersal fish (Edgar and Shaw 1995b). A few species ate mostly molluscs or polychaetes (Edgar and Shaw 1995b). Among the elasmobranchs, Elephant Fish ate mainly benthic molluscs, and Gummy Shark ate fish and cephalopods.

Declining condition and increasing mortality rates of fishes in autumn, with a concurrent decline in crustacean production, indicated a strong linkage between crustacean production and small fish production (Edgar and Shaw 1995a; 1995b).

In addition to direct dietary analysis, significant information on trophic relationships, integrated over a longer time period, can be obtained by studying stable isotopes. This is particularly valuable for determining the ultimate plant source in the food chain, and also the trophic level of fish. Longmore et al. (2002) analysed a range of fish species (mainly of fishery importance) from Western Port for stable isotopes of carbon and nitrogen. Samples of fish were taken by a variety of methods, and sampling sites were most concentrated in the Lower North Arm (Longmore et al. 2002).

On the basis of average stable isotope values for each species, the fish were classified into three groups:

- pelagic piscivores (e.g. Australian Salmon) with mixed algae as the most important ultimate source of primary production,
- pelagic/benthic feeders (e.g. Southern Sea Garfish, Yelloweye Mullet and Sand Flathead) dependent on *Amphibolis* and *Zostera* seagrass epiphytes, zooplankton and green algal detrital webs,
- primarily benthic feeders (flounders, Grass Whiting, King George Whiting and Rock Flathead) ultimately dependent on *Zostera* and *Amphibolis* seagrasses.

Changes in $\delta^{13}C$ with length for Southern Sea Garfish and Sand Flathead were consistent with an increasing dependence by older fish on seagrass/benthic microalgae, while changes in $\delta^{15}N$ with length for King George Whiting were consistent with a change in trophic level within the same food web (Longmore et al. 2002). Seagrass and/or seagrass epiphytes made significant contributions to the food supply for seven of the eight fishery species studied

(Longmore et al. 2002). Conversely, mangrove and saltmarsh made a very minor contribution to fish trophic webs in the bay (Longmore et al. 2002).

Hindell et al. (2004) used stable isotopes of C and N to investigate the plant basis of the diets of 20 species of fishery importance from two locations in each of Western Port (Hastings and Rhyll) and Corner Inlet. Sampling was conducted in winter and summer (Hindell et al. 2004). Seagrass, macroalgae, seagrass epiphytes, phytoplankton and benthic microalgae made a similar moderate contribution to fish diets, but mangrove–saltmarsh made a very small contribution (Hindell et al. 2004). The Rock Flathead was the only species for which seagrass had the greatest contribution to the diet (Hindell et al. 2004). Further analysis of King George Whiting, however, showed that the diet of this species was clearly supported by seagrass (Hindell et al. 2004). Western Australian Salmon had the highest trophic position, while Southern Sea Garfish had a low trophic position (Hindell et al. 2004).

5.9.2 Fisheries and Aquaculture

Commercial Fishing

There has been commercial fishing in Western Port since the early 1900's (or earlier) (Conron et al. 2016). In December 1997, commercial netting methods were no longer allowed in Western Port, so that since then there has only been a very low level of commercial fishing (Conron et al. 2016).

The commercial fishery catch had been gradually declining in Western Port until the netting buy-out in 2007 (Figure 5-88) after which the catch was reduced by 99%. From 2000 - 2007 the annual commercial catch was between 25 – 73 tonnes (the latter in 2006/07) (Figure 5-88), but from 2008 onwards the catch dropped significantly, and has been under one tonne from 2010 onwards (Figure 5-88). Before the buyout, 8 key species made up 80% by weight and 96% by value of the catch.

Unlike Port Phillip, garfish and mullet were important fishery species, reflecting the different (seagrass dominated) environment in Western Port. Today, the main fishing methods are long lines and hand line and the main target species is Gummy Shark with minor catches of Snapper, Elephant Fish, Pipi, Southern Calamari and King George Whiting.

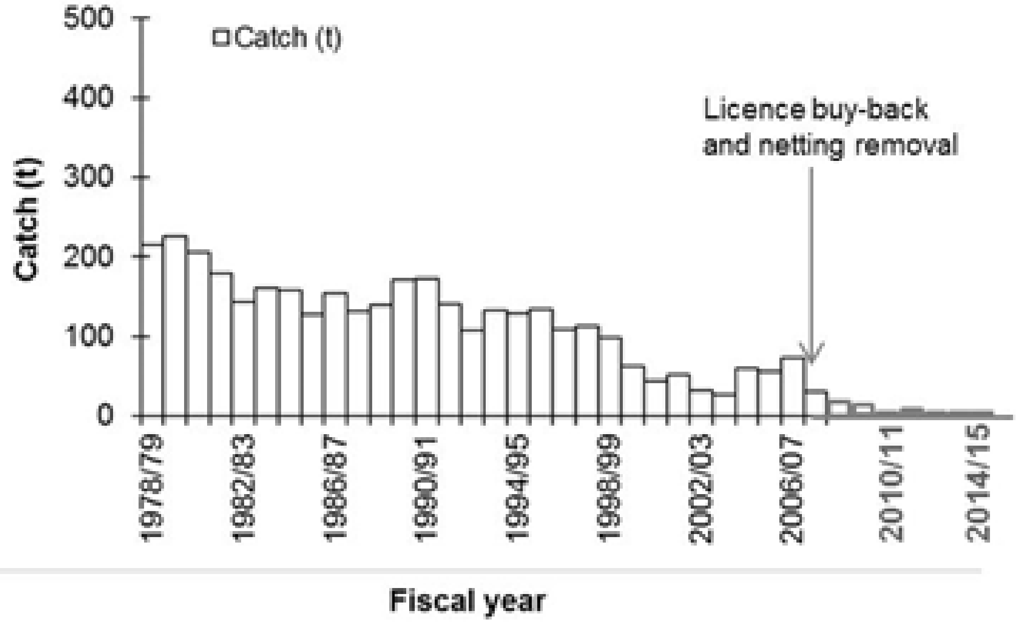


Figure 5-88. Total commercial catch in tonnes by fiscal year from 1978/79 to 2014/15

Recreational Fishing

The recreational fishery in Western Port is very important and represents the second-largest recreational fishery in Victoria (Conron et al. 2016). Recreational fishing pressure in Port Phillip and Western Port has replaced or exceeded that from commercial fishing as Melbourne's population and standard of living has increased. Part of the reasoning for the commercial netting buyout was to create a "recreational fishing haven" in Western Port. The recreational fishery is primarily managed by size and bag limits (Conron et al. 2016). The current Victorian government policy 'Target 1-Million' aims to increase the number people participating recreational fishing. The recent 'State-wide Recreational Catch Survey' (ASR, 2018) commissioned by the Victorian Fisheries Authority was reviewed for information on recreational fishing pressure, but the survey did not collect any data on the recreational catch.

Based on boat ramp survey results from 1998-2015 (Conron et al. 2016), most fishers in Western Port fished more than 5 days per year, primarily by line fishing from boats, although there is also a small amount of shore-based angling and some spearfishing. The majority (70%) of the catch is taken in summer and autumn. The main recreational target species are: King George Whiting, Elephant Fish, Snapper, Flathead, Southern Calamari, Garfish, Australian Salmon, and Gummy Shark.

Higher usage of boat-ramps on the western side of Western Port indicates that North Arm likely experiences higher fishing pressure than the rest of Western Port (Figure 5-89) Recreational fishing effort based on boat trailer counts at ramps tends to vary with the catch rates of fish (that is, seasonal availability of fish to catch), but has been relatively stable over the long term (Conron et al. 2016).

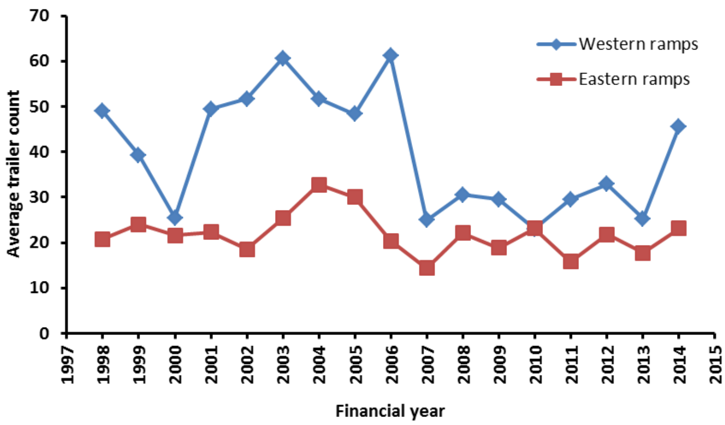


Figure 5-89. Time series of standardised trailer counts western and eastern boat ramps in Western Port

Source: Conron et al, 2016

The recreational fishery largely targets the same species that used to be targeted by commercial fishing: King George Whiting, Flathead, Snapper, Gummy Shark and Elephant Shark.

Aquaculture

There are currently no aquaculture fisheries reserves in the Lower North Arm. A large aquaculture fisheries reserve was established off Flinders (DPI 2005) after initial environmental baseline surveys (McKinnon et al. 2004). The reserve has been used for low-level growing-out of Blue Mussels, *Mytilus galloprovincialis*, primarily seeded with spat from the Beaumaris aquaculture reserve or more recently from spat cultured at Queenscliff by the Victorian Shellfish Hatchery Pty Ltd. (Jenkins 2019).

As discussed in Section 5.7.1, native flat oysters *Ostrea angasi* once formed extensive intertidal and subtidal beds in Western Port that formed the basis of a fishery from the mid-1980s to early 1900s. Oyster leases were established for a short time at Hastings Bay in the 1800s. (Bennett 2004, Ford and Hamer 2016). Natural beds of the oysters are no longer present in the bay and living individuals are sparse.

Blue Mussel culture is likely to continue at a low level only until reserves in Port Phillip are fully utilised, because of high maintenance costs (Jenkins 2019). There is also small-scale culture of culture of Angasi oysters, *Ostrea angasi*, at the reserve. Abalone culture at the reserve is possible in the future with trials planned by a number of licence holders (Jenkins 2019).

Pacific oysters, *Crassostrea gigas*, an introduced species, are now well established in Western Port, which has created significant interest in their culture, though approvals are yet to be granted (Jenkins 2019).

A small hatchery that cultures blue mussels, abalone and Angasi oysters is located on Phillip Island to the north of the San Remo bridge (Jenkins 2019).

5.9.3 Species of Fisheries Importance

King George Whiting

The King George Whiting, *Sillaginodes punctatus*, population in Western Port are juveniles up to approximately 4 years of age (Hamer et al. 2004; Conron et al. 2016). Older fish move out of Western Port onto the open coast 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, post-larvae of approximately 20 mm length enter bays and inlets of central Victoria, including Western Port (Jenkins and May 1994; Jenkins et al. 2000) (Figure 4). Consistent with this, Whiting post-larvae have been collected in ichthyoplankton samples in south-east Western Port in September (Kent et al. 2013).

The swimming ability of post-larval Whiting is relatively weak (Jenkins and Welsford 2002; Hindell et al. 2003), and dispersal within the bays is largely the result of passive dispersal by currents (Jenkins and Black 1994; Jenkins et al. 1999). Active behaviour is apparent, however, on a diurnal cycle where post-larvae are concentrated near the surface during the day but are distributed throughout the water column at night (Jenkins et al. 1998). In Port Phillip, there was a tendency for post-larvae to be distributed slightly closer to shore than predicted by purely passive dispersal (Jenkins et al. 1999).

Whiting larvae settle in shallow seagrass beds throughout Western Port, including the Crib Point area, from September to November (Robertson 1977; Jenkins et al. 2000; 2016). The initial settlement habitat of post-larval Whiting is typically shallow, sub-tidal seagrass (Robertson 1977; Jenkins and Hamer 2001), although settlement may occur in unvegetated areas adjacent to seagrass where the seagrass is relatively long and dense (Jenkins and Hamer 2001).

A few months after settlement, small juvenile Whiting tend to move from seagrass to nearby unvegetated habitat. The main factor influencing habitat selection appears to be prey availability (Jenkins and Hamer 2001). At Crib Point, Robertson (1977) found that newly-settled Whiting post-larvae were mainly associated with shallow, sub-tidal seagrass and fed on *harpacticoid copepods*, *gammarid amphipods* and *mysids*, however, by January, the small juvenile Whiting had moved onto unvegetated habitat within the seagrass flat and the diet was comprised mainly of juvenile ghost shrimp.

As juvenile Whiting grow, their primary habitat is on unvegetated sand at the edge of seagrass beds (Jenkins et al. 2012; Jenkins and Conron 2015). Analysis of the spatial distribution of Whiting catch rates based on boat-ramp angler interviews indicated that the distribution was correlated with seagrass distribution within Western Port (Jenkins and Conron 2015)Catch rates (indicating abundance) were relatively high in Lower North Arm, reflecting the relatively high cover of seagrass in the area (Jenkins and Conron 2015).

Snapper

Snapper, *Chrysophrys auratus*, in Western Port range from small juveniles to large, mature adults. Abundances of small juvenile (<6 months old) Snapper in Western Port were much lower than in Port Phillip, Corner Inlet or Gippsland Lakes (Hamer and Jenkins 2004). 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 (Hamer et al. 2005; 2011). Otolith microchemistry studies showed that while most 1-year old Snapper in Western Port had not originated from Port Phillip, at age 3 and 4 years old the population in Western Port was dominated by fish that had been spawned in Port Phillip (Hamer et al. 2005; 2011). The authors of these studies speculated that small (1-year old) juveniles may have been spawned within Western Port or in coastal waters offshore from Western Port (Hamer et al. 2005; 2011).

No Sparid (Snapper) larvae were identified in Western Port in the over 100 samples collected in 2019. Previous ichthyoplankton sampling in the south-east of Western Port and on the coast near Wonthaggi recorded sparid (most likely snapper) larvae near the coast but not within Western Port, suggesting that recruitment of small juveniles in Western Port comes from coastal spawning (Kent et al. 2013).

The distribution of adult Snapper in Western Port based on catch rates estimated from boat-ramp survey data was correlated with the deeper areas of Western Port (Jenkins and Conron 2015). Above minimum legal length (27 cm) Snapper were relatively abundant in the Lower North Arm offshore from Crib Point (Jenkins and Conron 2015). Catch rates of undersize Snapper tended to be higher in the Rhyll Segment (Jenkins and Conron 2015). The primary habitat of Snapper in Western Port based on angler surveys was reefs (Jenkins and Conron 2015).

Flathead

There are three main flathead species in Western Port: Sand Flathead, *Platycephalus bassensis*; Yank Flathead, *Platycephalus speculator*; and, Rock Flathead, *Platycephalus laevigatus*. Flathead are ambush predators that sit motionless on the bottom until making a rapid swimming movement to catch prey (Hirst et al. 2014). Sand and Yank Flathead in Western Port are found in unvegetated silt-sand habitats (Edgar and Shaw 1995a; Conron et al. 2016), while Rock Flathead are found on sandy habitat as small juveniles but move into seagrass habitat as adults (Edgar and Shaw 1995a). In the Lower North Arm, flathead (Sand Flathead where identified) were commonly collected on subtidal sand/mud habitat while Rock Flathead were collected on one occasion from subtidal algal habitat with a mini otter trawl (Kemp 2010). Rock Flathead have been collected from the seagrass flats at Crib Point (Robertson 1978) and from subtidal seagrass in the Lower North Arm, north of Hastings (Jenkins et al. 2015).

Flathead are not separated into species in boat ramp surveys, however, where they were identified, most were Sand Flathead (Jenkins and Conron 2015). The lower half of the Lower North Arm had the highest angler catch rates (an indicator of abundance) of flathead in Western Port (Jenkins and Conron 2015). Flathead were most commonly caught on sand habitat in a wide range of depths from 1 to 30 metres (Jenkins and Conron 2015).

Spawning of flathead based on reproductive condition is protracted but mostly occurs from spring to early autumn (Koopman et al. 2004; Hirst et al. 2014). Ichthyoplankton sampling in the south-east of Western Port recorded the presence of flathead larvae from October to March (Kent et al. 2013). Ichthyoplankton sampling conducted for this EES in the Lower North Arm has recorded the presence of flathead larvae in December, January and May. Flathead larvae have been recorded in Port Phillip in most months, but peak abundances also tend to be from spring to early autumn (Jenkins 1986; Neira and Sporcic 2002).

The catch rate of flathead based on boat ramp surveys in Western Port shows high variability at a scale of a few years but the longer-term trend is fairly stable (Conron et al. 2016). Short-term variability is likely to be related to recruitment of young fish, that in Port Phillip is in turn related to river flows and input of nutrients for primary production (Hirst et al. 2014).

Elephant Fish

The majority of Elephant Fish, *Callorhinchus milii,* caught in Western Port are adults (8 to 20 years of age) that enter the bay in the autumn to breed (Braccini et al. 2008). Based on observations of deposited eggs, Braccini et al. (2008) suggested that breeding occurs in

subtidal, unvegetated silt/mud areas that are characteristic of the Rhyll Segment. About 20 eggs are deposited per female per season (Conron et al. 2016). Egg cases are deposited in fine sediments in protected areas near seagrass beds (Conron et al. 2016). Eggs take up to 8 months to hatch and young (neonates) may spend about 1 year in Western Port before moving offshore (Conron et al. 2016).

Boat ramp survey data from 1998 to 2013 showed that up to about 2008, catch rates were highest in the Rhyll Segment but moderate catch rates were also recorded in the Lower North Arm (Jenkins and Conron 2015). Annual average catch rates of Elephant Fish in Western Port showed a decline from 2007 (Conron et al. 2016) after years of recreational fishing pressure. From 2008 to 2013, catch rates were further reduced and catches were only recorded in the Rhyll Segment, with no catch recorded from the Lower North Arm (Jenkins and Conron 2015). Although this result is affected by a reduction in the bag limit from 2 to 1 in 2008, and also reduced targeting (due to lower likelihood of catching them), a fishery assessment workshop concluded that there had been a real decline in abundance of Elephant Fish in Western Port (Conron et al. 2016). Elephant Fish were also in low abundance in Western Port prior to the 1980s, and this long-term variation may relate partly to environmental variables such as seagrass cover (Conron et al. 2016).

Gummy Shark

Gummy Shark, *Mustelus antarcticus*, in Western Port form a small part of the southern stock in Bass Strait (Marton et al. 2014). Boat ramp surveys show that Gummy Shark are present throughout Western Port with highest catch rates in the Western Entrance Segment and Upper North Arm (Jenkins and Conron 2015). Moderate catch rates were also recorded in the Lower North Arm (Jenkins and Conron 2015). Released Gummy Shark, that would have included undersize juveniles, were more concentrated in the Rhyll Segment (Jenkins and Conron 2015). This is consistent with research sampling that has shown that juvenile Gummy Sharks were common in the Rhyll Segment, indicating that this is an important pupping area (Stevens and West 1997).

Boat ramp survey data indicates that Gummy Shark were mostly caught on reef and/or sand habitat in intermediate depths (Jenkins and Conron 2015). Previous sampling of Gummy Shark south of French Island indicated that they were evenly distributed across seagrass, unvegetated and channel habitats (Edgar and Shaw 1995a). Annual catch rate data indicates that abundances of Gummy Shark in Western Port are relatively stable in the longer term (Conron et al. 2016), and are likely to be most influenced by changes to the broader stock in Bass Strait.

Australian Salmon

Australian Salmon are a pelagic, schooling fish known to undergo extensive migration (Kailola et al. 1993). There are two species of Australian Salmon found in Western Port (Robertson 1982), the Eastern Australian Salmon, *Arripis trutta*, that spawns off the coast off eastern Victoria to southern NSW, and the Western Australian Salmon, *A. truttaceus*, that spawns in the south of Western Australia (Kailola et al. 1993).

Juvenile Western Australian Salmon approximately 6 cm in length were collected on the tidal flats at Crib Point in late winter – spring (Robertson 1982). These fish were thought to have been spawned three to six months earlier in Western Australia (Robertson 1982). Juvenile Salmon grew over the summer period to approximately 14 cm by autumn, when they left the area (Robertson 1982). This species fed on a range of prey, including fish (e.g. gobies,

weedfish, hardyheads), and crustaceans (e.g. amphipods, mysids, shrimp and Ghost Prawns) (Robertson 1982).

Juvenile Eastern Australian Salmon were first collected at Crib Point in December at a size of approximately 7 cm (Robertson 1982). These fish attained a length of approximately 12 cm by the time they left the tidal flat in the following winter. The diet differed from that of the western species in that insects and zooplankton were included in the diet in addition to fish and crustaceans (Robertson 1982).

Feeding schools of subadult Western Australian Salmon, ranging from 19 to 34 cm in length, were observed on the water surface in the Lower North Arm in May, June, October and November (Hoedt and Dimmlich 1994). The diet of subadult Western Australian Salmon was studied from fish sampled by angling in the Lower North Arm and Western Entrance Segment (Hoedt and Dimmlich 1994). Salmon ranging from 19 to 34 cm in length were found to feed on pelagic clupeoid fish (Hoedt and Dimmlich 1994). Adult Australian Anchovy, *Engraulis australis*, were the dominant prey in spring – summer, but in late summer – autumn the diet was mainly juvenile clupeoids (mainly Australian Anchovy and Australian Sardine, *Sardinops sagax*) and in late autumn – early winter there was a significant contribution of Sandy Sprat, *Hyperlophus vittatus*, to the diet (Hoedt and Dimmlich 1994).

The boat ramp survey data did not distinguish between the two Australian Salmon species. Highest catch rates were recorded in the Rhyll Segment, while moderate catch rates were recorded in the Lower North Arm (Jenkins and Conron 2015).

Southern Sea Garfish

Southern Sea Garfish, *Hyporhamphus melanochir*, are a pelagic schooling species that generally inhabit shallow, sheltered areas with seagrass habitat (Kailola et al. 1993; Fowler et al. 2008). Southern Sea Garfish spawn from October to March with a peak in November - December (Kailola et al. 1993). Garfish have eggs with adhesive hairs that they attach to vegetation, particularly seagrass (Kailola et al. 1993). Ichthyoplankton sampling in the south-east of Western Port recorded Garfish larvae most commonly from November to March (Acevedo et al. 2010). Ichthyoplankton sampling in the Lower North Arm from December 2018 to July 2019 conducted to inform this EES has recorded the presence of Southern Sea Garfish larvae in February. Ichthyoplankton sampling in Port Phillip recorded larvae of Southern Sea Garfish from December to April (Jenkins 1986; Neira and Sporcic 2002).

The boat ramp survey indicated that garfish were caught throughout Western Port, with highest catch rates in the Rhyll Segment and the north-west of the bay from Hastings to Tooradin (Jenkins and Conron 2015). Garfish were caught in shallow water, generally at depths of 5 metres or less (Jenkins and Conron 2015), which is consistent with an association with seagrass.

Even though Garfish inhabit the water column, they have been shown to feed on seagrass (likely to have been drifting fragments) during the day-time and on invertebrates that emerge from the seagrass at night (Robertson and Klumpp 1983; Edgar and Shaw 1995b).

Southern Calamari

Southern Calamari, *Sepioteuthis australis*, are commonly found in bays and inlets of southern Australia, particularly in association with seagrass and algal habitats (Green 2015). Calamari grow rapidly; up to 5 % of their body weight per day, and complete their entire life-cycle in less than one year (Green 2015). Southern Calamari are capable of spawning year-round, but spawning mainly occurs during spring and summer (Green 2015). Females lay clusters of eggs on seagrass and algae, and in particular the seagrass, *Amphibolis australis* (Green 2015). Recent ichthyoplankton sampling in the Lower North Arm from December 2018 to July 2019 has not recorded the presence of Southern Calamari larvae (S. Chidgey, unpublished data).

The annual catch rate of Calamari in Western Port based on the boat ramp survey has varied considerably over time but over the long term is relatively stable (Jenkins and Conron 2015)

5.10 Seals and Penguins

5.10.1 Seals

Seal Rocks is a colony of Australian fur seals (*Arctocephalus pusillus doriferus)* that has been growing in numbers since the 1980's. Seal Rocks are a series of rocky islands southwest from Point Grant on Phillip Island (western entrance of Western Port). There were an estimated 30,000 total seals in the colony in 2010 with around 5,660 live pups from a total of 6,700 pups born (Kirkwood, Shaughnessy, Hoskins, & Arnould, 2010). Satellite tracking of 60 seals over 10 years showed that the seals rarely enter Western Port, remaining around the rocky shore lines at the edge of the western entrance.

Small numbers of seals enter Western Port and are seen around the jetties and wharves in Lower North Arm (CEE observations). Dann *et al* (1996) found an average of just over two seals per month along a total of 81 transects that were monitored in Western Port between 1991 and 1994. The seals that were found within Western Port were typically individuals and were young juvenile males or small females (Dann et al, 1996). While the population size at Seal Rocks has been growing since the 1980s, there has not been an increase in the number entering Western Port.

Figure 5-90. Individual Australian fur seal at Crib Point Jetty

Several other species of seals have been recorded in Western Port. These species do not have colonies in Western Port and do not specifically use Western Port for breeding or feeding. It is likely that they entered Western Port accidently. Other species include:

- New Zealand Fur Seal – 1 record (Menkhorst, 1995);
- Subantarctic fur seal – 1 record (Menkhorst, 1995);
- Australian sea lion – 1 record (Kirkwoodet et al ,1999);
- Leopard Seal – multiple records (Menkhorst, 1995) (Renwick and Kirkwood, 2004);
- Southern Elephant seal – 1 record (Menkhorst, 1995).

5.10.2 Penguins

Phillip Island has an estimated Little Penguin colony population of 32,000 adults. Little penguins are the smallest species of penguins and are found along the southern coast of Australia and New Zealand. Figure 5-91 shows the population of little penguins at Phillip Island has been increasing over recent years. In 2017-18 there was a recorded average daily number of 940 penguins that cross the beach at Penguin Parade, which is higher than the long-term average of 636 (Phillip Island Nature Parks, 2018).

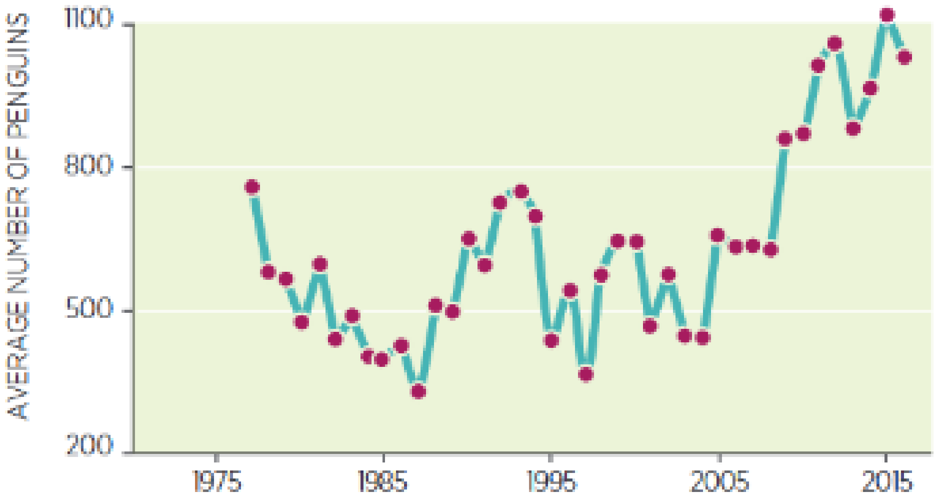


Figure 5-91. Penguins at Penguin parade Beach 1977-2018

Penguins spend approximately 80 per cent of their life in the ocean and return to land for breeding, moulting and resting. The Phillip Island colony spend most of their time in Bass Strait and swim an average of 15 to 50 km per day (Penguin Foundation, 2018). Penguin populations along Phillip Island are mainly at Penguin Parade which is at the southwestern end of the island. Thus, penguins can be found in the western entrance of Western Port. As the penguins spend the majority of their time at sea, they rarely swim up in Western Port or near Crib Point. Individuals are occasionally sighted in Lower North Arm.

5.11 Protected Matters

There are 33 marine threatened or migratory species listed under the EPBC Act and FFG Act that may occur in the vicinity of the Project at Crib Point, as shown in Table 5-25. This excludes bird species. Birds are addressed in Technical Report B *Terrestrial and freshwater biodiversity impact assessment* (Biosis, 2019). These include:

- 13 species listed under the EPBC Act, including:
  - 8 EPBC Act listed threatened species; and
  - 12 EPBC Act listed migratory marine species (including seven of the EPBC threatened species above).
- 26 FFG listed threatened species may occur (including six species also listed under the EPBC Act).

A summary of these species is provided in Table 5-25 and the following subsections including their likelihood of occurring within Western Port and in particular the North Arm of Western Port around Crib Point. Full details are provided in CEE, 2018.

Table 5-25. Listed threatened species potentially occurring in the 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
Brydes Whale	*Balaenoptera edeni*	Migratory	
Pygmy Right Whale	*Caperea marginata*	Migratory	
Killer Whale	*Orcinus orca*	Migratory	
Dusky dolphin	*Lagenorhynchus obscurus*	Migratory	
Burrunan Dolphin	*Tursiops australis*	Listed marine (NA)	Listed
Sharks			
White shark	*Carcharodon carcharias*	Vulnerable, Migratory	Listed
Grey nurse shark	*Carcharius taurus*		Listed
Mackerel Shark	*Lamna nasus*	Migratory	
Freshwater/Marine Migratory Fish			
Australian grayling	*Prototroctes maraena*	Vulnerable	Listed
Australian mudfish	*Neochanna cleaveri*		Listed
Marine Fish*			
Mangrove Goby	*Mugilogobius platynotus* *M paludis**		Listed
Southern Bluefin Tuna	*Thunnus maccoyii*		Listed
Australian Whitebait	*Lovettia sealii*		Listed
Reptiles			
Leatherback Turtle	*Dermochelys coriacea*	Endangered, Migratory	Listed
Loggerhead Turtle	*Caretta*	Endangered, Migratory	
Green Turtle	*Chelonia mydas*	Vulnerable, Migratory	
Marine Invertebrates			

Common name	Scientific name	EPBC	FFG
Southern hooded shrimp	*Athanopsis australis*		Listed
Ghost shrimp	*Pseudocalliax tooradin* **		Listed
Ghost shrimp	*Michelea microphylla*		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

5.11.1 Marine Mammals

Blue Whale

Crib Point is remote from Blue Whale aggregation areas and plausible migration pathways. It is highly unlikely that Blue Whales would occur in the North Arm of Western Port.

Southern Right Whales

Southern Right Whales intermittently pass along the central Bass Strait coast and may enter for short periods into Port Phillip and Western Port. They sometimes enter Western Port's western entrance and have been observed near Crib Point, but the bay is not known to be an aggregation or breeding area for Southern Right Whales. These whales do rarely enter Western Port or are spotted around the entrance to the Bay. However, this is because of individuals wandering from normal migration paths.

Humpback Whale

Central Bass Strait, including Western Port, is generally outside the eastern Australian Humpback Whale population's migratory path, and is not a feeding, breeding or calving area. Humpback whales may wander from their migratory path into Western Port from time to time, and there are records of Humpback Whales in Western Port as far north as Crawfish Rock (ALA, 2017). A humpback whale was sighted at Crib Point Jetty in 2019 (Venosta pers com). Whale records collated for the Two Bays Project show that a total of 175 humpback whales have been sighted in winter close to Phillip Island since records commenced in 2002 (Donnelly et al, 2018). The bay is not a known aggregation point or breeding point for the Humpback Whales.

Figure 5-92 shows all recorded whale sightings by the Two Bays Project in Western Port from 2014 through to 2017. Humpback whales were the more frequently seen, followed by the Southern Right Whale and a few sightings of Killer Whales. Most sightings occur along the shipping channel in the western entrance. Only six sightings were recorded in North Arm between 2014 and 2017.Reports of whale strikes are rare (Refer to Section 7.11.5 for more detailed description of whale strikes).

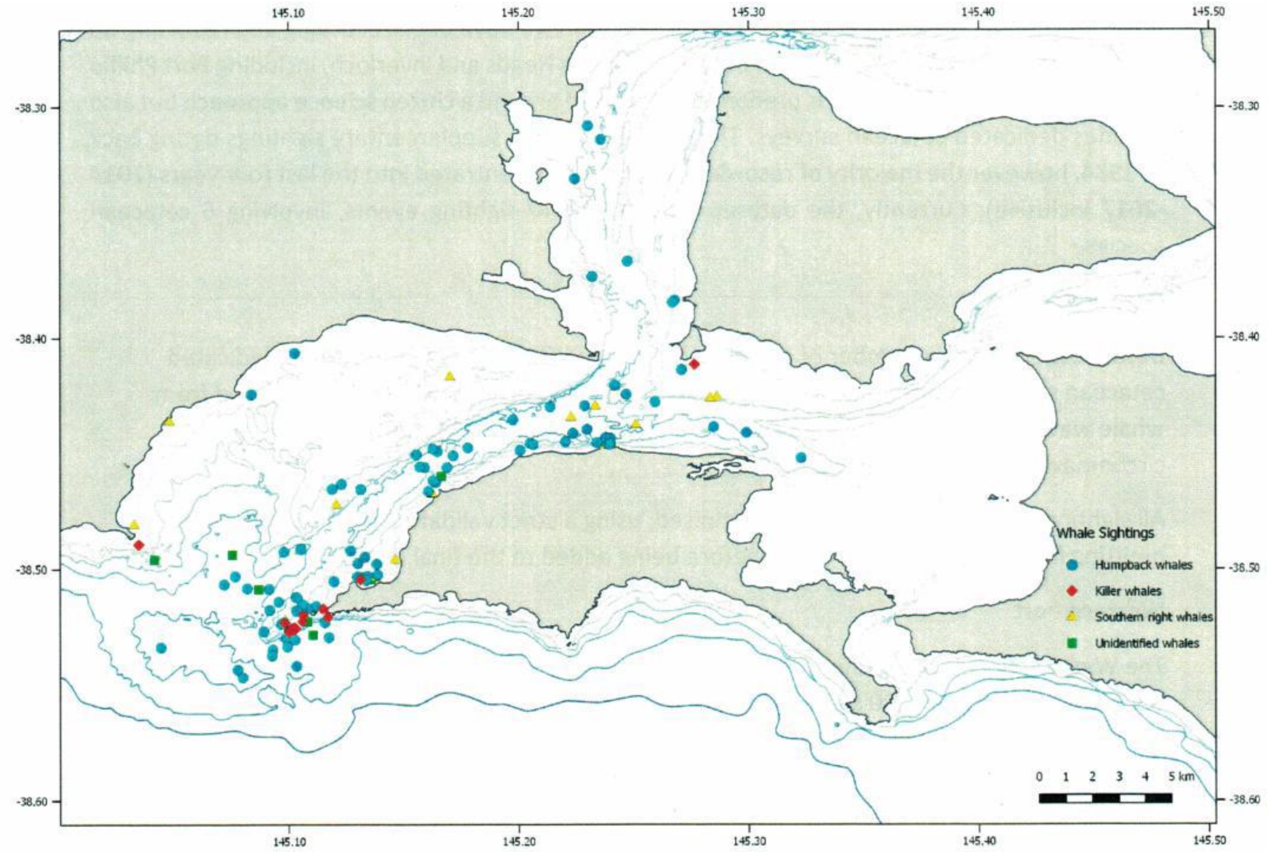


Figure 5-92. Whale Sightings in Western Port – 2014-2017

Brydes Whales

In Australia, Brydes Whales are mostly recorded from 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 Western Port or 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 Western Port 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 Western Port off Ventnor on Phillip Island.

Dusky dolphin

There are no records of Dusky Dolphins in Victorian waters and there does not appear to be any significant breeding or feeding grounds for Dusky Dolphins in the Western Port area.

Burrunan Dolphin

The bottlenose dolphin that is resident in Port Phillip and the Gippsland Lakes were recently described and 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). The taxonomic status of the small Western Port dolphin population has not been re-examined; however, they appear morphologically similar to the Port Phillip population and some individuals observed in Western Port are also known from Port Phillip (Dolphin Research Institute, pers. comm. 2020).

5.11.2 Fishes

White Shark

White Sharks occur in all oceans of the world, including Bass Strait and Western Port. 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 caught and observed in Western Port. They are highly mobile, and it is likely that individual great white sharks will pass through the North Arm from time to time.

Grey Nurse Shark

The distribution of Grey Nurse Sharks (western and eastern populations) in Australia is widely considered to be confined to Western Australia, southern Queensland and the entire New South Wales coast (DoEE, 2014). There are no recent confirmed 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 Western Port.

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 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 most permanent rivers and streams with cool, clear, moderate flow and a gravel substrate for both natural flow regimes, as well as rivers and streams with modified flow regimes (e.g. Yarra, Barwon, Bunyip) and varying water quality.

Adult Grayling populations are known in the Bunyip River, Lang Lang River and Cardinia Creek (Backhouse et al 2008) which open to Western Portmore than 25 km from Crib Point along the Upper North Arm channel, close to the Tidal Divide. Fish ladders are being installed in the Lang Lang River to improve passage of Grayling during up and downstream migrations.

Studies in the Bunyip River show that adult Graylings migrate downstream from their freshwater habitat to spawn just upstream of the brackish waters from March to July depending on freshwater flows (Koster et al 2013). Fertilised eggs do not appear to survive in marine waters, however newly hatched larvae have a wide salinity tolerance (Bacher and O'Brien 1989 in Crook et al 2006). It is generally known that 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). The extent of dispersion of the larvae and juveniles in the marine environment is not known, but it has been suggested that the populations of Grayling in Victorian streams comprise a single stock or series of stocks with a common marine recruitment source (Crook et al 2006). Hence, it is possible that larvae disperse from the river mouths in March through to July throughout Western Port and into Bass Strait via the Western and Eastern Entrances, and that juveniles migrate back from Bass Strait to eastern and northern Western Port streams (Bass, Lang Lang and Bunyip Rivers and Cardinia Creek) in spring and early summer. One Retropinnid fish juvenile was collected in September 2019 during the 12-month EES fish larval sampling program in North Arm (CEE 2019). This was most likely a juvenile Grayling migrating towards freshwater after a winter period of marine residency (Jenkins 2019).

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. None have been identified in Western Port, though suitable habitat may exist.

Pale or Flatback Mangrove Goby

In Western Port, there is only one record of the Pale Mangrove Goby (*Mugilogobius paludism)*, collected on unvegetated mudflat at Woolleys Beach near Crib Point in 2002 (Hindell and Jenkins 2003, Jenkins 2015). However, it is synonymous with Flatback Mangrove Goby (*Mugilogobius platynotus)*, which ranges from southeast Queensland to Victoria and is known to be widespread in Western Port.

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 central Bass Strait or in Western Port.

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, east of Western Port.

5.11.3 Turtles

Leatherback Turtles (*Dermochelys coriacea*) are occasionally seen in Victoria between April and May, when the waters of Bass Strait are warmest. Sightings and strandings have been recorded all along the Victorian Bass open coast, Port Philip Bay and the Gippsland Lakes.

There are no records from Western Port, however there have been numerous sightings nearby, including around Port Phillip Heads.

The Loggerhead Turtle (*Caretta caretta*) inhabit primarily 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 strandings. There are no records from Western Port.

The Green Turtle (*Chelonia mydas*) is a tropical species of turtle, 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. There is one record of a dead Green Turtle on Reef Island in eastern Western Port.

5.11.4 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. Further details are provided in CEE, 2019.

Three of these species are recorded from the North Arm: the ghost shrimps *Michelea microphylla* and *Pseudocalliax Tooradin* and the Hydroid *Ralpharia coccinea*. One further species record, the brittle star *Amphiura triscacantha*, appears to have been a misidentification (O'Hara and Barmby, 2000).

The ghost shrimp *Michelea microphylla* is known from only one specimen collected in sandy gravel in 19 m water depth north of Crib Point in 1965. It was proposed for listing under the FFG Act in 2000 (O'Hara and Barmby, 2000). It has not been found since 1965, including the comprehensive sampling program for the Western Port study in the 1970s (Coleman et al, 1978).

Recent surveys in Lower North Arm for the EES targeted threatened ghost shrimp potential habitat at a range of sites (Figure 5-93) including its original collection location (Mm 1965). Diver operated sediment suction sampling at the sites (Figure 5-94) found many common ghost shrimps, but no protected ghost shrimp species (CEE 2019, Poore 2019).

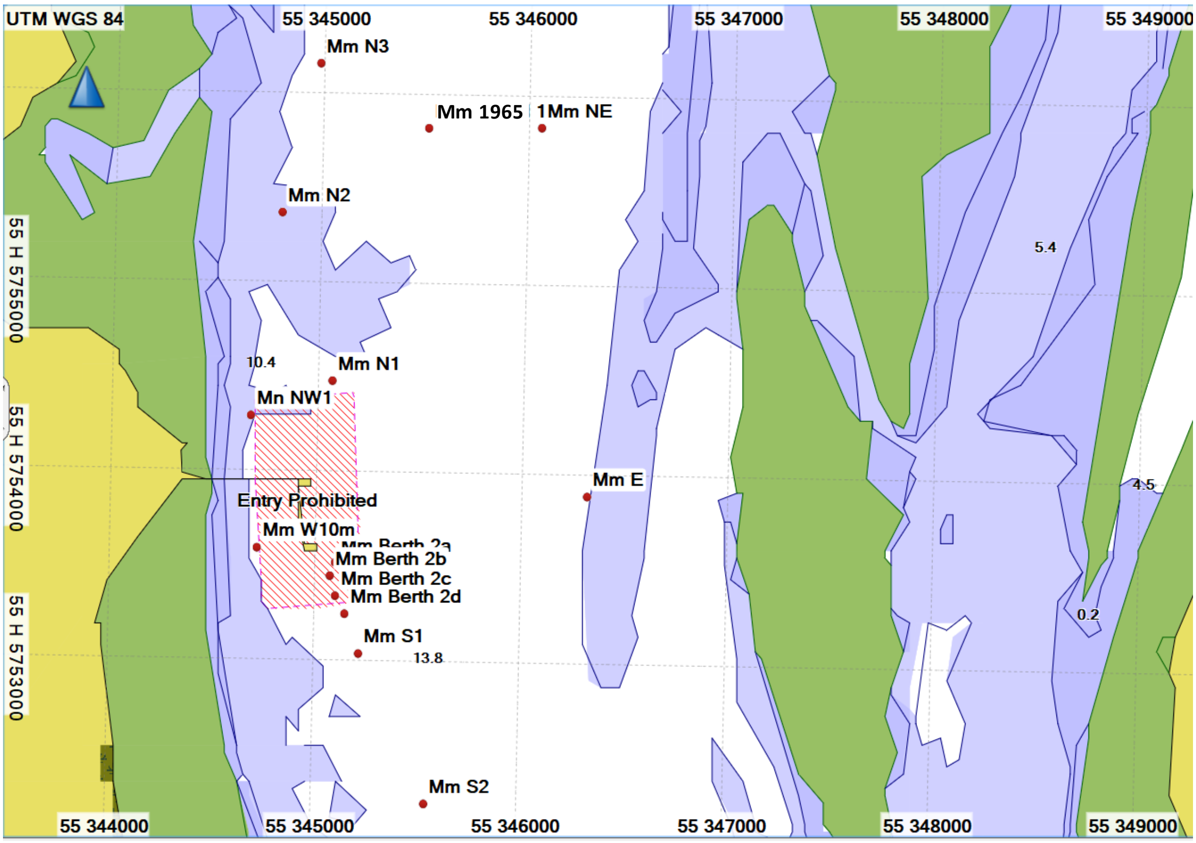


Figure 5-93. Threatened ghost shrimp sampling sites 2018, 19

Figure 5-94. Seabed features in 2019 where *M microphylla* was collected in 1965

The Western Port ghost shrimp *Pseudocalliax tooradin* also was proposed for listing on the FFG in 2000. Individuals were originally collected sub-tidally in grab samples north of Crib Point in 1965. The habitat where it was found at Crib Point comprised shallow, subtidal fine sand. *Pseudocalliax tooradin* subsequently has been captured at shallow depths elsewhere in Western Port and Port Phillip so may not be as rare as was initially thought when recommended for listing in 2000 (Poore 2019). It was not found in targeted ghost shrimp surveys initiated for the EES (CEE 2019, Poore 2019).

The Hydroid species *Ralpharia* coccinea has only been found growing episodically on the soft coral *Parerythropodium membranaceum* (Watson, 2015) at Crawfish Rock, 11 km northward from Crib Point along the main North Arm channel.

5.11.5 Significant Ecological Communities

There are no marine EPBC-listed Threatened Ecological Communities present in the study area. The nearest marine FFG-listed significant ecological community present is the San Remo Marine Community. This intertidal and marine community is unique to a 600 metre by 300 metre area of mixed sand, mud, boulders and weathered basalt substrate near the Eastern Entrance to Western Port, around 23 km from the Project Site. It is a diverse and species rich community of marine biota, including a unique assemblage of opisthobranch molluscs and bryozoans (DSE 2003).

5.11.6 Western Port Ramsar site

The Convention on Wetlands of International Importance (the Ramsar Convention) is a treaty negotiated between 18 countries and a number of NGOs at Ramsar, Iran in 1971. Australia became a Contracting Party in 1974 and it entered into force in 1975.

The Ramsar Convention established the criteria for declaring a site a Wetland of International Importance, which now include nine criteria covering species, ecological communities, waterbirds, fish and other taxa. The Ramsar Convention encourages signatory countries to designate wetland sites in order to conserve their ecological, botanical, zoological, limnological or hydrological importance. By listing a Ramsar site, countries agree to establish and oversee a management framework to conserve a wetland and ensure its wise use. Western Port All Ramsar sites are MNES under the EPBC Act.

The majority of Western Port was designated as a wetland of international significance under the convention in 1982. It is one of eleven Victorian Ramsar sites and the third most important area for wading birds in Victoria (Loyn et al. 2001). Western Port Ramsar Site is under increasing pressure from modifications to Western Port and to the terrestrial environment surrounding it, particularly within the area that contained Koo Wee Rup Swamp.

The expansion of Greater Melbourne has seen increasing numbers of people moving to the northern shores of Western Port, bringing substantial land use changes that may alter the quantity and quality of river discharges (Melbourne Water, 2011).

The Western Port Ramsar site covers 59,950 ha of Western Port. It comprises a large area of shallow intertidal mudflats, deep channels and some narrow strips of coastal land. The Ramsar site includes all areas of Western Port north of a line between Point Leo (Mornington Peninsula) and Observation Point (Phillip Island) and a line between Newhaven and San Remo (The Narrows), excluding the land areas of French Island and Phillip Island (Figure 5-95). The red dot shown on Figure 5-95 marks the location of the Crib Point Jetty.

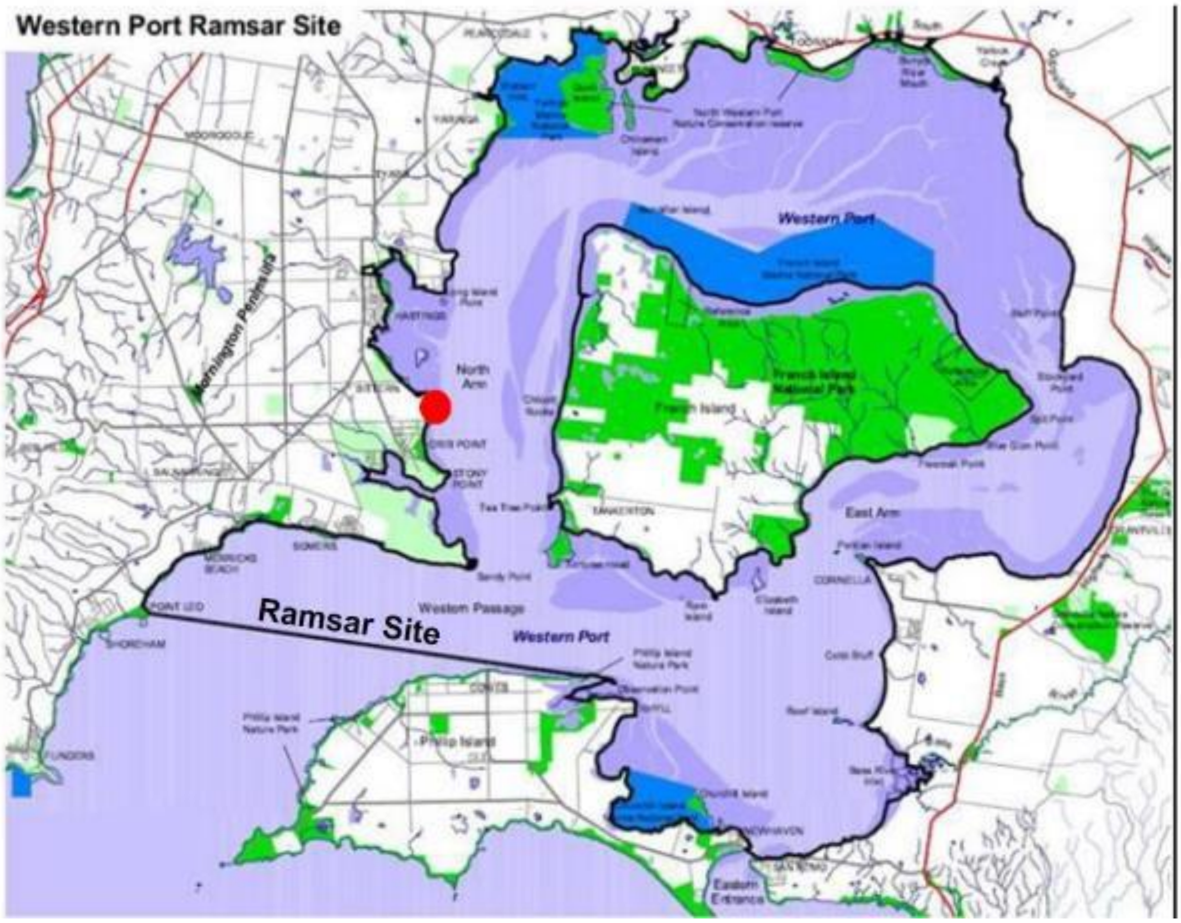


Figure 5-95. Ramsar Site and protected areas in Western Port

The existing values of Western Port meet seven of the nine criteria for designation as a Ramsar site (Table 5-26), as reviewed by KBR (2010) and DELWP (2017) and listed in the Australian Wetlands Database.

Table 5-26. Ramsar criteria for identifying Wetlands of International Importance

Criteria		Existing Value
Group A of the Criteria. Sites containing representative, rare or unique wetland types		
1	A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.	Western Port is a particularly good example of a natural wetland marine embayment with extensive intertidal flats, mangroves, saltmarsh, and seagrass beds within the South East Coastal Plain bioregion. Western Port is also a very good example of a saltmarsh-mangrove-seagrass wetland system.
Group B of the Criteria. Sites of international importance for conserving biological diversity **Criteria based on species and ecological communities**		
2	A wetland should be considered internationally important if it supports vulnerable, endangered, or critically	The site supports the fairy tern which is a species of global conservation significance, in addition to the dense leek-orchid which is listed

Criteria		Existing Value
	endangered species or threatened ecological communities.	as vulnerable under the EPBC Act. Saltmarsh vegetation within the site provides important habitat for the orange-bellied parrot, listed as critically endangered under the EPBC Act.
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.	Western Port is one of the most important areas for migratory waders in south-east Australia with wader surveys indicating that the Ramsar site supports up to 39 species, and includes 10 000 to 15 000 summer migrants (approximately 12 to 16 per cent of the Victorian population). It also supports seagrass and mangrove communities that are characteristic of the marine embayments of Southern Victoria.
4	A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.	The Ramsar site is one of the three most important areas in southeast Australia for migratory waders in total numbers and density. The site also provides important overwintering habitat for the orange bellied parrot. It also provides a number of important high tide roosts and breeding habitat.
Specific criteria based on waterbirds		
5	A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.	The Ramsar site regularly supports about 10 000 to 15 000 migratory waders, and periodically supports 1000 to 3000 ducks and 5000 to 10 000 Black Swans.
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.	The Ramsar site regularly supports more than one per cent of the estimated flyway population of five wader species. The site also regularly supports internationally significant numbers of several non-wader species.
Specific criteria based on fish		
7	A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.	Not considered applicable in KBR (2010) and DELWP (2017) reviews
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.	Seagrass beds within the Ramsar site are known to provide important nursery habitat for a number of fish species, including commercially significant species.
Specific criteria based on other taxa		

Criteria		Existing Value
9	A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent nonavian animal species.	Not considered applicable in KBR (2010) and DELWP (2017) reviews

In addition to fulfilling the majority of the Ramsar criteria for designation, Western Port contains a large number of Wetland Habitat types recognised under the Ramsar Convention.

Wetland habitats include:

- Marine subtidal aquatic beds; such as seagrass and algae beds, including near Crib Point;
- Rocky marine shores; such as the intertidal and subtidal rocky reefs;
- Estuarine Waters; such as the areas around the mouths of the rivers and creeks that drain into Western Port;
- Intertidal mud, sand or salt flats; such as the extensive vegetated and unvegetated mud and sand flats, including around Crib Point;
- Intertidal forested wetlands; such as the extensive fringing mangroves around the north and west shores of Western Port, including near Crib Point. The White Mangroves (*Avicennia marina*) found in Western Port are the most southerly mangroves in the world; and
- Intertidal marshes; such as the salt marshes behind the Mangroves in Western Port, including near Crib Point.

Waterbirds are identified by the Western Port Ecological Character Description (ECD) as a critical component of the Ramsar site (Kellogg Brown & Root 2010). These are described in EES Technical Report B: *Terrestrial and freshwater biodiversity impact assessment.*

As defined in the EPBC Act Policy Statement 1.1 Significant Impact Guidelines, an action is likely to have a significant impact on the ecological character of a declared Ramsar wetland, in this instance the Western Port Ramsar site, if there is a real chance or possibility that it will result in:

- areas of the wetland being destroyed or substantially modified
- a substantial and measurable change in the hydrological regime of the wetland, for example, a substantial change to the volume, timing, duration and frequency of ground and surface water flows to and within the wetland;
- the habitat or lifecycle of native species, including invertebrate fauna and fish species, dependent upon the wetland being seriously affected;
- a substantial and measurable change in the water quality of the wetland – for example, a substantial change in the level of salinity, pollutants, or nutrients in the wetland, or water temperature which may adversely impact on biodiversity, ecological integrity, social amenity or human health; or
- an invasive species that is harmful to the ecological character of the wetland being established (or an existing invasive species being spread) in the wetland.

The current management plan for the Western Port Ramsar site was released by DELWP in 2017. It identifies 17 priority threats to the values of Western Port as a Ramsar Site. Four of these threats are relevant to the Project:

- Invasive species: introduced marine pests (current and potential new invasions);
- Climate change: sea level rise;
- Climate change: increased frequency and intensity of storms leading to shoreline erosion; and
- Climate change: increased frequency and intensity of storms leading to increased sediments.

Industrial development resulting in habitat removal and associated impacts, as well as emissions of toxicants from rural, agricultural and urban areas were also identified as priority threats. The Project does not involve removal of habitat within the Ramsar boundaries.

The management plan also identifies management strategies for protecting the Western Port Ramsar site. Those with most relevance to the Project are:

- 3.6 Develop and implement a strategic approach to development in areas adjacent to the Ramsar site that consider the cumulative impact of multiple actions on ecological character; and
- 3.14 Develop and implement a marine pest strategy for Western Port.

These two strategies have not yet been developed or published. An action statement on the introduction of exotic organisms into Victorian marine waters was produced under the FFG Act in 2004.

5.11.7 Migratory Birds

To assist in providing an assessment of potential impact on migratory birds, assessment of the Project against the EPBC Act Policy Statement 1.1 Significant Impact Guidelines. Assessments on migratory birds is presented in Technical Report B *Terrestrial and freshwater biodiversity impact assessment* (Biosis 2020).

As defined in the EPBC Act Policy Statement 1.1 Significant Impact Guidelines, an action is likely to have a significant impact on an EPBC Act listed migratory species if there is a real chance or possibility that it will:

- substantially modify (including by fragmenting, altering fire regimes, altering nutrient cycles or altering hydrological cycles), destroy or isolate an area of important habitat for a migratory species
- result in an invasive species that is harmful to the migratory species becoming established in an area of important habitat for the migratory species
- seriously disrupt the lifecycle (breeding, feeding, migration or resting behaviour) of an ecologically significant proportion of the population of a migratory species.
- Significant impact judgements must be made on a case-by-case basis and with consideration for the context of the action. The potential for a significant impact on migratory shorebird species will depend on the:
    - timing, intensity, duration, magnitude and geographic extent of the impact
    - sensitivity, value and quality of the environment within and around the area
    - combined effects of impacts within and outside the area, direct and indirect impacts, as well as cumulative impacts already sustained
    - presence of this and other matters of national environmental significance.

The majority of waterbirds that use Western Port are nomadic or migratory. Nomadic species in Australasia move across the continent and the wider region to take advantage of suitable

resources as and where they are available. These birds are thus well suited to dealing with unpredictable rainfall and drought and consequent wetting and drying of wetlands. Other than the few sedentary species, all waterbirds using Western Port have nomadic ability.

Migratory birds make regular annual movements, often along defined flyways, between areas where they breed and areas, they use during the non-breeding portion of the year. Many have very specific annual routines and their migrations are highly predictable. The majority of shorebirds using Western Port breed in high latitudes of the northern hemisphere and are known as Holarctic species. These migrants are in southern Australia during the austral spring-summer.

5.11.8 Marine Conservation Reserves

The high environmental, social and economic worth of Western Port is recognised further through the declaration of Western Port as an UNESCO Biosphere Reserve and the presence of three Marine National Parks (see Figure 5-95).

UNESCO Biosphere Reserves are areas comprising terrestrial, marine and coastal ecosystems established to promote sustainable use compatible with the conservation of biodiversity. The Western Port Biosphere Reserve includes the Mornington Peninsula, Western Port, French and Phillip Islands and the southern part of the Western Port catchment.

Western Port contains three marine national parks:

- Yaringa Marine National Park (980 hectares), in the northwest corner of Western Port approximately 10 km north of Crib Point, contains area of saltmarsh, mangroves, bare intertidal mud and sand flats and subtidal seagrass, with bare sandy sediment in the deeper channels (French et al 2014);
- French Island Marine National Park (2,800 hectares) is located in the Upper North Arm approximately 12 km northeast of Crib Point, extending 15 km on the northern side of French Island. Habitat within the park is primarily intertidal and subtidal mud and sand flats supporting seagrass beds. A small patch of intertidal reef is present. Some mangroves are within the southern park boundary, but the majority of the shoreline mangroves and saltmarsh are outside of the park boundary (French et al 201); and
- Churchill Island Marine National Park (670 hectares), located approximately 18 km south southeast of Crib Point between Churchill Island and Long Point on the north-eastern side of Phillip Island. Habitats present include seagrass beds, mangroves, mudflats and sandy beaches.

5.12 Introduced Marine Species

5.12.1 Introduced Marine Species

The anthropogenic translocation and establishment of non-indigenous marine species (NIMS) is considered to pose one of the greatest threats to marine biodiversity, as well as specific environmental, economic and human health impacts. The coasts of Australia have proven to be particularly vulnerable to invasions of exotic marine species, and a recent assessment reports the number of introduced and cryptogenic marine species in Australia to be 429 (Hewitt and Campbell, 2008). Temperate harbours and embayments on the southern coasts are particularly vulnerable having been colonised by numerous species from temperate marine environments in the northern hemisphere, particularly the north-west Pacific and the Mediterranean/north-east Atlantic regions. While many of the exotic species now established in Australian waters have limited impact, a number of species are perceived to have caused high impact and are considered to be invasive marine pests. These include the Northern Pacific seastar (*Asterias amurensis*), the Japanese kelp (*Undaria pinnatifida*), the European shore crab (*Carcinus maenas*), and the Mediterranean fan worm (*Sabella spallanzanii*).

Shipping and other maritime vessel traffic is one of the most significant vectors for both the primary introduction and secondary dispersal of non-indigenous species. Ports, or the waters in the vicinity of ports, are therefore often “hot spots” for NIMS, and both ships’ ballast water discharge and hull biofouling (particularly sea-chests) are recognised as vectors for marine pest incursions. Once a pest becomes established in one port, this port can then become a source for secondary dispersal to nearby environments by natural means or to other domestic ports, marinas or harbours by maritime traffic. In Victoria this has occurred with both *Asterias amurensis* and *Undaria pinnatifida* – which have since been detected at various locations outside Port Phillip.

The risk posed by maritime traffic depends largely on the type of vessel or ship. Those that spend large amounts of time in port, such as bulk carriers, barges and drilling rigs, mean NIMS have more opportunity to colonise the vessel or disperse from it. Those that spend little time in port, such as container ships, pose a lower threat. Older vessels pose a greater threat as they are less likely to have good antifouling or effective ballast water management systems (to minimise the likelihood of translocating pests), while newer ships increasingly have effective ballast water management systems and good antifouling.

Going back a decade or so, a national port baseline survey program was undertaken to determine the marine pest status of Australia’s waters, and 35 ports around Australia were surveyed. As part of this program, the Port of Hastings (including Crib Point) was surveyed in 1997 (Currie and Crookes, 1997), along with three other Victorian ports: Portland (Parry *et al* 1997), Geelong (Curry et al, 1998) and Melbourne (Cohen et al, 2001).

In addition to determining the pest status in the surveyed ports, these surveys formed the basis for assessment of ballast water uptake and discharge risk associated with domestic ship voyages. A more general survey on marine pests in Western Port was undertaken in 2000 (Cohen *et al,* 2000). This latter survey did not follow the structured sampling protocols prescribed for the port surveys (Hewitt and Martin, 1996) but, instead, employed qualitative survey techniques to enable the survey of regions throughout Western Port, although there was still an emphasis on areas considered susceptible to infestation, such as marinas and aquaculture sites.

5.12.2 The Marine Pest Status of Western Port

During the 1997 baseline survey of the Port of Hastings, a total of 355 species were collected. Only seven of these were confirmed as introduced species:

- the European green crab *Carcinus maenus;*
- the European clam *Varicorbula gibba* (as *Corbula gibba*);
- the Asian bag mussel *Musculista senhousia*;
- the Asian bivalve *Theora lubrica*; and
- three cosmopolitan bryozoan species: *Bugula dentata*; *Bugula neritina*; and *Watersipora subtorquata*.

For comparison, nine exotic species were detected in the baseline port survey of Portland, 20 in Geelong, and 37 exotic or cryptogenic species in Melbourne. *Bugula dentata* was the only species considered abundant enough within the Port of Hastings to cause significant ecological impact, as its erect flexible growths were found on the surfaces of pier pylons of all commercial wharves. However, this species has since been reconsidered to be native (Hewitt *et al,* 1999), with a widespread distribution in the Indo-Pacific.

The 2000 survey of marine pests in Western Port increased the number of recorded exotic species in the bay to 14 (Cohen *et al,* 2000). Species additional to those in the 1997 port survey were:

- Four species of ascidians (*Ascidiella aspersa*, *Ciona intestinalis*, *Styela plicata* and *Styela clava)*,
- the Mediterranean fanworm *Sabella spallanzanii*;
- the bivalve *Crassostrea gigas*; and
- two green algal species (*Codium fragile* subsp. *fragile* and *Ulva lactuca).*

Only the crab *Carcinus maenas* appeared to be widely distributed in Western Port in 2000, with the remainder apparently limited in their distribution. *Sabella spallanzanii* and *Styela clava* were found on mussel ropes transferred to Flinders from Port Phillip, but were not found on the nearby Flinders Pier or on the sea floor below the mussel farms.

A single occurrence of the Japanese kelp *Undaria pinnatifida* in Western Port is known from near Flinders Pier (G. Parry, *pers comm*.). These plants were removed and there were no further findings in subsequent monitoring of the site.

In late 2007 several juvenile New Zealand green-lipped mussels (*Perna canaliculus*) were found in the sea chests of one of the vessels that voyages between Port Kembla and Hastings when it was dry-docked for routine maintenance (Lewis 2019). Although follow up searches found no mussels near the relevant wharf at Hastings, the finding demonstrates a potential pathway for marine pest introduction to Western Port.

None of the large pests found in Port Phillip (*U. pinnatifida, A. amurensis, S. spallanzanii*) have ever been observed during the BlueScope marine biological monitoring program (MSE, 2009) or biological monitoring of the Crib Point, Long Island Point or BlueScope jetties (Bok *et al*, 2017). However, since the last marine pest surveys in 2000, no targeted marine pest survey has been conducted in Western Port (Lewis 2019).

5.12.3 Marine Pest Management Arrangements

The environmental and economic threat posed by marine pests to Western Port is recognised by the Port of Hastings Development Authority (PoHDA) and Parks Victoria. The PoHDA prohibits in-water cleaning of ship hulls and propellers. The discharge of ballast waters is also prohibited in port waters (PoHDA, 2017).

Parks Victoria manages the three Marine National Parks which protect representative areas of Victoria's marine biodiversity, and has identified marine pests as one of the major threats to the biodiversity of the parks.

The Australia Government is responsible for the regulation of ballast water in Australia. In 2016 the Commonwealth *Biosecurity Act 2015* came into force and this enabled Australia to ratify the International Maritime Organization (IMO) Ballast Water Management Convention, which came into force on 8 September 2017. Ships in Australian waters have to manage ballast water according to the Australian Ballast Water Management Requirements which align with the International Convention for the Control and Management of Ships Ballast Water and Sediments 2004. The *Biosecurity Act 2015* currently covers ballast water, but does not deal with the issue of biofouling, which is widely recognised as posing a similar or greater risk of introducing marine species to Australian waters.

Currently, biofouling risks are managed through the National Biofouling Management Guidelines (Commercial Vessels, 2009) and Anti-Fouling and In-Water Cleaning Guidelines (2015). A major review of Australia's marine pest management arrangements was undertaken in 2014-15 (DAWR, 2015). The review made a number of recommendations for improving the way Australia prevents, eradicates and manages the introduction of marine species in Australia. One of the key recommendations was that Australia introduce new biofouling regulations consistent with International Maritime Organisation Biofouling Guidelines. A revision of a 2011 biofouling regulation impact statement was issued on 1 April 2019.

The contribution of the development to marine pest risks in Western Port will require management under present Port, State and Commonwealth regulations. Issues related to specific aspects of the FSRU, such as development of hull fouling and cleaning, will be addressed in subsequent stages of the project assessment (Lewis 2019).

5.13 Port of Hastings

5.13.1 Port of Hastings Development Authority

The Port of Hastings is one of the four major commercial ports within Victoria. Port of Hastings is managed by the PoHDA established in 2004 (Port of Hastings Corporation, 2009) and has been used as an active trading port since the 1800s. In the 1960s the land around Hastings was reserved for port related uses and the bays naturally deep channels and close range to oil and gas fields means that the port has played an important role in the energy sector. As the port was identified to be a potential area for larger scale industrial processes in the 1970s, large areas were put aside and preserved to allow for future use.

HMAS Cerberus is located south of the Port of Hastings. HMAS Cerberus is used as a naval base primarily for training purposes. There are five jetties around the Port of Hastings which include:

- the naval wharf at HMAS Cerberus
- Stony Point Jetty
- Crib Point Jetty

- Long Island Point Jetty
- BlueScope Steel Wharves.

5.13.2 HMAS Cerberus Naval Base

HMAS Cerberus is a navy base that has been used by the Royal Australian Navy since the 1920s. The base covers 1,500 ha at Hanns Inlet and is primarily used for technical training.

Long Island Precinct

The Long Island precinct is the largest development around Hastings with a total zoned are of 2,000 ha. Only 500 ha of the total 2,000 is currently in use and is occupied by BlueScope Steel and Esso-BHP Billiton facilities (Port of Hastings Corporation, 2009). Both the BlueScope Wharves and Long Island point jetty are within the precinct.

The precinct is a major contributor to the import / export of crude oil, unleaded petroleum and diesel and steel. The Long Island Point Facility is 158 ha and began operation in the 1970s. The site employs around 80 people directly with other contracting roles and provides the final stages to processing liquefied gasses. In 2016/17 the facility had an output of 6 ML of crude oil, 600 tonnes of ethanol, 2.5 ML of propane, 2 ML of butane and an average of 25 trucks loaded with LPG per day (ExxonMobil, 2019).

BlueScope was originally part of BHP Billiton which purchased 600 ha of land at Western Port in 1967. BlueScope separated from BHP in 2002 and the BlueScope wharves account for the steel imports and exports in Western Port. In 2017/18 BlueScope exported 95,941 tonnes of steel and imported 57,834 tonnes.

Crib Point

The Crib Point Jetty was constructed in the 1960s and is used as a liquids berth. The jetty has an existing pipeline connecting to Long Island for the transport of unleaded petrol. However, the use of Crib Point Jetty is currently less frequent than of Long Island Point Jetty and the BlueScope wharves.

Stony Point

Stony Point Jetty is primarily used for passenger ferries, the Royal Australian Navy, fishing industry, small commercial vessels and harbour tugs. There are around 10 ferries that depart from Stony point each day and a similar number that arrive at the jetty from French Island. Approximately five ferries come to Stony Point from Philip island per day. In total there is over 12,000 ferry trips per year between Stony Point and French Island or Philip Island.

Shipping Anchorages

Commercial shipping anchorages are located in East Arm approximately 1.5 km north of Cowes Jetty and Western Entrance approximately 4 km east of Flinders Jetty. These anchorages are used occasionally by cruise ships and drilling rigs (Cowes anchorage) and small tankers (Flinders anchorage).

Shipping Movements and Dredging

The total amount of shipping numbers varies from year to year but has been around 150 import/export ships for the last four to five years as well as other vessels such as cruise ships, tugs and other various vessels. Per annum there are around 100 cargo ships, over 12,000 ferry trips between Stony Point to French Island and Phillip Island, several cruise ships and hundreds of recreational vessels that use the Port of Hastings. Within the 2017/18 financial

year period, PoHDA reported that a total of 125 cargo, non-cargo and cruise ships (250 shipping movements) visited Western Port (PoHDA pers com Apr 2019).

Port of Hastings is one of Victoria's four major ports. It has significantly less vessel traffic compared to other ports around Victoria and Australia (Figure 5-96). The largest port by port call is Melbourne with over 3,000 vessels per annum.

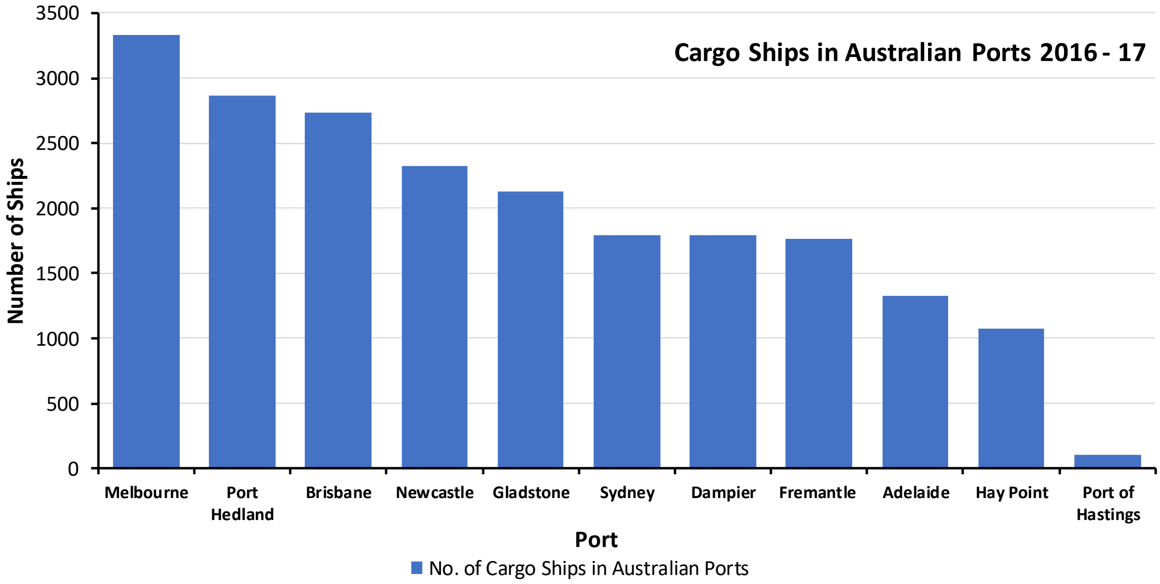


Figure 5-96. Cargo Vessel Numbers in Australian Ports

Dredging has occurred in Western Port since the 1870s in parts of North Arm. Dredging for port purposes began in 1916. Since 1916 there has been an estimated 2.75 million m^3 of material removed. A total of 1.6 million m^3 of material has been dredged in Western Port since 1964 (Table 5-27) show that total of 1.6 million m^3 for port related purposes. The last dredging campaign was in 2002 at the BlueScope berths. Bed levelling to maintain declared depths is a routine maintenance activity in many ports including Western Port. This process involves smoothing the seabed in areas where tidal currents or other processes cause localised shallow areas such as sand waves in channels or berths. It may also be used to level high points remaining from earlier dredging. No dredging is proposed for the Gas Import Jetty Works.

Table 5-27. Dredging Campaigns in Western Port since 1964

Date	Dredging Location	Disposal Location	Method	Volume (m^3)
1964 – 1965	Crib Point	Tankerton Dredged Material Ground (DMG)	Bucket Dredger Loading Hopper Barges	384,000
1968 – 1969	Long Island Point (phase 1)	Hastings Bight	Cutter Suction Dredger Pumping Direct	153,000
1969-1970	Long Island Point (phase 2)	Peck point DMG	Bucket Dredger	294,000

Date	Dredging Location	Disposal Location	Method	Volume (m^3)
			Loading Hopper Barges	
1971 - 1972	John Lysaght (Aus)	Old Tyabb Reclamation	Cutter Suction Dredger Pumping Direct	676,000
1975 - 1976	Main Shipping Channel	Grossard Point DMG	Unknown	10,000
1980	Main Shipping Channel	Tankerton DMG	Tailer Suction Hopper Dredger	10,000
1988	Main Shipping Channel	Tankerton DMG	Tailer Suction Hopper Dredger	24,000
1994	Main Shipping Channel	Tankerton DMG	Tailer Suction Hopper Dredger	35,000
2002	BHP Berths	Old Tyabb Reclamation	Cutter Suction Dredger Pumping Direct	16,000

5.14 Western Port Catchment

5.14.1 Development in Western Port Catchment

Western Port has a catchment size of 3,721 km^2 and an estimated population of 45,000 people in 2018/19 (Port Phillip and Westernport Catchment Authority, 2018/19). There is rapid growth in the northern parts of the catchment (Casey Shire and Cardinia Shire) and steady growth in the rest of the catchment. By the year 2041, the population in the Western Port catchment is projected to be about 250,000 people (sum of municipality projections by *id.population*, 2020).

Ongoing development continues the long-term trend of changes in the Western Port catchment. In the early 1850s the catchment around Koo Wee Rup was drained to dry the surrounding swampland and allow transport routes, settlements and farming. Large artificial drains were constructed to connect Cardinia Creek and Toomuc Creek to the Bay. By 1897 the original drainage works were complete including the large Bunyip River Drain and several other smaller drains. The original Koo-Wee Rup Swamp has been converted from a wetland to a highly productive horticulture and grazing area.

In the 1960s the land around Hastings was reserved for port related uses and the bays naturally deep channels and close range to oil and gas fields means that the port has played an important role in the energy sector. As the port was identified to be a potential area for larger scale industrial processes in the 1970s, large areas were put aside and preserved to allow for future use. Several large-scale industries were established in the 1970s including BlueScope Steel and BP Refinery (since closed and converted to a petroleum importation facility).

5.14.2 Threats to Western Port Habitats

As outlined in the historical summary in the previous section, the environment of Western Port has changed over the last two hundred years and will continue to evolve in the future.

Melbourne Water, with inputs from EPA, Port Phillip and Western Port Catchment Management Authority, Parks Victoria, South East Water and a range of local experts prepared "*A Summary of Current Knowledge and Future Research"* for Western Port. Table 3-2 of the report listed the identified threats to the marine environment that can be summarised as follows.

- **Water and sediment quality**, due to population growth, land use change and climate change;
- **Hydrodynamic and atmospheric conditions**, due to climate change;
- **Pest plants and animals**, due to port activities, shipping, boating, tourism and urban growth; and
- **Habitat and species**, due to population growth as reflected in coastal and industrial development, urban growth and new structures.

This consolidated list of threats is adopted for the assessment of cumulative impacts in Section 8.

6.0 Hydrodynamic Modelling

6.1 Purpose of Hydrodynamic Modelling

The purpose of hydrodynamic modelling is to predict contours of temperature and chlorine oxidants in the vicinity the FSRU as the basis for the marine impact assessment. Another purpose of the modelling is to predict the rate of entrainment of plankton and other small marine organisms in seawater taken into the FSRU, for various purposes including heat exchange with LNG, firefighting, ballast water and freshwater production, for the marine impact assessment.

The largest flow of seawater into and from the FSRU is involved in the open loop regasification process. This process involves the extraction and discharge of up to 471,000 m^3/d of seawater from Western Port. The seawater would be taken in through sea chests on the side of the FSRU, pass through heat exchangers and be discharged back to Western Port through six ports on the east side of the FSRU at 7 °C cooler than ambient seawater.

There are three regasification trains, each with heat exchangers on the FSRU and two discharge ports. Depending on the rate of gas production, two, four or six seawater discharge ports can be operating concurrently. The hydrodynamic modelling simulated the dilution and transport of the open loop seawater discharge at the peak production rate (6 ports) and at a normal average production rate (4 ports) over a typical year. The seawater discharge rates for the continuous discharges in open loop operation are listed Table 6-1, including the freshwater generator and the seawater filter. Intermittent flows for ballast, water curtain and fire water testing are listed separately.

Table 6-1. FSRU Flows During Open Loop Operation

Open Loop Process	Peak Flow rate (m^3/d)	Average Flow Rate (m^3/d)	Temp (°C)	Notes
Continuous discharges				
Regasification Process (Open Loop)	468,000	312,000	-7	Maximum at full production, Discharge through six high velocity ports on east side of FSRU
Freshwater Generator	2,100	2,100	8	Discharge at rear of FSRU
Seawater filter discharge	700	700	0	Discharge at rear of FSRU on starboard side
Total for open loop	**471,000**	**315,000**		**Total rounded**

The discharge during open loop operation would create seawater plumes that are cooler, and therefore more dense than the surrounding seawater. During periods of moderate to strong tidal currents, the plumes would be entrained into the tidal flow within 20 m to 40 m of the discharge. During periods of low currents (around the turn of the tide), the plumes would descend and form a pool of cooler seawater on the seabed. The pool would be mixed and carried away as the current speed increases in the next tidal cycle (CEE, 2018a).

In open loop operation, cooling water for the engines and auxiliary machine systems will be redirected to the open loop regasification cycle instead of being directly discharged to sea, to reduce water use and also reduce the temperature fall in the open loop seawater discharge.

In the alternative, closed loop operation, the LNG would be heated using gas-fired boilers and there would be a discharge of warm seawater (the seawater used to cool the FSRU's generators and auxiliary systems) which is from 5°C to 12°C warmer than ambient seawater. Table 6-2 shows the various flows and temperature changes in closed loop operation for the discharges in continuous operation.

In closed loop operation, there would be a minimum discharge of 157,600 m^3/d from the various cooling systems, atmospheric dump condenser and the freshwater generator. There is a Main Generator Freshwater Cooler on each side of the vessel and both these coolers can be operating in unison. Thus, at peak production in closed loop, the discharge would total 187,000 m^3/d (excluding the intermittent flows for ballast water, water curtain and fire water testing).

The warm seawater would be discharged via several closely-spaced pipes at the rear of the vessel. Closed loop operation involves a smaller rate of seawater discharge than open loop.

Table 6-2. FSRU Flows During Closed Loop Operation

Closed Loop Process	Flow rate (m^3/d)	Temp (°C)	Notes
Continuous discharges			
Main Generator FW Cooler	29,300	12	Duty - discharge to rear starboard
Auxiliary FW Cooler	45,800	5	Discharge to rear starboard
Atmospheric Dump Condenser	80,400	0	Discharge to rear port side
Freshwater Generator	2,100	8	Discharge at rear of FSRU
Subtotal - minimum discharge	**157,600**		**Average**
Main Generator FW Cooler	29,300	12	Peak Duty - discharge to rear port
Total for closed loop	**187,000**		**Peak**

The discharge during closed loop operations would create plumes that are warmer, and therefore more buoyant, than the surrounding seawater. During periods of low currents around the turn of the tide, the plumes would rise due to buoyancy.

Ballast Water and Minor Discharges

There are additional discharges of seawater that occur intermittently, including ballast water (which is taken in and released to maintain vessel stability), water curtain and fire water testing, as listed in Table 6-3. During gas production, the LNG tanks on the FSRU are progressively emptied and ballast water is taken into the FSRU to maintain the vessel's stability. The ballast water is discharged over the approximate 36-hour period when LNG is loaded into the FSRU from the visiting LNG carrier. The ballast water is discharged intermittently through a 0.71 m diameter pipe at the rear starboard quarter of the FSRU.

During LNG unloading (when an adjacent LNG carrier is moored adjacent to the FSRU) a seawater spray ("water curtain") is discharged at a rate of 240 m^3/hr on the starboard side of the FSRU to ensure there is no direct contact between LNG and the hull of the FSRU vessel (as a safety precaution). A fire water pump is tested for one hour every two weeks with a discharge rate of 1,550 m^3/d, so the discharge is about 70 m^3 per test. The water spray and fire pump discharge seawater at ambient temperature.

Table 6-3. FSRU Intermittent Discharges during Open and Closed Loop

Open Loop and Closed Loop	Flow rate (m^3/d)	Temp (°C)	Notes
Intermittent Discharges			
Ballast water discharge	35,000	0	Only during LNG transfer. Up to 53,500 m^3 in 2 days
Water curtain between vessels	1,500	0	Only during LNG transfer
Fire water discharge	70	0	For 1 hour every 2 weeks
Average in peak month	**7,000**		**Assuming peak 8-day cycle**

For both open loop and closed loop operation, the seawater taken into the FSRU would be chlorinated by electrolysis to control biological fouling in the pumps, pipes and heat exchangers. The electrolysis process converts the chloride ions (Cl^-) in seawater to hypochlorite ion and hypochlorous acid, which further react rapidly with bromine in seawater to form hypobromite ion and hypobromic acid. These are known as chlorine-produced-oxidants (CPO). On discharge, the remaining concentration of CPO in seawater would be no more than 100 µg/L.

It is apparent that there are complex hydrodynamic mixing and transport patterns to be reproduced in the modelling to determine the dilution and extent of the discharge plumes. This work involved development and use of near-field models of plume behaviour (Ref. CEE, 2018a), and development and use of 3-D regional models of dilution and transport (by Water Technology in 2017 and HydroNumerics in 2019). The near-field model simulates conditions along the axis of each plume, allowing for merging of plumes from the separate ports and the interaction of the plumes with the seabed and the water surface. The regional model uses a three-dimensional grid of cells, down to a grid size where each cell is 20 m by 20 m by 1 m deep, to simulate the subsequent spread, transport and dilution of the seawater discharges.

The objectives of this Section on hydrodynamic modelling are to:

- Establish the extent and dilution of the plumes of cooler seawater on the sea floor and warmer seawater in the water column;
- Establish the distribution of residual chlorine in the discharged seawater; and
- Establish the rate of entrainment of plankton and larvae in seawater into the intakes of the FSRU under open loop and closed loop operations.

6.2 Near-field Hydrodynamic Modelling of Open Loop Discharge

The purpose of near-field hydrodynamic modelling was to establish the initial dilution and plume geometry close to the point of discharge. The initial dilution is due to the initial momentum and buoyancy of the discharge plumes. Higher dilution is achieved when the plumes discharge from the ports at a high velocity, as this creates high shear and rapid mixing between the plumes and the adjacent seawater. Because the open loop seawater discharge is cooler than the adjacent seawater, the plumes are denser (increased density of 0.8 kg/m^3 for a 7 °C temperature difference) and therefore descend towards the seabed. Shear between the descending plumes and the adjacent seawater adds to the rate of mixing and dilution.

6.2.1 Near-field Hydrodynamic Model

Initial dilution was calculated using the CEE computer model INITDIL. This model has been published in peer reviewed publication in the open literature (Wallis, 1985), verified against the performance of existing outfalls around the world (Wallis, 1981; Wallis 2016) and found to successfully predict the dilution of plumes from actual discharges (including the dense brine discharge from the Wonthaggi desalination plant, Wallis, 2019).

The near-field model operates at a small length scale (steps of less than 0.1 m long) and uses a coordinate system that follows the centreline of the plumes. The model calculates the velocity, diameter and location of the plume centreline, calculates the initial dilution with distance along the plume for both dense and buoyant plumes, and estimates the thickness of the diluted seawater field when the plume reaches the seabed (dense plume) or the water surface (buoyant plume). The initial dilution is predicted for various current speeds with the worse-case being slack water.

6.2.2 Need for Discharge at High Velocity

The near-field modelling explored a wide range of discharge arrangements and concluded that, for the open loop discharge scenario, the dilution is strongly influenced by momentum-induced mixing rather than by the effects of gravity due to the density difference. Given the relatively shallow water depth and the high rate of discharge, a high-velocity port was necessary to achieve the substantial initial dilution necessary to reduce the temperature difference and residual chlorine concentration to acceptable levels.

Based on the results of the near-field modelling carried out in 2018, it was recommended that with open loop operation (which has the higher rate of discharge), six ports should discharge horizontally at a velocity of not less than 5 m/s (CEE, 2018a).

6.2.3 Effect of Water Depth on Dilution

The FSRU is a floating vessel that moves up and down with the tide. The vessel also moves up and down in the water column, depending on whether it holds a full load of LNG or is nearly empty. Ballast water compensates partly but not fully for changes in the LNG load. The near-field model was used to explore the effect of changes in water depth (between the discharge ports and the seabed) on initial dilution. These simulations were made for the "worst-case" of slack water, and for various stages of the tide.

Four cases were examined in 2018 using the 6-port configuration:

- 10.2 m - Low tide and fully laden vessel;
- 12.5 m - Low tide and empty vessel;
- 13.2 m - High tide and fully laden vessel; and
- 15.5 m - High tide and empty vessel.

Figure 6-1 shows the predicted initial dilution for these cases for the discharge from the regasification trains as shown in Table 6-1. At low tide and with a fully laden vessel, the initial dilution is 20:1. This is the lowest dilution for the 6-port configuration. At high tide, or with a part or empty vessel, the depth below the port is greater and the predicted initial dilution is higher at 26:1. Over the tide and loading cycles, the dilution would vary from 20:1 to 26:1.

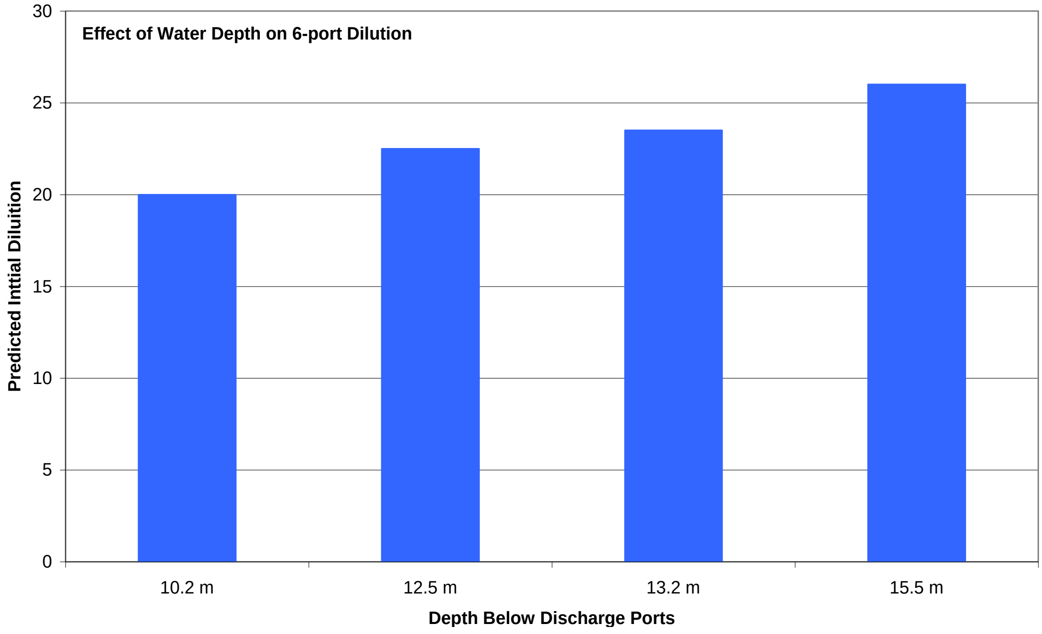


Figure 6-1. Effect of Water Depth on Initial Dilution

6.2.4 Effect of Discharge Angle on Dilution

Some FSRU vessels, in other parts of the world, discharge the cooler seawater vertically downwards. Figure 6-2 shows the predicted initial dilution with discharges at different angles, from six ports of 0.45 m diameter at peak discharge from a fully loaded FSRU at low tide. With vertical discharge, the dilution is predicted to be 6:1. As a check, it was noted that the dilution of 6:1 predicted by INITDIL matches the dilution predicted by an alternative plume model published by Cederwall (1968) of 6:1. With horizontal discharge, as is proposed for the Project, the dilution is predicted to be 20:1 (at low tide).

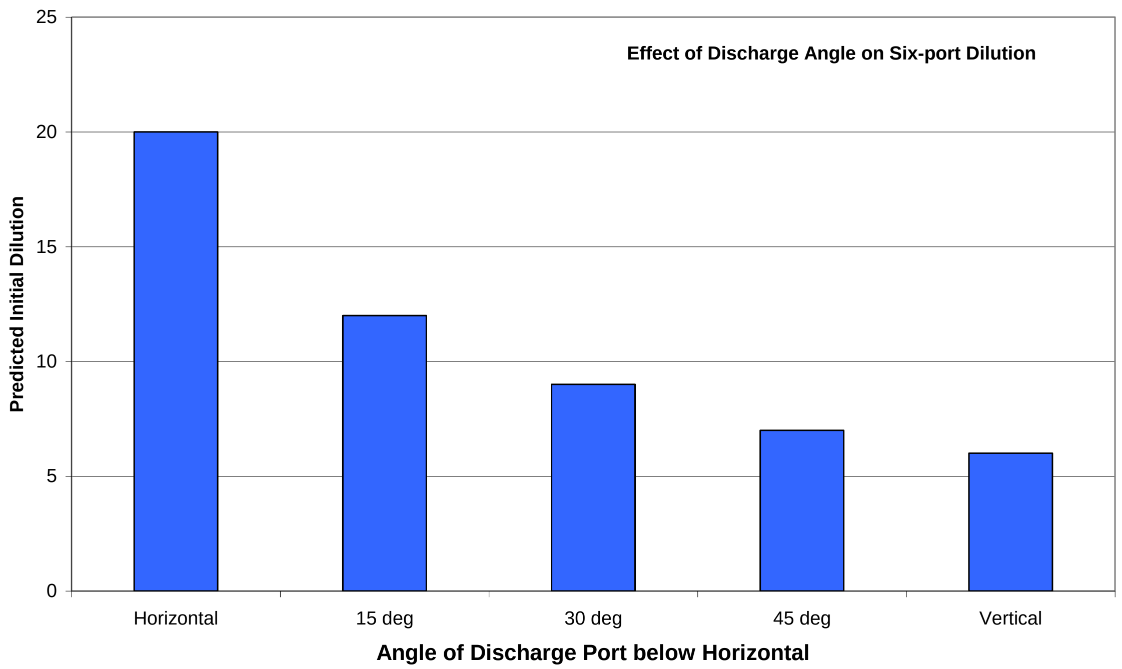


Figure 6-2. Effect of Discharge Angle on Initial Dilution

As can be seen in Figure 6-2, the dilution increases from 6:1 with vertical discharge to 20:1 with horizontal discharge. As a check, it was noted that the dilution of 20:1 for high velocity horizontal discharge predicted by INITDIL matches the dilution predicted by the alternative plume model published by Cederwall (1968) of 21:1.

As the port angle becomes closer to horizontal, the length of the plume between the port and the seabed increases as the angle increases, so there is more interfacial mixing and thus higher dilution. The conclusion drawn from these predictions is that the ports should discharge horizontally to maximise dilution. The ports should be close to the water surface, but not so close as to be visually obvious. It is recommended that the top of the ports should always be at least 1.5 m below the water surface in all vessel loading conditions.

6.2.5 Findings from Near-Field Modelling of Open Loop Discharge

The near-field modelling (CEE, 2018) of the discharge plumes for open loop operation concluded that:

- A high velocity discharge is required (greater than or equal to 5 m/s) to achieve the initial dilution necessary to limit the extent of cooler seawater and residual chlorine levels;
- There should be six ports – two for each LNG regasification train - to maintain the high velocity discharge with lower levels of LNG production (e.g. if only one train is in operation);
- Ports should discharge horizontally at 1.5 m below the water surface when the FSRU is empty (which is as high in the water column as practical);
- The predicted initial dilution of 20:1 is sufficient to reduce the seawater discharge temperature difference from 7 °C to about 0.3 °C below ambient seawater temperature; and
- The predicted initial dilution of 20:1 is sufficient to reduce the discharge chlorine oxidant concentration of 100 µg/L to 5 µg/L at the end of the near-field plume.

6.2.6 Patterns of Near-field Plume Behaviour

The near-field plume calculations take into account:

- Dilution due to entrainment in tidal currents with distance along the path of each plume;
- Merging of adjacent plumes;
- Interaction of the plumes with the water surface; and
- Interaction of the plumes with the seabed.

At times of moderate to strong north/south tidal currents, the diluting plumes would entrain seawater in the tidal currents flowing across the path of the plumes, which would cause the plumes to turn in the direction of the currents. Shear, and therefore dilution, is more rapid in a turning plume. After a travel distance of about 40 m, the plumes would be mixed vertically and be mixed into the tidal currents.

A series of near-field plume calculations were made for a range of current speeds, and a table created to translate the near-field plume behaviour into the corresponding input to the regional model. The regional model uses a 20 m by 20 m grid, so the near-field predictions were granulated to this grid. Table 6-4 shows the outcome. As an example, for a current speed of 0.2 m/s, the plumes turn into the current with the centreline of the plumes at 40 m from the FSRU and the horizontal width of the plumes being 40 m. In this example, the plumes are added to the regional model in cells that extend from 20 m to 60 m east of the FSRU, and from 1 m to 12 m below the surface.

At faster current speeds, the plumes turn faster, and end up closer to the FSRU. At weak current speeds, the plumes travel further from the FSRU and occupy the whole depth.At times of weak tidal currents (near or at slack water with current speed of < 0.03 m/s), the plumes travel out from the FSRU due to the high momentum of the discharge, and after a distance of about 45 m, have mixed through the water column from the surface to the seabed. The individual plumes merge and further mixing at the outer edges of the plumes allows dilution to continue to slowly increase with distance. After a distance of about 80 m from the FSRU, the plumes have slowed considerably, are close to maximum dilution, and have moved down towards the seabed due to gravity. Thus, in the regional model, the plumes at slack water are added over the distance of 40 m to 80 m from the FSRU from the water surface to the seabed.

Table 6-4. Near-field Plume Prediction for Use in Regional Model

Current Speed (m/s)	Distance in m from FSRU to Centre of Plumes	East-West Width of Plumes (m)	Top of Plumes (m below surface)	Base of Plumes (m below surface)
> 0.03	40	40	0	14
0.1	40	40	0	14
0.15	40	40	0	13
0.2	40	40	1	12
0.3	40	40	1	12
0.4	40	40	1	12
0.5	20	40	2	12
0.6	20	40	2	12
0.7	10	40	2	12

Current Speed (m/s)	Distance in m from FSRU to Centre of Plumes	East-West Width of Plumes (m)	Top of Plumes (m below surface)	Base of Plumes (m below surface)
0.8	10	40	2	12
0.9	10	20	2	12
1.0	10	20	2	12

Currents at Crib Point are driven by many factors but principally by the diurnal tidal cycle (refer to the description of currents in Western Port in Section 5). Typically, the flood tide currents (in the main channel, averaged over the depth) are in the range of 0.05 m/s to 0.55 m/s while the ebb tide currents are 0.05 m/s to 0.65 m/s, but over a shorter period (Ref RH-DNV, 2015). The current patterns in the main channels are elliptical, with east/west currents evident at high and low tide, generated by the bathymetry of Western Port. There is seldom zero current speed, even at slack water.

Figure 6-3 shows the north/south tidal currents at Crib Point Jetty as measured at mid-depth by ADCP #1 (refer to Section 5). Current speeds near the seabed are lower than currents higher in the water column. The peak flood tide current near the seabed is about 0.55 m/s while the peak ebb tide current averages about -0.6 m/s (negative current velocity is to the south). Zero current (at slack water) was measured to occur around 20 minutes.

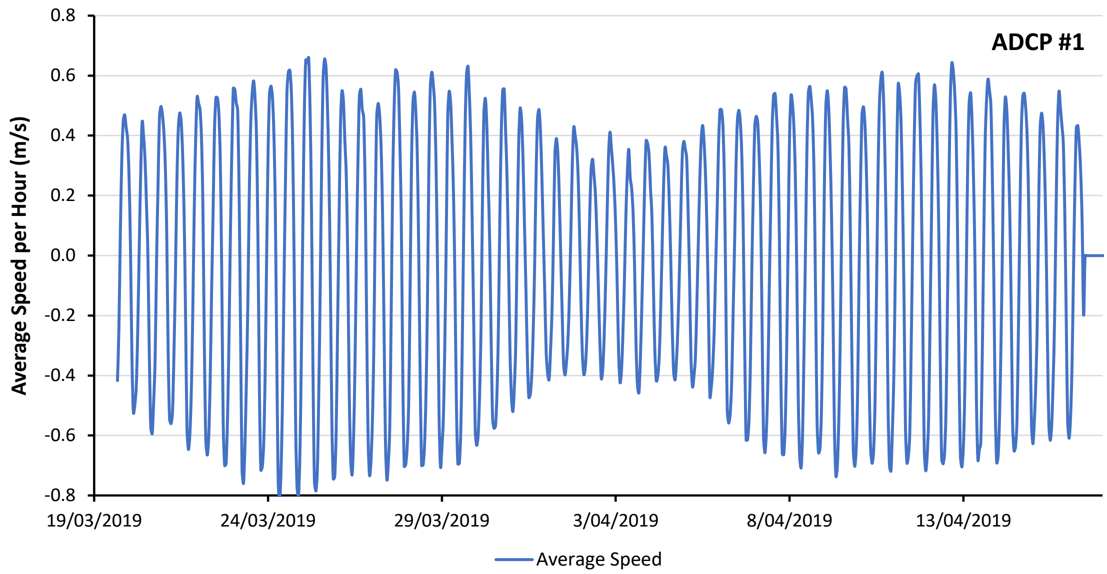


Figure 6-3. Mid-depth Currents Measured at Crib Point Jetty

Figure 6-4 is a schematic diagram of the hydrodynamic processes that influence dilution at slack water. At the discharge ports, the plumes are 7 °C cooler than the adjacent seawater and are therefore 0.8 kg/m^3 denser. At slack water, the plumes travel east from the FSRU and slowly descend to the seabed, spreading and diluting on the way due to shear between the descending plume and the ambient seawater. The subsequent calculations are for the proposed 6-port discharge at times of low current speeds. There is more dilution and less sinking at times of stronger currents.

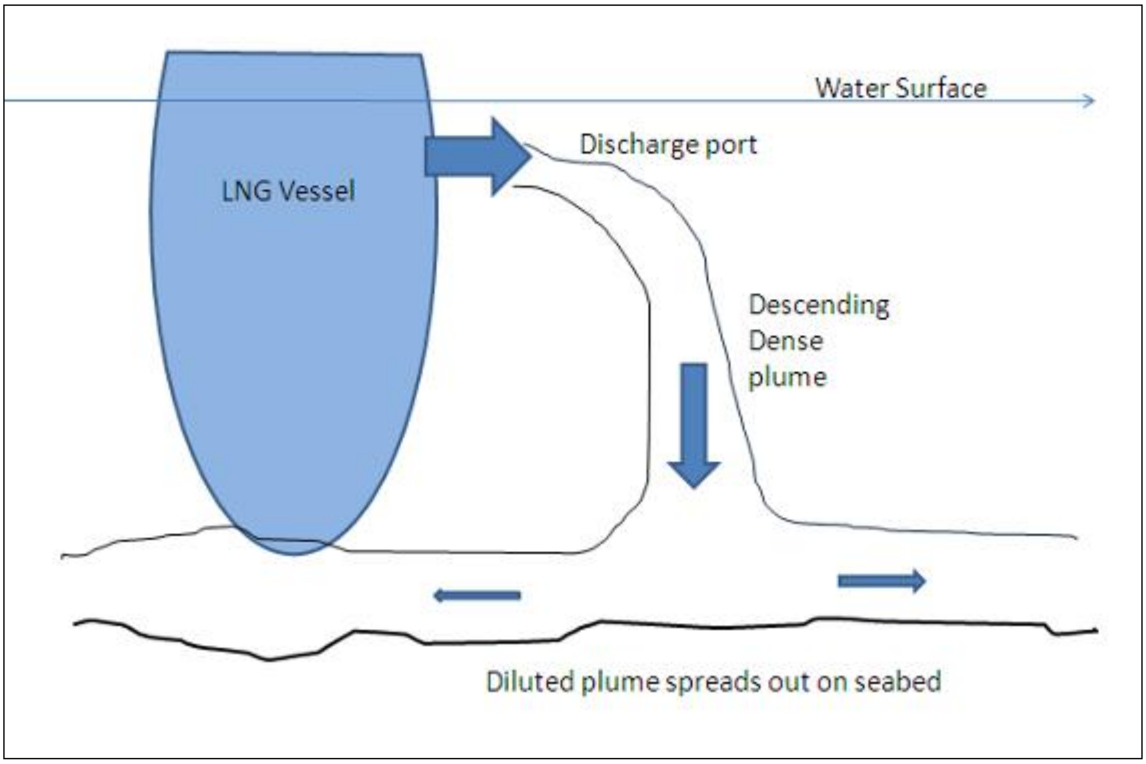


Figure 6-4. Diagram of Descending Dense Plume and Bottom Cold Pool

At slack water, a layer of diluted but still cooler seawater forms on the seabed under the discharge ports. The longshore currents at slack water are weak (the travel distance for a current of 0.05 m/s over 20 minutes is only 60 m) and so the cooler seawater accumulates in a "pancake" on the seabed. At the end of slack water (which lasts for about 20 minutes) the pancake is predicted to be up to 300 m in diameter and 1.5 m thick (effectively expanding to the length of the FSRU).

As the current speed increases, the layer thickness decreases, as the shear due to the tidal current strips the upper layer off the "pancake", while the currents also push the residual pool along the seabed. The behaviour was predicted in the CEE report on near-field modelling and has been observed to be reproduced by the regional multi-layer HydroNumerics model.

6.2.7 Estimated Vertical Mixing - Dynamic Richardson Number

The formation of the pancake of cooler seawater on the seabed and the subsequent erosion of the pancake as the tidal currents increase in the following tide was predicted by CEE in 2018 by calculating the rate of vertical mixing as a function of the Richardson Number. The vertical mixing rate is proportional to the shear velocity (effectively higher shear creates internal waves which create upward mixing) and inversely proportional to the density difference between the fluids (CEE, 2018).

The Richardson Number provides a method of estimating the rate of vertical mixing. If the Richardson Number is large, there is a large density difference between the pancake and the adjacent seawater compared to the shear from the tidal current. Thus, mixing is inhibited. As the current speed increases, the Richardson Number falls below the critical value of 0.25 and the pancake field is mixed into the passing seawater. The minimum mixing rate varies from 0.0002 m/s at a current speed of 0.1 m/s to 0.0010 m/s at a current speed of 0.5 m/s. These

may appear to be small, but they correspond to mixing rates of 0.72 m/hr to 3.6 m/hr, which are significant rates of mixing in comparison to the maximum pancake thickness of 1.5 m.

6.2.8 Dynamic Behaviour of Diluted Cooler Seawater Field

There are two distinct patterns for the dilution of the discharged cooler seawater:

1. The first pattern is at higher current speeds. When the tidal current speed exceeds about 0.08 m/s (which occurs for more than five of the six hours of a tidal cycle), the discharge plumes are entrained by the passing tidal flow and mix quickly through the water column.
2. The second pattern occurs at times of weak to zero current speeds at slack water. At these times (which occur for about 15 to 20 minutes each slack water), a field of diluted discharge forms on the seabed below the FSRU (the pancake) (Figure 6-4). As described above, this field accumulates for about 20 minutes during slack water and is eroded and transported away in the following 30 minutes as the current's speeds increase. These two distinct dilution patterns are seen in the predictions of both the near-field and regional hydrodynamic models.

6.2.9 Summary of Near-field Dilution Predictions

The near-field model INITDIL was used to predict the dilution for each of the discharge scenarios – open loop, closed loop, ballast water and minor discharges. The near-field plume modelling takes into account the interaction of the discharge plumes with the seabed and the water surface, and also accounts for the merging of adjacent plumes and the extra dilution at times of strong tidal currents. These predictions were applied as inputs in the regional hydrodynamic model.

Figure 6-5 shows the predicted near-field dilution for the FSRU operating in open loop mode with six high velocity ports. At slack water, the predicted dilution is 20:1 at 50 m distance along the plume (in this case, on the seabed). The corresponding temperature reduction at the seabed is 0.3 °C and the chlorine concentration is 5 µg/L. Higher dilutions, and lower temperature changes and chlorine concentrations, are predicted for times of stronger tidal currents.

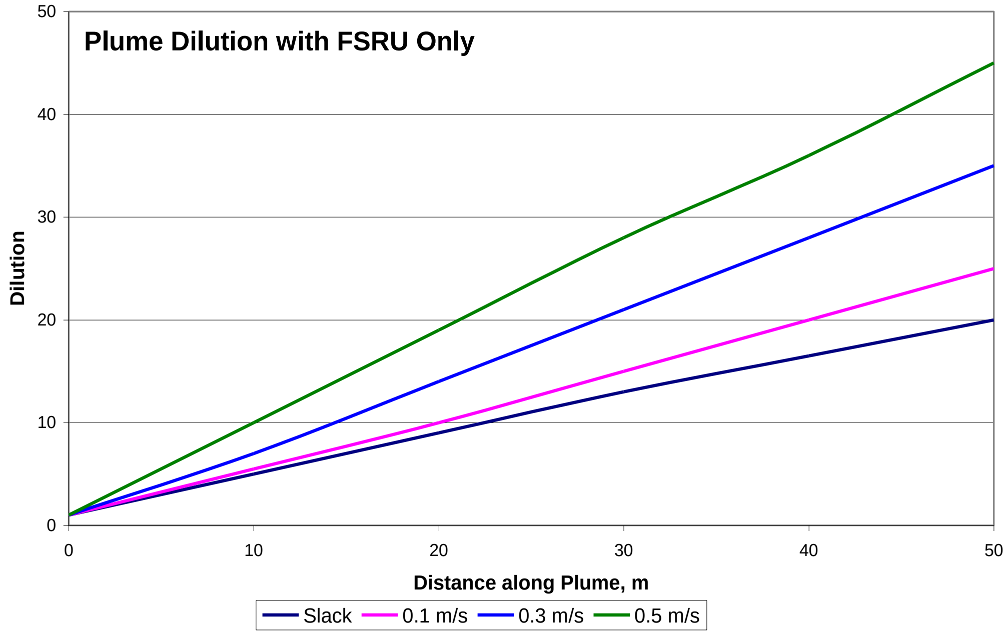


Figure 6-5. Plume Dilution with Distance (FSRU Only)

Figure 6-6 shows the predicted near-field dilution for the FSRU operating in open loop mode with an LNG carrier beside the FSRU. In this scenario, the high velocity ports are obstructed by the LNG carrier and the dilution is substantially reduced. At slack water, the predicted dilution is only 6:1 at 50 m distance along the plume (in this case, on the seabed). The corresponding temperature decrease on the seabed is 1.2 °C and the residual chlorine concentration is 17 µg/L. Low dilution is predicted because the discharge jets are obstructed by the LNG carrier.

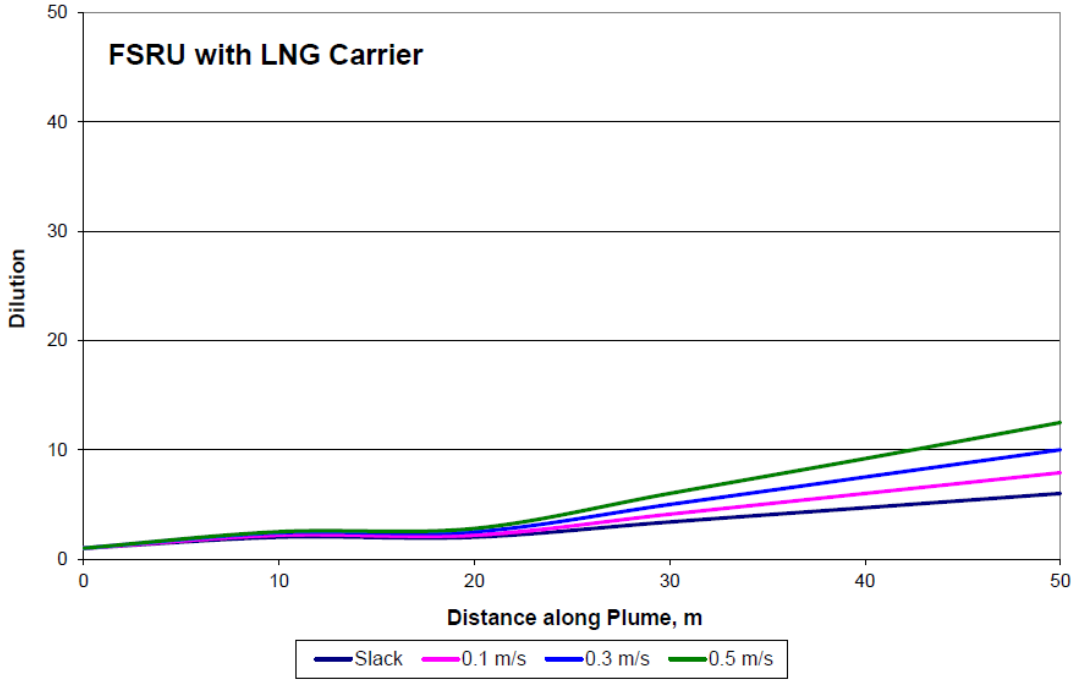


Figure 6-6. Plume Dilution with Distance (With LNG Carrier)

6.3 Regional Hydrodynamic Modelling

A regional hydrodynamic model was used to quantify:

- The extent of the discharge plume of cooler seawater on the sea floor;
- The extent of the discharge plume of warmer seawater in the water column;
- The distribution of residual chlorine in the discharged seawater; and
- The entrainment of plankton and larvae released from various zones in Western Port.

A three-dimensional (3-D) model of all of Western Port (AEM3D) was applied by HydroNumerics to quantify the outcomes for the four issues. The model was originally developed for Melbourne Water and EPA Victoria and was adapted to represent the discharges from the FSRU.

Western Port hydrodynamics have been studied extensively since the 1970's, with a number of studies using hydrodynamic models to simulate a range of processes including circulation, sediment transport, catchment inputs, water quality, algal production, seagrass meadows and mangrove habitats. These previous modelling studies provide guidance on the required attributes of a regional model for this Project.

Early two-dimensional (2-D) models by Hinwood and O'Brien (1974) and Hinwood (1979) reproduced the tide heights and tidal currents throughout Western Port. The addition of prevailing winds to the model produced a small residual circulation that moved clockwise around French Island. Tidal flows entered and exited mostly through the western entrance to Bass Strait. Other 2-D models were developed in the decades that followed and examined the fate of sediment loads into the bay (e.g. Hancock et al. 2001, Wallbrinket al. 2003, Hughes et al. 2003), or to investigate specific issues such as shipping (Lee, 2011).

More recent applications of 2-D depth-averaged models include higher resolution simulations of the whole Western Port bay down to 50-100 m grid scales in the navigation and port areas (Symonds et al. 2016). The models used, whilst different in terms of numerical solution and grid structure, consistently predicted hydrodynamic conditions that agreed well with measured data.

Two-dimensional models are usually considered adequate for representing circulation in well-mixed and rapidly flushed environments like Western Port. However, during the drought conditions from 1998 to 2011, salinity increased as high as 40 psu (practical salinity units) in the northern tidal mudflats of Western Port (Lee, 2011) so 3-D models were developed to simulate the processes of atmospheric heat exchange, evaporation and representation of stratified flow that is necessary to model density gradients. Harrison et al. (2011) applied 3-D models with grids of varied lateral resolution and six vertical layers. A 3-D model is required to predict plume behaviour in the FSRU operations.

More recent 3-D models of the whole Western Port bay have been applied with increased grid resolution (down to 50 m over tidal flats and channels in the northern sections of the bay) to simulate general circulation, sediment transport from catchments and bed load, light environment over seagrass meadows and mangrove seed dispersion (HydroNumerics, 2016, Cinque et al. 2018, and Hurst 2018).

The 3-D regional hydrodynamic model specifically simulated the formation, growth and subsequent erosion of the pancake of cooler seawater on the seabed under the FSRU and LNG carrier. The difference between the near-field model and the regional model is that the near-field model simulates dilution along the plume assuming a continuous supply of seawater

whereas the regional model simulates the reduced dilution in the situation of zero currents (so the same patch of water accumulates repeated parcels of the discharge over the period of slack water). This leads to a lower dilution than predicted by the near-field model.

6.3.1 Model Features

Previous modelling studies lead to a list of features that a hydrodynamic model should have to be fit-for-purpose for this assessment. The first group includes whole-of-bay circulation and detail in the Project study area at Crib Point, where the localised impacts of the FSRU are likely to occur. The second group focuses on the attributes required to adequately predict the extent of impacts from residual chlorine and temperature discharges, and the entrainment rates for plankton and other small biota constituents from various habitats in the Bay.

In summary, the model requirements are:

- Model domain that includes the whole of Western Port and part of Bass Strait so the model can reproduce the complex and interconnected processes that govern circulation of water within Western Port;
- Sufficient grid resolution to model flows that respond to complex bathymetric features such as the channels and tidal flats that make up a large portion of the Bay. This includes wetting and drying of shallow intertidal areas. Previous modelling suggested that grid resolutions of less than 400 m and down to 100 m are required to achieve this;
- Incorporating best available ocean boundary data, as this is the predominant forcing mechanism for bay hydrodynamics. This includes both tidal oscillations and atmospheric pressure-driven low frequency oceanographic oscillations;
- Heterogeneous surface wind forcing to account for the variability of the wind field over Western Port in response to topography, which has been demonstrated in previous modelling studies;
- Sufficient model grid resolution in the Project study area to account for the FSRU, local bathymetric features and near-field plume dynamics. These features have scales of less than 100 m;
- Capacity to model the influence of the FSRU on local flows and the changing position of discharge ports (relative to the seabed) during rise and fall of the tide, and the loading of LNG and export of gas from the FSRU;
- Three-dimensional grid to account for near-field plunging and dispersion of slightly dense (cooler) FSRU discharge and potential formation of cool water pools during slack tides;
- Vertical mixing that responds to changes in ambient shear, and reduced mixing during slack tide when cool water pooling occurs; and
- Particle release and tracking to provide estimates of entrainment into the FSRU intake of plankton and other small biota from different regions of the bay.

As noted above, the 3-D Aquatic Ecosystem Model (AEM3D) of Western Port (HydroNumerics, 2016, Cinque et al. 2018 and Hurst 2018) was customised to simulate the FSRU seawater intake and discharge at Crib Point Jetty. The key model changes were to incorporate a finer resolution grid at Crib Point (20 m by 20 m by 1 m deep) and to apply spatially and temporally varying oceanographic and meteorological boundary conditions sourced from the Bureau of Meteorology (BOM) OceanMaps regional modelling platform.

The model configuration included the simulation of the effects of the moored FSRU on local currents. To account for sub-grid scale near-field dilution of the FSRU seawater discharge, the near-field discharge plume model (as described above) was developed by CEE (2018a) and used to configure the initial conditions for the discharge plumes as a function of current speed in the regional model. The near-field plume model accounted for the processes of initial or exit momentum from the discharge ports, ambient current during discharge and the descent

under gravity that determine the location and dilution of the discharge plume in the near-field (i.e. up to 60 m from the discharge ports).

6.3.2 AEM3D Hydrodynamic Model

The AEM3D hydrodynamic model originates from the ELCOM-CAEDYM model developed 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), and has been applied to numerous estuarine and oceanographic systems (e.g. Chan et al. 2001, Spillman et. al. 2007, Hillmer and Imberger 2007 and Silva et al. 2014). AEM3D is currently applied to Western Port by Melbourne Water and was previously applied by EPA Victoria.

The hydrodynamics component in AEM3D predicts velocity, temperature and salinity distribution on a 3-D grid in water bodies subjected to external 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 large vessels. The simulation method 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 hydrodynamic algorithms in AEM3D are based on the Euler-Lagrange method for advection of momentum with a conjugate-gradient solution for the free surface. Passive and active scalars (i.e. tracers, salinity and temperature) are advected using a conservative scheme.

6.3.3 Bathymetry Inputs

The datasets used to develop the model bathymetry and grid were:

- Victorian Coastline DEM (VCDEM) raster data at 10 m resolution from Spatial Systems CRC – used for depths shallower than 30 m Australian Height Datum (AHD);
- Bass Strait Depth Zone Contour Lines (BSDZCL) from the 1:250,000 National Bathymetric Map Series from DELWP – used for depths greater than and equal to 30 m AHD; and
- Western Port DEM (WPDEM) raster data at 2.5 m resolution from Frontier SI (formerly Spatial Systems CRC) – used for Crib Point region.

The Victorian Regional Channels Authority (VRCA) provided a 0.5 m resolution bathymetric dataset for the region around Berth 2 at Crib Point Jetty. The data were interpolated to a 2 m grid. The VCDEM data was combined with the BSDZCL data to generate a 50 x 50 m model grid in the region around Crib Point, extending to 200 x 200 m grid then 500 x 500 m grid for the rest of the model domain.

Then a finer grid with 20 x 20 m spacing in the Crib Point region (in place of the 50 x 50 m grid portion) was developed. This grid provided higher resolution around the proposed FSRU location for the purpose of modelling discharge scenarios. The model grid had a vertical resolution of 1 m in the Project site and up to 8 m in the deeper regions at the Bay entrance and in Bass Strait.

6.3.4 Meteorological Inputs

The Australian Community Climate and Earth-System Simulator (ACCESS) weather model outputs were used at 1.5 km resolution and 1-hour time step to provide heterogonous meteorological inputs at the surface of the model domain. Meteorological and oceanographic inputs for the period from November 2018 to November 2019 were used for the modelling assessments.

6.3.5 Oceanographic Inputs

Data to define the ocean boundaries for the model were obtained from the Ocean Modelling, Analysis, and Prediction System (OceanMaps) supplied by the BoM at 3-hourly intervals with sea level, surface salinity and daily temperature profiles at 10 km spatial resolution. As the BoM OceanMaps model provides 3-hourly sea level without the tidal components, the Oregon State University's Tidal Data Inversion Software (OTIS) was used to generate an hourly time series of the tidal component of surface height based on the latitude and longitude of each boundary cell.

The daily vertical temperature profile from the OceanMaps model near the Bay entrance was used as the model boundary conditions for temperature and 3-hourly surface salinity used to define the salinity at the boundary. An example of the sea level at the ocean boundary is shown in Figure 6-7.

The upper panel in Figure 6-7 shows the regular tidal cycles, and the weekly variation from spring tides to neap tides and back to spring tides. The lower panel illustrates the low frequency sea level changes by a 14-day moving average of the hourly tidal data. The long period variations can be up to +/- 20 cm over a period of a week or more.

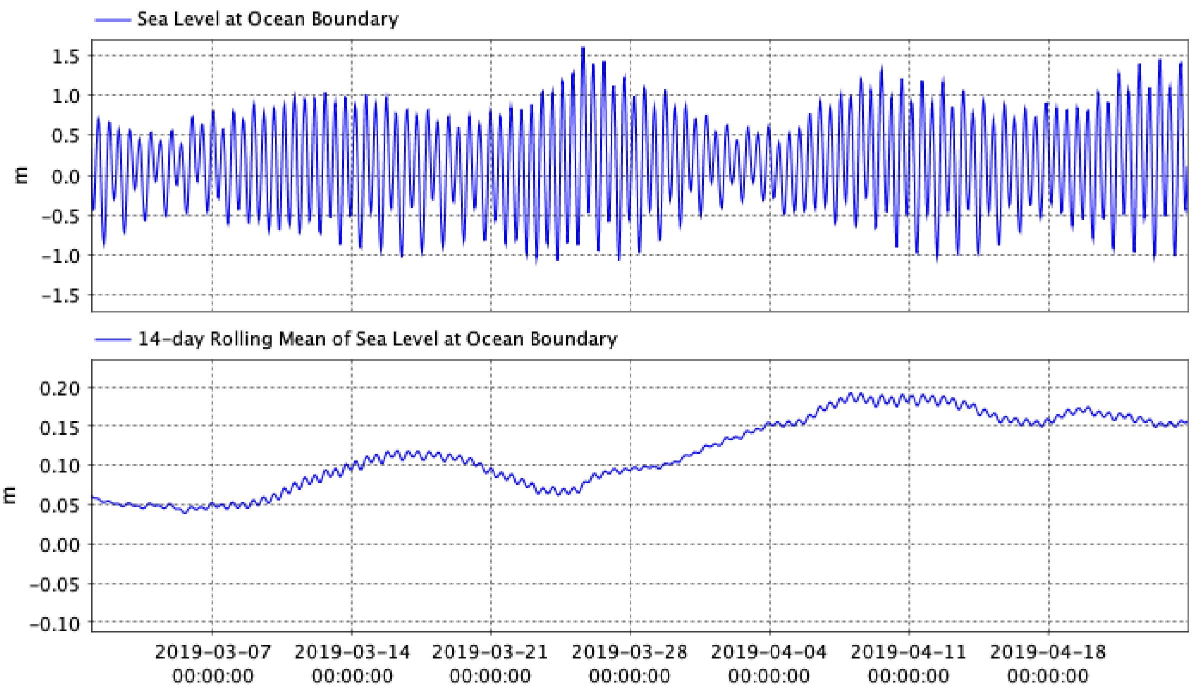


Figure 6-7. Sea-level at the Ocean Boundary during March-April 2019

6.3.6 Model Calibration

The model performance was checked against the ADCP water level measurements collected in March and April of 2019. Figure 6-8 shows the comparison between predicted and measured surface water levels across the three ADCP locations while Figure 6-9 shows the comparison over time for the Crib Point ADCP site.

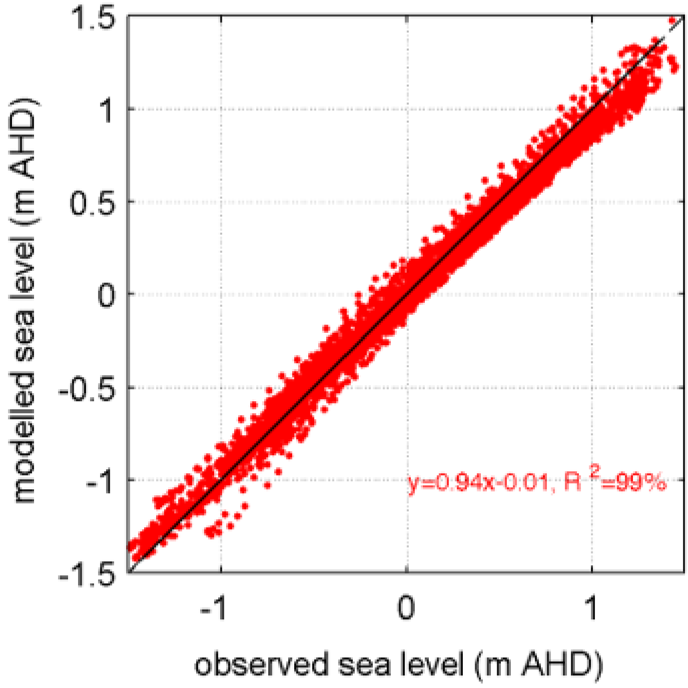


Figure 6-8. Comparison of Predicted and Measured Sea Level at Three ADCP Sites

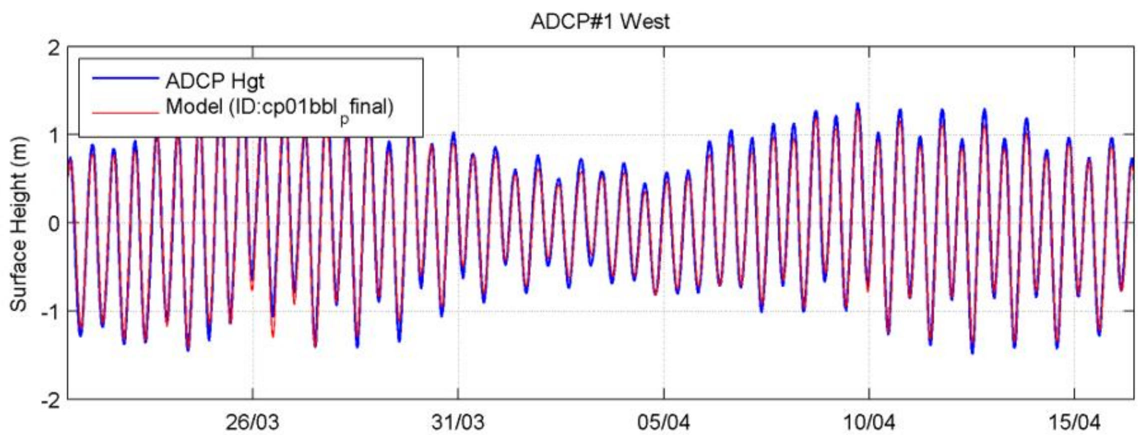


Figure 6-9. Comparison of Predicted and Measured Sea Level at Crib Point Site

The current speed predictions from the model were checked against the ADCP current measurements for the same period in March and April of 2019. The model was calibrated by adjusting the bottom drag, mixing energy dissipation rate and mixing rate, as described below. The 50 x 50 m grid was mostly used for calibration because it allowed for faster simulation times. Duplicate tests using the 20 x 20 m grids demonstrated comparable results for the same parameter settings.

The bottom drag coefficient (C_d) was adjusted to match the drag used in previous projects (Harrison et al. 2011 and HydroNumerics, 2016) to account for different bed characteristics in the Bay, the most pronounced being the difference between unvegetated sandy bed and seagrass vegetated bed. Drag values were low to moderate (C_d = 1 x 10^{-3} to 5 x 10^{-3}) in the sandy channels and high on seagrass meadows (C_d = 0.15) and fringing mangrove stands (C_d = 0.25).

The coefficient of dissipation (C_e) was then optimised. High coefficient values result in rapid dissipation of vertical mixing energy that reduces the momentum loss at the bottom via friction. As C_e approaches 1, the predicted current velocities were faster (particularly near the surface) than the observed currents because of a lack of momentum loss at the seabed. Low values of C_e (<0.1) lead to sustained mixing energy and improved the correlation between modelled and observed currents.

The third parameter that was adjusted was the mixing time rate coefficient (Ct). By applying a small value of Ct, vertical mixing is rapid and completed within each model time step, and so only a small amount of remaining energy is dissipated later. For larger coefficients, Ct ~ 50, there is only partial mixing within a model time step.

Because of the strong tidally driven flows in Western Port, the processes of bed shear and internal shear are the dominant mechanisms generating mixing energy in the water column and are a function of the bottom drag. Different combinations of bottom drag, dissipation rate, and mixing rate produced similar predictions of currents; with the exception of cases with weak vertical mixing (i.e. high values of both C_e and Ct). The calibrated model uses the heterogeneous bottom drag coefficient map (as described above), low dissipation rate coefficient of C_e = 0.018 and high mixing time rate coefficient Ct= 50.

The small discrepancies between the predicted and measured results have a very minor influence on the impact assessment of the FSRU operation. They are addressed in the Hydrodynamics report (HydroNumerics, 2019) and are summarised below.

The six panels in Figure 6-10 are as follows:

- Predicted (blue) and measured (red) north/south currents at 9 m above seabed;
- Predicted (blue) and measured (red) east/west currents at 9 m above seabed;
- Predicted (blue) and measured (red) north/south currents at 5 m above seabed;
- Predicted (blue) and measured (red) east/west currents at 5 m above seabed;
- Predicted (blue) and measured (red) north/south currents at 2 m above seabed;
- Predicted (blue) and measured (red) east/west currents at 2 m above seabed.

The model reproduced the tidal pattern of currents very well, including the timing of changes in the observed current direction.

The simulated north-south currents match the measured currents at the three depths very well at 2 m and 5 m above the seabed, but slightly over-estimate the peak current speeds at the surface on the spring tides, although are a close match on the neap tides. This difference on the spring tides will tend to slightly over-estimate the extent of impact.

The simulated east-west currents match the measured currents at the three depths every well at all three depths. The east-west current components are small throughout the tide cycles, with noticeable east-west currents only at slack water. At slack high water, the model shows a small net current to the east, which is generated by the flow of water from the shallow banks near the shore (where the tide turns 10 minutes before slack water in the channel).

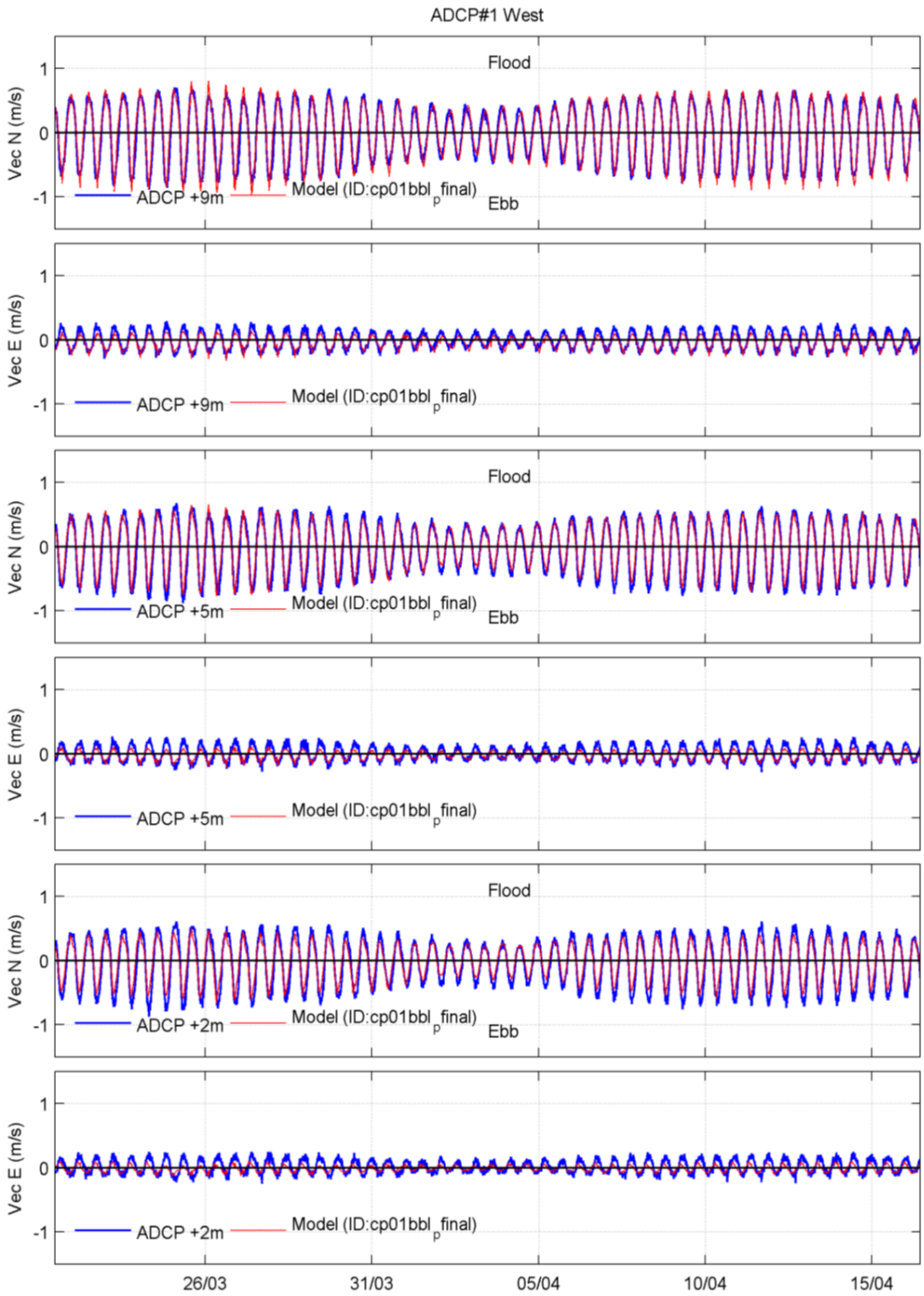


Figure 6-10. Comparison of Predicted and Measured Currents at Crib Point Site

Overall, the comparison shows that the model provides a satisfactory prediction of the variation in currents at Crib Point with time and through the vertical profile. The net water transport is well resolved. Further comparisons are provided in the Hydrodynamics report (HydroNumerics, 2019). The dominant north/south tidal currents are predicted well.

Figure 6-11 shows a comparison of the predicted (red arrows) and measured (blue arrows) average currents at Crib Point. There is reasonable agreement, although the model shows a higher current to the south. Figure 6-12 shows a comparison of the predicted (red arrows) and measured (blue arrows) 75 percentile surface currents at Crib Point. There is good agreement for both current speed and current direction.

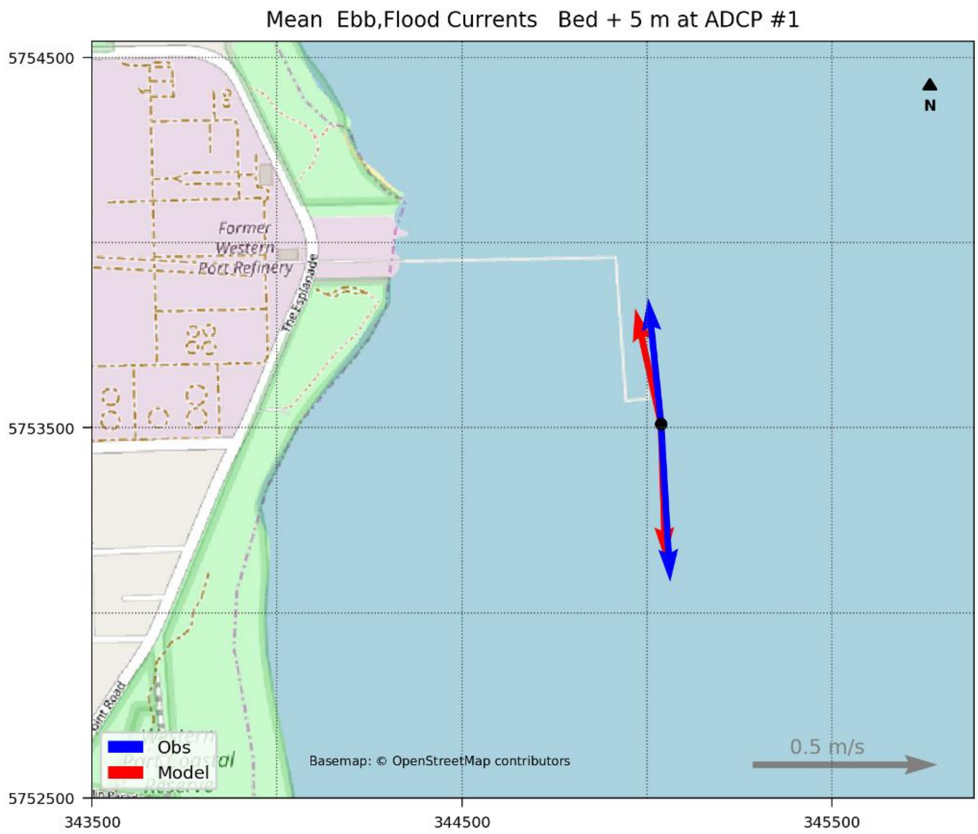


Figure 6-11. Comparison of Predicted and Measured Mid-depth Currents at Crib Point

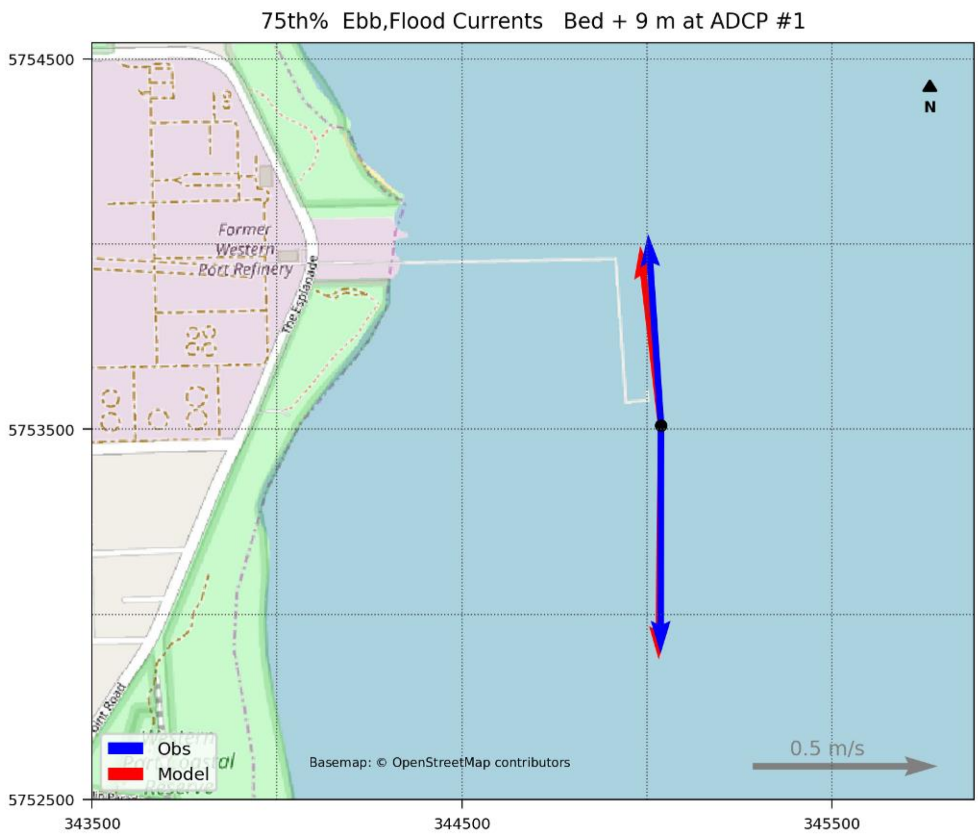


Figure 6-12. Comparison of Predicted and Measured Surface Currents at Crib Point

Figure 6-13 shows the spatial pattern of north/south currents from the regional hydrodynamic model for a section across from Crib Point for a flood tide (incoming tide with orange speed contours) and an ebb tide (outgoing tide with blue speed contours). The figure shows that currents speeds increase with height above the seabed. Also, current speeds are slower in shallower water inshore at the jetty, on the sand bar and near French Island to the east. Peak currents on the incoming tide are up to 0.65 m/s (to the north), and peak currents on the outgoing tide are up to 0.75 m/s (to the south).

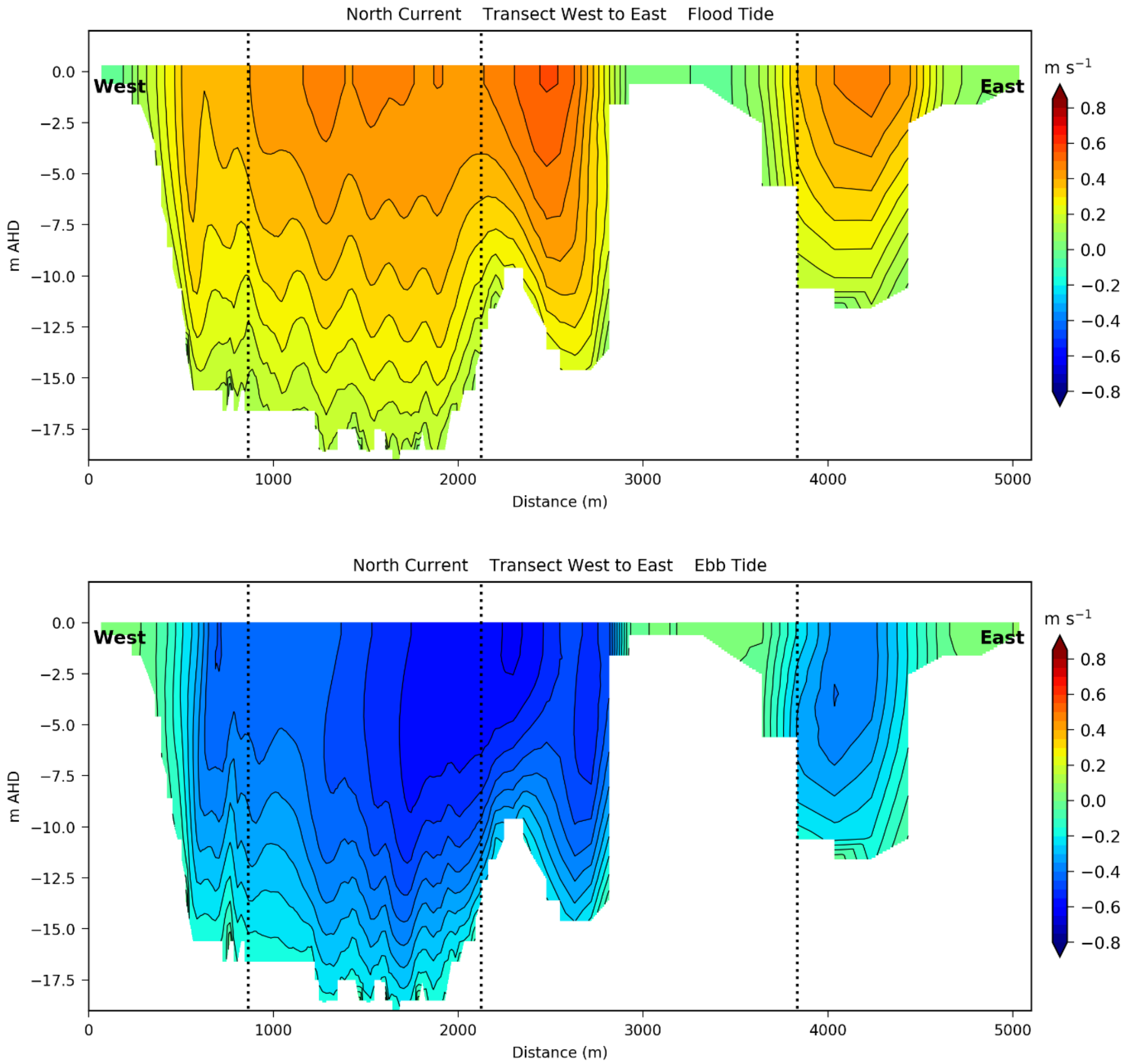


Figure 6-13. Spatial Pattern of Predicted Currents at Crib Point

The large spatial variation in currents is apparent in Figure 6-13. This is part of the reason why the predicted and measured currents cannot match precisely, as the model is predicting currents in a 20 m by 20 m by 1 m grid while the ADCP measured currents on a single vertical line.

Both the model predictions and the ADCP current measurements show a small net flow to the south at the west meter and a small net flow to the north at the east meter.

6.4 Temperature Predictions

This section describes the use of the near-field and regional hydrodynamic models to predict the effects on seawater temperature from the discharge of cooler seawater when the FSRU is operating in the open loop mode, and from the discharge of warm seawater when the FSRU is operating in the closed loop mode.

In the open loop mode, seawater would be pumped from Western Port into the FSRU, passed through heat exchangers and discharged back into the Bay 7°C cooler than the ambient seawater. Model simulations assume a consistent temperature decrease of 7°C.

There are three heat exchangers (regasification units) on the FSRU, each with two ports. Thus, depending on the level of gas production, two, four or six ports would be operating. An indicative month-by-month gas production is shown in Section 1.0. Peak gas production involves discharge through six ports on the east side of the FSRU, along with ballast and minor discharges from other ports at the rear of the vessel.

Peak production has been modelled as a worst case; and average production (two trains) and one-third production (one train) have also been modelled for comparison. Average production involves discharge from two regasification trains through four ports.

6.4.1 Guideline Value for Temperature Change

As stated in Section 5, the Guideline Value adopted for temperature change is the interquartile range calculated from the 2019 temperature records on a 6-hourly, 12-hourly and 24-hourly basis. The calculated value of 0.5 C represents the short-term variability in water temperature that the local biota are currently accustomed to. A significant exceedance of this temperature change in ambient seawater could cause stress to the marine biota, and the Guideline Value is defined as a small temperature change, within the range of natural variations, that should avoid stress.

6.4.2 Near Field Modelling of Discharge Plumes

The near-field model is to used predict the path and dilution of the discharge plumes close to the discharge ports, and provide a detailed plume pattern for input into the regional model.

CEE modelled the trajectory of the discharge plumes using a 3-D plume model that takes account the entrainment of seawater around the perimeter of the plume, conservation of mass, conservation of lateral momentum (with entrainment into the plume of seawater from a northward or southward current), and conservation of vertical momentum (allowing for the effect of gravity in pulling the slightly dense plume towards the seabed).

With faster currents, the plumes entrain the transverse momentum of the ambient tidal current more rapidly and the combined plumes turn with the current, thereby limiting the lateral (east) travel. Due to the high initial velocity of the plumes (with a discharge velocity greater than or equal to 5 m/s), there is always a significant initial dilution, which increases as the tidal current speed increases.

With weaker currents, there is more lateral travel, and also greater sinking of the discharge plumes towards the seabed. The resultant combined plume geometry, for a range of current speeds, is set out in Table 6-4. At times of weak or zero current (which occurs for about 20 minutes at slack water per tide - when the current speed is 0.03 m/s or less) the temperature at the end of the diluted plume is approximately 0.3°C cooler than ambient seawater. The median current is 0.4 m/s and the extra mixing with this current means that the seawater temperature difference at the end of the diluted plume is only 0.14 C cooler than ambient.

6.4.3 Regional Modelling of Plumes

The regional model predicts the dilution and extent of the temperature changes in the region of the FSRU. To provide sufficient detail to match the initial plumes, a 20 m x 20 m model grid was used in the area of the FSRU, with a larger grid at distance.

The near-field model outputs (Table 6-4) defined the initial 'footprints' of the seawater discharge in the regional model. The FSRU seawater discharge was represented in the regional model by continually updating the seawater temperature of the model cells in the plume footprint (as determined by the near-field model) at each time step of the regional model.

The temperature in the defined cells east of the FSRU (Δt) was reduced in each model time-step (of 20 sec) to achieve conservation of heat:

$$\Delta t = 5.4\frac{m3}{s} x\ 7\ oC\ x\ 20\,\mathrm{sec}\ \div (volume\ of\ nominated\ cells, m3)$$

The subsequent movement and dilution of the diluted seawater discharge is governed by the modelled flow in the regional model. The FSRU was the only source of heat change (i.e. no additional boundary and atmospheric exchange is included in the model) so the results identify only the impacts to seawater temperature that are produced directly by the FSRU discharge.

The effect that the FSRU hull has on local flow around the vessel was taken into account in the regional model. The effect of exchange of heat with the atmosphere is very small on the cumulative effects of discharge of cooler seawater (refer to Section 8). If the atmospheric exchange of heat is included, the predicted temperature contours are marginally smaller than shown in this Section (so the plotted results show the "worst-case").

6.4.4 Discharges in Open Loop Operation

As shown in Table 6-1, during peak open loop operation there is a large seawater discharge from the six regasification ports as well as additional minor discharges at the rear of the vessel from the freshwater generator and seawater filter.

The minor freshwater generator and seawater filter flows from the FSRU in open loop operation are much smaller than the seawater discharge from the regasification trains and are not below ambient seawater temperature. Therefore, they do not contribute to temperature changes in the receiving waters. Thus, the minor flows are not included in the temperature assessment for open loop, which focuses on the large discharge of cooler seawater from the six regasification discharge ports. The flows used in the temperature assessment are 468,000 m^3/d for peak mode (6 ports) and 312,000 m^3/d for average mode (4 ports).

The FSRU would need to be refilled with LNG 12 to 40 times per year depending on the rate of sales of gas to the Victorian gas network. The refilling operation involves an LNG carrier mooring on the starboard side of the FSRU and transferring LNG via temporary connecting flexible cryogenic hoses. During the transfer operation a seawater curtain is sprayed in the 5 m space between the FSRU and the LNG carrier for the whole period of LNG transfer. There is also an emergency firewater system that is tested for 1 hour every two weeks. The water curtain and fire water use ambient seawater and have negligible effect on the seawater temperature distribution.

When LNG is added to the FSRU, there would be an intermittent discharge of ballast water as set out in Table 6-3. The ballast tanks are assumed to be discharged (total volume of approximately 53,500 m^3) during the period of transfer of LNG to the FSRU - expected to take from 24 to 36 hours (depending on the size of the LNG carrier). The ballast water is discharged at ambient seawater temperature from a point near the rear of the FSRU. The fire water and

water curtain are minor volumes of flow which are also discharged at ambient temperature. Therefore, the intermittent flows have negligible effect on the seawater temperature distribution and hence do not need to be included in the temperature modelling.

When the LNG carrier is moored beside the FSRU it obstructs the six high velocity jets discharging the open loop cooling water. This would substantially reduce initial dilution. The effects of this obstruction are represented in the model predictions presented in the following sections.

6.4.5 Flow Pattern with Moderate to Strong Currents – Peak Open Loop Production

As explained in Section 6.2, there are two distinct patterns for the dilution of the discharged cooler seawater in open loop operations. The first pattern is at higher current speeds, when the tidal current speed exceeds about 0.08 m/s. In this pattern, the plumes are entrained by the passing tidal flow and mix quickly through the water column.

Figure 6-14 shows an example of a simulated plume entrained in the tidal current at peak open loop production. The upper panel provides tidal information. The blue line is the tide height, and the green line is the current velocity. The dots represent the point in the tidal cycle (peak ebb current of -0.5 m/s) from which the simulations in the lower panel were generated.

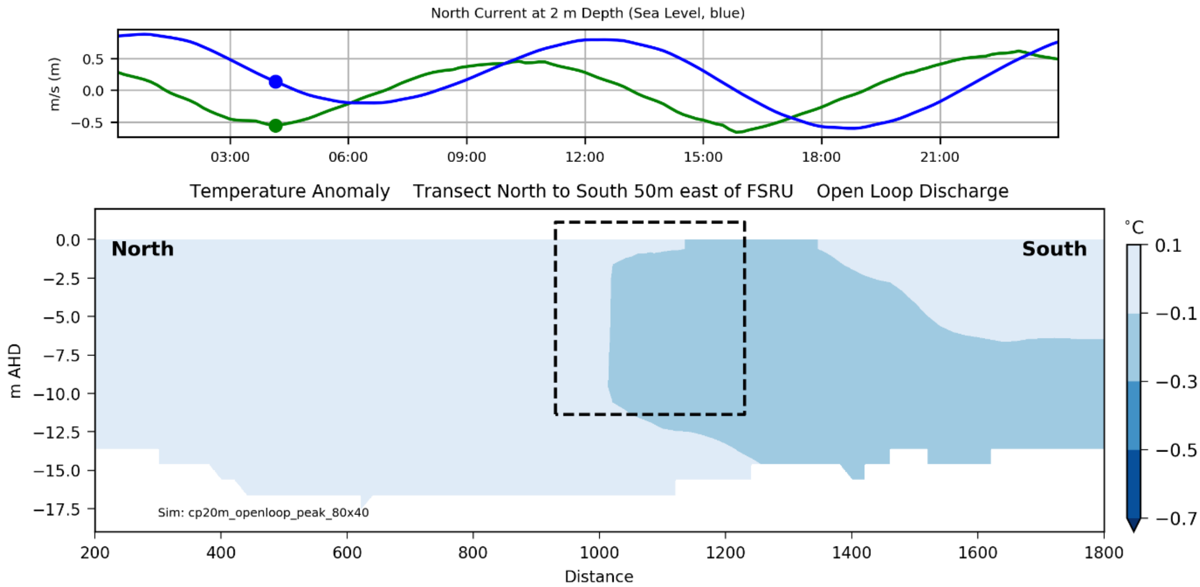


Figure 6-14. Cross-section North to South of Simulated Temperature Anomaly

The lower panel (Figure 6-14) shows a north to south cross-section through the water at 50 m east of the FSRU. The proposed location of the FSRU is shown by the black dotted rectangle (note the different horizontal and vertical scales). The light blue shading shows ambient seawater travelling from the north (on the left) to the south (as occurs during the ebb tide in Western Port). The ambient seawater temperature anomaly (i.e. change from ambient seawater temperature) is represented as being between – 0.3°C and +0.1°C (respective of ambient seawater temperature) on the temperature scale on the right of the figure and effectively represents ambient seawater temperature. Note the variation in seabed topography shown by the varying depths along the section – the maximum depth is 16 m at the front of the FSRU.

The diluting plume is shown by the darker blue shading that extends south from the FSRU. Immediately south of the FSRU, the diluted plume occupies the full water column from the surface to the seabed, and the centreline of the plume gradually sinks down towards the seabed under the influence of gravity. The ambient seawater temperature anomaly in the

plume is shown as being between 0.1°C and 0.3°C (i.e. typically about 0.2°C reduction from ambient seawater). This corresponds to a dilution of 23:1 (for 0.3°C temperature decrease from ambient seawater) to 35:1 (for 0.2°C decrease).

In summary, with moderate to strong currents, the plumes are entrained by the passing tidal flow and mix quickly through the water column. Based on the frequency distribution for tidal currents at Crib Point, this flow pattern occurs for approximately 95 % of the time (current speed > 0.05 m/s – refer to Figure 5-6, Section 5).

Diluting Plume in Moderate to Strong Currents – Peak Open Loop Production

Figure 6-15 shows a plan view of the same plume at mid-depth from open loop operations at peak production, halfway through the ebb tide. The location of the FSRU is shown by the black rectangle. The Crib Point Jetty and the shoreline can be seen to the west of the FSRU.

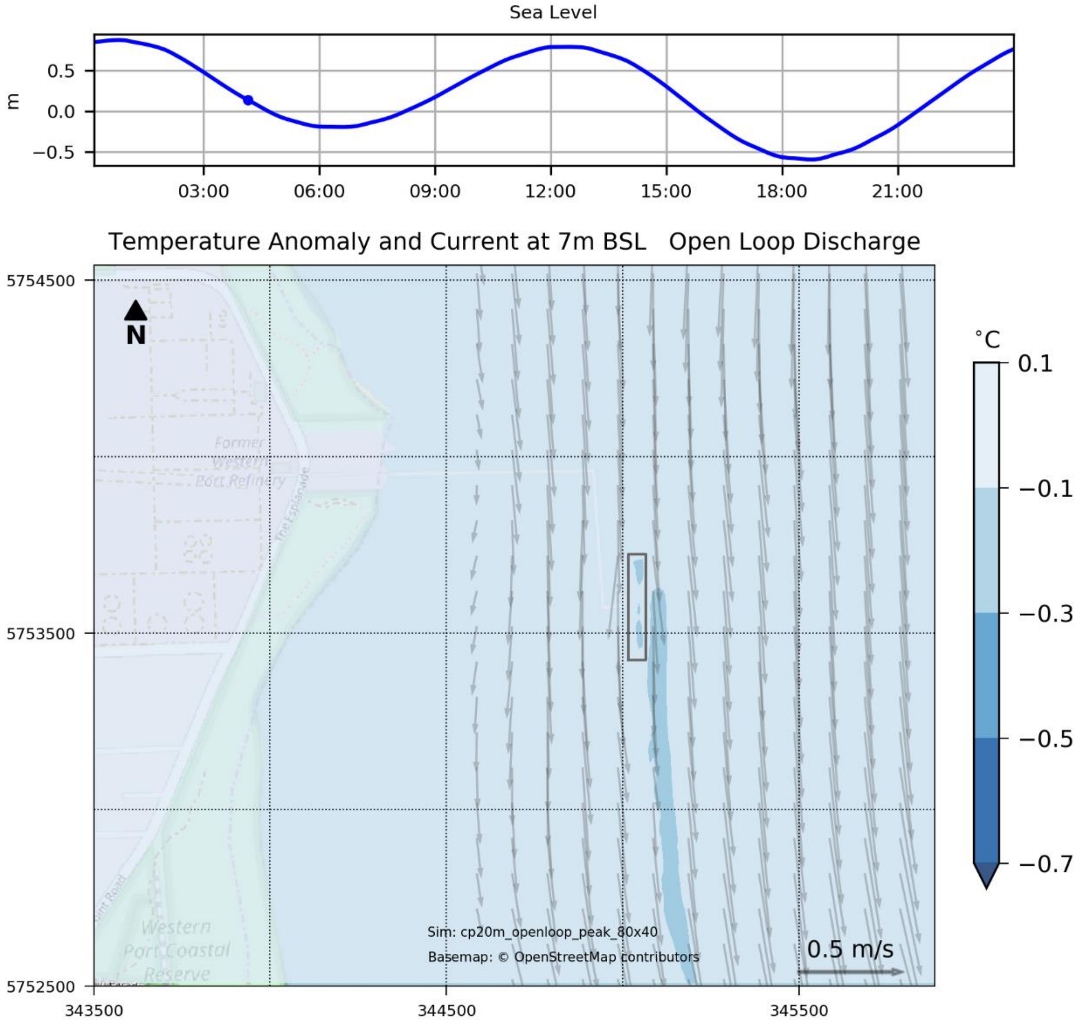


Figure 6-15. Plan View of Simulated Temperature Anomaly: (7 m below Sea Level during Ebb Tide)

The arrows on the light blue shading in the lower panel show ambient seawater travelling from the north to the south (as occurs during the ebb tide in Western Port). The diluting plume at mid-depth is shown by the slightly darker blue shading that extends a kilometre south from the FSRU. The temperature reduction in the plume at mid-depth is between 0.1°C and 0.3°C below ambient seawater (i.e. typically a 0.2°C reduction below ambient, corresponding to a dilution of about 35:1).

Comparison with Guideline Value for Temperature Change

As identified in Table 5-8 (refer to Section 5), the Guideline Value for seawater temperature change in the area of Crib Point is 0.5°C. The largest predicted temperature change with moderate to high currents is 0.3°C and thus within the Guideline Value limit.

6.4.6 Flow Pattern with Weak Currents – Peak Open Loop Production

This section shows the predictions of the regional model for the second flow pattern – with weak currents at slack water. Based on the frequency distribution for tidal currents at Crib Point, this flow pattern occurs for approximately 5 % of the time (current speed < 0.05 m/s – refer to Figure 5-6, Section 5).

Figure 6-16 shows a north to south cross-section through the water column at low tide slack water, for the section at 50 m east of the FSRU.

The diluting plume is shown by the darker blue shading that extends from the discharge ports on the FSRU down to the seabed. The combined plumes extend to the east of the FSRU due to their discharge momentum and then sink towards the seabed where the cooler seawater spreads radially as a dense flow. The lowest temperatures occur on the seabed under the discharge ports, and are about 0.7°C below ambient seawater. This corresponds to a dilution of only 10:1 (for 0.7°C reduction). The cause of the low dilution is that the same patch of seawater receives a continuing stream of discharge with little movement of the patch.

A wide shallow layer of diluted cooler seawater forms on the seabed. The section in Figure 6-16 intersects the descending plume which is the vertical column of cooler seawater. The 0.5°C temperature anomaly extends for about 200 m along the seabed. At the front of the FSRU, the simulated plume is about 1.5 m thick.

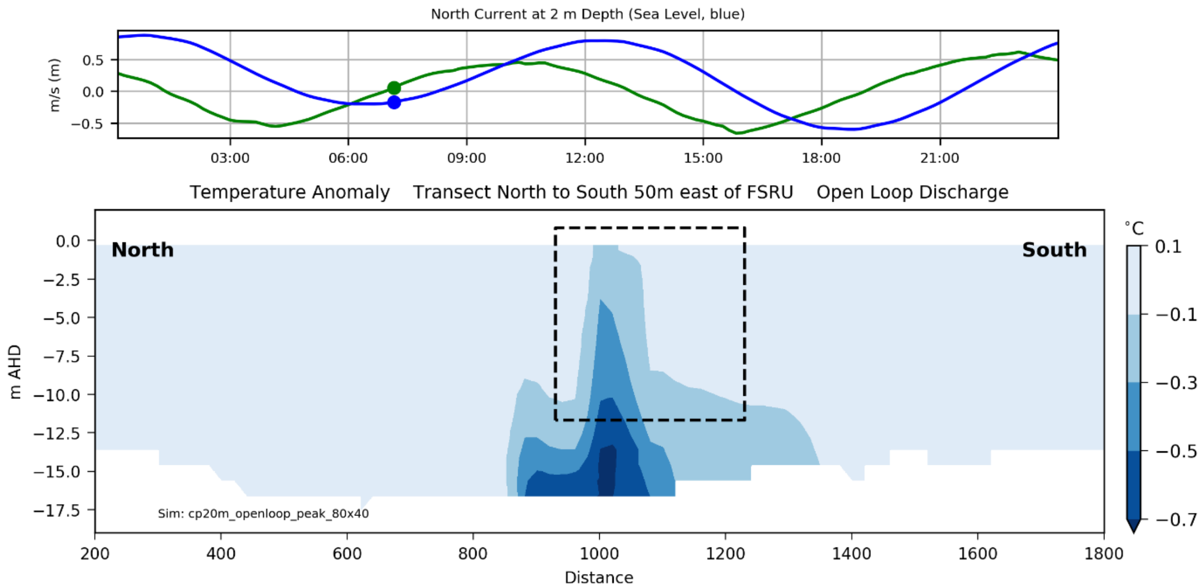


Figure 6-16. Cross-section North to South of Simulated Temperature Anomaly (Slack Low Tide) Plan View of Diluting Plume with Weak Currents – Mid-depth and Seabed

Figure 6-17 shows a plan view of the plume near slack water at mid-depth for open loop operations at peak production. The sea level plot (blue line in upper panel) shows the simulation is at slack water after an ebb tide.

The arrows on the light blue shading in the lower panel show ambient seawater turning from the south to the north (as occurs at the end of the ebb tide in Western Port). The diluting plume is shown by the darker blue shading that extends beneath and just to the east of the FSRU.

The ambient seawater temperature anomaly in the plume at mid-depth is mostly between 0.1°C and 0.3°C with a small area of 0.3°C to 0.5°C temperature reduction adjacent to the discharge ports.

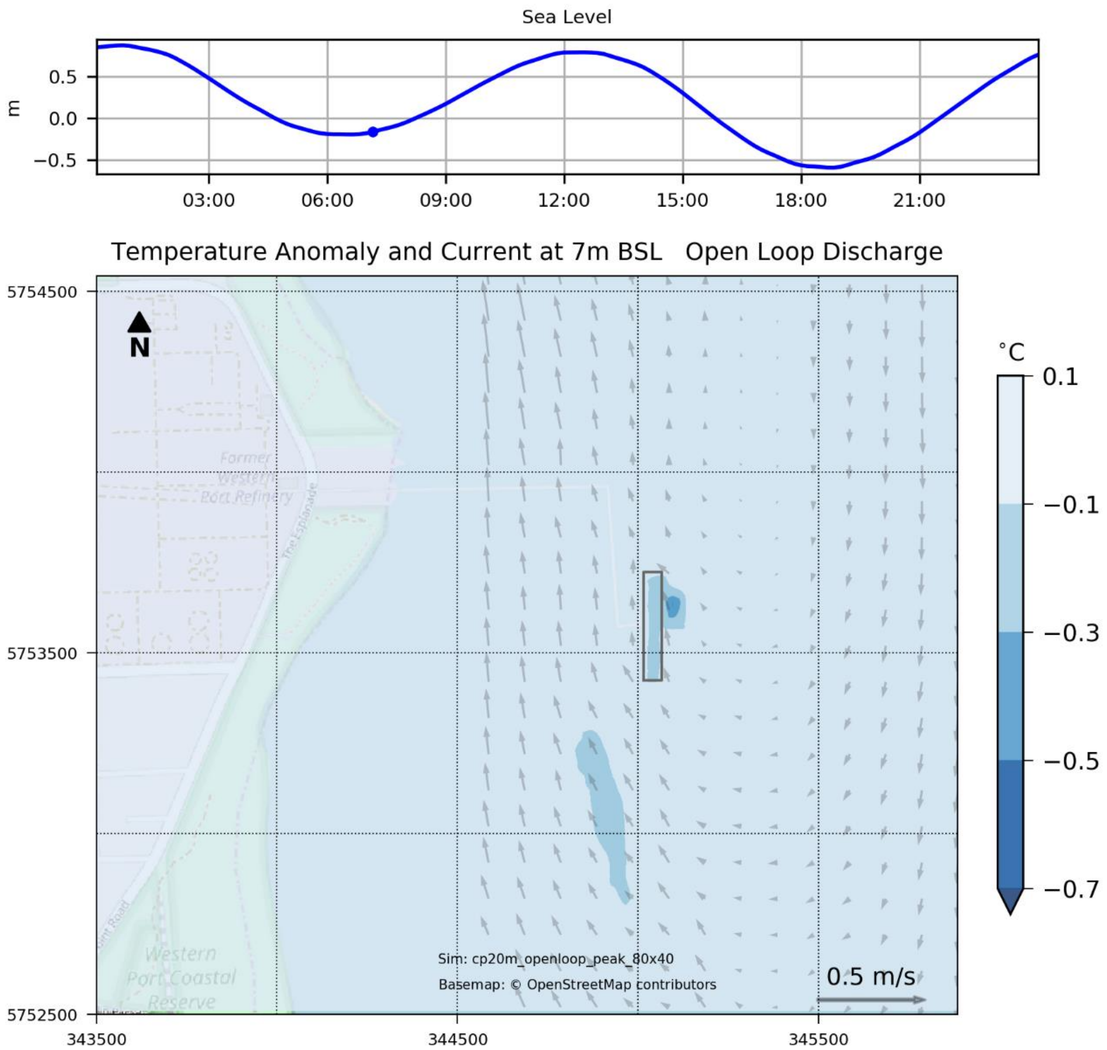


Figure 6-17. Plan View of Simulated Temperature Anomaly (Mid-depth at Slack Low Water)

It is apparent from the cross-section in Figure 6-16 that the temperature anomaly is greater on the seabed than at mid-depth. Thus, Figure 6-18 shows a plan view of the plume near slack water, but at the seabed.

The long, diluted plume that extends more than 1 km to the south (remnant plume from the ebb tide) is apparent with a seawater temperature anomaly between 0.1°C and 0.3ºC below ambient seawater. Just under the discharge ports of the FSRU is a small area of 0.5°C to 0.7°C below ambient seawater temperature.

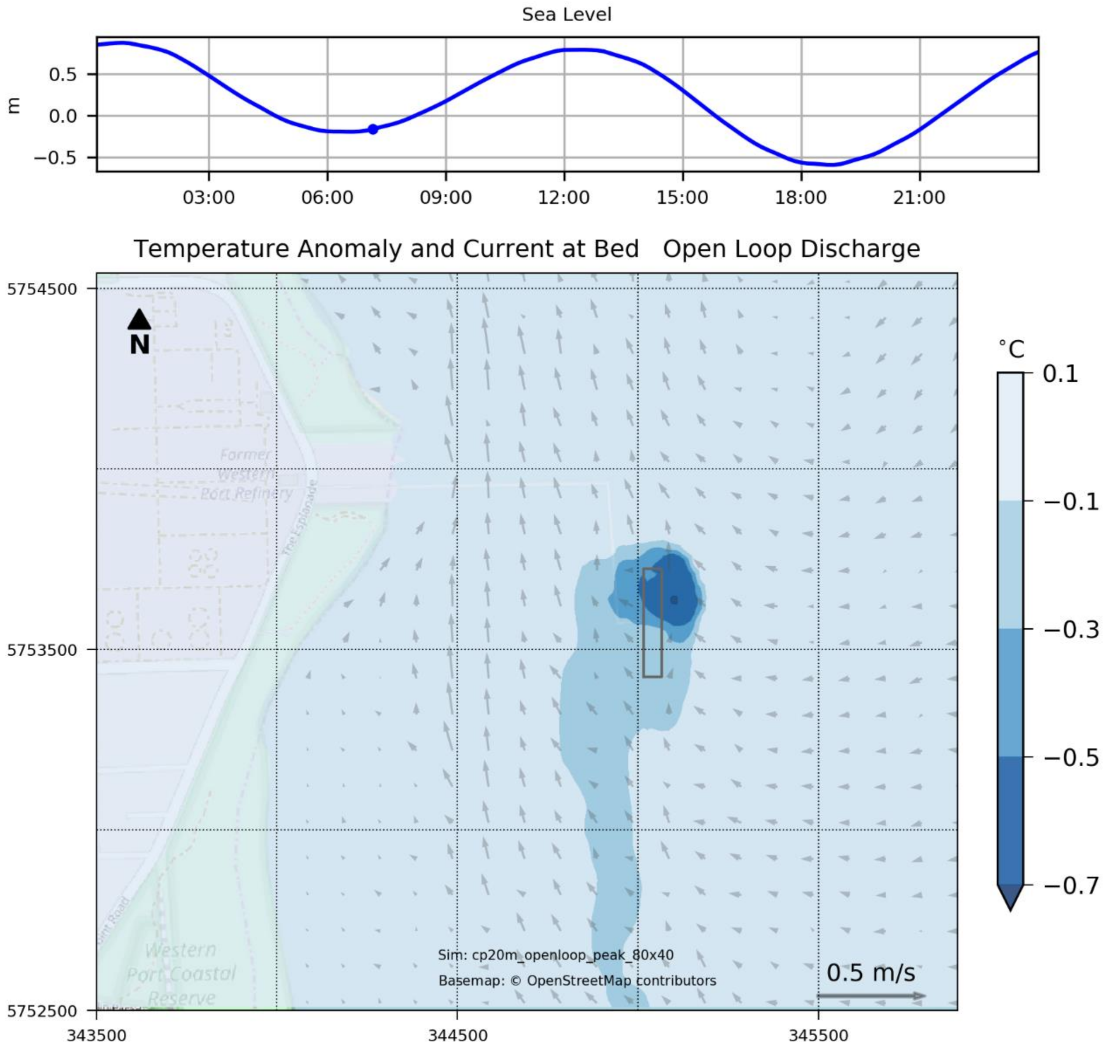


Figure 6-18. Plan View of Simulated Temperature Anomaly on Seabed

6.4.7 Comparison with Guideline Value for Temperature Change

As identified in Section 5, the guideline value for temperature change in the area of Crib Point is 0.5°C. It is evident that the predicted temperature change at peak open loop production with low currents is more than 0.5°C over a small area of seabed near the FSRU for a short period over slack water.

Seawater temperature conditions at mid-depth with weak currents comply with the Guideline Value limit of 0.5°C. There is a small area just under the discharge ports of the FSRU (about 180 m diameter) on the seabed above the Guideline Value limit of 0.5°C for a brief period each slack water. The seawater temperature anomaly in the centre of the patch reaches about 0.8°C.

In summary, in open loop operations at peak production, during each slack water a small zone of about 180 m diameter on the seabed under and adjacent to the FSRU that exceeds the Guideline Value temperature change of 0.5°C (up to around 0.8°C). The zone extends over the lower third of the water column. Note, however, that the Guideline Limit for seawater temperature change is a 12-hour moving average. Over the 12-hour period, the seawater temperature change on the seabed is within the Guideline Value limit of 0.5°C.

6.4.8 Temperature Impacts During Open Loop (FSRU Only)

Open Loop Peak Production (FSRU Only)

Figure 6-19 shows the peak (5 percentile) contours of seawater temperature with peak open loop production and only the FSRU at Berth 2. The outer temperature contour is a reduction of 0.3°C and the small inner contour is a reduction of 0.5°C. The area of seabed with a temperature anomaly of 0.5°C below ambient seawater is about 100 m long north/south and about 80 m wide east/west, with an area of 0.7 ha. This zone corresponds to the location of the six discharge ports on the side of the FSRU.

Figure 6-21 shows a time series plot of seawater temperature for the same case of peak open loop production and only the FSRU at Berth 2. For reference, the tide height is shown in the top panel. The lower panel shows the temperature anomaly (reduction) at the seabed under the FSRU discharge ports. The trace shows that the periods of low temperature are episodic, occurring for about 30 minutes every slack water (or about 7 % of the time). Thus, the contours of the 5-percentile temperature change shown in Figure 6-19 capture the events with large temperature decrease.

The events with a large temperature decrease at the seabed correspond to the times when the "pancake" of cooler seawater forms on the seabed in slack water, as described earlier. The temperature decrease is greater at slack low tide than at slack high tide because there is a smaller depth of water, and thus less dilution in the plume, at slack low tide.

Over a 28-day of the model simulation, there are 108 slack water events. In these events, the reduction in temperature on the seabed under the FSRU ranged from 0.5°C to 1.0°C (below ambient seawater temperature). Between these events, when there are stronger tidal currents, the temperature decrease on the seabed is only about 0.1°C.

At 340 m north of the FSRU, the temperature on the seabed generally decreased to 0.5°C below ambient seawater (with three brief larger events) while at 340 m south the decrease is 0.4°C (and less than 0.5°C). At 200 m west of the FSRU, the decrease in temperature reached 0.25°C while at 200 m east the decrease is typically 0.3°C (both less than 0.5°C).

Open Loop Average Production (FSRU Only)

The flows and temperature flux at average production are two-thirds of the peak production and therefore the temperature changes are correspondingly smaller. Figure 6-20 shows the peak (5 percentile) contours of seawater temperature with average open loop production and only the FSRU at Berth 2. The only temperature contour shows a reduction of 0.3°C and there is no zone with a 5-percentile contour change of 0.5°C. In reality, the discharge plume will be below 0.5°C over a small area (potential impact area of 0.5 ha under the FSRU).

Figure 6-22 shows a time series plot of seawater temperature for the case of average open loop production with only the FSRU at Berth 2. The plot shows the same series of events as Figure 6-21 but with smaller temperature differences. On the seabed between events, the temperature decrease on the seabed is only about 0.1°C. The temperature decrease is greater at slack low tide than at slack high tide.

At 340 m north of the FSRU, the temperature on the seabed reduced to 0.4°C below ambient seawater while at 340 m south the decrease is typically 0.35°C (both less than 0.5°C).

At 200 m west of the FSRU, the seawater temperature on the seabed reduced to 0.2°C while at 200 m east the decrease is typically 0.2°C (both less than 0.5°C).

In summary, at peak and average production flows with open loop operations, the larger temperature anomalies with cooler seawater last on the seabed for about 7 % of the time.

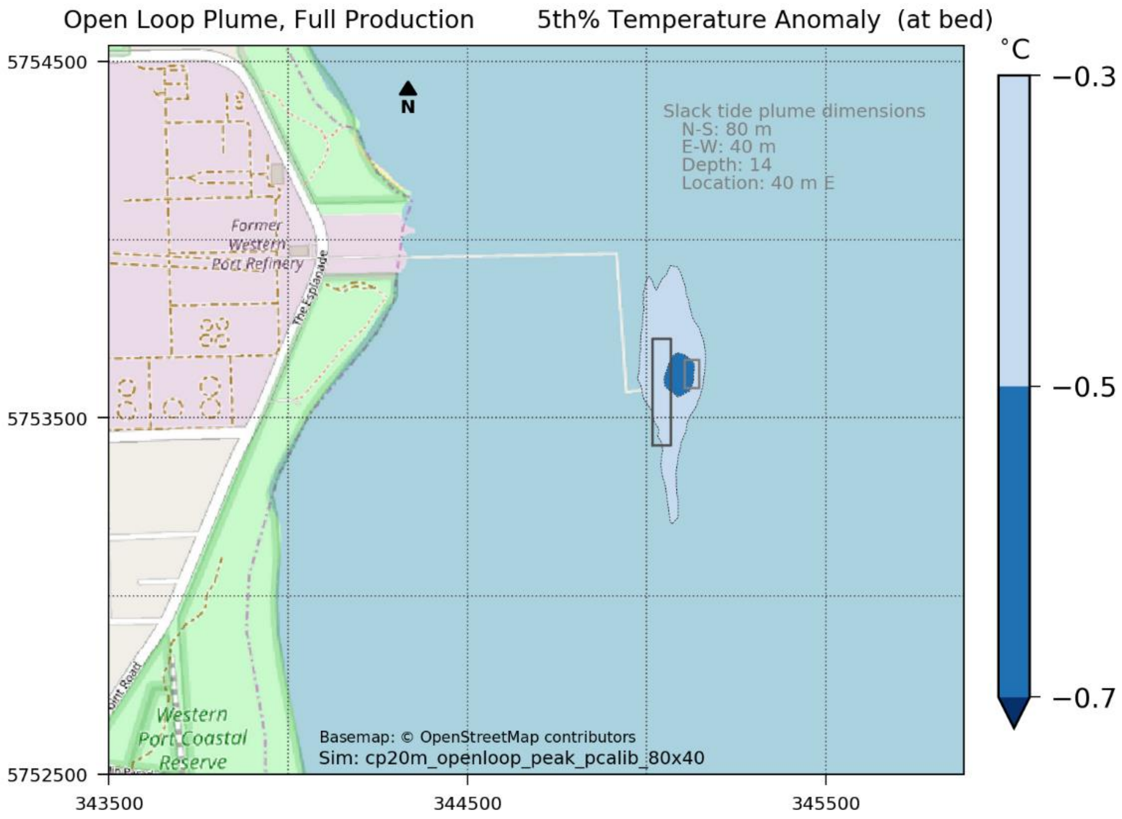


Figure 6-19. Peak Open Loop Temperature Change (FSRU only)

**Note: small box east of the FSRU shows where slack water plume is added to the model*

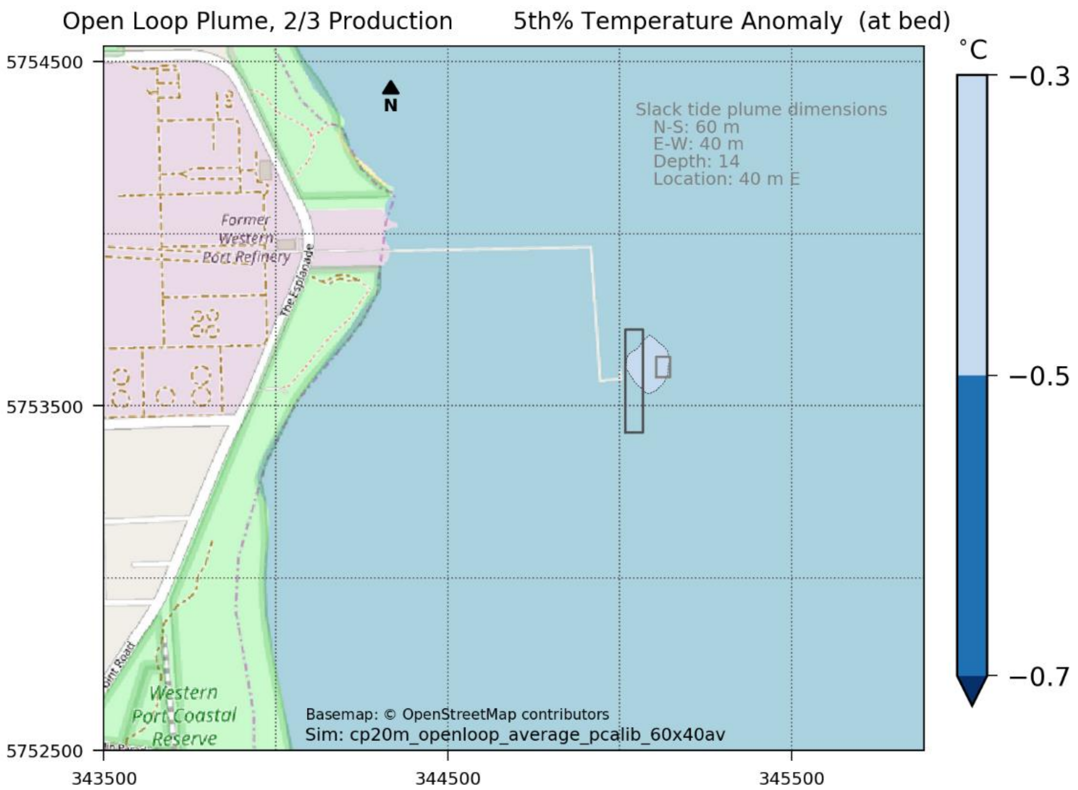


Figure 6-20. Average Open Loop Temperature Change (FSRU only)

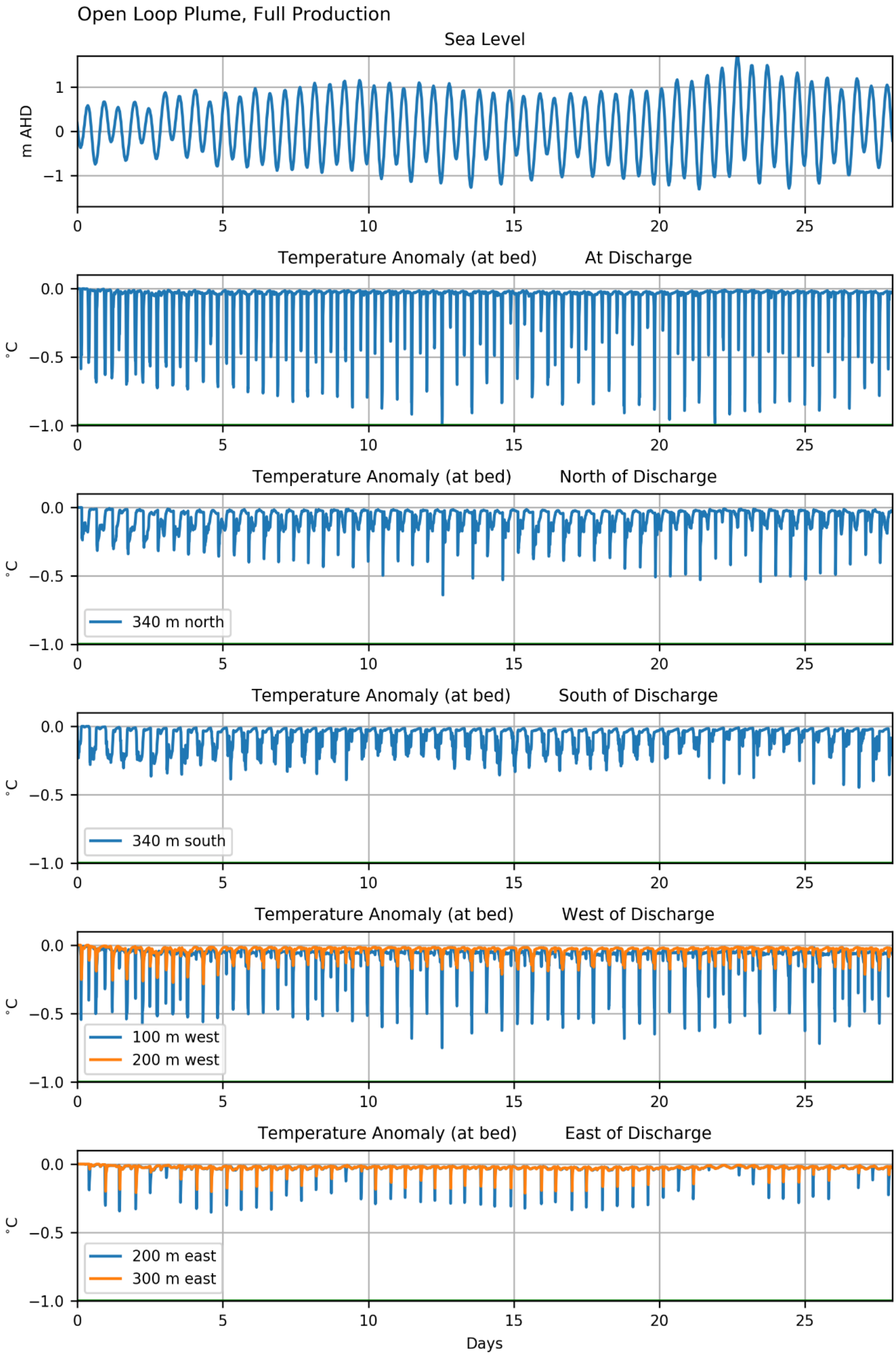


Figure 6-21. Peak Open Loop Time Series Temperature Change (FSRU only)

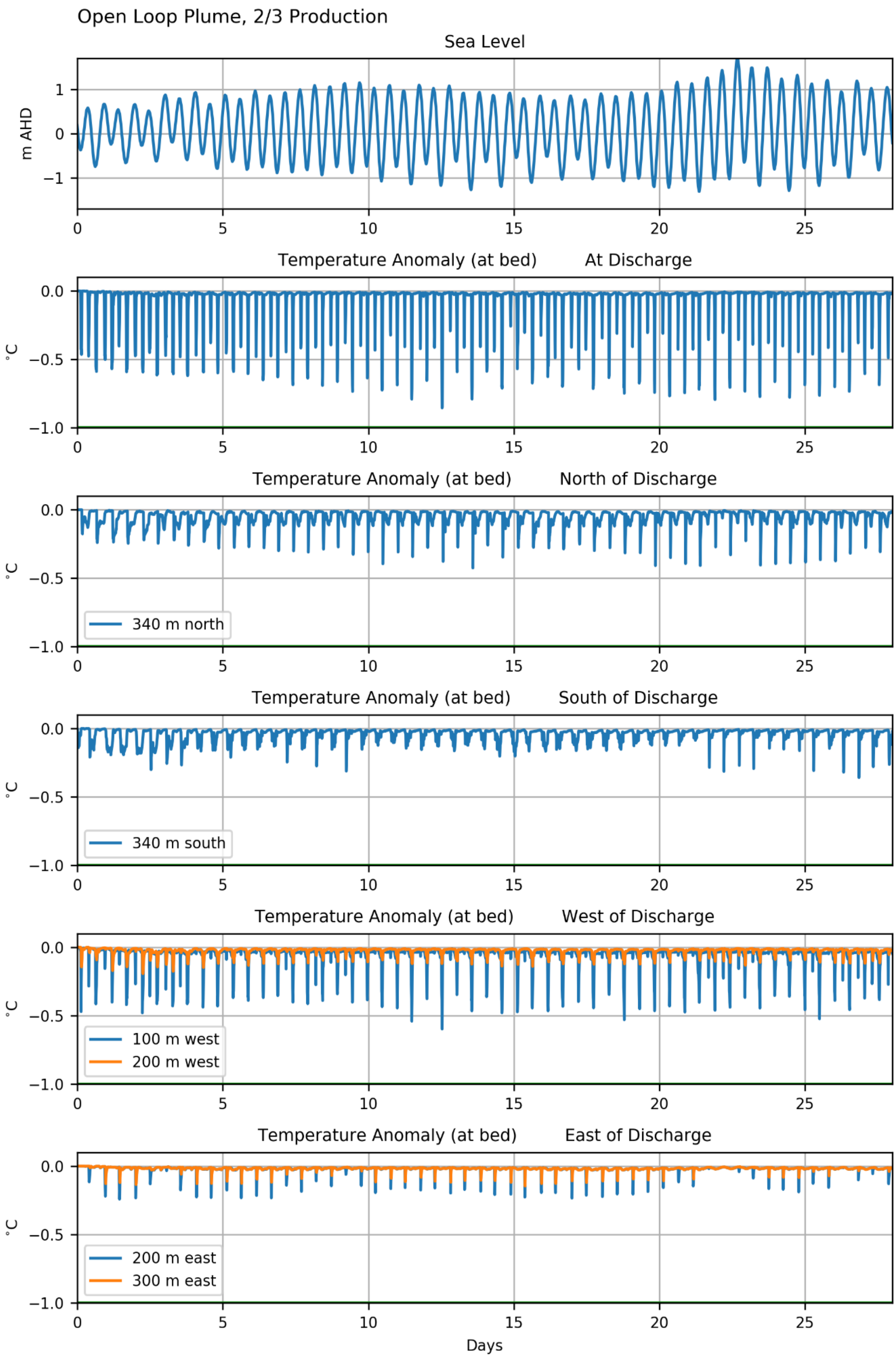


Figure 6-22. Average Open Loop Time Series Temperature Change (FSRU only)

6.4.9 Temperature Impacts During Open Loop (FSRU With LNG Carrier)

When there is an LNG carrier moored next to the FSRU, there is a different flow pattern because the LNG carrier obstructs the high velocity discharge jets. A pool of cooler seawater from the discharge forms in the space between the FSRU and the LNG carrier, and the pool sinks to the seabed. As mixing from the high-velocity discharge ports is limited, there is little initial dilution (refer to Figure 6-6). Thus, with a moored LNG carrier, a much larger pool of cooler seawater forms on the seabed.

Open Loop Peak Production (FSRU With LNG Carrier)

Figure 6-23 shows the peak (5 percentile) contours of seawater temperature with peak open loop production and two vessels, FSRU with an LNG carrier at Berth 2. The outer temperature contour is a reduction of 0.3°C from ambient seawater, the central contour is a reduction of 0.5°C and the large inner contour is a decrease of 0.7°C. The area of seabed with a temperature reduction of 0.5°C is about 800 m long north/south and about 300 m wide east/west, extending over an area of about 20 ha.

Figure 6-25 shows a time series plot of seawater temperature for the same case of peak open loop production and two vessels at Berth 2. The temperature anomaly (reduction) at the seabed under the discharge ports is still episodic but the seawater temperature decrease generally ranges from 4°C to 6°C (which corresponds to very little dilution of the discharge plumes).

The events with a large temperature decrease at the seabed correspond to the times when a large “pancake” of cooler seawater forms and remains on the seabed. The greatest temperature anomaly on the seabed under the two vessels is typically at 7 °C (essentially the same temperature anomaly as in the seawater discharge). The pool lasts for most of the tide cycle because it is under the two vessels and mixing is restricted by the presence of the vessels. Occasionally, the pool temperature decrease was 1°C. At 340 m north of the FSRU, the temperature on the seabed reached 1.0 °C below ambient seawater while at 340 m south the decrease is typically 0.6°C. At 200 m west of the FSRU, the temperature ranged down to 0.5°C below ambient seawater while at 200 m east the decrease is typically 0.1°C (the pool spreads north and south rather than east).

Open Loop Average Production (FSRU With LNG Carrier)

The flows and temperature flux at average production are two-thirds of the peak production and therefore the seawater temperature changes are correspondingly smaller. Figure 6-24 shows contours of the 5-percentile temperature anomaly at average open loop production. The outer temperature contour is a reduction of 0.3°C, the central contour is a reduction of 0.5°C and the large inner contour is a reduction of 0.7°C. The area of seabed with a seawater temperature decrease of 0.5°C is about 600 m long north/south and about 250 m wide east/west, extending over an area of about 12 ha.

Figure 6-26 shows a time series plot of seawater temperature for the case of average open loop production with two vessels, FSRU with an LNG carrier at Berth 2. The plot shows the same series of events as Figure 6-25 but with smaller temperature differences. On the seabed, the seawater temperature decrease is about 7 °C.

At 340 m north of the FSRU, the temperature on the seabed decreased down to 0.8°C below ambient seawater while at 340 m south the decrease is typically 0.5°C. At 200 m west of the FSRU, the temperature decrease is 0.5°C while at 200 m east the decrease is typically 0.1°C.

Summary

In summary, at peak and average production in open loop operations, with the FSRU and an LNG carrier, there is a much larger pool of cooler seawater on the seabed and it lasts for several hours. At peak production, the 5-percentile temperature anomaly extends over 20 ha; at average production, the 5-percentile temperature anomaly extends over 12 ha. Without an LNG carrier (Section 6.4.8), the 5-percentile temperature anomaly briefly covers only 0.7 ha at peak production, and 0.5 ha at average production.

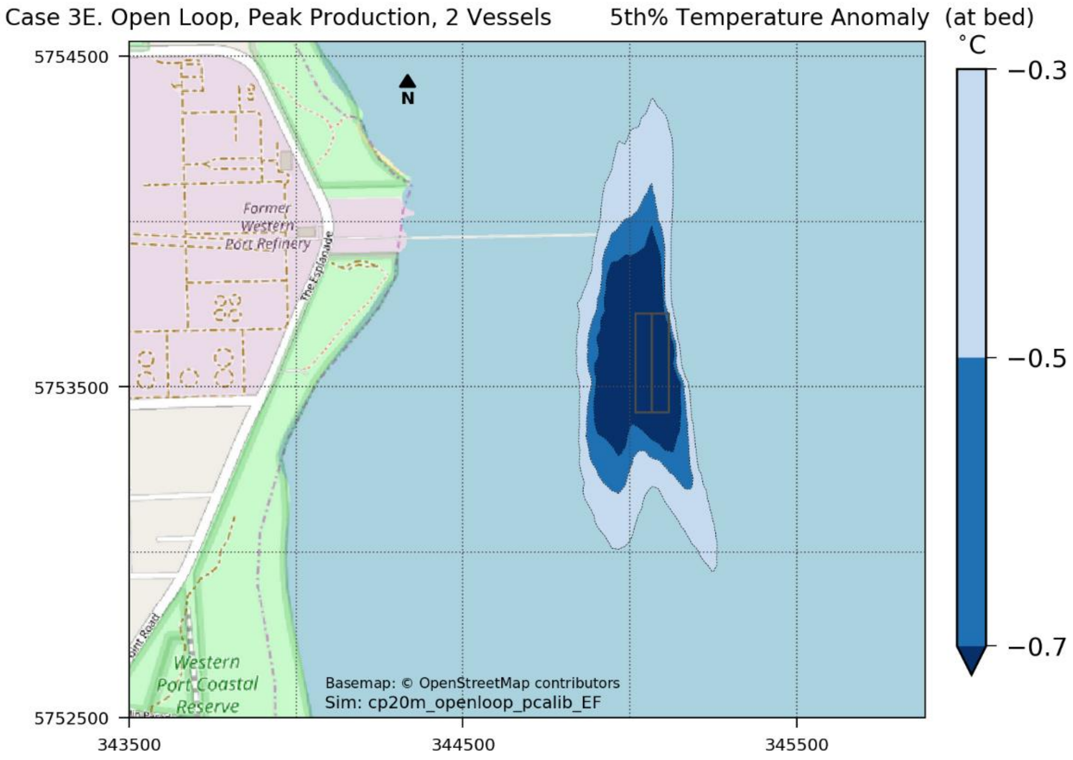


Figure 6-23. Peak Open Loop Temperature Change (FSRU with LNG)

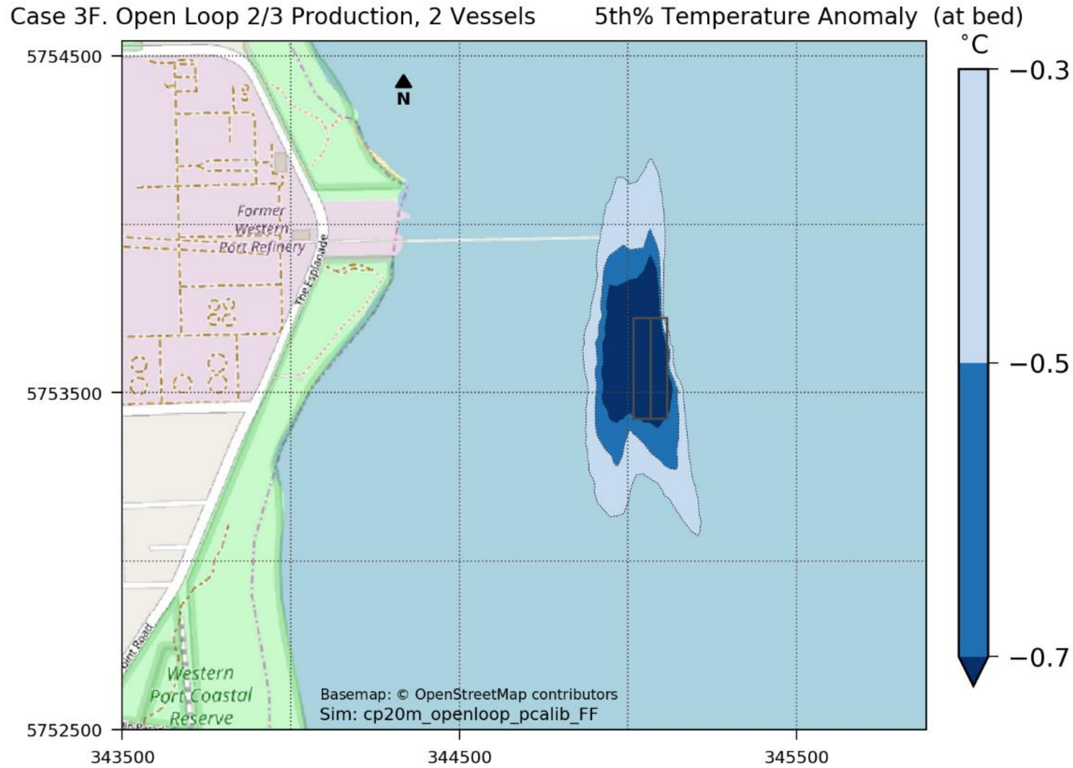


Figure 6-24. Average Open Loop Temperature Change (FSRU with LNG)

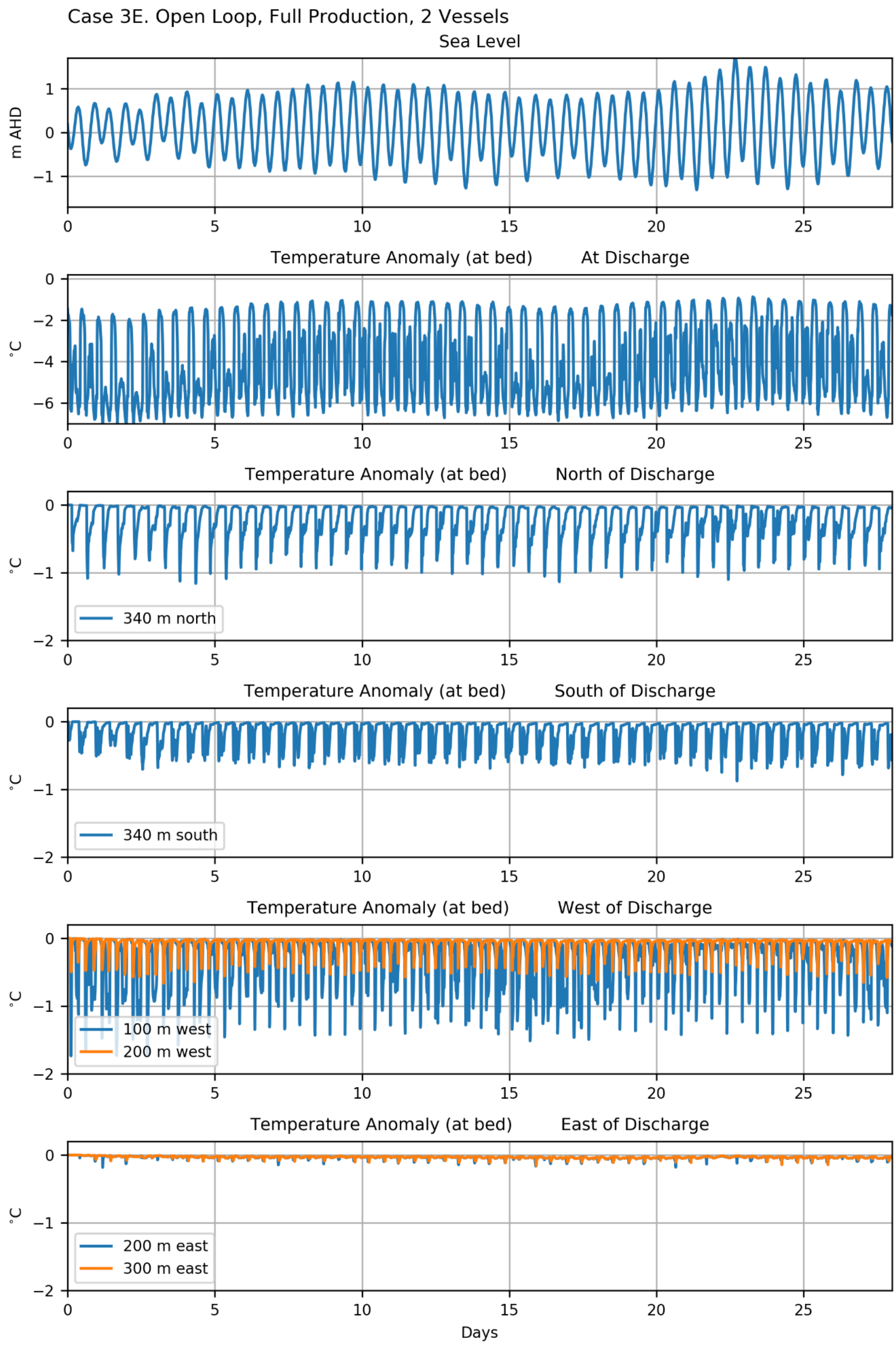


Figure 6-25. Peak Open Loop Time Series Temperature Change (FSRU with LNG)

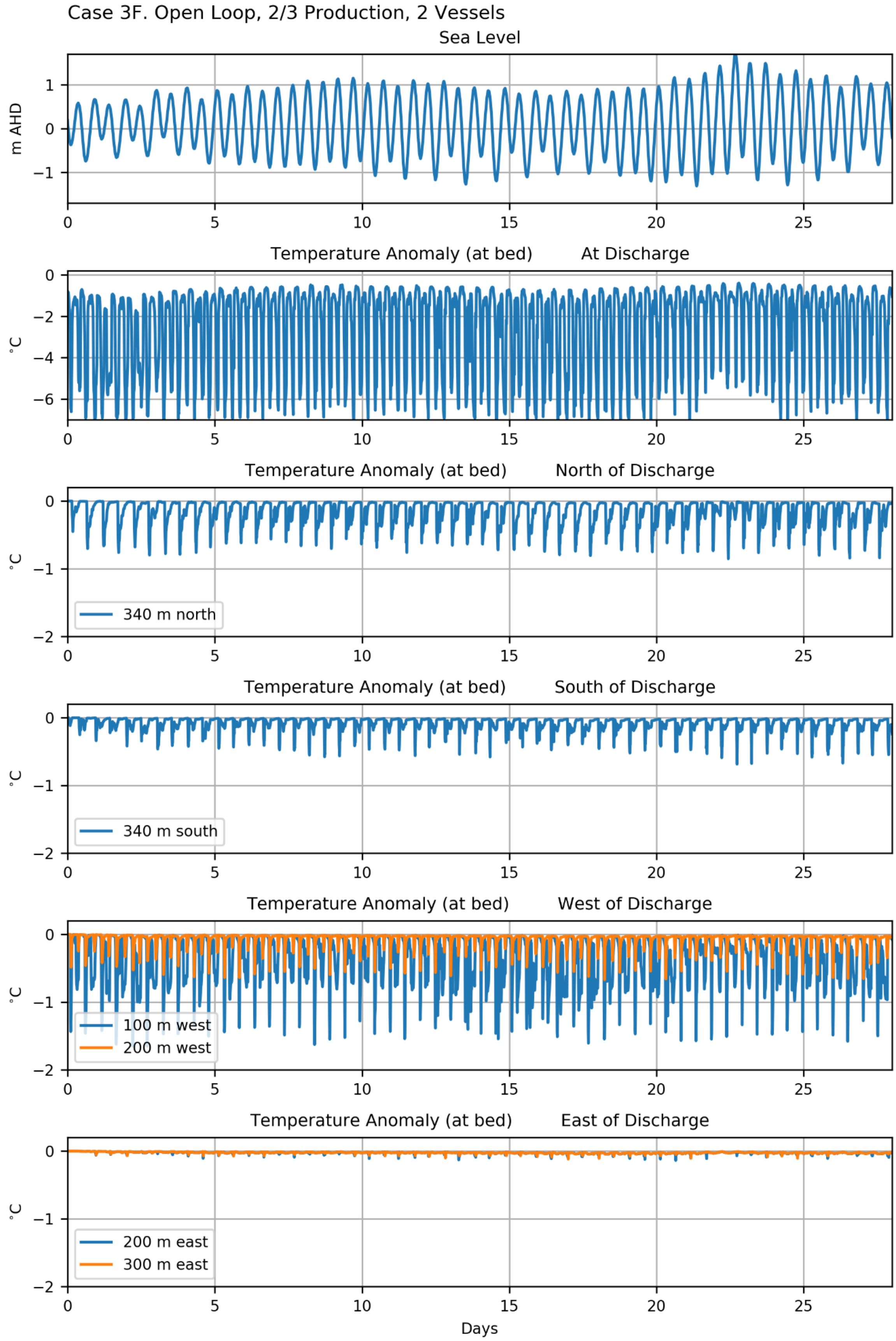


Figure 6-26. Average Open Loop Time Series Temperature Change (FSRU with LNG)

6.4.10 Temperature Impacts During Open Loop (1/3 Peak Production, FSRU With LNG Carrier)

There may be periods when the FSRU is operating at one-third peak production. This section describes the predictions of the regional model for open loop operations with an LNG carried moored parallel to the FSRU and the production rate reduced to one-third of the peak.

Figure 6-27 shows a plan view of the peak seawater temperature anomaly (5 percentile temperature change at the seabed) for this open loop operating scenario. The location of the FSRU and LNG carrier is shown by the black rectangles. The Crib Point Jetty and the shoreline can be seen to the west of the FSRU.

The outer temperature contour is a reduction of 0.3ºC, the central contour is a reduction of 0.5 °C and the small inner contour is a reduction of 0.7ºC. The area of seabed with a seawater temperature decrease of 0.5°C is about 400 m long north/south and about 200 m wide east/west, extending over an area of about 6 ha. This area represents the zone occupied by the pancake of cooler seawater at slack water and is mostly under the FSRU and the adjacent Crib Point Jetty.

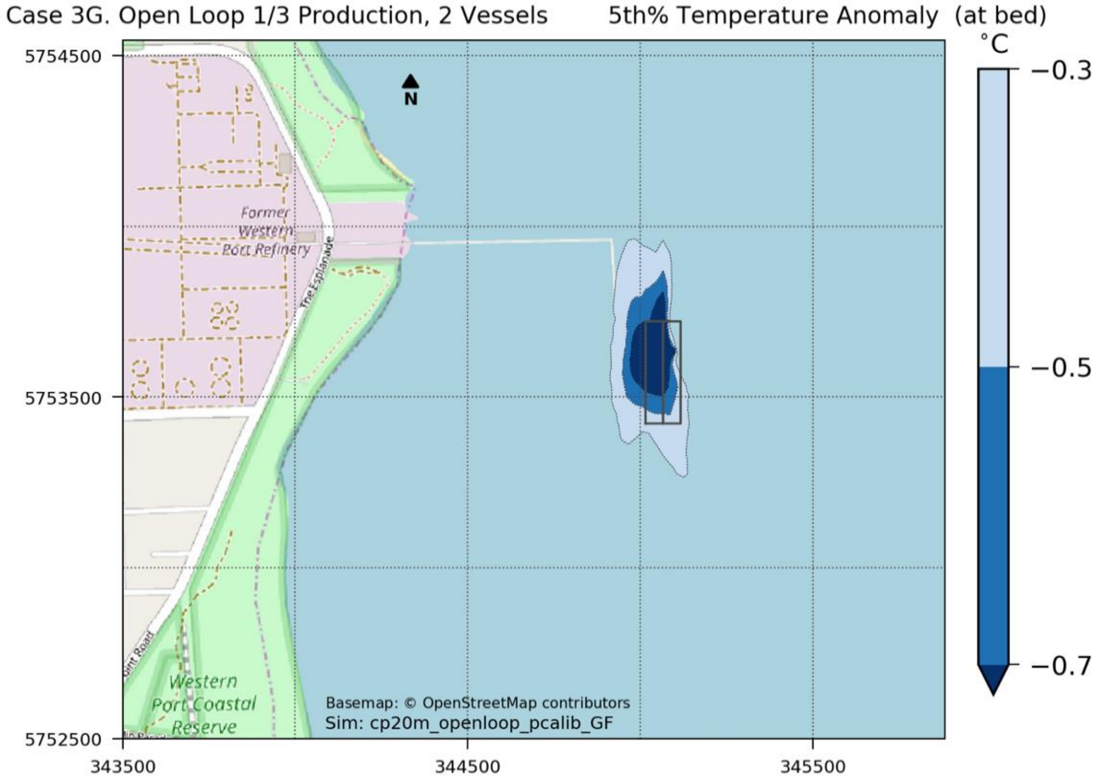


Figure 6-27. 1/3 Open Loop Temperature Change (FSRU with LNG carrier)

In summary, for open loop operations, FSRU with LNG carrier, at one-third peak production, there is a small zone with a seawater temperature reduction of 0.5°C that extends about 400 m north/south and 200 m east/west over an area of seabed of about 6 ha.

6.4.11 Port Side Discharge - Temperature

As described earlier, when an LNG carrier is moored next to the FSRU, the LNG carrier obstructs the high velocity discharge ports. As mixing of the discharge jets is limited, there is little initial dilution and a pool of cooler seawater from the discharge forms in the space between the FSRU and the LNG carrier, and sinks to the seabed. Thus, with a parallel LNG carrier, there is a much larger pool of cooler seawater formed on the seabed.

An option to avoid the obstruction would involve installing the discharge ports on the west side of the FSRU (with the discharge ports facing the Crib Point Jetty and the shore). This arrangement has the benefit that the jets would not be obstructed and thus a high initial dilution is achieved even when there is an LNG carrier moored beside the FSRU. There also are some disadvantages (the seawater discharge is through the Jetty and towards the shore, and there are constraints on where the FSRU can be moored at Berth 2).

Figure 6-28 shows the peak (5 percentile) contours of seawater temperature for west-side discharge at peak open loop production with the FSRU and LNG carrier moored at Berth 2. The outer temperature contour is a reduction of 0.3°C from ambient, the central contour is a reduction of 0.5°C and the large inner contour is a decrease of 0.7°C. The area of seabed with a seawater temperature reduction of 0.5°C is about 400 m long north/south and about 110 m wide east/west, extending over an area of about 4 ha.

This is substantially smaller than the area when compared with a temperature reduction of 0.5°C for east-side ports of 20 ha. The area with reduced temperature is mostly under the Crib Point Jetty, which is an area of disturbed seabed, although it is acknowledged that the jetty piles and dolphins provide artificial solid habitat that attracts a range of reef-orientated biota that may be affected by a discharge.

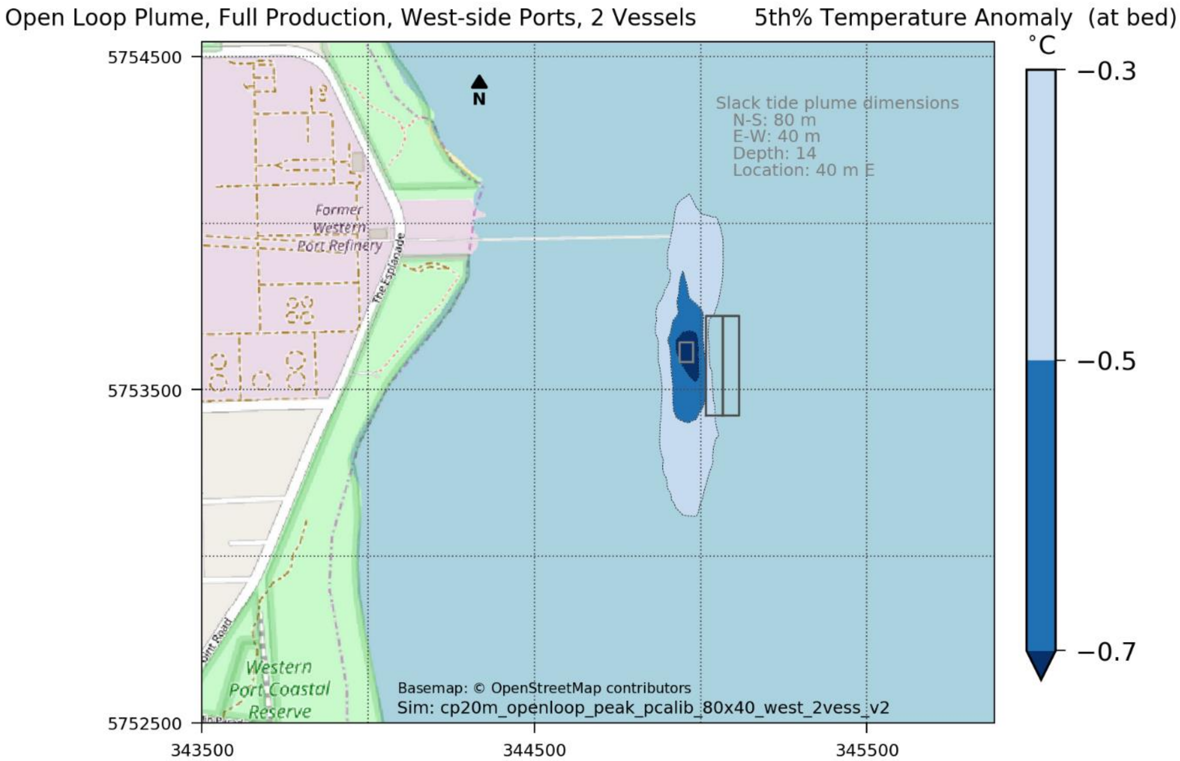


Figure 6-28. Peak Open Loop with Ports on West Side of FSRU (FSRU with LNG carrier)

**Note: small box east of the FSRU shows where slack water plume is added to the model*

The west-side port option is a practical alternative with advantages and disadvantages (as described above) in comparison to the proposal, which uses ports on the east side. Advantages are realised in the scenario where an LNG carrier is moored adjacent to the FSRU. This is forecast to occur 12-40 times per year for a period of up to 36 hours each time. There is no advantage with respect to temperature for the periods when no LNG carrier is moored alongside the FSRU. It remains as a possibility and is not part of the current project.

6.4.12 Discharges in Closed Loop Operation

This section describes the predictions of the regional model for closed loop operations. In closed loop the LNG would be heated using gas-fired boilers and there would be a discharge of warm water from the cooling of the main generators and auxiliary machinery. The warm seawater would be discharged via several closely-spaced pipes at the rear of the vessel. Table 6-2 shows the sources and volumes of seawater discharge from closed loop which is variable depending on whether one or two of the main generator freshwater coolers are in operation. For the assessment of closed loop mode, the total discharge of 187,000 m^3/d was used.

The combined seawater discharge during closed loop operations would create plumes that are warmer than the surrounding ambient seawater, and therefore more buoyant. During periods of low currents around the turn of the tide, the plumes would rise and dilute quickly due to buoyancy.

The FSRU would need to be refilled with LNG 12 to 40 times per year, depending on the rate of sales of gas to the Victorian gas network. The refilling operation involves an LNG carrier mooring on the starboard side of the FSRU and transferring LNG via temporary connecting pipes over a period of 24 to 36 hours. During the transfer operation, the seawater curtain is sprayed in the 5 m space between the FSRU and the LNG carrier for the period of LNG transfer. Fire water is tested for one hour every two weeks. The water curtain and fire water use ambient seawater and have negligible effect on the seawater temperature distribution.

When LNG is added to the FSRU, the FSRU ballast tanks are discharged. The ballast water is discharged at ambient seawater temperature from a point near the rear of the FSRU. The ballast water has negligible effect on the seawater temperature distribution and hence is not included in the temperature modelling.

The two warm flows from generators and machinery coolers, and the discharge from the atmospheric dump condenser, would be discharged from a series of pipes at a velocity of 3 to 5 m/s near the rear of the FSRU on the starboard side. The pipe outlets are on average 8 m below the water surface and point downward at angles of 30 to 45 degrees below the horizontal.

Near-field modelling by CEE using INITDIL showed that the three discharges would have an initial dilution of 10:1 at slack water and averaging 15:1 at moderate to strong currents. The three discharge jets would scour a hole in the seabed about 1.2 to 1.5 m deep, and about 8 m in diameter, where they would mix together.

After minimum dilution, the temperature in the discharge jets would be between 0.4°C to 0.5°C above ambient seawater. This anomaly is within the Guideline Value limit for temperature of 0.5°C.

6.4.13 Discharges in Closed Loop Operation with LNG Carrier

This section describes the predictions of the regional model for peak closed loop operations – with weak currents at slack water, and an LNG carrier obstructing the path of the discharge plumes. Based on the combined frequency distribution for tidal currents at Crib Point and the peak 40 LNG unloading events per year, this flow pattern occurs for approximately 0.5 % of the time (current speed < 0.05 m/s – refer to Figure 5-6 (Section 5) and 40 days of LNG transfer/year).

6.4.14 Temperature Impacts During Closed Loop (FSRU Only)

With closed loop operation there is a reduction in the rate of seawater intake and discharge (the discharge rate in closed loop is about 40 % of the discharge rate in open loop operation) and also a change in the temperature of the seawater discharge (the closed loop discharge is about 4°C above ambient seawater, whereas the open loop seawater discharge is about 7°C below ambient seawater). With closed loop operations there is a 75 % reduction in the heat flux transferred to Western Port waters compared to open loop, and also a change from discharging cooler seawater (open loop operation) to discharging warmer seawater (closed loop operation).

In closed loop operations, the seawater discharges are from pipes at the rear of the FSRU pointing downward towards the seabed. The seawater jets strike the seabed and then, because the closed loop discharges are warmer, the plumes rise through the water column, generating extra mixing and dilution. The pancake of cooler seawater formed in open loop has no equivalent in closed loop, as the warm plume mixes upward through the water column.

Figure 6-29 shows the peak (95 percentile) contours of warmer seawater temperature with peak closed loop production and only the FSRU at Berth 2. The outer temperature contour is +0.3°C and in small inner contour is +0.5ºC. The area of seabed with a seawater temperature anomaly of more than 0.5°C is about 50 m diameter at the rear of the FSRU and corresponds to an area of about 0.2 ha.

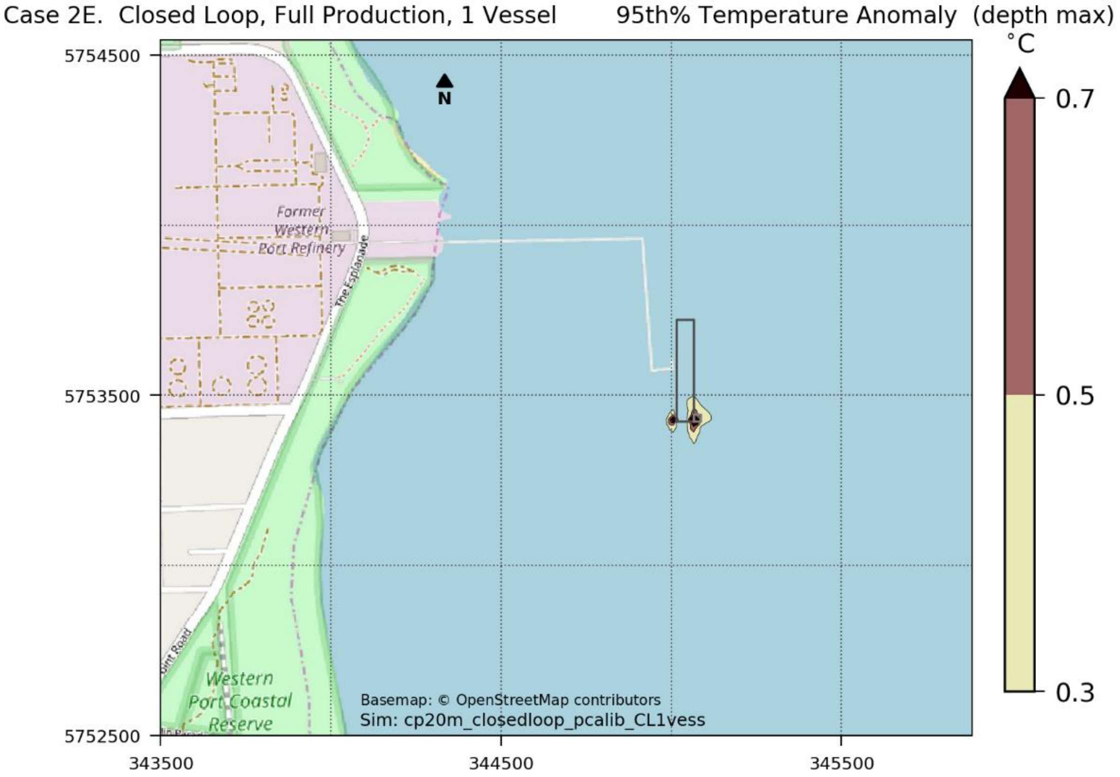


Figure 6-29. Peak Closed Loop Temperature Change (FSRU Only)

Figure 6-30 shows a time series plot of seawater temperature at the seabed below the closed loop discharges, and at points north, south, west and east of the FSRU operating at peak production in closed loop.

In the port just above the seabed, the seawater temperature increase is 1 to 1.5°C. However, the zone of elevated temperature change is small. At sites north, south, west and east of the FSRU the seawater temperature change is only 0.1°C. An area of seabed of about 0.2 ha has a temperature anomaly of 0.5°C.

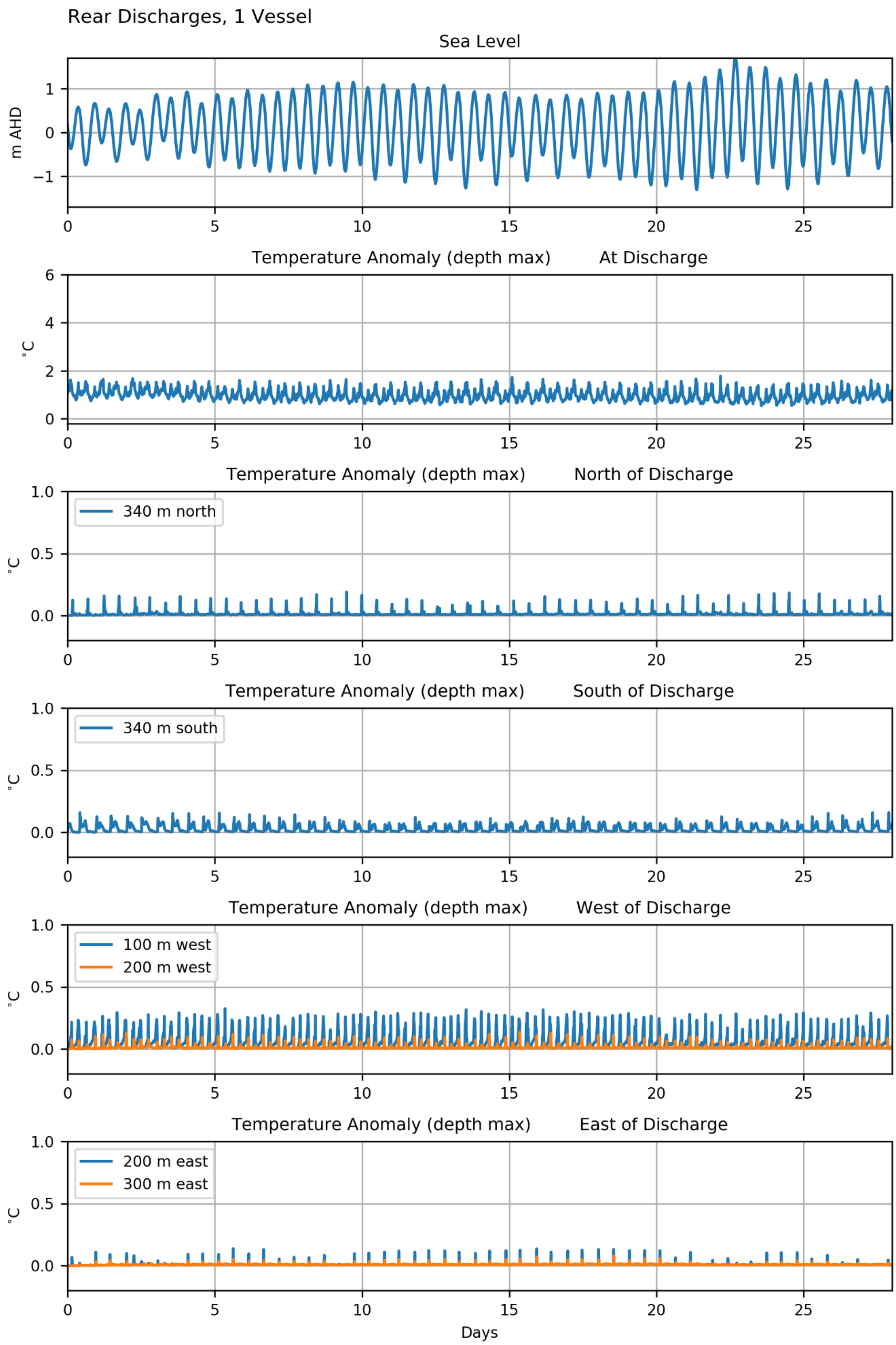


Figure 6-30. Peak Closed Loop Time Series Temperature Change (FSRU Only)

6.4.15 Temperature Impacts During Closed Loop (FSRU With LNG Carrier)

Figure 6-31 shows the peak (95 percentile) contours of warmer seawater temperature with peak closed loop production and both the FSRU and an LNG carrier at Berth 2. The outer temperature contour is +0.3°C and in small inner contour is +0.5°C. The area of seabed with a seawater temperature anomaly of more than 0.5°C is very small at about 50 m diameter at the rear of the FSRU and corresponds to an area of about 0.3 ha.

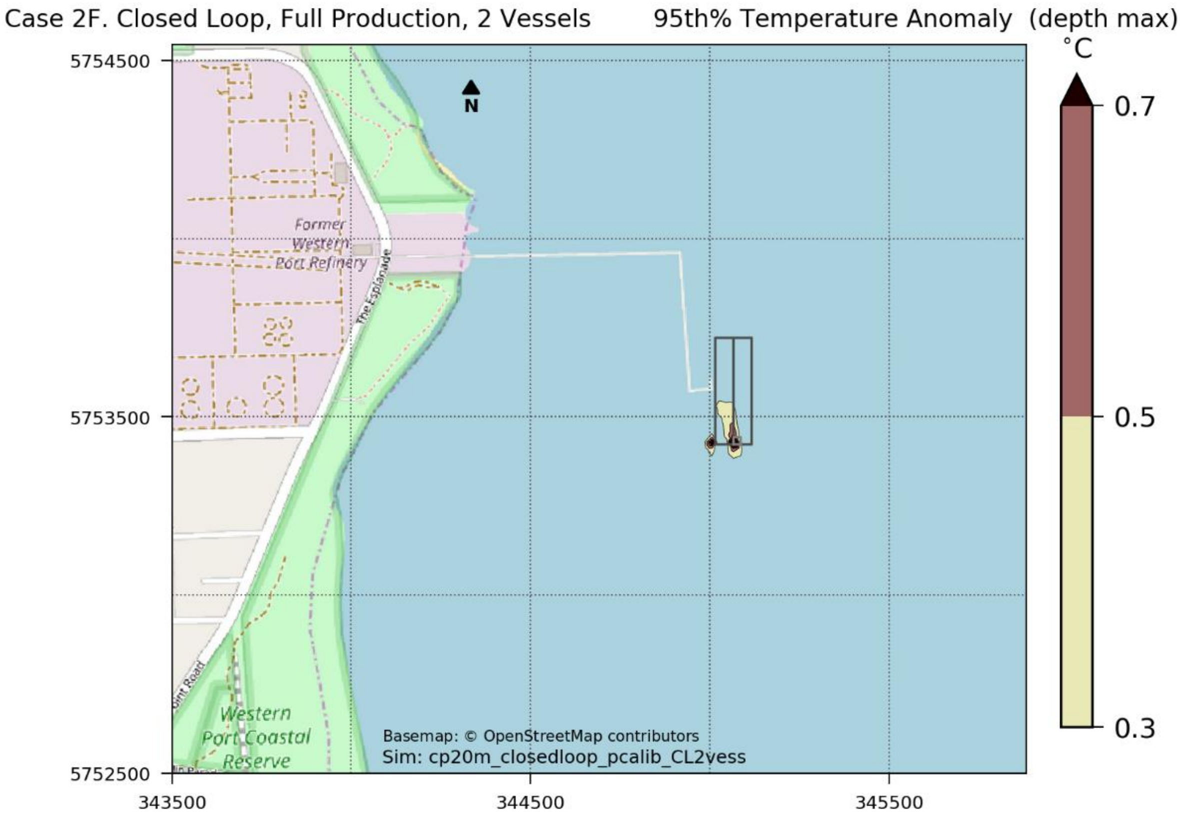


Figure 6-31. Peak Closed Loop Temperature Change (FSRU with LNG)

Figure 6-32 shows a time series plot of temperature at the seabed below the closed loop discharge with the FSRU and LNG carrier moored at Berth 2, and at points north, south, west and east of the FSRU operating at peak production. On the seabed at the rear of the FSRU the seawater temperature increase on the seabed is 1 to 1.5°C where the discharge jets hit the seabed. However, the zone of elevated temperature change is small. At sites north, south, west and east of the FSRU the seawater temperature decrease is only 0.1°C. An area of seabed of about 0.3 ha has a temperature anomaly of 0.5°C.

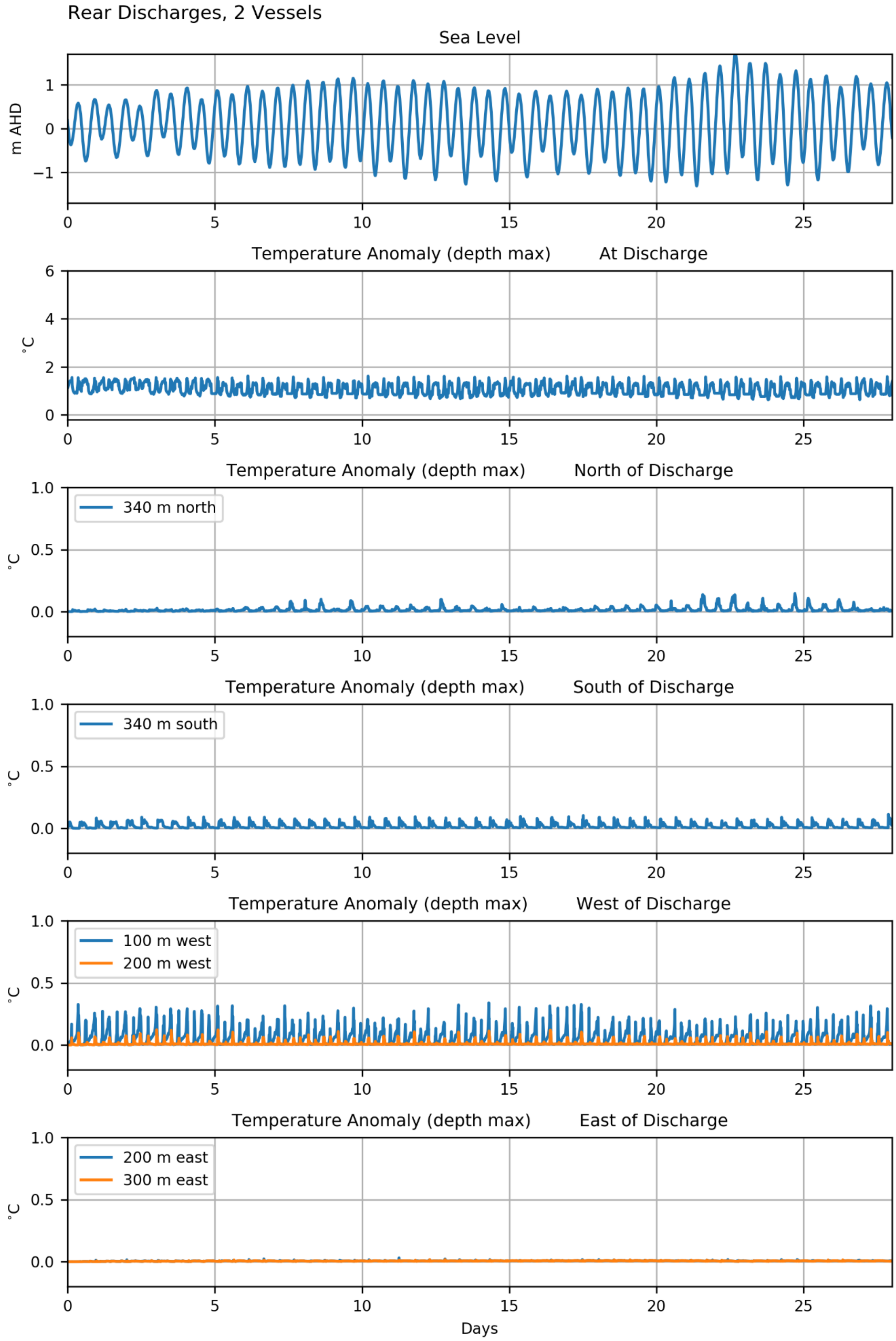


Figure 6-32. Peak Closed Loop Time Series Temperature Change (FSRU with LNG)

6.4.16 Summary of Results for Temperature Predictions

This section summarises the temperature predictions of the regional model for the various conditions and flow patterns in the proposed operation of the FSRU.

In open loop operations, with FSRU only (no LNG carrier moored in Berth 2) there is a small footprint (less than 1 ha) of temperature anomaly where a pool of cooler seawater forms on the seabed for a short period at slack water. The pool (or pancake) lasts for less than an hour before the increase in tidal currents stimulates mixing.

When an LNG carrier is moored alongside the FSRU, the situation changes considerably. In open loop operations, with FSRU and an LNG carrier berthed adjacent to the FSRU, there is a larger footprint (of 6 to 20 ha) of temperature anomaly where a larger pool of cooler seawater forms on the seabed for and after each period of slack water. The size of the pool of cooler seawater decreases as the production rate decreases.

In closed loop operations, with FSRU only, there is a small footprint (of 0.2 ha) of temperature anomaly corresponding to a small zone of warmer water.

In closed loop operations, the discharges are minimally affected by the LNG carrier due to the discharges in closed loop being at the back of the FSRU. In closed loop operations, with the FSRU and an LNG carrier, there is a slightly larger footprint (of 0.3 ha) of temperature anomaly with a pool of warmer water adjacent to the seawater discharges.

Table 6-5 summarises the area where the diluted seawater discharge temperature differs from ambient seawater by more than 0.5°C. Using the modelled scenario of 40 LNG carriers per year, each moored for up to 36 hours, the larger footprints would apply for 60 days per year (with continuous open loop operation). These larger footprints would occur during slack water between tides and would decrease as tidal currents increase, stimulating mixing.

Table 6-5. Summary of Results for Temperature Predictions

Production rate	Operating Mode	Vessels at Crib Point Jetty (Berth 2)	Area above/ below 0.5 °C
Peak	Open loop	No LNG Carrier	0.7 ha
Average	Open loop	No LNG Carrier	0.5 ha
Peak	Open loop	With LNG Carrier	20 ha
Average	Open loop	With LNG Carrier	12 ha
One-third Peak	Open loop	With LNG Carrier	6 ha
Peak	Closed loop	No LNG Carrier	0.2 ha
Peak	Closed loop	With LNG Carrier	0.3 ha

6.5 Chlorine Produced Oxidants Predictions

This section describes the use of the near-field and regional hydrodynamic models to predict the concentration of chlorine produced oxidants (CPO) in the vicinity of the FSRU.

6.5.1 Purpose of Chlorine in Pipe Network

Seawater taken into the FSRU for all purposes passes through an electrolysis cell that converts the sodium chloride (NaCl) naturally present in seawater to sodium and chlorine ions (Na^+ and Cl^-). The chlorine is highly reactive, and is converted in less than a minute to a hypobromite ion by reacting with the natural bromide in seawater that further reacts with organic matter. There also is a reaction with ammonia to form hypochlorite. Because of the range of products formed from the original chlorine ion, the “chlorine” test actually measures “chlorine produced oxidants” (CPO). Nonetheless, it is conventional to refer to these as "residual chlorine” even though they are actually residual CPO.

The electrolysis process on the FSRU would produce a chlorine concentration in the incoming seawater of 500 µg/L (0.5 mg/L). This concentration would decay rapidly in the pipe network to less than 200 µg/L and by the time the flow has passes through pumps and pipes, the residual chlorine concentration in all seawater discharges is assured by the FSRU supplier to be less than 100 µg/L. Thus, all near-field and regional model predictions are based on a chlorine concentration of 100 µg/L in all seawater discharges (except ballast water).

Ballast water is stored for a week to a month in the ballast storage tanks on the FSRU and there is substantial further decay of the chlorine during the storage period. The estimated chlorine concentration in discharged ballast water is 21 µg/L.

The objective of the chlorine in the pipe network is to control biofouling (i.e. the growth of mussels and other marine organisms in the pipes and heat exchanger). The growth of marine organisms would block the flow if not controlled. It should be noted that organisms inhabiting the pipes are subjected to a continuous dose of chlorine in the range of 100 to 500 µg/L (depending on the position in the pipe network). The effect of a continuous low dose over many hours is to damage the organism and thus prevent growth.

Marine organisms that enter and leave the pipe network in seawater are subjected to a short-term dose of chlorine from 500 µg/L down to 100 µg/L for a maximum of 5 minutes (other than in ballast water) before being discharged. Within a further 3 to 5 minutes, the organisms are exposed to a chlorine concentration of less than 10 µg/L, due to the dilution of the discharged seawater flows. Marine organisms sensitive to chlorine will be affected – but a proportion will survive this short-term event (refer to Section 7).

Nonetheless, a precautionary approach must be followed in determining the potential environmental effects from use of chlorine to control biofouling in the FSRU and 100 % loss of plankton (conservative assumption) in the seawater flow through the heat exchangers has been assumed in this assessment.

6.5.2 Guideline Value for Chlorine from CSIRO Report

The present ANZECC/ARMCANZ Guidelines for Water Quality (2018) do not list Guideline Values for CPO in aquatic environments. ANZECC 2000 Guidelines listed a freshwater 95 % species protection Guideline Value of 3 µg/L for chlorine which could be used for marine waters (ANZECC/ARMCANZ, 2000). CSIRO was contracted to review all available toxicity data for chlorine and develop a 99 % species protection for marine waters (CSIRO, 2019).

The conclusions of the CSIRO review may be summarised as follows:

- *For continuous exposure and 99 % species protection in marine waters, the short-term Guideline Value for chlorine (CPO) is 2.0 µg/L where the concentration is relatively consistent over time.*
- *Where the concentration is intermittent or variable over time, such as the tidally varying conditions in the North Arm of Western Port, the recommended short-term Guideline Value is 6.0 µg/L for 99% species protection.*

Hence, for this assessment, a Guideline Value of 6 µg/L is used for chlorine. Note that this Guideline Value applies over a 12-hour tidal cycle. Thus, time-averaged chlorine concentrations were predicted for a 12-hour tidal cycle in the hydrodynamic modelling and used for the marine risk assessment, as well as 5 percentile chlorine concentrations for review.

6.5.3 Near-Field and Regional Modelling of Discharges

The same near-field and regional hydrodynamic models used to predict the dilution and transport of the discharge plumes (refer to Sections 6.2 and 6.3) were used in the chlorine simulations. The following assumptions were adopted in the chlorine modelling:

- Chlorine concentration in the seawater discharges is 100 µg/L (for all discharges other than ballast water);
- No decay of chlorine with time after discharge. This is a conservative assumption as Zeng et al. (2009) showed that an initial residual chlorine concentration of 2.35 mg/L reduced to around 0.8 mg/L (66 % reduction) in less than 1 minute at 15 ^{o}C. This was followed by a slower first-order decomposition over 15 minutes to 0.5 mg/L (79 % reduction) and almost to completion (more than 90 % reduction) in 30 to 40 minutes.

The same two distinct flow patterns for the dilution of the discharged cooler seawater applies to chlorine modelling. The first flow pattern occurs at higher current speeds. When the tidal current speed exceeds about 0.08 m/s, the discharge plumes are entrained by the passing tidal flow and mix quickly through the water column. The second, and different, flow pattern occurs at times of weak to zero current speeds. At these times a field of diluted seawater discharge forms on the seabed below the FSRU (the pancake). This field accumulates for about 20 minutes during slack water and is eroded and transported away as the current's speeds increase. These two distinct dilution patterns are seen in the predictions of both the near-field and regional hydrodynamic models for chlorine (as well as temperature).

6.5.4 Outcomes of Regional Chlorine Modelling – FSRU Only

In the following sections that present the results of the chlorine modelling, contours of chlorine of less than 6 µg/L below the Guideline Value for chlorine have been included to provide the context for the shape and extent of more diluted areas of the diluting chlorinated discharge plume. Also, plots of chlorine concentrations during the 20-minute periods of weak currents are presented to illustrate the spatial extent of short-term peak concentrations (while noting that the Guideline Limit is based on a 12-hour average).

6.5.5 Chlorine Impacts During Open Loop (FSRU Only)

Open Loop Peak Production – Time-averaged Chlorine

Figure 6-33 shows the contours of time-averaged chlorine concentration for peak open loop production and only the FSRU at Berth 2. The largest time-averaged chlorine contour is 1.2 µg/L which is well under the Guideline Limit of 6 µg/L.

Open Loop Average Production - Time-averaged Chlorine

Figure 6-34 shows the contours of time-averaged chlorine concentration for average open loop production and only the FSRU at the berth. The largest time-averaged chlorine contour is 1.2 µg/L which occupies two small areas, and is well under the Guideline Limit of 6 µg/L.

Short-term Chlorine Peak

Even though the Guideline Limit for chlorine is 6 µg/L over 12 hours, the short-term peaks in chlorine concentrations are of interest. Figure 6-35 shows the 95-percentile chlorine concentration in open loop operations at the peak rate of production. The chlorine contours show a small zone of about 4 ha exceeding 6 µg/L on the seabed under the discharge ports and a larger zone exceeding 4 µg/L extending for about 800 m north/south and 250 m east/west. The plumes extending further to the north and south of the FSRU are the diluting "pancakes" of seawater discharge being carried away from the FSRU by the flood and ebb tidal currents, respectively, and demonstrate that chlorine is diluted to a low concentration with distance from the FSRU within the following tide cycle. As noted above, the predicted contours do not include the effects of chlorine decay which would further reduce the chlorine concentrations with distance.

Figure 6-36 shows the 95-percentile chlorine concentration in open loop operations at the average rate of production. The chlorine contours show a small zone of about 1 ha exceeding 6 µg/L on the seabed under the discharge ports, a somewhat larger zone above 4 µg/L extending for about 200 m north/south and 150 m east/west, and plumes extending about 1 km to the north and south of the FSRU. These plumes are episodic, resulting from the diluting "pancakes" of seawater discharge being carried away from the FSRU by the flood and ebb tidal currents, respectively. The average rate of production occurs for about 90 % of the year. The 6 µg/L Guideline Value does not apply to the 95-percentile plots due to the short-term exposure represented in Figure 6-35 and Figure 6-36.

Time Series Plots of Chlorine Concentration

Figure 6-37 shows the instantaneous chlorine concentration in peak open loop operations over a 28-day period of model simulation. The chlorine concentration is shown on separate plots for (1) the seabed directly under the discharge ports – peak chlorine concentrations of 10 to 14 µg/L; (2) at 340 m north - peak chlorine concentrations of 6 to 9 µg/L; (3) at 340 m south - peak chlorine concentrations under 6 µg/L; (4) at 100 m west and 200 m west – peaks over 6 µg/L at 100 m but under 6 µg/L at 200 m west; and (5) at 200 m and 300 m east of the discharge ports- peak chlorine concentrations under 6 µg/L.

Figure 6-38 shows the time-averaged chlorine concentration in peak open loop operations over a 28-day period of model simulation. The time-averaged chlorine concentration is shown on separate plots for the seabed directly under the discharge ports and sites north, south, west and east of the FSRU. At all sites, the time-averaged chlorine concentration is well under the Guideline Value of 6 µg/L. Thus, under peak open loop operating conditions, the Guideline Value for chlorine is met.

Figure 6-39 shows the time-averaged chlorine concentration in open loop operations over a 28-day period of model simulation at the average rate of production. The time-averaged chlorine concentration is shown on separate plots for the seabed under the discharge ports and sites north, south, west and east of the FSRU. Under average open loop operating conditions, the Guideline Value for chlorine is met.

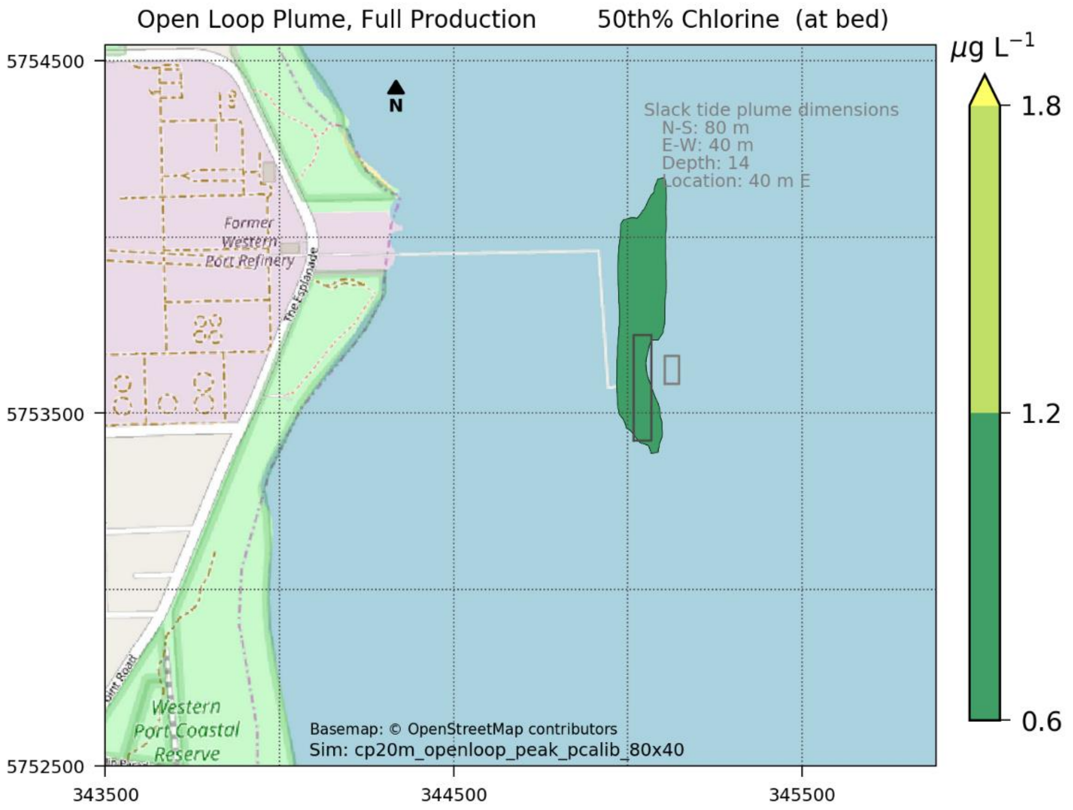


Figure 6-33. Peak Open Loop, Time Averaged Chlorine Concentration (FSRU only)

**Note: small box east of the FSRU shows where slack water plume is added to the model*

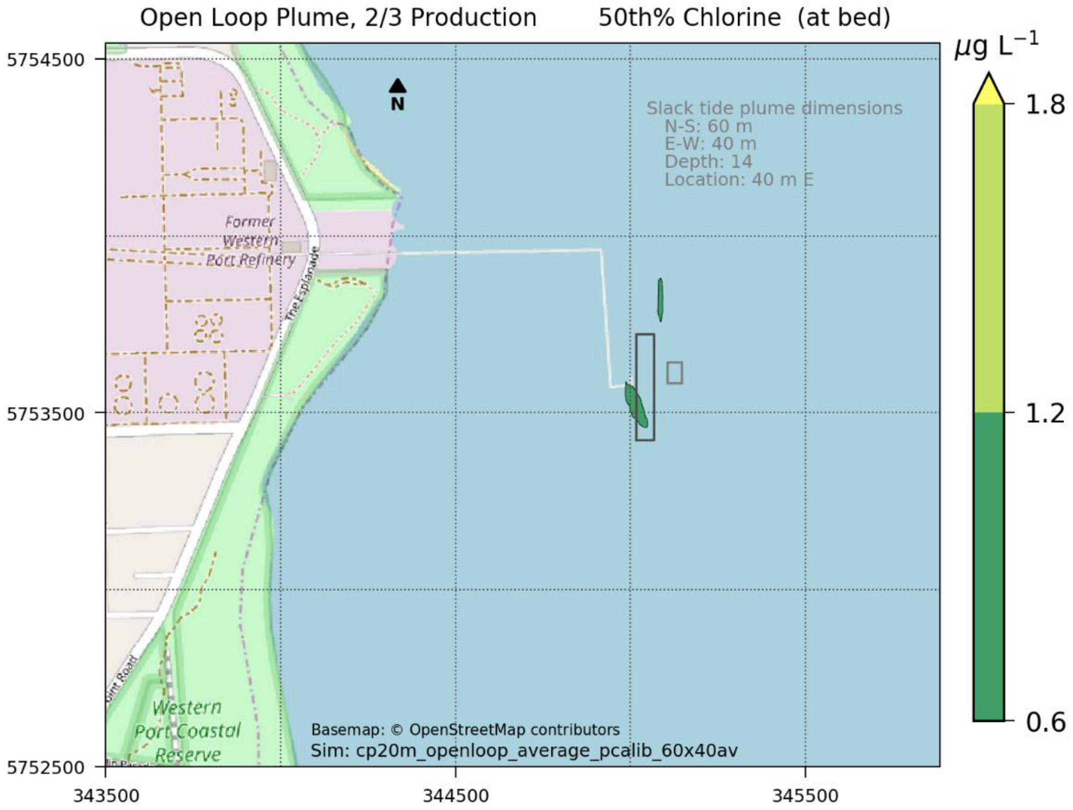


Figure 6-34. Average Open Loop, Time Averaged Chlorine Concentration (FSRU only)

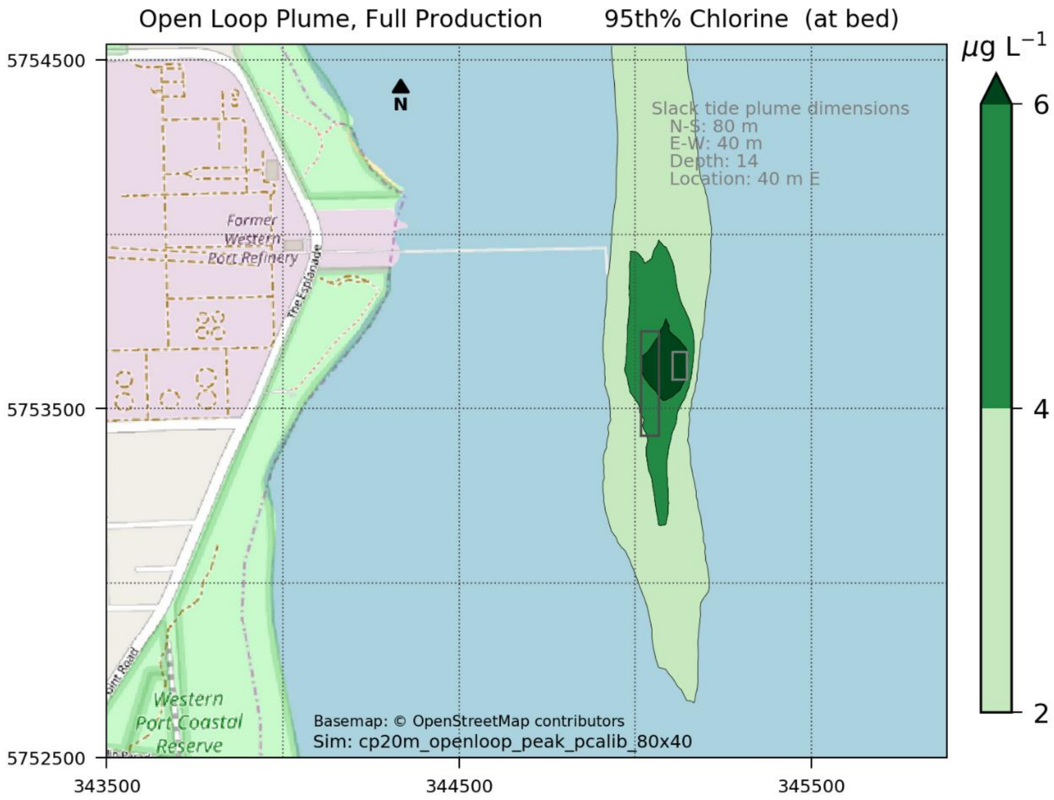


Figure 6-35. Peak Open Loop, 95% Chlorine Concentration (FSRU only)

**Note: small box east of the FSRU shows where slack water plume is added to the model*

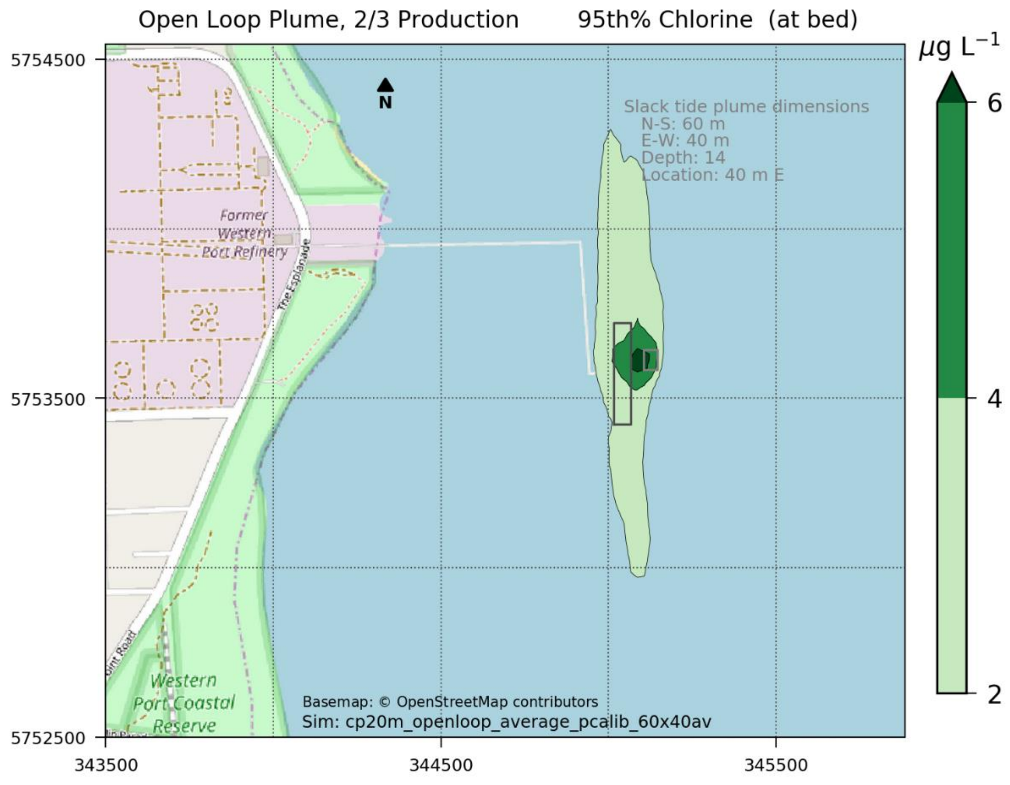


Figure 6-36. Average Open Loop, 95% Chlorine Concentration (FSRU only)

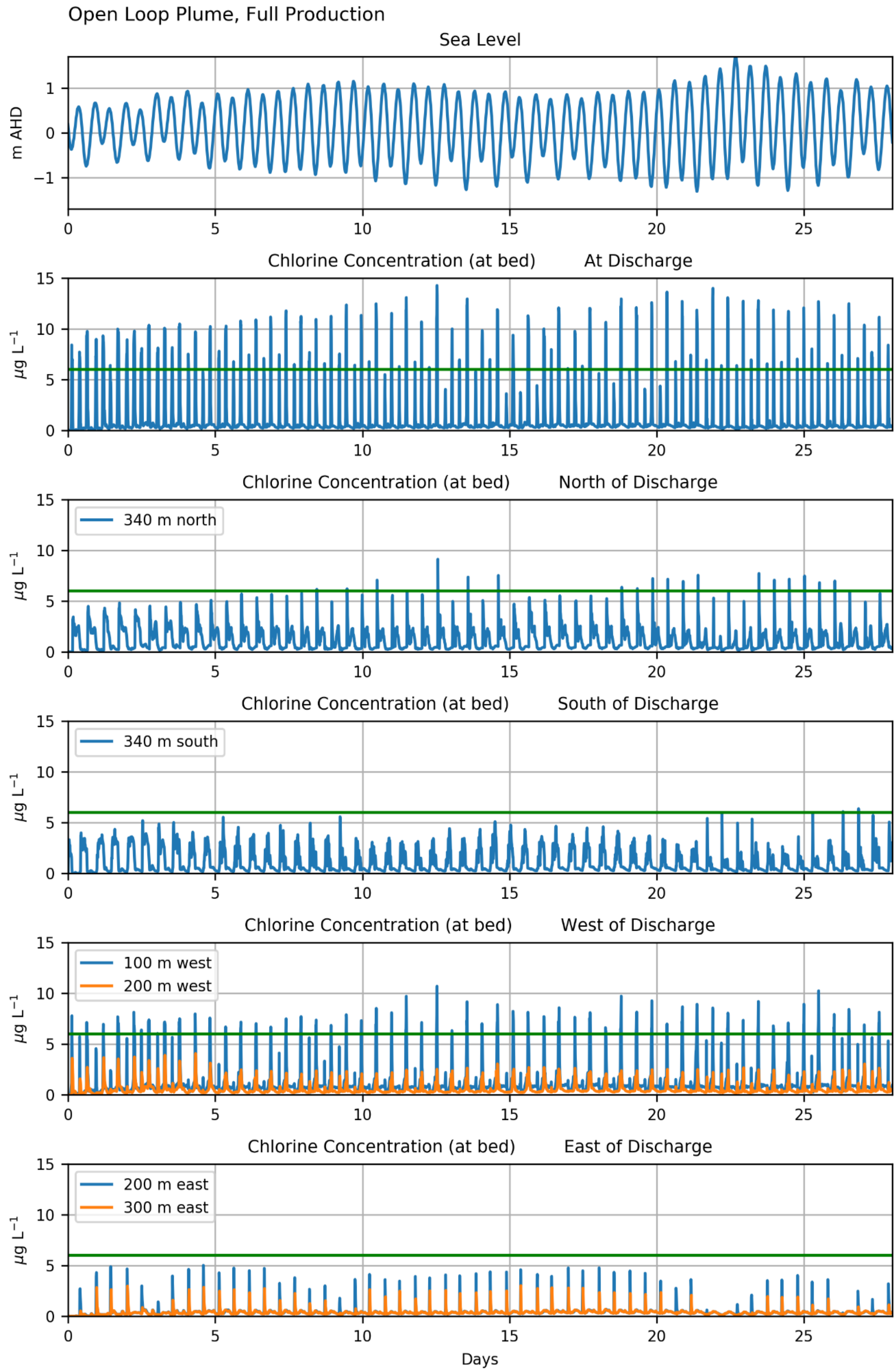


Figure 6-37. Peak Open Loop Time Series Chlorine Concentration (FSRU only)

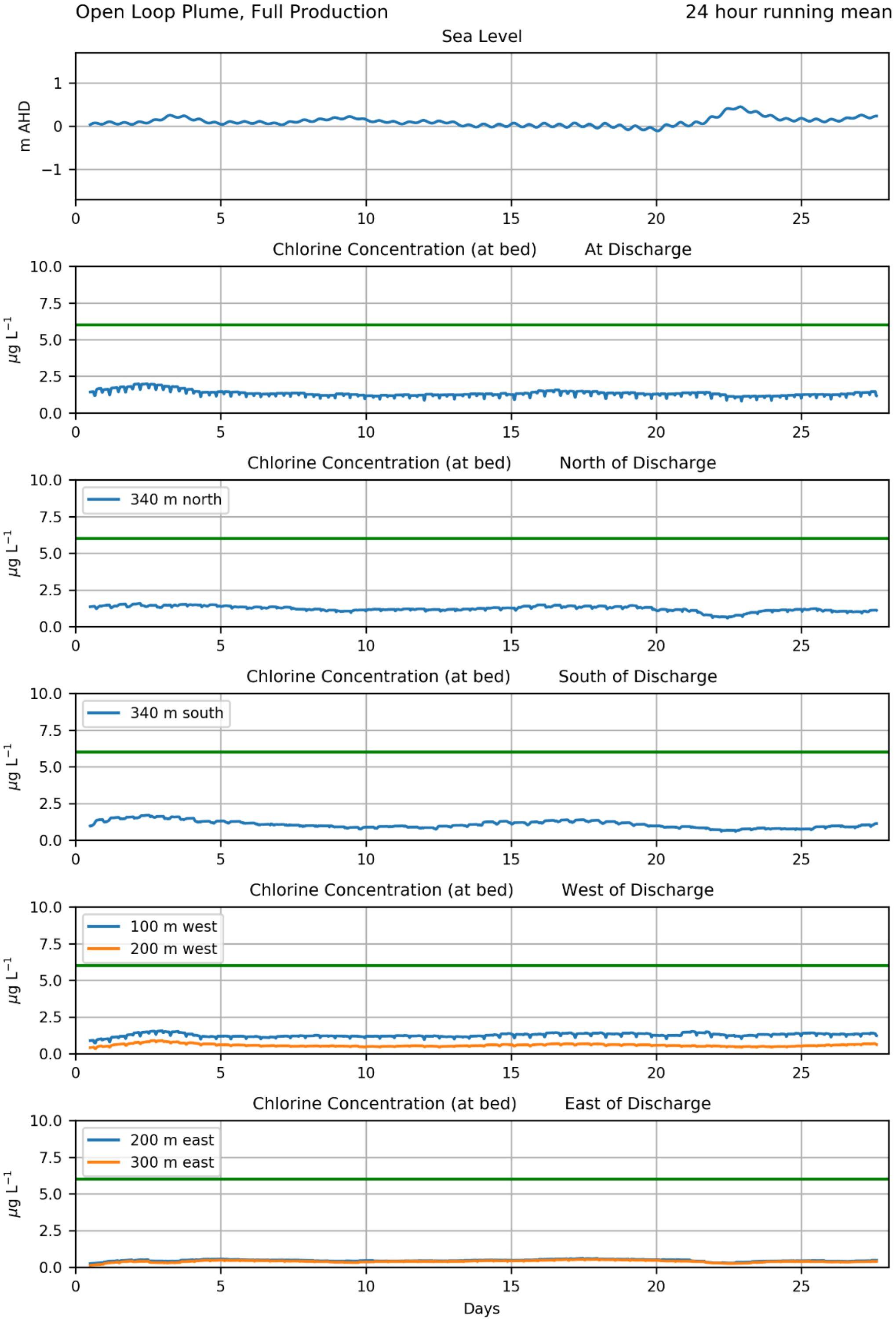


Figure 6-38. Peak Open Loop Time-Averaged Chlorine Concentration (FSRU only)

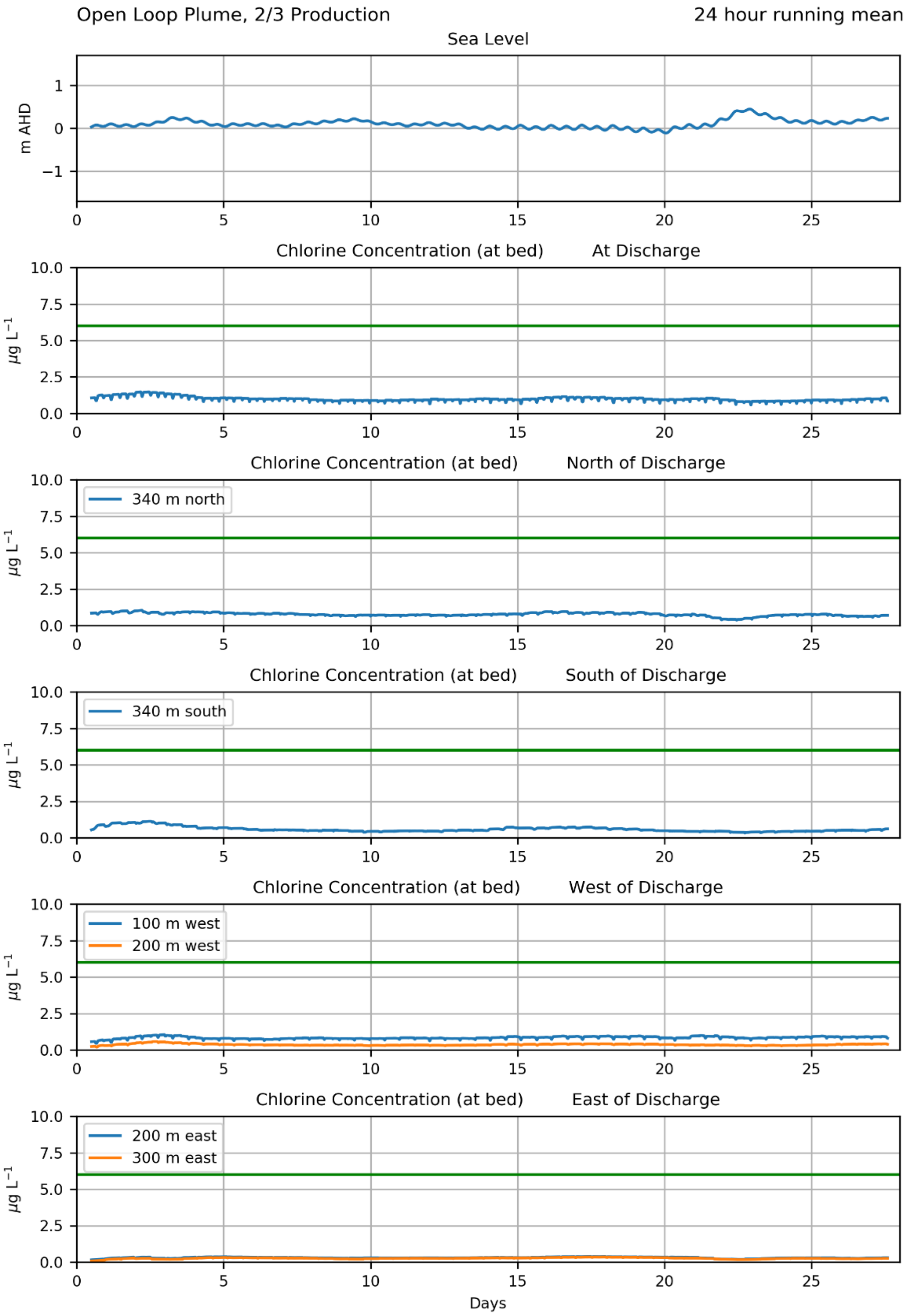


Figure 6-39. Average Open Loop Time-Averaged Chlorine Concentration (FSRU Only)

Summary for Chlorine Concentration in Open Loop Operations

In summary, in open loop operations, FSRU only, at peak and average rates of production, the time-averaged chlorine concentrations meet the Guideline Value of 6 µg/L for chlorine.

6.5.6 Chlorine Impacts During Open Loop (FSRU With LNG Carrier)

When there is an LNG carrier moored next to the FSRU, there is a different flow pattern because the LNG carrier obstructs the high velocity discharge jets. As mixing from the high-velocity discharge jets is limited, there is little initial dilution (refer to Figure 6-6). Thus, with a parallel LNG carrier, a much larger pool of cooler seawater forms on the seabed and higher concentrations of chlorine would be evident.

Open Loop Peak Production (FSRU With LNG Carrier)

Figure 6-40 shows the contours of time-averaged chlorine concentration for peak open loop production with the FSRU and an LNG carrier at Berth 2. The largest time-averaged chlorine contour is 6 µg/L and it extends for about 300 m north/south and 160 m east/west, covering an area of 5 ha adjacent to the two vessels and the Crib Point Jetty. The Guideline Limit of 6 µg/L is exceeded in this area.

Figure 6-42 shows the contours of the 95 % chlorine concentration for peak open loop production with the FSRU and an LNG carrier at Berth 2. The largest instantaneous chlorine contour is 6 µg/L and it extends for about 1100 m north/south and 300 m east/west, covering an area of 24 ha adjacent to the two vessels and the Crib Point Jetty. The plume extends along the depth contours through the Port area north of Berth 2 and for almost 1 km south of Berth 2. These chlorine concentrations only occur for short periods during slack water and thus, the Guideline Limit of 6 µg/L does not apply to these short-term concentrations.

Open Loop Average Production (FSRU With LNG Carrier)

Figure 6-41 shows the contours of time-averaged chlorine concentration for average open loop production with the FSRU and an LNG carrier at Berth 2. The largest time-averaged chlorine contour is 6 µg/L and it extends for about 200 m north/south and 120 m east/west, covering an area of 2 ha adjacent to the two vessels and the Crib Point Jetty. The Guideline Limit of 6 µg/L is exceeded in this area.

Figure 6-43 shows the contours of the 95 % chlorine concentration for average open loop production with the FSRU and an LNG carrier at Berth 2. The largest instantaneous chlorine contour is 6 µg/L and it extends for about 750 m north/south and 300 m east/west, covering an area of 18 ha adjacent to the two vessels and the Crib Point Jetty. The plume extends along the depth contours through the Port area north of Berth 2 and for almost 1 km south of Berth 2. The Guideline Limit of 6 µg/L does not apply to these short-term concentrations.

Time Series Plots

Figure 6-44 shows the instantaneous chlorine concentration in peak open loop operations with an LNG carrier moored next to the FSRU. It is estimated that this scenario will occur for about 18 to 60 days of the year. The predicted chlorine concentration is shown on separate plots for (1) the seabed directly under the discharge ports – peak chlorine concentrations up to 100 µg/L; (2) at 340 m north - peak chlorine concentrations of 10 to 15 µg/L; (3) at 340 m south - peak chlorine concentrations up to 10 µg/L; (4) at 100 m west and 200 m west – peaks over 6 µg/L at both west sites; and (5) at 200 m and 300 m east of the discharge ports - peak chlorine concentrations under 6 µg/L. Figure 6-45 shows the time-averaged chlorine concentration in open loop operations over the 28-day period of model simulation at the peak rate of production. The time-averaged chlorine concentration on the seabed directly under the

discharge ports is elevated at 50 to 75 µg/L, is marginal at 100 m west of the discharge but at other sites, the time-averaged chlorine concentration is under the Guideline Value of 6 µg/L.

Figure 6-46 shows the time-averaged chlorine concentration in average open loop operations over a 28-day period of model simulation. The time-averaged chlorine concentration on the seabed directly under the discharge ports is elevated at 50 to 75 µg/L and is marginal at 100 m west of the discharge. At other sites, the time-averaged chlorine concentration is under the Guideline Value of 6 µg/L.

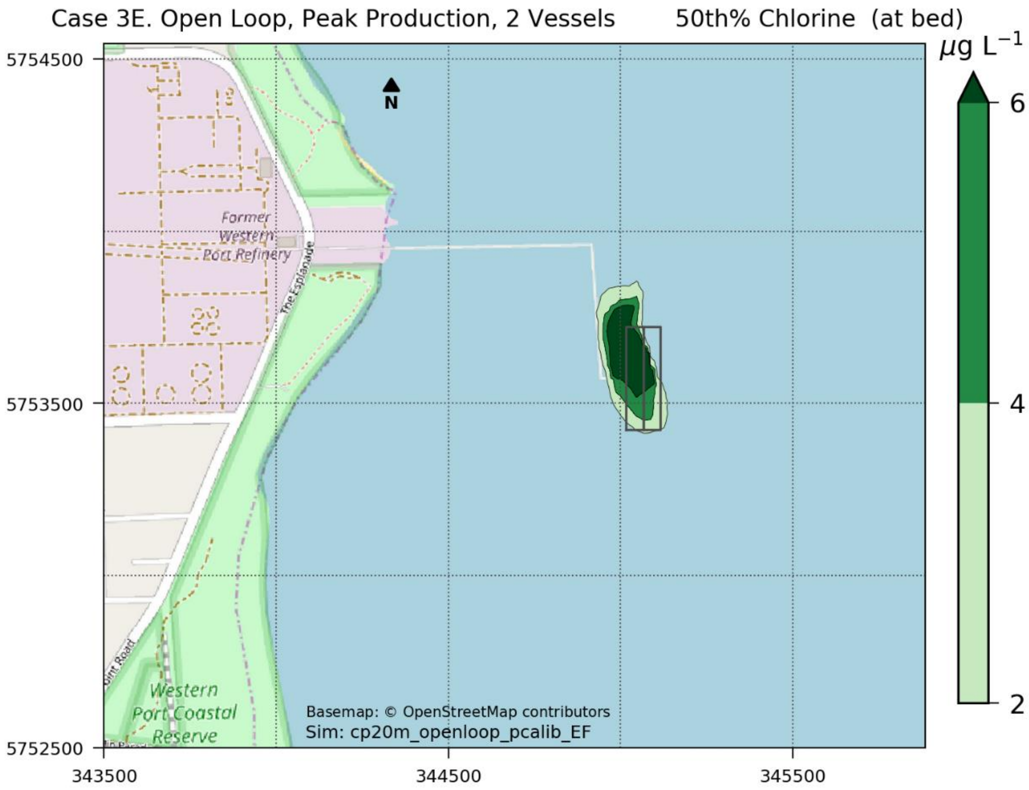


Figure 6-40. Peak Open Loop, Time Averaged Chlorine Concentration (FSRU with LNG)

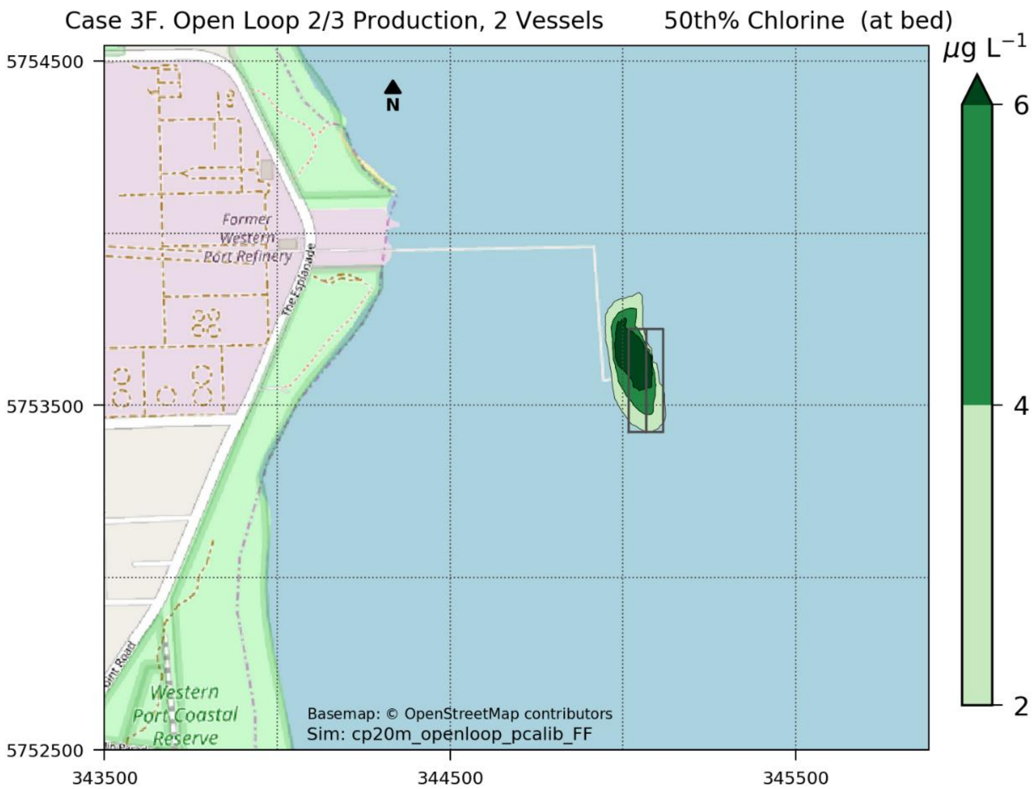


Figure 6-41. Average Open Loop, Time Averaged Chlorine Concentration (FSRU with LNG)

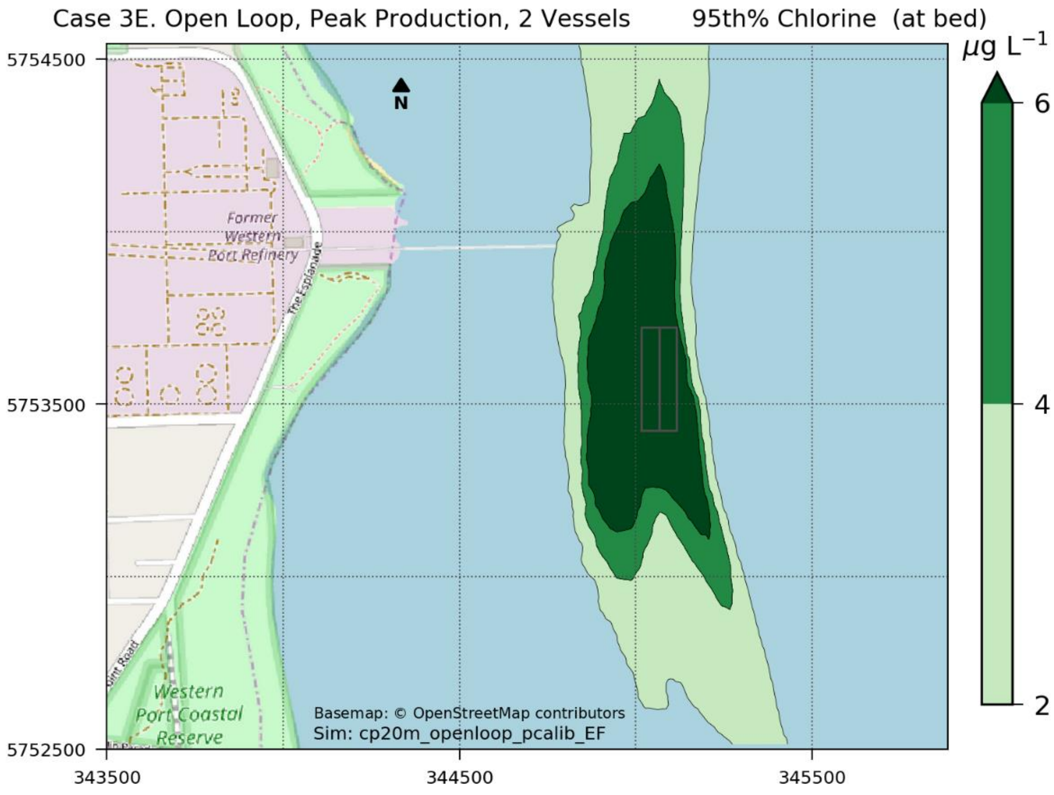


Figure 6-42. Peak Open Loop, 95% Chlorine Concentration (FSRU with LNG)

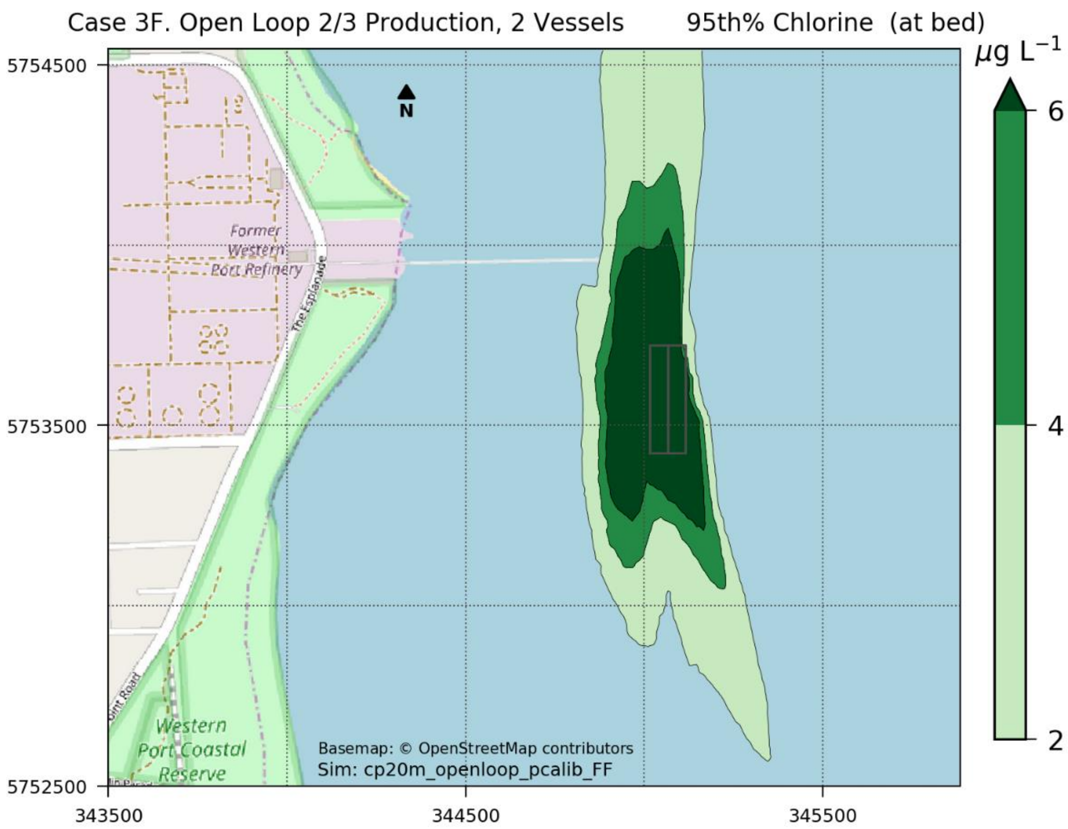


Figure 6-43. Average Open Loop, 95% Chlorine Concentration (FSRU with LNG)

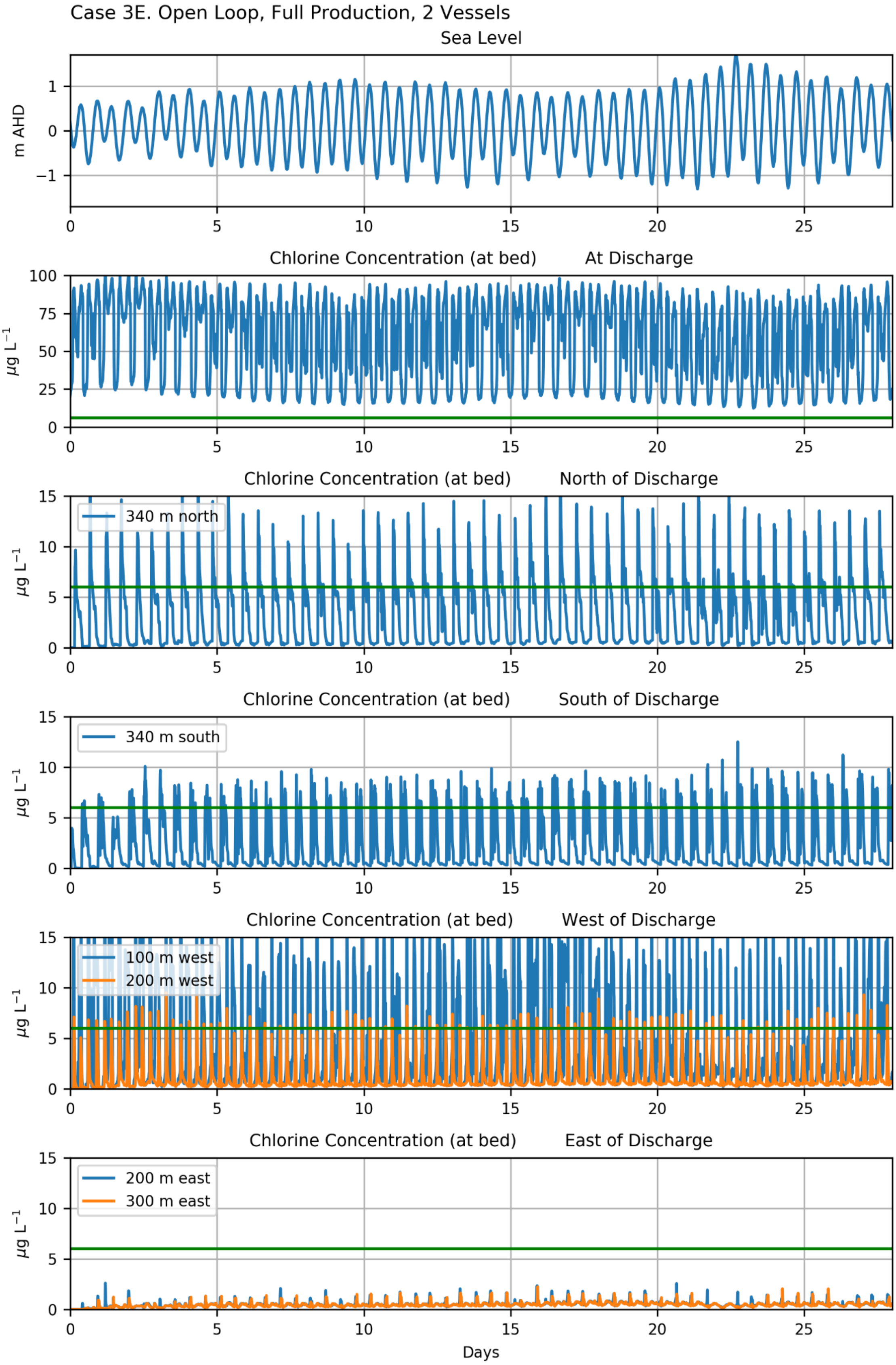


Figure 6-44. Peak Open Loop Time Series Chlorine Concentration (FSRU with LNG)

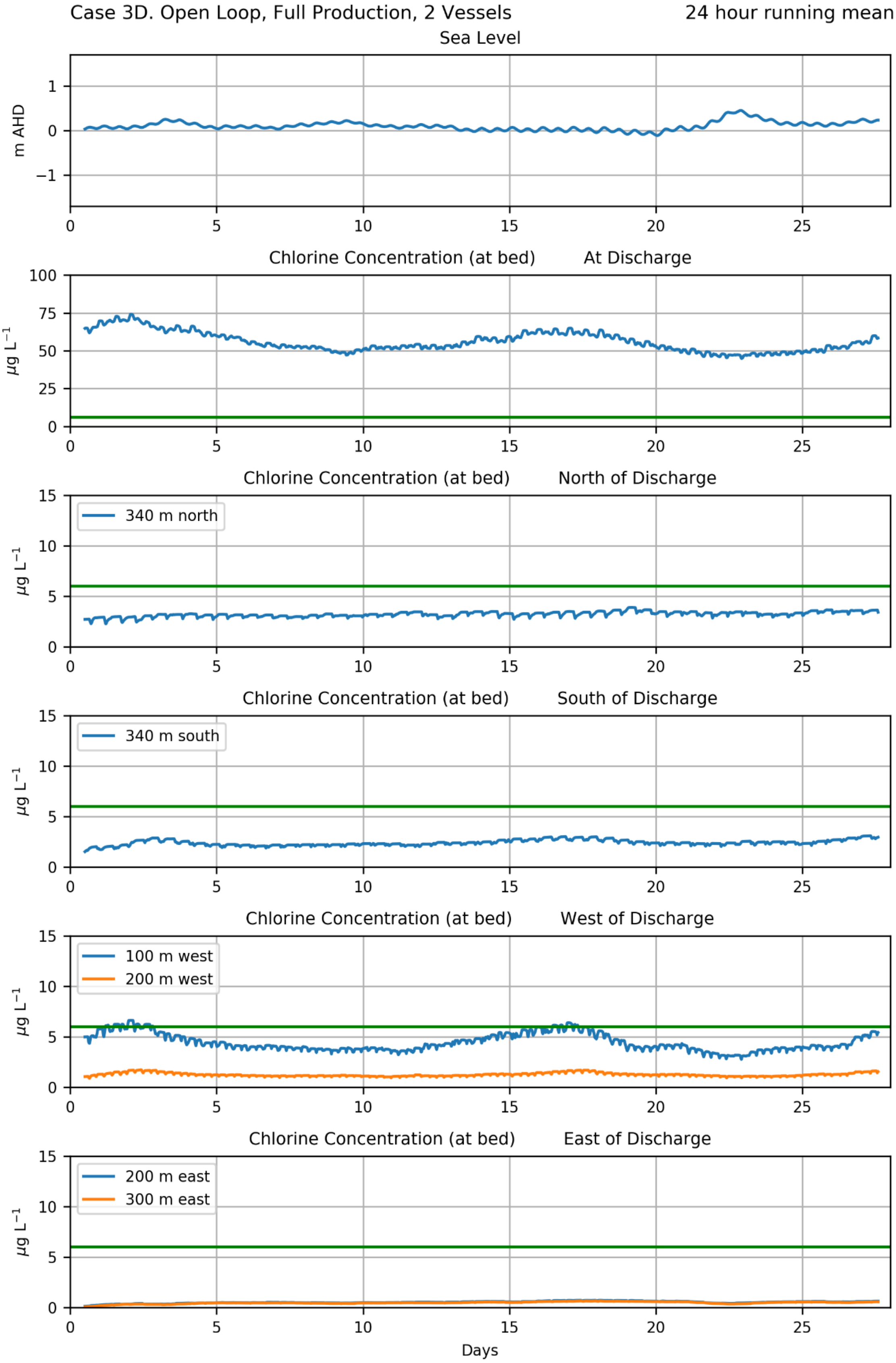


Figure 6-45. Peak Open Loop Time-Averaged Chlorine Concentration (FSRU with LNG)

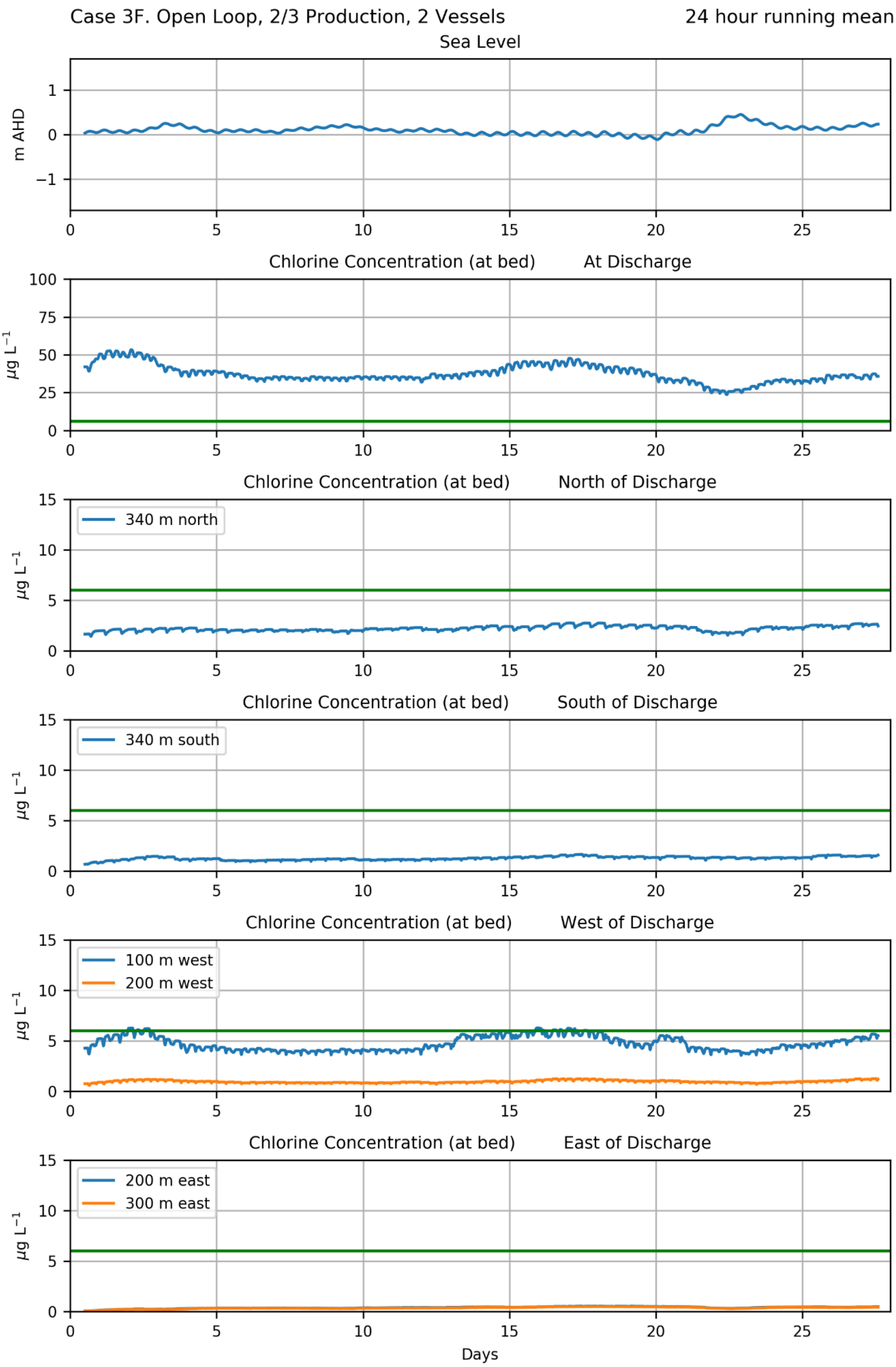


Figure 6-46. Average Open Loop Time Averaged Chlorine Concentration (FSRU with LNG)

6.5.7 Port Side Discharges – Chlorine

With an LNG carrier moored beside the FSRU, the LNG carrier obstructs the high-velocity discharge jets during open loop production. Thus, the initial dilution and mixing is greatly reduced and the plumes sink to the seabed and form a large 'pancake' of cooler seawater under the two vessels on the seabed.

An option to avoid the obstruction would involve installing the discharge ports on the west side of the FSRU (with the discharge ports facing the Crib Point Jetty and the shore). This arrangement has the benefit that the jets are not be obstructed by the LNG carrier and thus a high initial dilution is achieved even when there is an LNG carrier moored beside the FSRU. As noted earlier, there also are some disadvantages, including that the discharge is through the Jetty and towards the shore, and there are constraints on where the FSRU can be moored at Berth 2.

Figure 6-47 shows the time-averaged chlorine concentration for the west ports at peak open loop production and two vessels at the Berth 2. The highest chlorine concentration is 2 µg/L, over a small zone to the north of the ports (under the Jetty). This peak time-averaged concentration is the same as for the east side ports and well within the time-averaged chlorine limit of 6 µg/L.

Overall, the chlorine patterns for the west side ports are a mirror image of the patterns for the east side ports, but marginally larger in footprint because of the lower current speeds and shallower water on the west side compared to the east side.

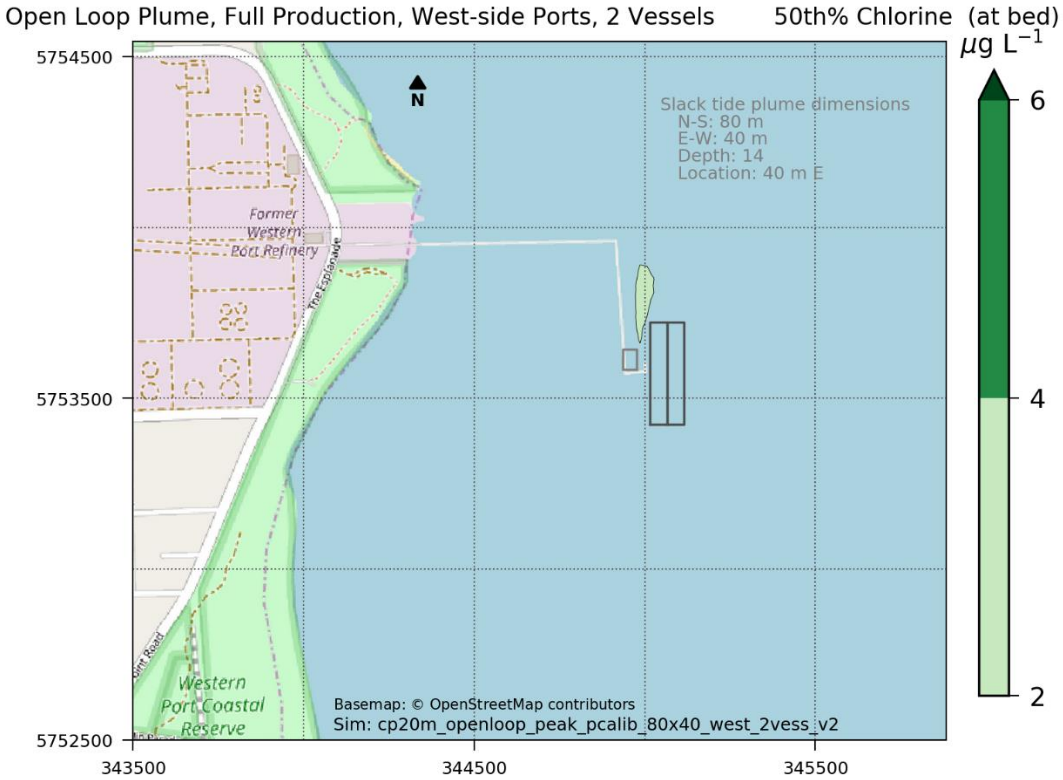


Figure 6-47. Peak Open Loop, Time-Averaged Chlorine Concentration (Port Side)

**Note: small box east of the FSRU shows where slack water plume is added to the model*

The west-side port option is a practical alternative with advantages and disadvantages (as described above). Advantages are realised in the scenario where an LNG carrier is moored adjacent to the FSRU. There is no advantage with respect to chlorine for the periods when no LNG carrier is moored alongside the FSRU. It remains as a possibility and is not part of the current project.

6.5.8 Chlorine Impacts for Closed Loop Operations (FSRU Only)

Figure 6-48 shows the time-averaged chlorine concentration in closed loop operations, peak production. The highest time-averaged chlorine contour is 6 μg/L. Thus, under typical peak closed loop operating conditions, the Guideline Value of 6 μg/L for chlorine is met except for a small zone of about 40 m diameter around the discharge ports, with a footprint of 0.2 ha.

For illustrative purposes, Figure 6-49 shows the 95-percentile chlorine concentration in closed loop operations at peak production. This scenario corresponds to the peak 20-minute concentration each tidal cycle during slack water. The Guideline Value of 6 μg/L does not apply to this short averaging condition.

The chlorine contours in Figure 6-49 show two small zones of discharge on either side of the FSRU. The larger zone exceeding 6 μg/L is about 180 m in length north to south and 90 m from east to west. There is a larger zone exceeding 4 μg/L that extends about 300 m north/south and 18 m east/west. The extent of chlorine is limited because there is less seawater discharged in closed loop than in open loop operations (hence less residual chlorine is discharged) and the seawater discharge is warm and thus, creates extra mixing due to buoyant rise.

The smaller zone exceeding 6 μg/L is about 70 m diameter around the point of discharge at the rear of the FSRU.

In summary, the total area exceeding the time-averaged Guideline Value of 6 µg/L for closed loop operations with only the FSRU present is 0.2 ha.

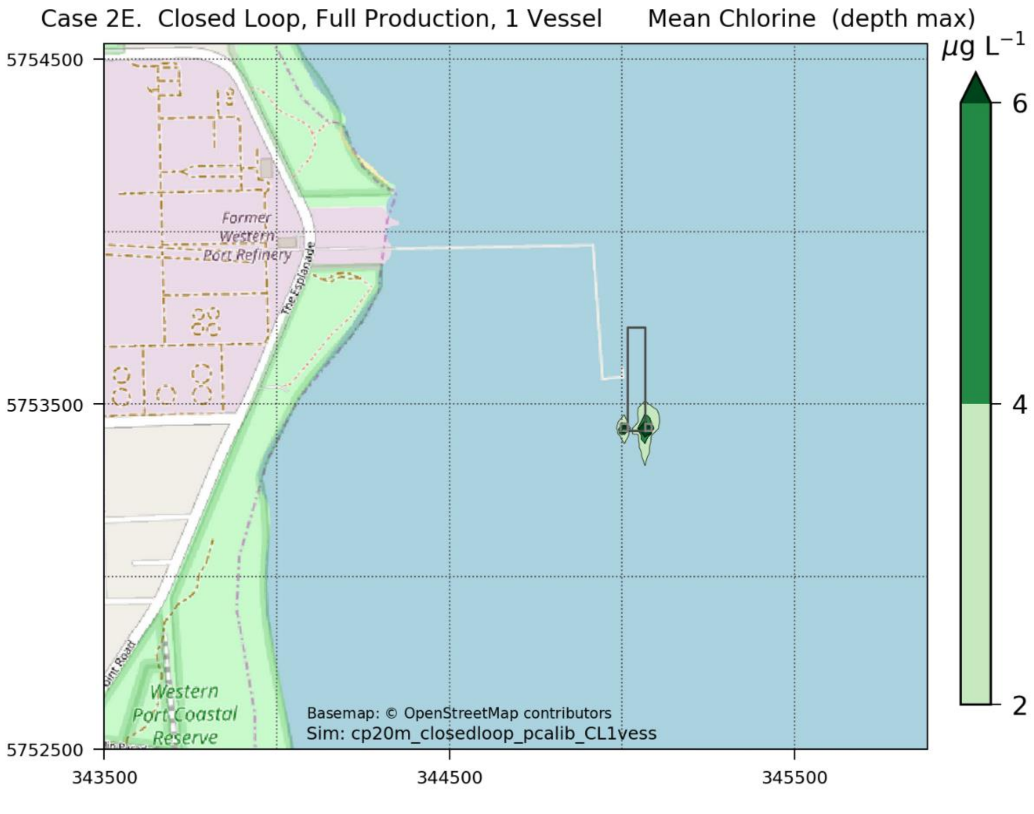


Figure 6-48. Closed Loop, Time Averaged Chlorine Concentration (FSRU only)

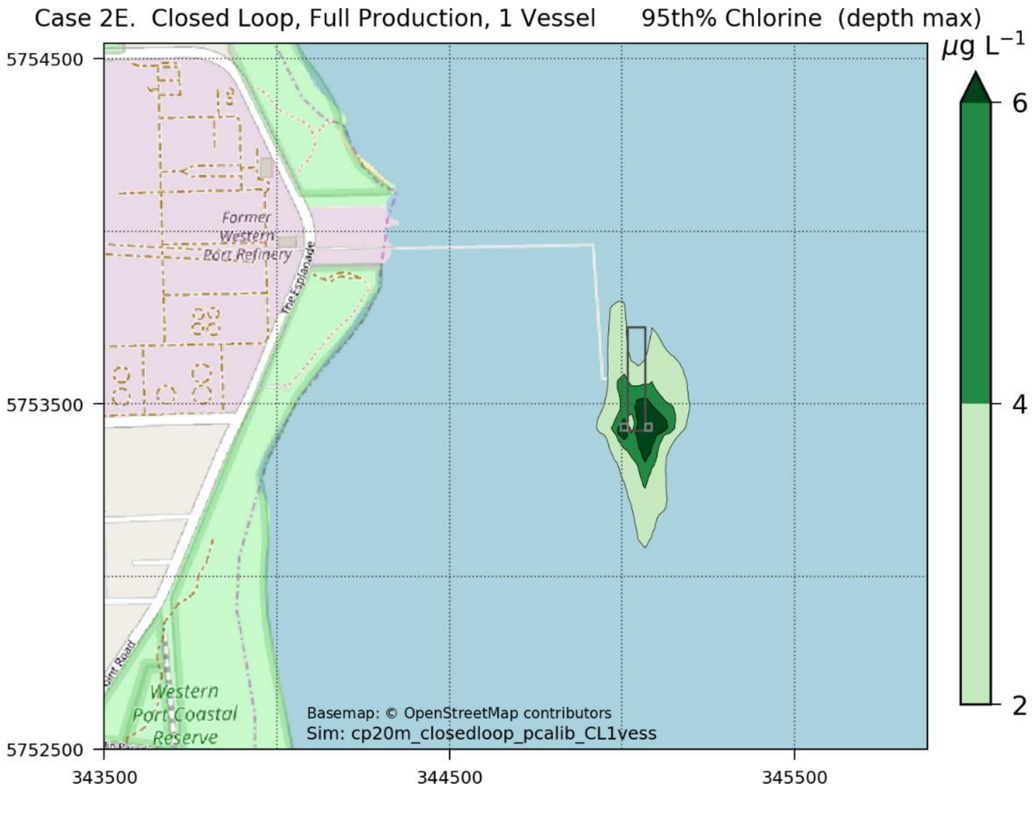


Figure 6-49. Closed Loop, 95% Chlorine Concentration (FSRU only)

Time-Averaged Chlorine Concentration – Closed Loop (FSRU Only)

Figure 6-50 shows the time-averaged chlorine concentration in closed loop operations, with FSRU only. The time-averaged chlorine concentration on the seabed directly under the discharge ports is elevated at 25 to 28 µg/L but meets the time-averaged Guideline Value of 6 µg/L at all other sites.

Summary for Closed Loop and FSRU Only

In summary, in closed loop operations, with FSRU only, the time-averaged chlorine concentration is under the Guideline Value of 6 µg/L for chlorine except for a small zone of about 0.2 ha at the discharge ports. There are short-term peaks in chlorine at slack water that are localised to the proposed FSRU location.

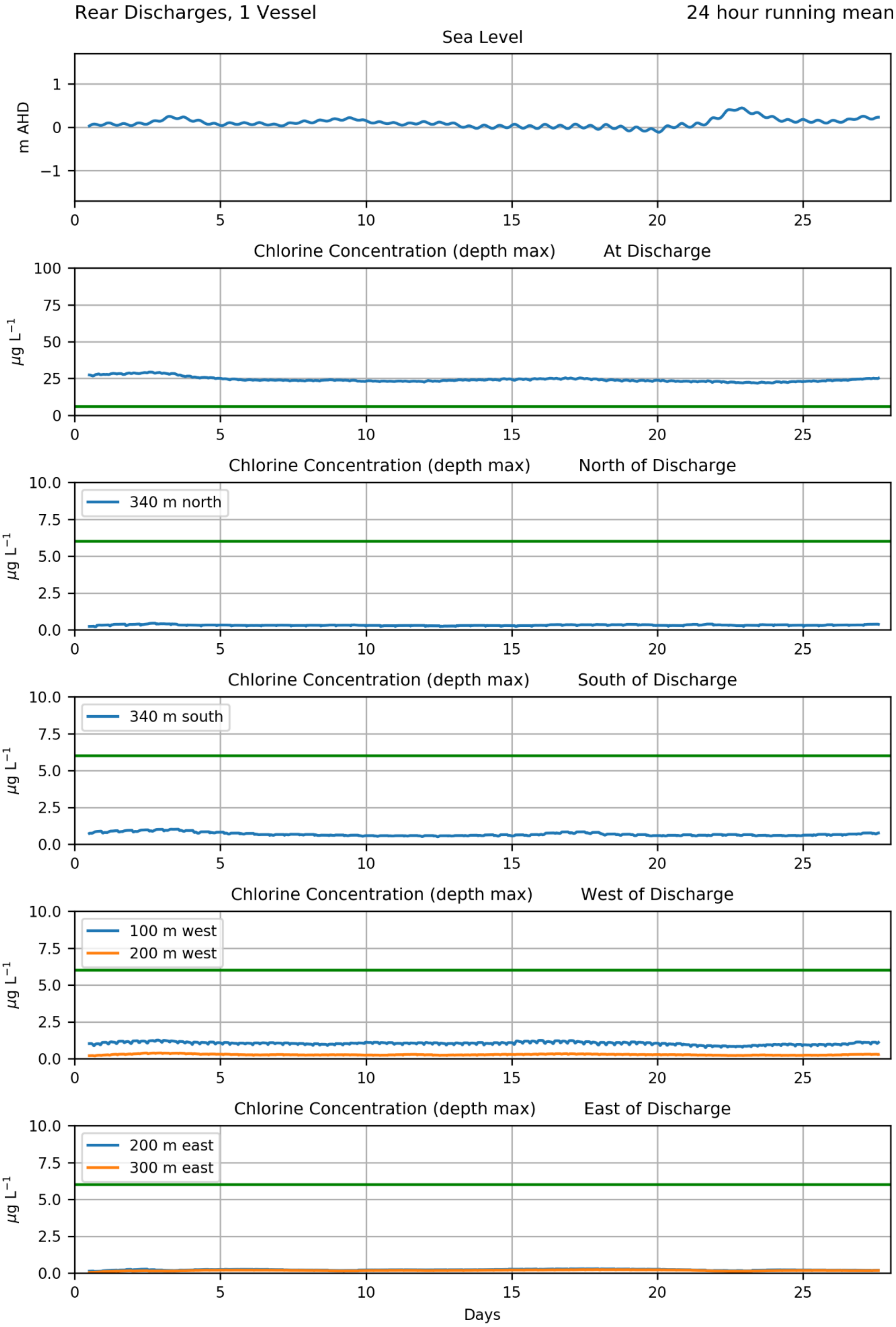


Figure 6-50. Closed Loop Time Averaged Chlorine Concentration (FSRU only)

6.5.9 Chlorine Impacts During Closed Loop (FSRU With LNG Carrier)

This part of the report presents the modelling results for closed loop operations with an LNG carrier moored parallel to the FSRU. AGL advised that in closed loop operation, the discharge flows and chlorine levels in the discharge are much the same whatever the rate of gas production, and thus only the peak closed loop plots are presented.

Closed Loop – FSRU with LNG Tanker

Figure 6-51 shows the 12-hour, time-averaged chlorine concentration in closed loop operations, and FSRU with LNG carrier at Berth 2. The highest time-averaged chlorine contour is 6 µg/L over a very small area around the discharge ports. Thus, under typical peak closed loop operating conditions, the Guideline Value of 6 µg/L for chlorine is met except for a small zone of about 40 m diameter around the discharge ports, with a footprint of 0.2 ha.

For illustrative purposes, Figure 6-52 shows the 95-percentile chlorine concentration in closed loop operations at full production. This scenario corresponds to the maximum 20-minute concentration each tidal cycle. The Guideline Value of 6 µg/L does not apply to this short averaging condition.

The chlorine contours in Figure 6-52 show two small zones (corresponding to the two discharge sites at the rear of the FSRU) extending about 200 m north/south and an average of 12 m east/west. The footprint is under the two vessels and the adjacent Crib Point Jetty. There is a larger zone exceeding 2 µg/L that extends about 700 m north/south and 200 m east/west.

Time-Averaged Chlorine Concentration – Closed Loop - FSRU with LNG Carrier

Figure 6-53 shows the time averaged chlorine concentration in closed loop operations, and FSRU with an LNG carrier at Berth 2. The time-averaged chlorine concentration on the seabed directly under the discharge ports is elevated at 25 to 30 µg/L but meets the time-averaged Guideline Value of 6 µg/L at all other sites.

Summary for Closed Loop - FSRU With LNG Carrier

In summary, in closed loop operations with FSRU and an LNG carrier at Berth 2, the time-averaged chlorine concentration is under the Guideline Value of 6 µg/L for chlorine except for a small zone of about 0.2 ha at the discharge ports. There are short-term peaks in chlorine at slack water that are localised to the proposed site of the vessels.

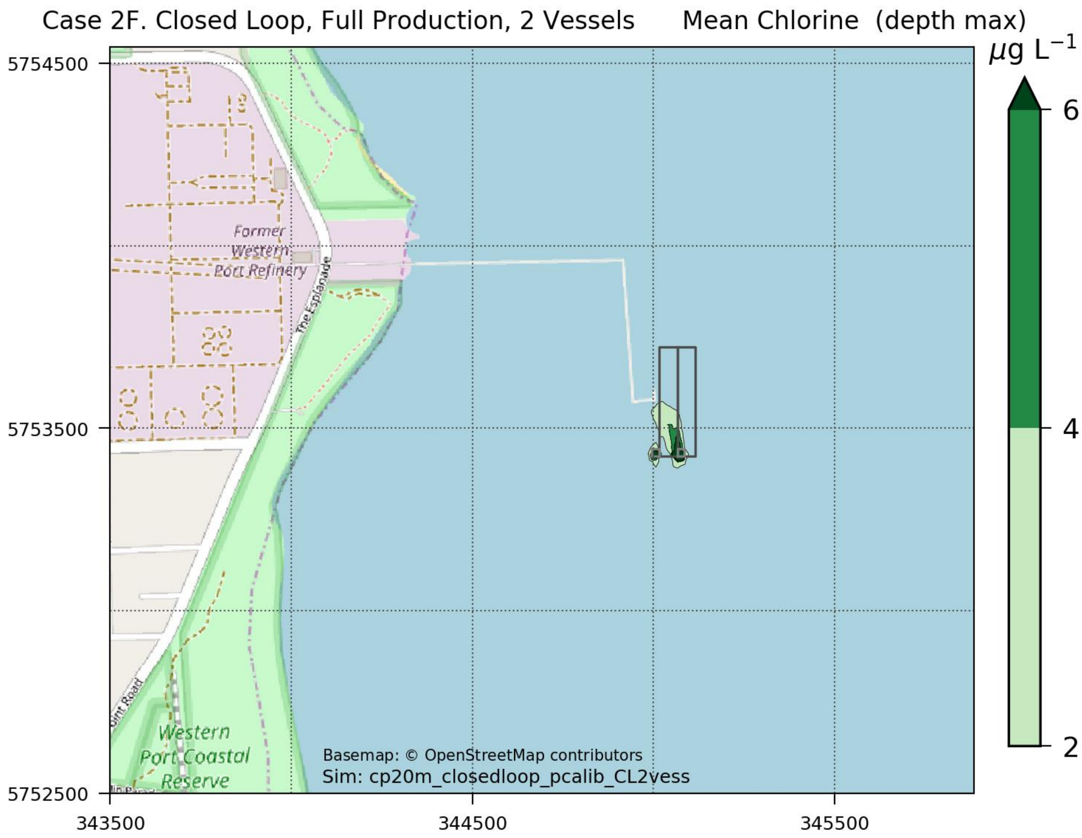


Figure 6-51. Closed Loop, Time Averaged Chlorine Concentration (FSRU with LNG)

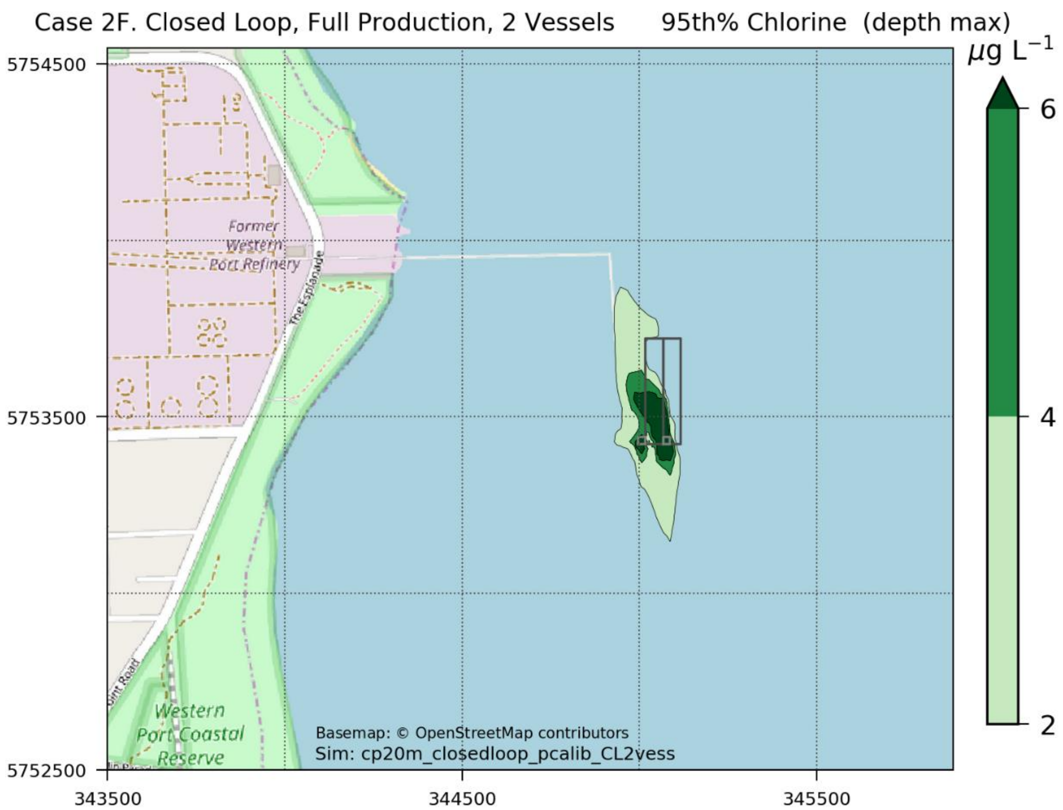


Figure 6-52. Closed Loop, 95% Chlorine Concentration (FSRU with LNG)

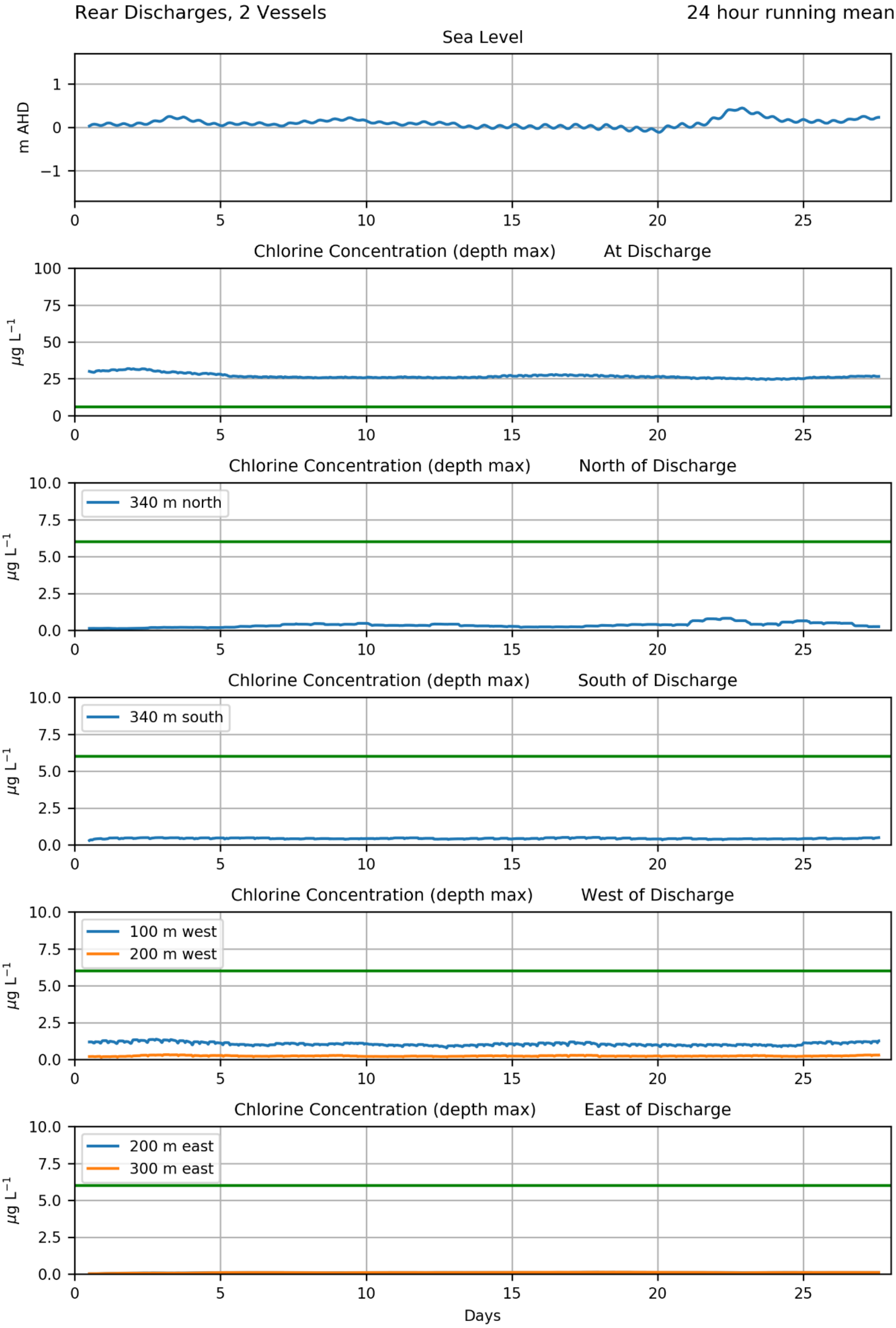


Figure 6-53. Closed Loop Time Averaged Chlorine Concentration (FSRU with LNG)

6.5.10 Ballast Water Discharge

As noted earlier, ballast is stored in tanks on the FSRU for a week to four weeks before it is discharged. Thus, a reduced chlorine concentration of 21 µg/L applies to the ballast water, to account for the decay in chlorine during storage.

Figure 6-54 shows the 95-percentile chlorine concentration resulting from ballast water discharge.

The chlorine contours in Figure 6-54 show that the highest chlorine level in this scenario is 4 µg/L in a small zone on the seabed at the point of discharge. It can be inferred that the discharge of ballast water does not cause an exceedance of the Guideline Value of 6 µg/L for chlorine.

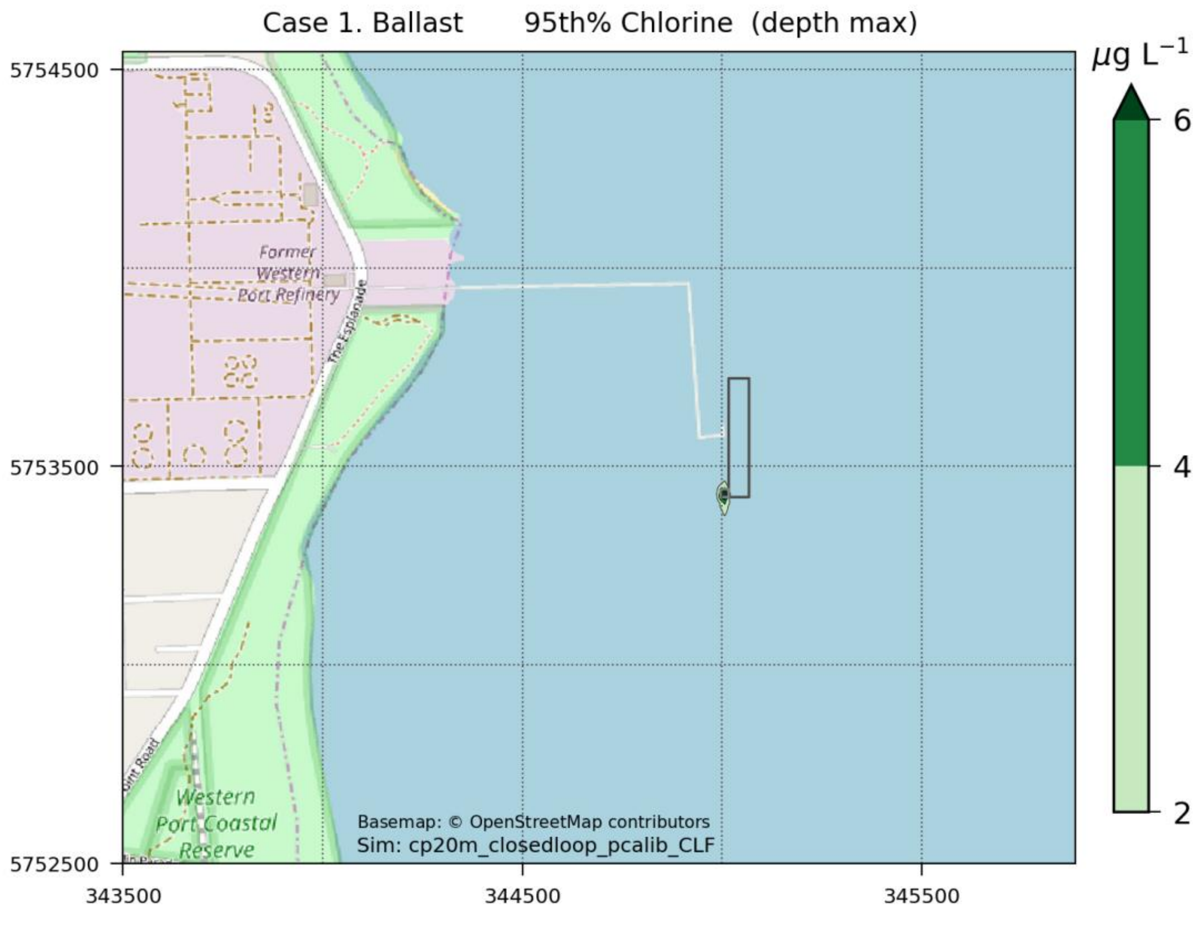


Figure 6-54. Ballast Water, 95% Chlorine Concentration (FSRU only)

6.5.11 Summary of Results for Chlorine Predictions

This section summarises the chlorine predictions of the regional model for the various conditions and flow patterns in the proposed operation of the FSRU.

In <u>open</u> loop operations, with the FSRU only, the time-averaged chlorine level is less than the Guideline Value of 6 µg/L at all sites in the regional model. A small zone in the water column next to the discharge ports has higher chlorine levels over a short distance.

The moored LNG carrier changes the situation considerably. In open loop operations, with the FSRU and an LNG carrier, there is a larger footprint (of 1 to 5 ha) of chlorine above 6 µg/L on a time-averaged basis, due to a pool of cooler seawater forming on the seabed before and after each period of slack water. The size of the pool of cooler seawater decreases as the production rate decreases as there would be a lower volume of seawater being discharged (in open loop). With peak open loop production the area above 6 ug/L is 5 ha; with average production, the area above 6 ug/L is 2 ha and with 1/3 peak production the area above 6 ug/L is 1 ha.

In closed loop operations, and with or without an LNG carrier, there is a small footprint of 0.2 ha of chlorine above the Guideline Value at the discharge sites.

Table 6-6 summarises the area where the time-averaged chlorine concentration is predicted to exceed the Guideline Value of 6 µg/L. Using the modelled scenario of a maximum of 40 LNG carriers per year, each moored for up to 36 hours, the larger footprints would apply for 60 days per year (with continuous open loop operation). These larger footprints would occur during slack water between tides and would decrease as tidal currents increase, stimulating mixing.

Table 6-6. Summary of Results for Chlorine Predictions

Production rate	Operating Mode	Vessels at Crib Point Jetty (Berth 2)	Area above 6 µg/L
Peak	Open loop	No LNG Carrier	Complies
Average	Open loop	No LNG Carrier	Complies
Peak	Open loop	With LNG Carrier	5 ha
Average	Open loop	With LNG Carrier	2 ha
One-third Peak	Open loop	With LNG Carrier	1 ha
Peak	Closed loop	No LNG Carrier	0.2 ha
Peak	Closed loop	With LNG Carrier	0.2 ha

6.6 Biota Entrainment Predictions

This section describes the use of the regional hydrodynamic model to predict the entrainment of plankton and other small marine organisms in the seawater taken into the FSRU.

All the seawater discharges in open loop and closed loop operations, and for ballast water and miscellaneous discharges, must have a corresponding intake of seawater. All seawater is taken in through sea chests on the side of the FSRU at approximately mid-depth. The sea chests have been designed to minimise the entrainment of fish and larger organisms, and debris, is described in Section 1.3 and Section 7.

6.6.1 Entrainment Assumptions

The following assumptions were adopted for modelling biota entrainment:

- Neutrally buoyant particles that are uniformly distributed in the water column were used to simulate the movement of plankton and other small marine organisms. The entrainment simulations over-estimate the capture of those organisms (such as some fish larvae) that remain close to the water surface or the seabed. However, there is strong vertical mixing in Western Port that should ensure that most plankton would be uniformly distributed in the water column.
- The particles are distributed throughout the release zone at the beginning of each simulation. As a check, one set of particles was released at the water surface and a second set in a subsequent run released at the seabed, and from a comparison of the outcomes, it was established that the same rates of entrainment ensued.
- The entrainment calculations are for a constant seawater intake rate of 450,000 m^3/d (open loop operations). The entrainment rates were then adjusted to account for different discharge flow rates (e.g. peak open loop, average open loop and closed loop production). The adjustments are made in the tables presented later in this section.
- Entrainment occurs when a tracked particle enters the entrainment zone beside the FSRU (Table 6-7) that corresponds to the intake volume of seawater for the sea chest.
- The FSRU intake sea chests are assumed to have a north-south length of 14.5 m and a height of 2.5m (and always being at least 2 m below the water surface and 3 m above the seabed). There is a sea chest on each of the port and starboard sides of the FSRU at 42.5 to 57 m from the aft of the vessel.
- The travel time from the sea chests via the pumps through the pipes and heat exchanger to the discharge ports is a maximum of 5 minutes before discharge. It is assumed that all plankton in the entrained seawater become non-viable in this time.
- Particles were tracked for two 28-day periods (a full lunar cycle of two neap and two spring tides). Thus, entrainment rates are quoted in terms of “percentage of particles entrained in 28 days” and “average percentage of particles entrained per day”. However, the entrainment results should be considered in the context of the life cycle of the populations, and other biological stresses and factors influencing population dynamics. The 28-day timeframe can be longer than the time taken to renew populations. The biological context and implications of these entrainment results are addressed in Section 7.

6.6.2 Model for Particle Release and Tracking

The regional hydrodynamic model was used to assess the fate of particles released from different zones within the Bay. The zones were defined for various biological reasons and are illustrated in Figure 6-55. Zone 8 represents the Upper North Arm of Western Port. Zones 2, 3, 5, 6 and 7 represent various segments in Lower North Arm. Zone 4 was incorporated into Zone 3. Zones 9 and 10 represent the Western Entrance. Note that Zone 1 immediately around the FSRU was used as a test case for the model configuration and is not used for the analysis.

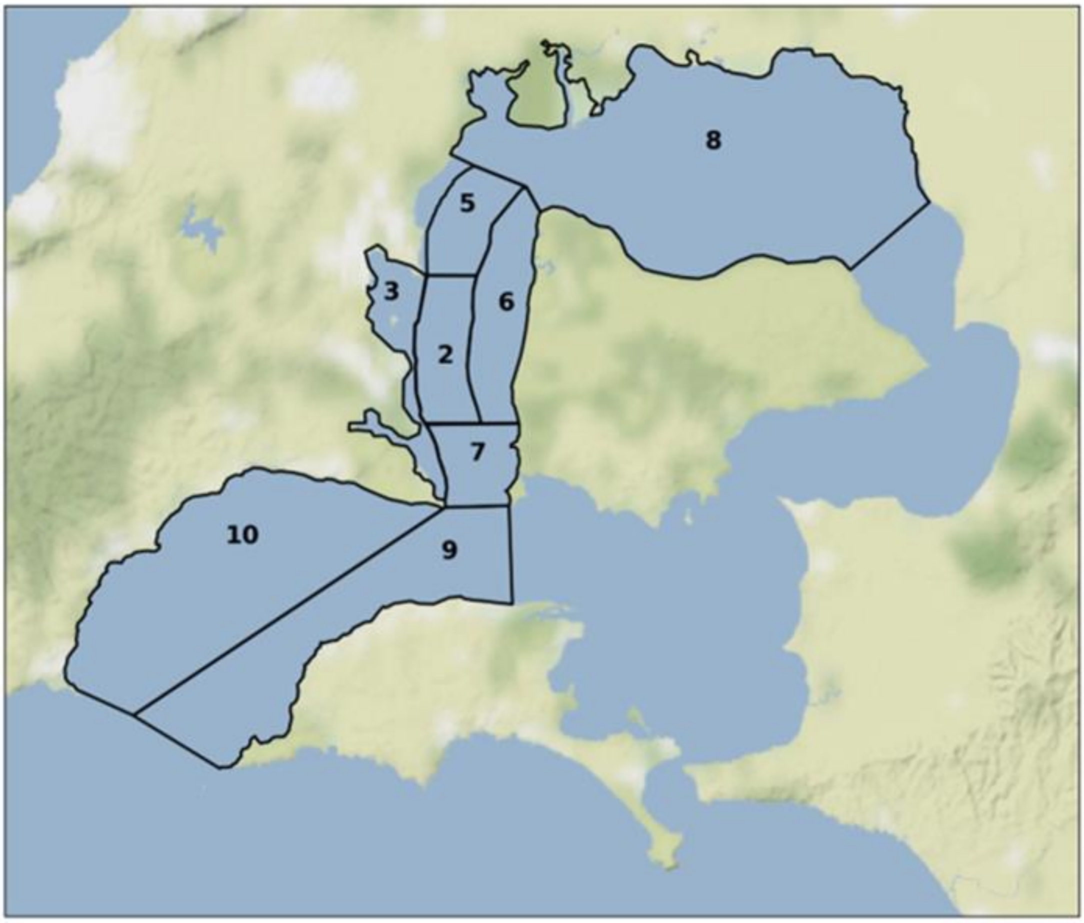


Figure 6-55. Particle Release Zones in Western Port

The particles are neutrally buoyant and were initially spaced evenly within each zone – with one particle in each corner of a 50 m by 50 m mesh. The number of particles released ranged from 3,137 to 63,921 depending on the size of each zone (i.e. the larger the zone, the more particles it contained at the beginning of the tracking). The model was run for a spin-up period of 10 days prior to the release of particles in each of the zones, and then for 28 days.

The particles were tracked from several different starting conditions during the simulations, which are listed below.

- Uniform distribution at the surface during a spring rising tide (all Zones);
- Mixed distribution (lateral and vertical) during spring rising tide (all Zones);
- Mixed distribution (lateral and vertical) during spring falling tide (all Zones);
- Uniform distribution at the seabed released during a spring rising tide (Zone 2, 3, 7);
- Uniform distribution at the surface released during a neap rising tide (Zone 2, 3, 7);

- Mixed distribution (lateral and vertical) during neap rising tide (Zone 2, 3, 7); and
- Mixed distribution (lateral and vertical) during neap falling tide (Zone 2, 3, 7).

It was found that slightly different entrainment rates occur with different starting conditions. This reflects the outcome of two processes: (1) Starting direction of movement - whether the starting condition moved particles from a zone towards or away from the FSRU seawater intake (e.g. rising tide vs falling tide); and (2) Tidal condition - whether the starting condition pushed more particles past the FSRU seawater intake (e.g. spring tide) rather than fewer particles (e.g. neap tide).

Mixed initial distributions were achieved by running the model for two tidal cycles after achieving a uniform distribution of particles at the surface. The tracking period was then for 28 days with the position of each particle recorded every 10 minutes. To allow longer run times, the 50 x 50 m model grid was used for the particle release and capture simulations.

To check the effect of starting time, runs were made starting in June 2018 and November 2018 with very similar results as described in the entrainment sensitivity analysis in the regional modelling report (HydroNumerics, 2019).

Figure 6-56 provides an example of the movement of particles released in Zone 2 in steps of 5 days as the simulation progresses. After the first 5 days, the particles released in North Arm near Hastings have spread throughout North Arm, down to the entrance of the Western Channel and across to Rhyll. After 10 days, particles have spread throughout the Bay, apart from the far east of the Bay near Corinella and the far south near San Remo. After 15 days, particles have spread throughout the Bay, and continue to spread until the end of the 28-day simulation.

6.6.3 Model for Particle Entrainment

As noted above, the FSRU seawater intake chests are 14.5 m long, 2.5 m high and at approximately mid-depth. The dimensions of the entrainment volume associated with each sea chest were calculated as a function of the current speed, as shown in Table 6-7.

The number of released particles from each zone that entered the seawater intake entrainment volume was determined for each 10-minute time step of the model (taking into account the current speed in that time step). Particles that entered the entrainment volume were added to the count of entrained particles and removed from further analysis. This process was repeated for each of the initial distributions and starting times in the simulations.

Table 6-7. Dimensions of entrainment zone from the FSRU sea chest.

Current speed, m/s	Top of entry zone, m	Base of entry zone, m	Width of entry zone, m	Travel in 10 sec, m
0.03	3	11	21.7	0.3
0.1	4	10	8.7	1
0.15	4.1	9.9	6.0	1.5
0.2	4.3	9.7	4.8	2
0.3	4.7	9.3	3.8	3
0.4	4.9	9.1	3.1	4
0.5	5.1	8.9	2.7	5

Current speed, m/s	Top of entry zone, m	Base of entry zone, m	Width of entry zone, m	Travel in 10 sec, m
0.6	5.2	8.8	2.5	6
0.7	5.4	8.6	2.3	7
0.8	5.5	8.5	2.2	8
0.9	5.5	8.5	1.9	9
1.0	5.5	8.5	1.7	10

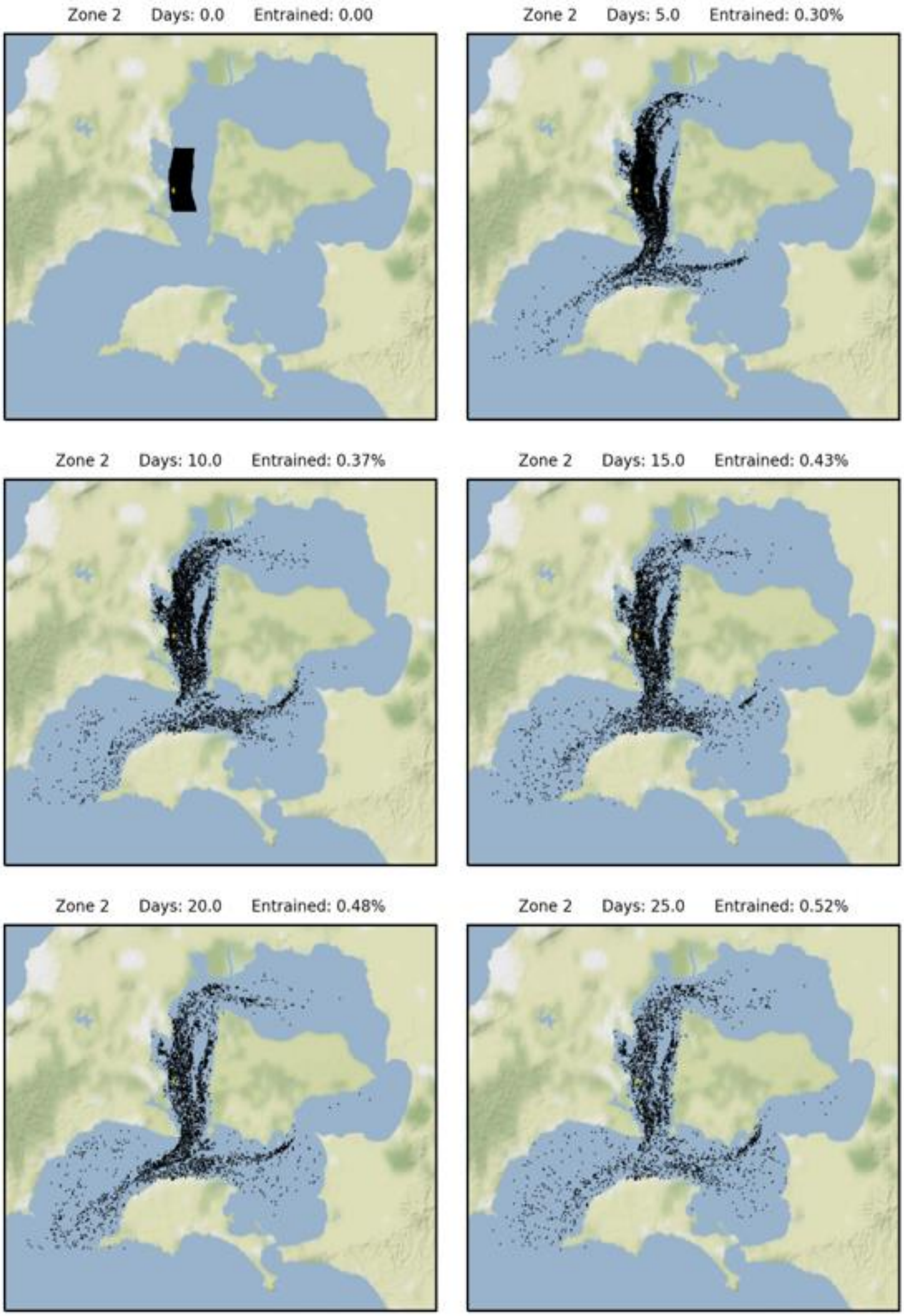


Figure 6-56. Movement of Particles from Zone 2 in Steps of 5 Days

6.6.4 Results of Particle Entrainment at 450,000 m^3/d

Figure 6-57 shows the percentage of particles from each zone entrained in 28 days at the nominal peak seawater intake rate of 450,000 m^3/d.

Zone 2, where the FSRU is located, had the highest entrainment rate of 0.75 % of particles in 28 days. Zone 3, which represents Hastings Bay, had the next highest entrainment of 0.41 % of particles in 28 days. The entrainment percentage decreases with increasing distance from the FSRU to 0.13 % in 28 days for Zone 8 in the north of the Bay and 0.05 % in 28 days for Zone 9 at the Western Entrance.

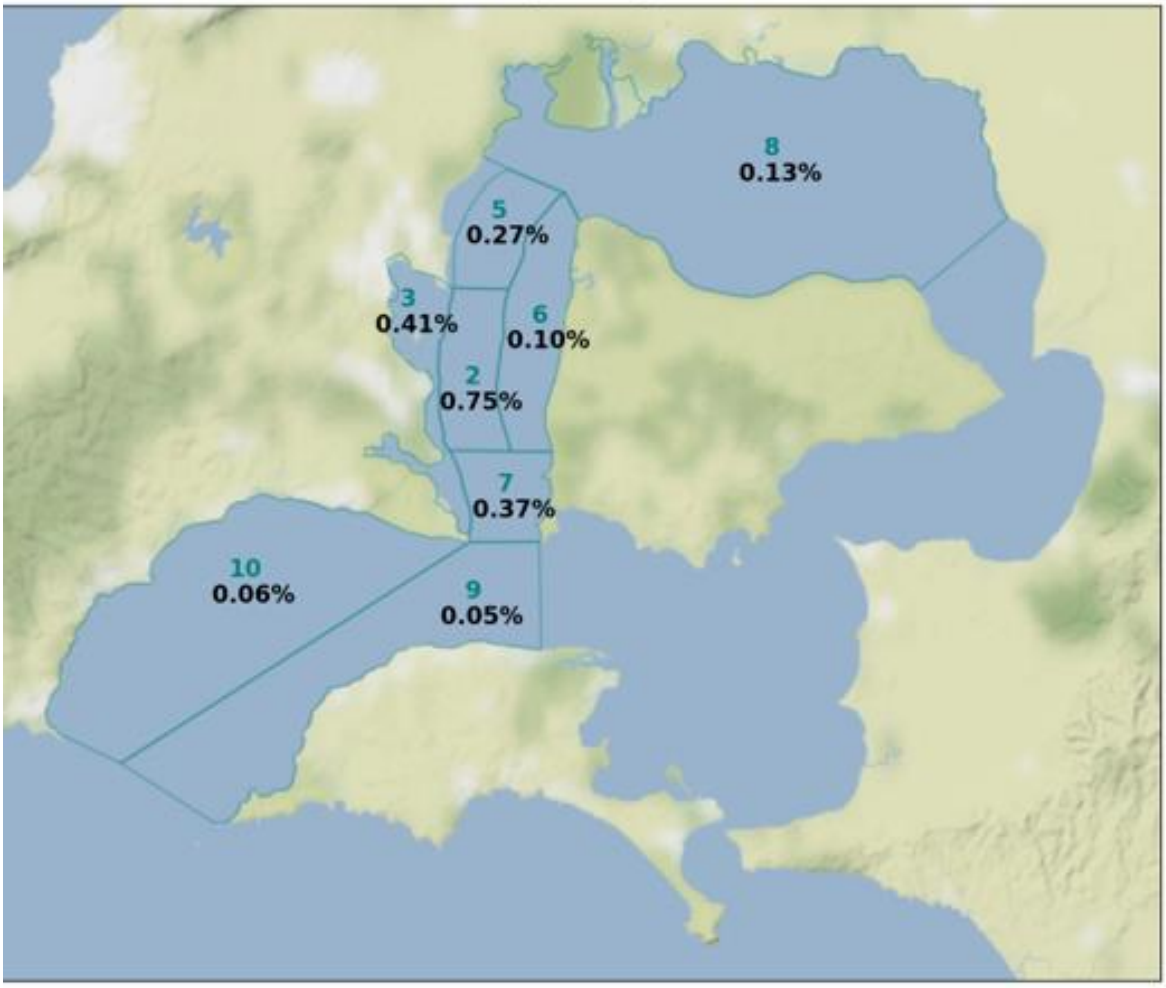


Figure 6-57. Percentage Entrainment of Particles in 28 Days at 450,000 m^3/d Intake

Over the whole of North Arm (Zones 2 to 7 inclusive), 0.38 % of particles were entrained into the FSRU during the 28-day simulation (assuming peak open loop operations every day). This is equivalent to approximately 0.014 % of particles being entrained each day.

For comparison, 35 % of the particles released in North Arm are flushed from the Bay in the 28-day simulation, which is equivalent to 1.2% per day. The rate of flushing of particles to Bass Strait is approximately 85 times greater than the rate of entrainment of particles into the FSRU seawater intake.

6.6.5 Results of Particle Entrainment at 312,000 m^3/d

Figure 6-58 shows the percentage of particles from each zone entrained in 28 days at the average seawater intake rate of 312,000 m^3/d. Entrainment rates for the average seawater

intake range from 0.47 % of particles in 28 days for Zone 2, where the FSRU is located, to 0.03 % in 28 days for Zone 9 at the Western Entrance.

Over the whole of North Arm, 0.26 % of particles were entrained into the FSRU during the 28-day simulation (assuming average production every day). This is equivalent to approximately 0.009 % of particles being entrained each day.

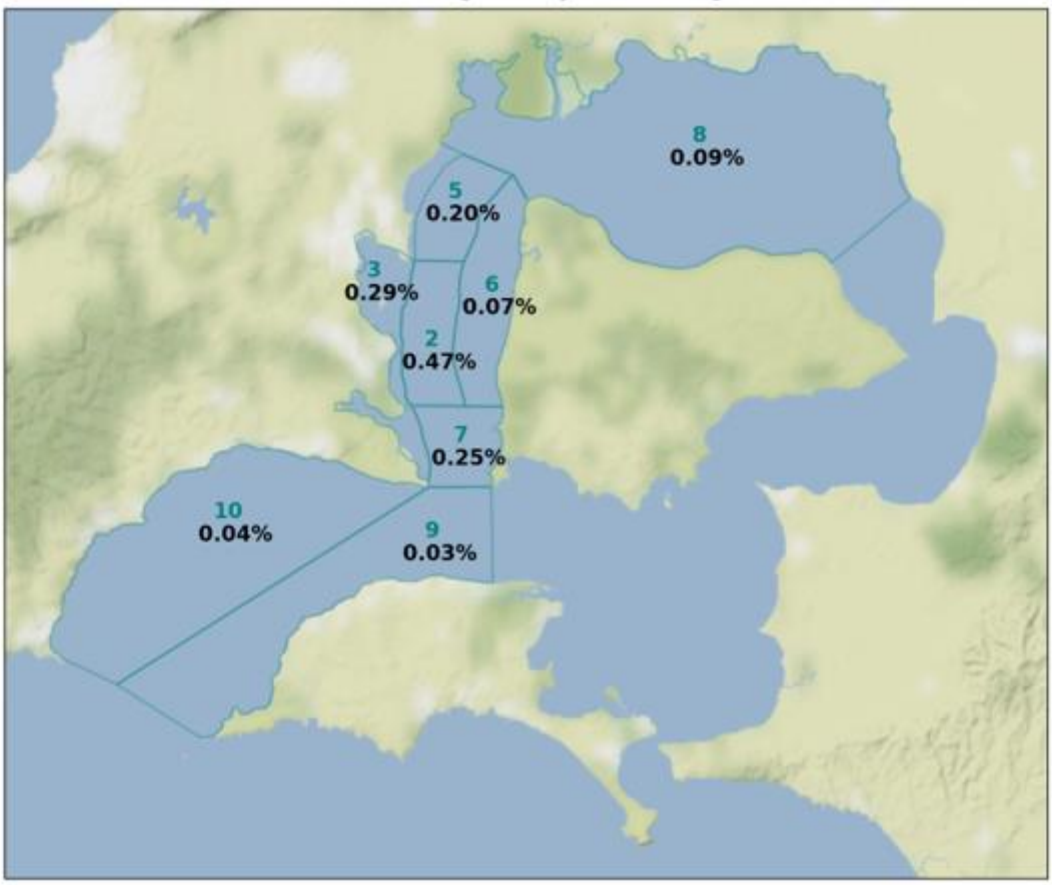


Figure 6-58. Percentage Entrainment of Particles in 28 Days at 312,000 m^3/d Intake

The design flows for the FSRU changed marginally as the project developed and thus the intake rates and entrainment rates were altered accordingly. Table 6-8 summarises the rates of entrainment for North Arm for various seawater intake rates from 471,000 m^3/d to 158,000 m^3/d. The flushing rate remains constant, and the ratio of entrainment to flushing ranges from about 1 to 90 at peak flows to 1 in 200 at average production and even less in closed loop operation.

Table 6-8. Rates of Entrainment from North Arm by the FSRU at Various Intake Rates

Seawater intake, m3/d	Entrainment per day	Entrainment in 28 days	Flushing in 28 days	Entrainment to Flushing
471,000	0.015%	0.40%	35%	1 in 88
450,000	0.014%	0.38%	35%	1 in 92
315,000	0.010%	0.27%	35%	1 in 132
187,000	0.006%	0.16%	35%	1 in 220
158,000	0.005%	0.13%	35%	1 in 260

6.6.6 Rate of Entrainment, Flushing and Mixing Over Time

Zone 2 has the highest rate of entrainment. Figure 6-59 depicts the fate of particles released in Zone 2, showing the rate of entrainment with time, rate of flushing with time and the rate of mixing to other parts of Western Port Bay.

The rate of entrainment for Zone 2 in 28-days varied from 0.52 % to 0.81 %, depending on the tides just after the particles were released, with 0.75 % being the typical rate for the 28-day simulation. Over the same 28-day simulation, 35 % of the particles were flushed to Bass Strait and 35 % of particles were mixed from Zone 2 to other areas of Western Port. About 20 % of the particles remained in Zone 2.

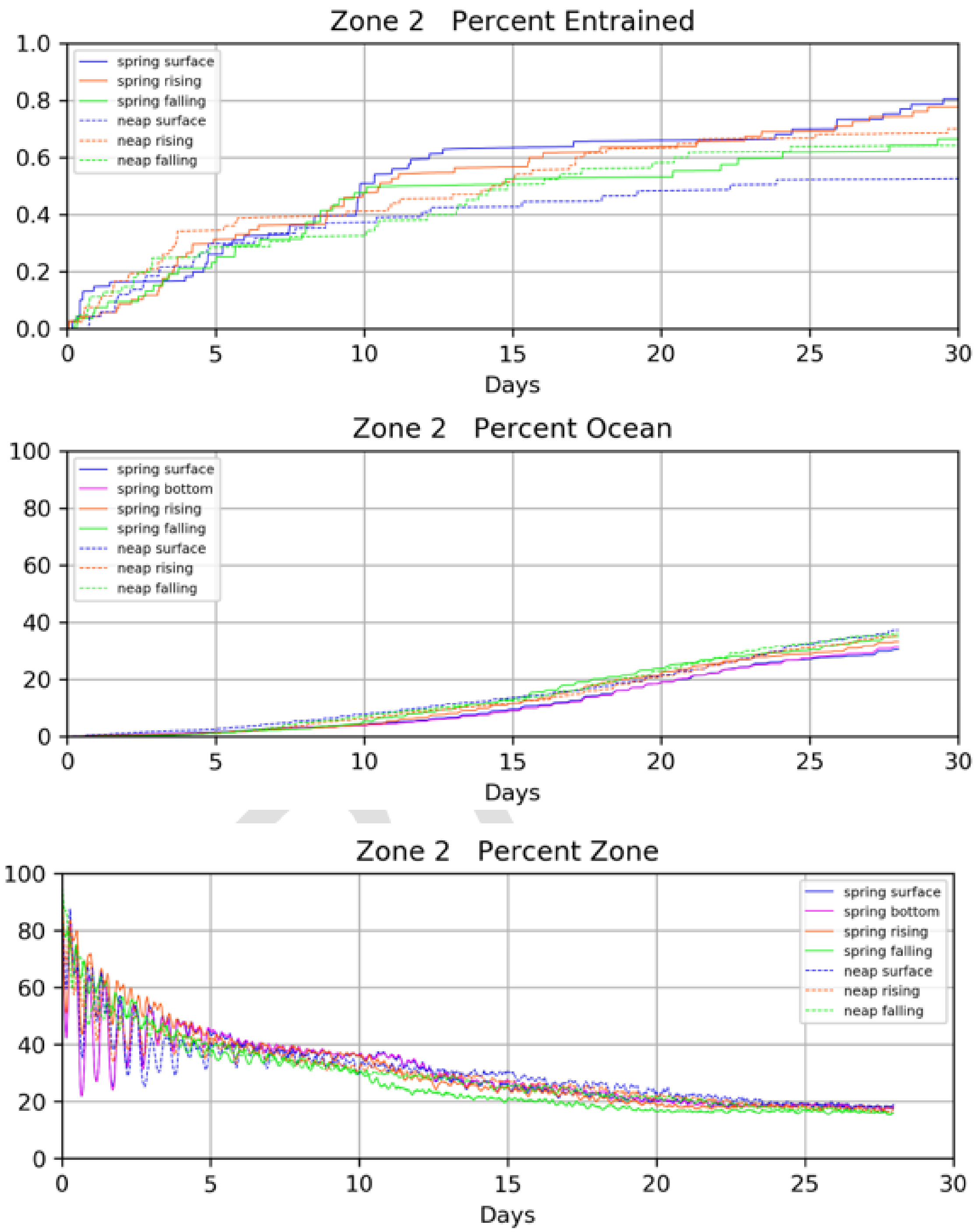


Figure 6-59. Fate of Particles Released in Zone 2

Zone 9 has the lowest rate of entrainment. Figure 6-60 depicts the fate of particles released in Zone 9, in terms of the rate of entrainment, rate of flushing and the rate of mixing to other parts of Western Port Bay.

The rate of entrainment in 28 days for Zone 9 varied from 0.01 % to 0.08 %, depending on the tides just after the particles were released, with 0.06 % being the typical rate for the 28-day simulation. Over the same 28-day simulation, 85 % of the particles were flushed to Bass Strait and 8 % of particles were mixed from Zone 2 to other areas of Western Port. Few residual particles (less than 10 % of the original set) remained in Zone 9 at 28 days after release.

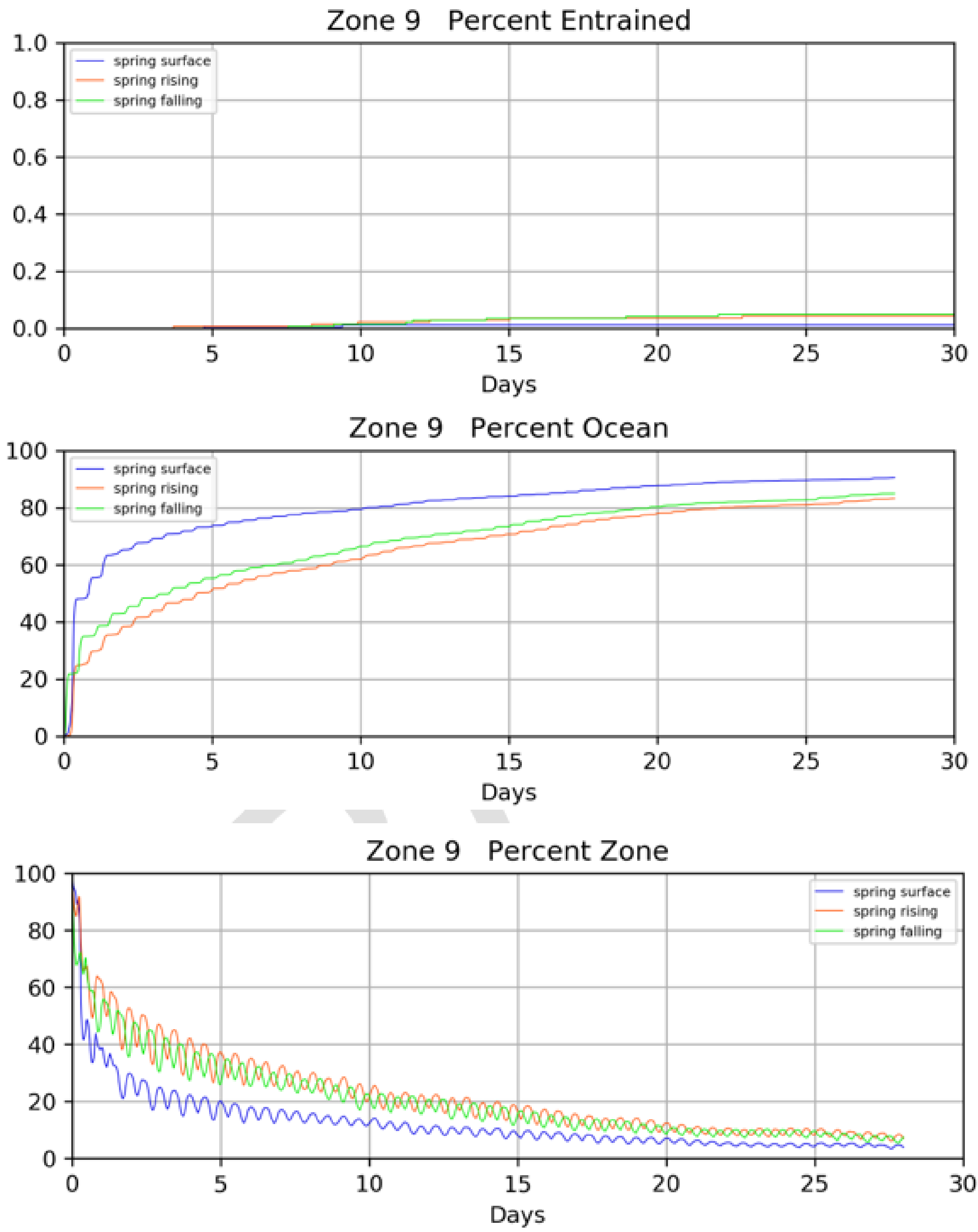


Figure 6-60. Fate of Particles Released in Zone 9

Zone 8 covers the north section of the Bay and has the longest residence time. Figure 6-61 depicts the fate of particles released in Zone 8, in terms of the rate of entrainment, rate of flushing and the rate of mixing to other parts of Western Port Bay.

The rate of entrainment in 28 days for Zone 8 varied from 0.12 % to 0.16 %, with little difference between simulations for different tides after the particles were released, and with 0.13 % being the typical rate for the 28-day simulation. Over the same 28-day simulation, only 9 % of the particles were flushed to Bass Strait but 40 % of particles were mixed from Zone 9 to other areas of Western Port (principally the Lower North Arm). More than 60 % of particles remained in Zone 9 after 28 days. Thus, this Zone can be a reservoir for supply of plankton for other parts of Western Port.

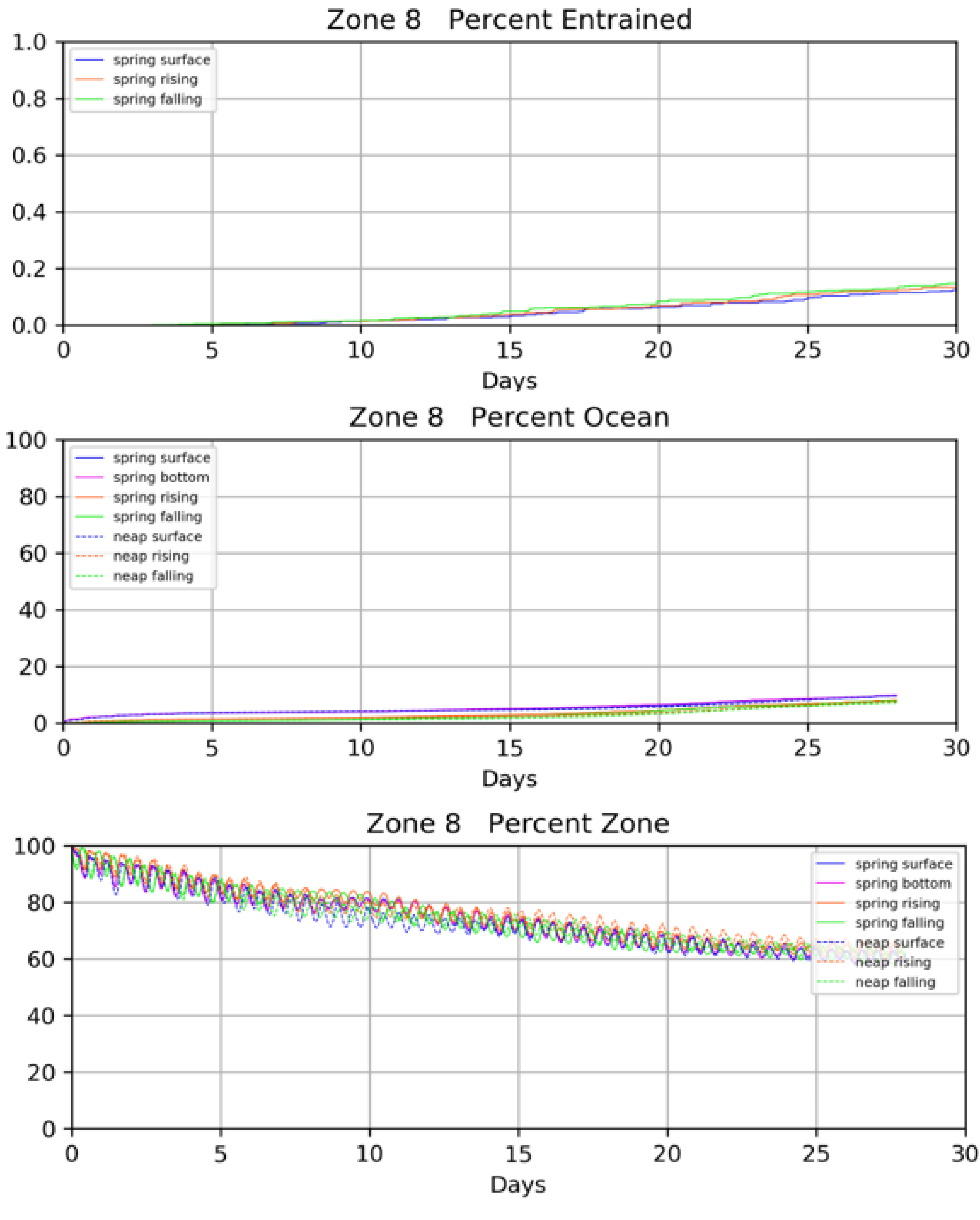


Figure 6-61. Fate of Particles Released in Zone 8

6.6.7 Outcomes for Entrainment

The results of the biota entrainment modelling show that the highest entrainment occurs for particles released in Zone 2 (the main channel close to Crib Point), where 0.52 % to 0.81 % of particles are predicted to be entrained in 28 days when the FSRU is operating at peak production, open loop operations (refer to Table 6-8).

The rate of entrainment was highest for the zone that encompasses Crib Point but much smaller for the zones at the Western Entrance (where flushing is the dominant process for loss of particles) and the north zone (which is well away from Crib Point

Dispersion of particles through the remainder of the bay, including loss to the ocean (which is highest for areas nearer to the entrance to the Bay) are the dominant mechanisms for loss of particles from all the Zones.

Table 6-9 provides a summary of entrainment rates for the whole of North Arm over various time periods for three seawater intake rates for regasification

Table 6-9. Summary of North Arm Entrainment Rate Predictions

North Arm	Peak Production open loop 471,000 m³/d	Average Production open loop 315,000 m³/d	Closed loop 187,000 m³/d	Loss to Bass Strait
Number of Days	**Entrainment**	**Entrainment**	**Entrainment**	**Flushed from Zone 2**
1	0.04 %	0.03 %	0.02 %	0.4 %
7	0.13 %	0.08 %	0.05 %	2.7 %
14	0.22 %	0.14 %	0.09 %	7 %
21	0.30 %	0.20 %	0.12 %	18 %
28	0.40 %	0.27 %	0.16 %	26 %

Note: Daily seawater intake amount does not include ballast water and other minor uses

Table 6-10 summarises the fate of particles for periods of 7, 14 and 21 days for each of the Zones with peak production in open loop operations (471,000 m³/d). For example, for Zone 2 (Crib Point zone), after 14 days, 0.52 % of the particles have been entrained into the FSRU, 24 % remain in the zone travelling up and down with the tides, 11 % have been flushed to Bass Strait and 64 % have been mixed to other Zones in Western Port.

The entrainment results need to be considered in the context of the life cycle of the populations, and other biological stresses and factors influencing population dynamics. The 28-day timeframe can be longer than the time taken to renew populations. The biological context and implications of these entrainment results are addressed in Section 7.

Table 6-10. Summary of Entrainment Model Predictions (for Peak Open Loop Flow)

Zone 2				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.31%	38 %	3 %	59 %
14	0.52%	24 %	11%	64 %
21	0.63%	20 %	22%	57 %
Zone 3				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.13%	33 %	20 %	47 %
14	0.21%	21 %	26 %	53 %

21	0.29%	19 %	32 %	49 %
Zone 5				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.01%	18 %	0 %	82 %
14	0.08%	10 %	2 %	88 %
21	0.19%	7 %	15 %	78 %
Zone 6				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.02%	55 %	2 %	43 %
14	0.04%	41 %	4 %	55 %
21	0.07%	40 %	12 %	48 %
Zone 7				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.10%	17 %	18 %	65 %
14	0.16%	9 %	32 %	59 %
21	0.21%	8 %	46 %	46 %
Zone 8				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0	81 %	2 %	17 %
14	0.04%	72 %	5 %	23 %
21	0.09%	65 %	7 %	28 %
Zone 9/10				
Duration, days	**Entrainment in period**	**Remaining in Sector**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.01%	26 %	61 %	13 %
14	0.03%	17 %	75 %	8 %
21	0.04%	11 %	82 %	7 %

6.7 Conclusions of Hydrodynamic Modelling

6.7.1 Chlorine and Temperature Modelling

This section summarises the results of the near-field and regional hydrodynamic modelling for the temperature anomaly and the concentration of chlorine produced oxidants (CPO) from the various seawater discharge rates and discharge locations on the FSRU.

Table 6-11 summarises the area where the diluted seawater temperature differs from ambient seawater by more than 0.5ºC (Guideline Value for temperature), and also the area where the time-averaged chlorine concentration exceeds 6 µg/L (Guideline Value for chlorine).

There would be a short length of the discharge plumes where the chlorine and temperature limits are exceeded (for a distance of about 40 m from the FSRU).

Table 6-11. Summary of Results for Chlorine and Temperature Predictions

Production rate	Operating Mode	Vessels at Crib Point Jetty (Berth 2)	Chlorine above Guideline Value (6 µg/L)	Temperature above/below Guideline Value (0.5 ºC)
Peak	Open loop	No LNG Carrier	Complies	0.7 ha
Average	Open loop	No LNG Carrier	Complies	0.5 ha
Peak	Open loop	With LNG Carrier	5 ha	20 ha
Average	Open loop	With LNG Carrier	2 ha	12 ha
One-third Peak	Open loop	With LNG Carrier	1 ha	6 ha
Peak	Closed loop	No LNG Carrier	0.2 ha	0.2 ha
Peak	Closed loop	With LNG Carrier	0.2 ha	0.3 ha

6.7.2 Biota Entrainment Modelling

The entrainment rates for peak open loop, average open loop and closed loop operation are summarised in Table 6-12. The rate of entrainment is small compared to the rate of flushing to Bass Strait from Zone 2 (Crib Point zone in North Arm).

Table 6-12. Summary of Entrainment Rates and Flushing to Bass Strait

North Arm	Peak Production open loop 471,000 m^3/d	Average Month open loop 315,000 m^3/d	Closed loop 187,000 m^3/d	Loss to Bass Strait
Number of Days	**Entrainment**	**Entrainment**	**Entrainment**	**Flushed from Zone 2**
1	0.04 %	0.03 %	0.02 %	0.4 %
7	0.13 %	0.08 %	0.05 %	2.7 %
14	0.22 %	0.14 %	0.09 %	7 %
21	0.30 %	0.20 %	0.12 %	18 %
28	0.40 %	0.27 %	0.16 %	26 %

Note: Daily seawater intake amount does not include ballast water and other minor uses

7 Risk and Impact Assessment

The purpose of this section is to assess the marine environmental effects of the three main stresses that would be caused by the proposed regasification project in Western Port. The three main stresses are:

- entrainment of plankton and other small organisms in seawater taken into the FSRU cooling or heating water systems
- decease or increase in seawater temperature due to discharges from FSRU; and
- increase in chlorine produced oxidants in the seawater discharges from the FSRU.

In addition, this section includes an assessment of risks and potential impacts associated with:

- contamination from leaks and spills
- physical processes, such as seabed scour and light spill
- biological disturbance, such as introduction of marine pests and whale strike.

This section concludes with an assessment of potential cumulative impacts.

7.1 Multiple Beneficial Uses of Western Port

As discussed in Section 5, the majority of Western Port was designated as a Wetland of International Importance under the Ramsar Convention on Wetlands (Ramsar) in 1982. It is one of eleven Victorian Ramsar sites and the third most important area for wading birds in Victoria (Loyn et al. 2001). The Western Port Ramsar site includes all intertidal and subtidal areas of Western Port north of a line between Point Leo (Mornington Peninsula) and Observation Point (Phillip Island) and a line between Newhaven and San Remo, excluding the land areas of French Island and Phillip Island (Figure 7-1). The Western Port Ramsar site covers 59,950 ha of Western Port. It comprises a large area of shallow intertidal mudflats, deep channels and some narrow strips of coastal land.

The red dot in Figure 7-1 marks the location of the Crib Point Jetty.

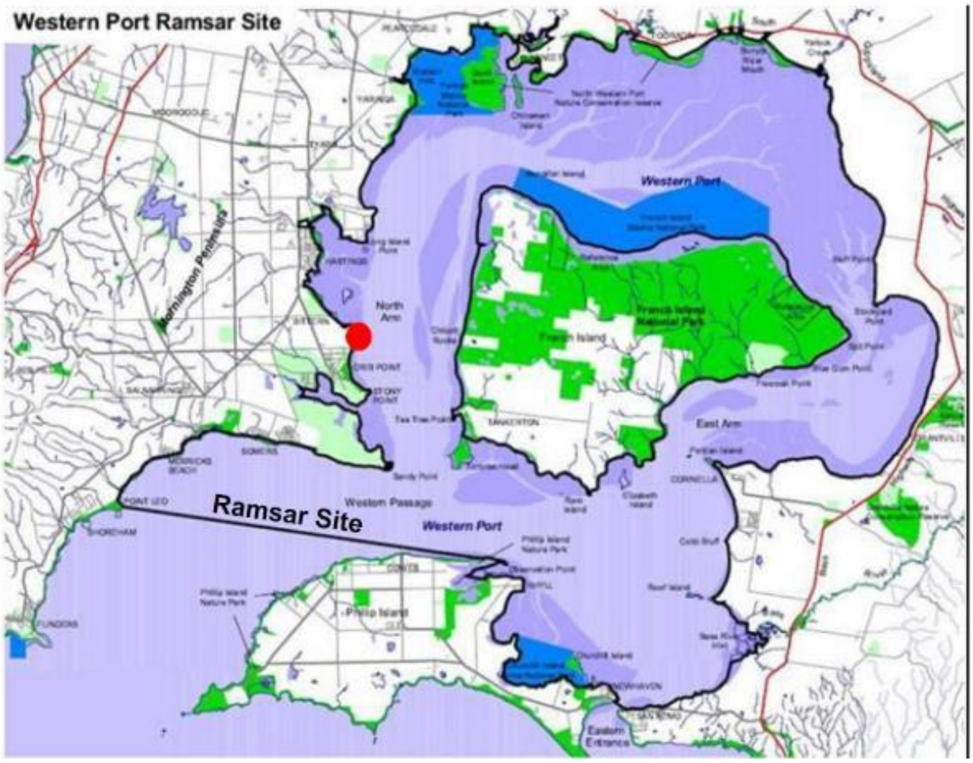


Figure 7-1. Western Port Ramsar Site Area

While Western Port retains many of the marine biodiversity values required to fulfil the criteria requirements as a Ramsar Wetland, Western Port has experienced major changes in the catchment over the past 150 years including:

- draining of Koo Wee Rup Swamp,
- conversion of much of the catchment from wetland to agriculture; and
- increasing urbanization of the catchment.

Western Port was designated a Ramsar site in 1982. Since then, the population of Melbourne has increased from 2.8 million people to more than 4.5 million people in 2020.

The Western Port catchment has an estimated population of 45,000 people in 2018/19 (Port Phillip and Westernport Catchment Authority, 2018/19) with continuing rapid urban development in the northern parts of the catchment (Pakenham to Koo Wee Rup), along the Mornington Peninsula, on Phillip Island and, to a lesser extent at Lang Lang, Corinella and Grantville.

The Port of Hastings has been used as a trading port since the 1800s. In the 1960s the land around Hastings was reserved for port related uses. In the 1970s large areas were designated special use zones (SUZ1) and preserved to allow for future port-related use. Currently there are five jetties within or in the vicinity of the Port of Hastings including the naval wharf at HMAS Cerberus, Stony Point Jetty, Crib Point Jetty, Long Island Point Jetty and BlueScope Wharf. The Port of Hastings caters for approximately 150 vessels (300 vessel movements) (PoHDA, 2017/18). per year along the 32 km-long shipping channel in North Arm.

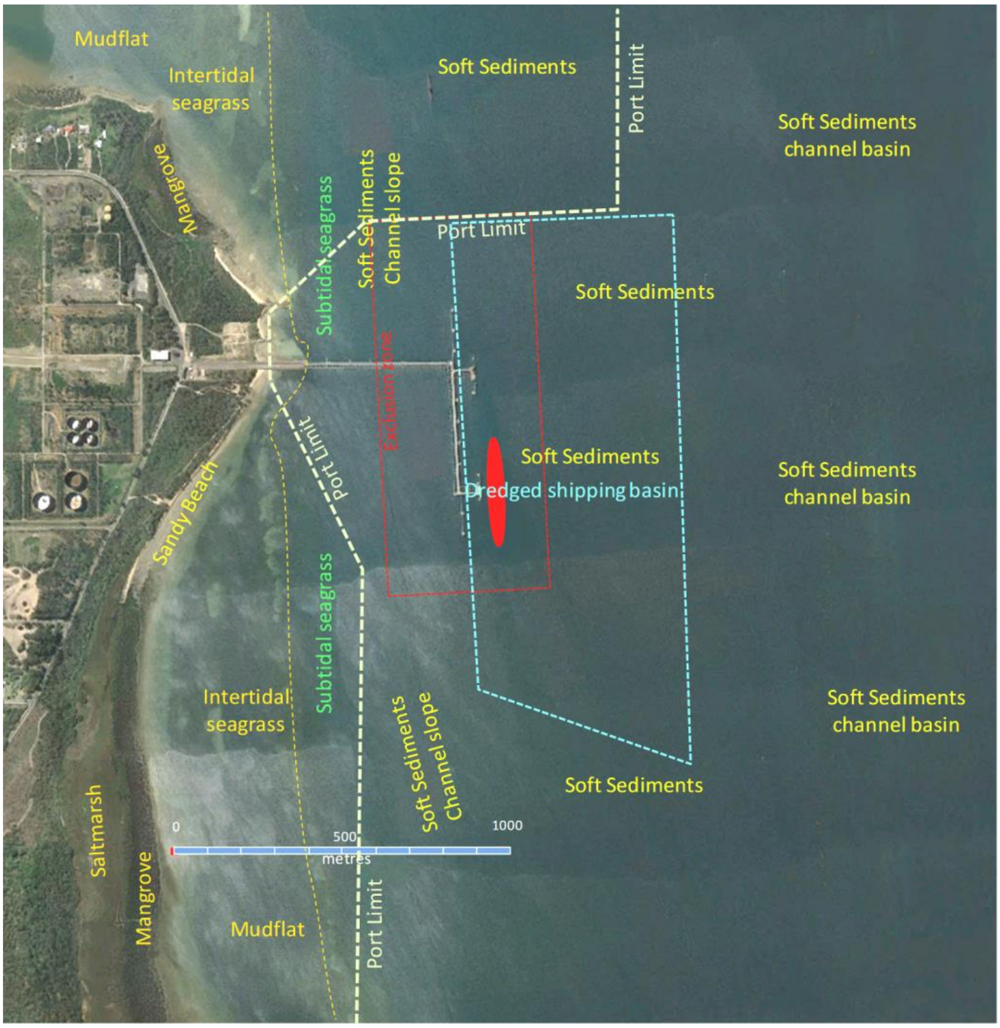


Figure 7-2. Hastings Port Area, Crib Point Jetty

The FSRU (red vessel in Figure 7-2) would be berthed at Crib Point Jetty (Berth 2) in the berth pocket that has been dredged and maintained to a depth of 14 metres. The adjoining berth pocket for Berth 1 at Crib Point Jetty (to the immediate north of Berth 2) is maintained to a maximum depth of 15.7 metres. The approach channel to the berth pockets is maintained to a depth of 14.2 metres (VRCA Port of Hastings Harbour Master's Directions August 2019). Berth 2 at Crib Point Jetty is approximately:

- 600 m offshore from the low tide mark
- More than 500 m from the intertidal zone
- Approximately 400 m offshore from the known seagrass areas
- At least one kilometre from saltmarsh and mangrove communities.

The Crib Point Jetty berth pockets consist primarily of soft sediments that are regularly disturbed by tidal activity and turbulence from berthing activities at Berth 1 that are ongoing.

Victorian State Environment Protection Policy (Waters) 2018 (**SEPP Waters**) includes 'Shipping and Navigation' as a Beneficial Use of North Arm. Many marine environmental aspects of the Project relate to environmental changes that occur only within the Port Limits and more specifically within the previously-dredged area of the existing Port of Hastings at Crib Point (refer to zone outlined in blue in (Figure 7-2).

A further long-term stress on Western Port is climate change. A recent study by DELWP in 2017 identified the following threats to the values of Western Port as a Ramsar Site relating to climate change:

- sea level rise;
- increased frequency and intensity of storms leading to shoreline erosion; and
- increased frequency and intensity of storms leading to increased sediments.

To take all these changes over time into account, this assessment considers the cumulative effects of the FSRU operation.

7.2 Integrated Ecosystem of Western Port

An understanding of the patterns in the local marine ecosystem and the factors that affect the major communities informs the assessment of potential effects of the proposed FSRU operations at Crib Point Jetty (Berth 2). The marine habitat distribution and ecosystem components in Western Port in general, including the locality of Crib Point in particular, have been described and plotted in Section 5.

Western Port has a wide range of habitats, from rocky shores to deep channels with strong currents, mangroves, saltmarshes, seagrass beds, intertidal mudflats (important to shorebirds) and subtidal soft sediments that harbour a diverse invertebrate fauna. The waters of Western Port are inhabited by phytoplankton and zooplankton that drift passively with the currents, and larger drifting animals such as jellyfish. Soft sediments are a major habitat in Western Port, covering about two thirds of the bay. Western Port harbours some of the southernmost mangroves in the world, composed of a single species, *Avicennia marina*.

Figure 7-3 is a schematic diagram of the Western Port ecosystem. The green area depicts seagrass and intertidal ecosystems. The blue area depicts plankton and pelagic biota. The red area depicts demersal and benthic ecosystems. The major primary producers are mangroves (18 km^2), The major primary producers are mangroves (18 km^2), seagrass (approximately 129 km^2) and phytoplankton (through the water column), with contributions from benthic microalgae and epiphytes (Boon et al, 2011; Blake and Ball, 2001).

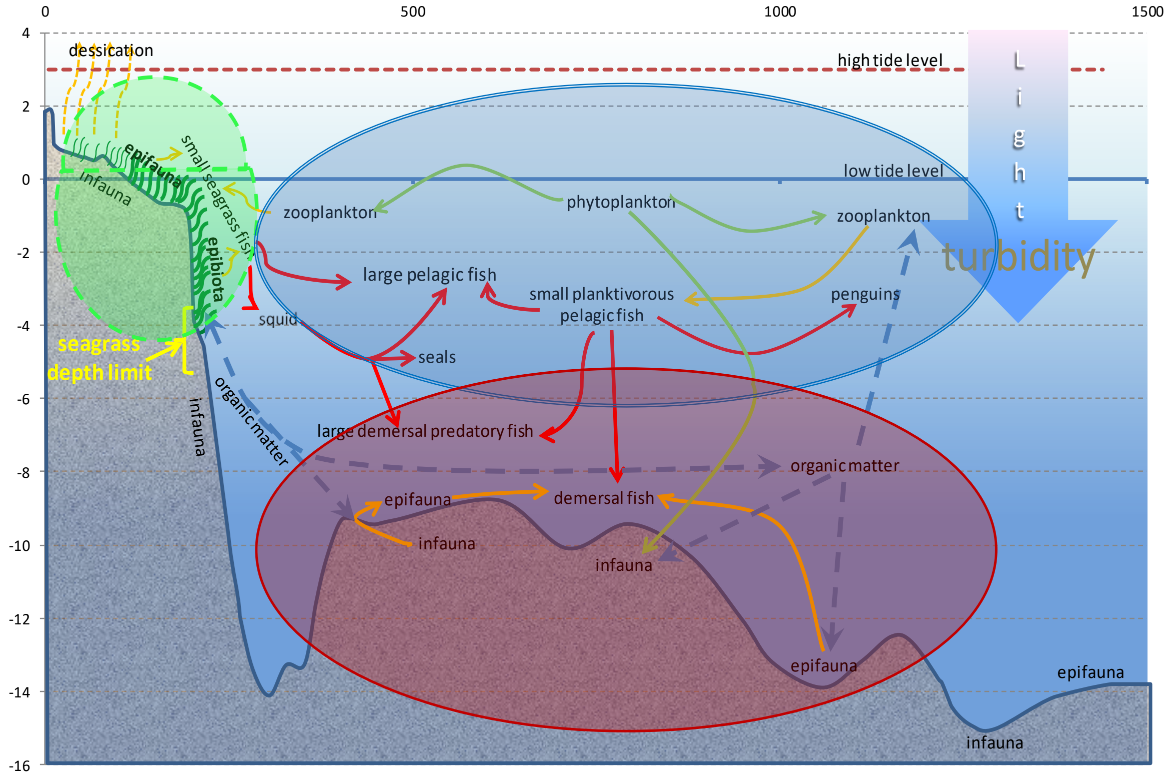


Figure 7-3. Schematic Diagram of Western Port Ecosystem

Mangroves and saltmarsh grow in extensive communities from the upper high tide mark to approximately mid-tide along much of the northern and eastern shores of Western Port including the shore north and south of Crib Point. The nearest saltmarsh/mangrove communities to Crib Point Jetty are 1 km from the proposed FSRU location.

Seagrasses in North Arm comprise three predominant species that extend from the intertidal *(Zostera muelleri)* to the lower intertidal and shallow subtidal (*Zostera nigricaulis* and *Halophila australis*). As listed in Table 7-1, the lower limit of seagrass (*Zostera nigricaulis*) in North Arm is at 7.5 m below mean sea level (MSL) at The Bluff (approximately 10 km north of Crib Point). Seagrass extends down to 1.5 m depth at Long Island Point and also at Stony Point. Towed video records indicate that seagrass inshore of the Crib Point Jetty extends to approximately 4.7 m depth (MSL).

Table 7-1. Summary of Seagrass Depth Limits (*Zostera muelleri*)

Segment	Sites	Depth limits (m below MSL)		
		Max	Min	Median
Lower North Arm	36	-7.5	-1.3	-4.7
Upper North Arm	11	-4.7	-1.7	-2.8
Confluence Zone	4	-4.0	-1.6	-2.3
Rhyll	3	-2.9	-1.0	-1.3
Corinella	5	-2.9	-1.0	-1.3

In North Arm the seabed slopes down from the low tide mark, to about 10 m depth. Recreational fishers frequently target this area and can be seen anchored along this narrow line on the east and west sides of North Arm. Below 10 m, the seabed slopes more steeply into the deeper channel.

Section 5 describes the seabed deeper than 10 m in the North Arm and Crib Point Jetty area as soft sediment, with broken shell and sparse small rubble at the surface. Sedentary, attached or partly buried animals (sea squirts, tube worms, scallops, bryozoans, sponges, lamp shells and some fish) are sparse or patchy in this area or even absent where the seabed is predominantly sediments. There are burrows of common ghost shrimps in areas of sandy seabed.

The rubble and shell content of the seabed varies substantially and may be more abundant in distinct patches. These patches provide an opportunity for attachment of sponges, bryozoans and other invertebrates, and points of aggregation of fish that are mostly found near the seabed (demersal species) such as snapper. There is substantial, small scale patchiness in the seabed in most of Western Port. However, the seabed and associated biota are relatively uniform in the dredged shipping basin.

The plankton in the water column in the deeper channel of North Arm is described in Section 5. The phytoplankton, zooplankton and fish larval communities appear to be more productive in the shallow and intertidal communities. The composition of these communities is different in Western Port from the adjacent waters of Bass Strait or nearby Port Phillip Bay. The zooplankton community in North Arm is similar to East Arm, and the major zooplankton species appear to have remained the same from the 1970s to 2019-20.

Western Port is an important recreational fishing area, with peak fishing activity during the summer months. It is a nursery area for a range of fish. Although some key recreational fish caught in Western Port such as snapper and King George whiting do not breed in Western Port, juveniles use Western Port as a nursery area.

7.3 Risk Workshops on Marine Environment Risks

General environmental risks associated with the Project were identified during the referral stage of the Project. These general risks were reported in the referral submission and associated documents and guided the Minister’s listing of issues to be addressed in the EES.

The further development of the Project description, refinement of risk pathways, collation of available information, modelling and targeted investigations commenced at the initiation of the EES. This iterative process was informed by discussions with regulators, advice from independent experts, Technical Reference Group (TRG) and public consultation meetings.

Project Risk Workshops were conducted on:

- 20 September 2019 - Risk Workshop at AECOM offices in Melbourne involving a range of scientists and environment managers from consultants and agencies to develop a list of potential environmental risks and systematic risk assessment approach, including draft likelihood and consequence definitions.
- 8 October 2019 - Risk Workshop at AECOM offices in Melbourne involving a range of scientists and environment managers to make the initial assessment of the likelihood and consequences of the potential environmental risks. The outcome from this Workshop is the list and preliminary ranking of 53 potential risks as assessed in this section.

7.4 Identified Risks

The risks defined in the Risk Workshops included direct risks from the Project processes on the local marine environment, as well as general risks that are common with normal shipping practices. The identified risks are summarised in Table 7-2.

The aspects and implications of the Project on the marine environment near Crib Point and the North Arm of Western Port were based on existing information and the field studies and hydrodynamics carried out in this project.

The Project involves three broad components for consideration of marine environment risk:

1. Operation of a floating storage and regasification facility (FSRU) that would be continuously moored at Crib Point Jetty (Berth 2):
   - Intake of seawater and corresponding entrainment risks;
   - Discharge of cooler seawater;
   - Discharge of warmer seawater; and
   - Discharge of chlorinated seawater.
2. Ship related operations:
   - The FSRU entering the port from an international origin and mooring at the existing Berth 2.
   - From 12 to 40 LNG carriers entering the port from an international origin and mooring next to the FSRU to unload LNG to the FSRU.
3. Port operation and facility improvements at Crib Point Jetty including the implementation of a pipeline to transport natural form the FSRU to the shore.

Table 7-2 numbers and lists the identified risks for the Project associated with the broad components listed in Section 7. Each individual risk is assessed and rated in Sections 7.6 to 7.11.

Table 7-2. List of Potential Marine Risks for Main Stresses

Risk ID	Risk name
ME 1 to ME 9	Entrainment: effects on various Western Port habitats and species groups
ME 10 to ME 19	Cooler Seawater effects on various Western Port habitats and species groups
ME 20 To ME 29	Warmer Seawater: effects on various Western Port habitats and species groups
ME 30 to ME 40	Chlorinated Seawater: effects on various Western Port habitats and species groups
ME 41 to ME 44	Contamination: effects on various Western Port habitats and species groups
ME 45 to ME 48	Physical Processes: effects on various Western Port habitats and species groups
ME 49 to ME 53	Biological Disturbance: effects on various Western Port habitats and species groups

7.4.1 Environmental Risk Context - Operation of an FSRU

Risks ME 1 – ME 40 include the direct potential risks from the operation of the FSRU. The environmental context to the risks in regard to Western Port are discussed below.

- The proposed FSRU open loop regasification process uses Western Port seawater, with a natural temperature range approximately 11°C to 23°C, to heat the cold LNG from a temperature of -163°C to ambient, with the cooler seawater being discharged);
- The FSRU operating in peak open-loop conditions would use up to 468,000 m^3/d of seawater in the regasification process (excluding ballast and minor users), involving the intake and discharge of this volume of seawater back into Western Port; and
- A small additional amount of seawater is required for other processes (e.g. freshwater production, firefighting system, ballast water).

Hence, the initial key impact pathways for the FSRU that differ from normal shipping activities in the port are:

- Intake of substantial volumes of seawater through sea chests. This risk pathway is known as ***entrainment***;
- Discharge of substantial volumes of **cold or warm** seawater into Western Port; and
- Residual amounts of **chlorine oxidants** in all discharges.
- A further risk associated with discharge is the aggregation of marine fauna in the discharge plumes.

The proposed FSRU location at Crib Point Jetty, located in North Arm of Western Port, is:

- a Ramsar listed wetland of international significance;
- assigned as an area of 'High Conservation Value' in the SEPP Waters;
- considered to contain "Water dependent ecosystems and species that are largely unmodified" in the SEPP Waters.

Hence, it was recognised that assessment of environmental risks associated with ***entrainment*** of substantial volumes seawater containing plankton, larvae and small fish and ***discharge*** of colder, chlorinated seawater into the waters of North Arm required:

1. Further investigation of marine environmental conditions specific to North Arm; and
2. Further detailed modelling of physical processes based on a more detailed description of the Project processes.

Figure 7-4. Oil carrier departing Western Port, September 2019

7.4.2 Environmental Risk Context - Shipping Operation in Existing Commercial Port

Risks ME 41 – ME 53 are the typical risks associated with normal port and shipping activities. The Port of Hastings has operated as a significant commercial port since the 1960s. The port includes four major commercial ship berthing areas - at Stony Point, Crib Point, Long Island Point and BlueScope. Shipping activities include light commercial shipping and tug facilities at Stony Point, fuel oil and petroleum import and storage at Crib Point (since 1966), oil and gas processing, storage and export at Long Island Point and bulk material import and export at Blue Scope.

The operation of the LNG carriers proposed to enter, moor and depart the Port of Hastings associated with the Project are consistent with present and past operations within the port. Their operation must comply with the same Port and State environmental guidelines, regulations and environmental management plans as other similar vessels.

Risk Pathways

The risk pathways identified in the Risk Workshops for the general ship-related operations of the LNG carriers and the FSRU and the jetty operations in the Port of Hastings are listed below:

- Contaminants and spills to marine environment
    - Waste discharge to marine environment
        - Sewage;
        - Waste oil;
        - Organic wastes; and
        - Solid wastes and litter.
    - Refuelling;

  - Leaks and spills chemicals, fuels, lubricants;
  - Hull and propeller antifouling treatments; and
  - Hull and propeller cleaning.
- Physical disturbance of marine habitats and biota
  - Seabed scour and turbidity;
  - Vessel grounding; and
  - Light spill.
- Biological disturbance
  - Ballast water;
  - Introduced marine species or pests; and
  - Whale ship-strike.

7.4.3 Environmental Risk Context - Port Operations, Maintenance and Facility Improvements

Normal operation of the Port includes a range of routine operations, regular facility maintenance, berth and mooring upgrade programs, vessel services and maintenance and maintenance of navigational depth by seabed levelling. The size of the proposed LNG carriers is within Western Port's present channel and navigational capacity.

No dredging would be required either in the approach channels or at Crib Point to accept the FSRU or LNG carriers. Installation of Jetty Infrastructure including marine loading arms and gas piping would be required at the Crib Point Jetty. Operations related to vessel movement for the project are consistent with existing routine operations within the port and must comply with existing Port and State environmental guidelines, regulations and environmental management plans.

7.5 Initial Mitigation Measures for Identified Risks

During the Project referral stage, several mitigation measures were identified and incorporated into the Project design. The mitigation measures are outlined in Section 1.3 and are:

- Locating the sea chest near mid-depth in the water column and away from the water surface (2 m below surface) and above the seabed (3 m above seabed);
- Limiting the intake velocity to 0.15 metres per second (m/s), allowing most mobile biota to avoid being entrained;
- Locating the sea chests so the intake velocity is horizontal, allowing fish and other mobile biota to detect the flow and swim away;
- Provide 100 millimetres (mm) x 100 mm screen to prevent larger organisms from being entrained;
- Provide six ports on the east side of the FSRU for discharge of regasification flow;
- Ensure discharge velocity is 5 m/s or more through each operating port

Further explanation of the mitigation measures is provided in the sections below,

7.5.1 Initial Mitigation Measures for Seawater Intake

The proportions of Lower North Arm seawater taken into the FSRU for various operation scenarios and that may entrain marine biota was modelled in detail (Section 7.6). Table 7-6 shows the proportion of Lower North Arm water entrained in one month of peak FSRU production would be 0.4 % of the volume of Lower North Arm, compared with 26 % of the volume that would naturally exchange with Bass Strait. Hence the proportion planktonic particles entrained by the FSRU in one month would be a small proportion (one sixty-fifth) of the natural loss to Bass Strait.

Further explanation of the mitigation measures to further reduce the entrainment of pelagic and planktonic organisms is provided in Section 7.5.1 while potential entrainment scenarios are discussed in detail in Section 7.6.

The seawater inlets on the FSRU would be located more than 60 m offshore from the marine Crib Point Jetty and almost 100 m south from the Berth 2 jetty structures.

Principles for the design of water intake structures to minimise the effects on the marine ecosystem are well-documented and regulated (DSE 2008, USEPA 2001a, USEPA 2001b, USEPA 2004). USEPA 2004 presents rules to reduce the intake of fish and invertebrates into cooling water and desalination plant systems. These principles were incorporated into the design of the intakes on the FSRU as discussed below.

Some planktonic or epipelagic species, larvae or eggs tend to aggregate close to the sea surface, while benthic and demersal species tend to aggregate close to the sea bed (Acevado et al 2010, Kimmerer and McKinnon 1878a, Jenkins 2019 a, b). Others may associate with buoyant material drifting near the surface (most seagrass and some kelp debris) or the seabed (most macroalgal debris). Hence, the intake should be positioned to avoid the surface and bottom layers as shown in Figure 7-5, the seawater intake should be located at mid-depth to avoid as far as possible the parts of the water column where some biota may aggregate. Thus, the FSRU seawater intake should be at least 2 m below the water surface and at least 3 m above the seabed (taking account of tides and different loading levels of the vessel).

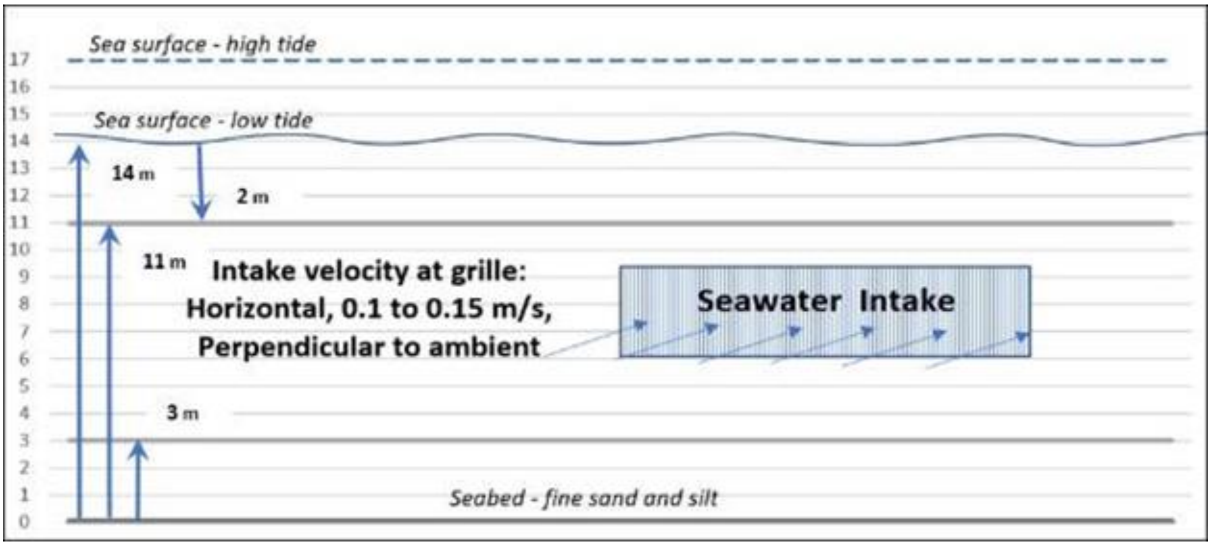


Figure 7-5. Seawater Intake Depth Design

Intake water speed and direction are detectable by most marine biota found in the water column and are the primary measures that substantially reduce entrainment of actively swimming marine biota (EPA 2001b). USEPA 2004 states: "*To develop a threshold that could be applied nationally and is effective at preventing impingement of most species of fish at their different life stages, EPA applied a safety factor of two to the 1.0 ft/s threshold to derive a threshold of 0.5 ft/s. This safety factor, in part, is meant to ensure protection when screens become partly occluded by debris during operation and velocity increases through portions of the screen that remain open… The data suggest that a 0.5 ft/s* (0.15 m/s) *velocity would protect 96 percent of the tested fish."*

The seawater intake opening on the FSRU should be designed so that seawater is drawn into the intake with a horizontal velocity of <0.15 m/s.

The seawater intake should be oriented parallel to the ambient tidal currents and mounted to the hull of the FSRU (Figure 7-5).

The intake should be fitted with a screen to deter large biota from entering (large fish, squid, penguins, cormorants or seals) or prevent large, slow-moving invertebrates (eg, jellyfish such as *Catostylus mosaicus*) from being entrained. The spacing and configuration of the screen should be determined in relation to local practicalities including potential fouling by marine growth and blinding by drifting material (for example seagrass leaves, plastics). The screen configuration for the Victorian Desalination Plant (VDP) was specified as "an external screen space no greater than 100 mm x100 mm or, if the screen space is greater than 100 mm in any one direction, then the space should be no greater than 50 mm in any other direction" (DSE 2008). The adopted screen at VDP is shown in Figure 7-6.

Figure 7-6. Intake for Wonthaggi Desalination Plant (Photo by M Venturoni)

In summary, the mitigation measures for the seawater intake design are as follows.

1. The intake should have a screening screen with spaces 100 mm by 100 mm in the vertical dimension to prevent larger marine biota such as penguins and large fish from entering the intake and becoming trapped, injured or killed.
2. The intake should be designed so seawater is taken in horizontally. This allows fish and other free-swimming marine biota to sense the intake current and swim away from the intake.
3. Limit the intake velocity to 0.15 m/s at peak production so that fish and other biota can swim away from the intake without becoming impinged or entrained.

The inclusion of these mitigation measures reduces the risk of larger marine biota (including fish, invertebrates and some smaller fish - see USEPA 2004) throughout the water column and biota associated with buoyant and dense debris from being impinged on the screens or entrained into the heat exchange system. The risk to other smaller fish is the same as for fish eggs and larvae as discussed in Section 7.6.14. In addition, the intake is located 60 m offshore and 100 m south of the jetty. Thus, there is a negligible risk of entrainment of fish living under

Crib Point Jetty. The resulting likelihood is considered ***rare*** and the consequence on local populations as ***negligible****,* which gives a risk rating of **Very Low.**

7.5.2 Initial Mitigation Measures for Seawater Discharge

AGL advised that the seawater discharges from the FSRU would contain up to 100 µg/L of residual chlorine. In open loop operations the seawater discharge would be 7^{o}C cooler than the ambient seawater. Dilution modelling demonstrated that the potential impacts of this discharge on the marine environment could be reduced by improving the mixing of the discharged seawater with ambient seawater.

As described in Section 6.2, the near-field modelling explored a wide range of discharge arrangements and concluded that, for open loop operations, the dilution is strongly influenced by momentum-induced mixing. A high-velocity discharge arrangement must be provided to achieve the substantial initial dilution necessary to reduce the seawater temperature difference and chlorine concentration to acceptable levels.

Based on the results of the near-field modelling in 2018 (refer to Section 6.2), it was recommended that with open loop operation (which is the main mode of operation), there should be six discharge ports at minimum 10 m spacing approximately 2 m below the surface that discharge seawater horizontally at a velocity of not less than 5 m/s.

At a discharge of 468,000 m^3/d, the initial dilution would be a minimum of 20:1 at low tide and a fully laden vessel (the worst case). At high tide, and with an empty vessel, the predicted initial dilution is higher at 26:1. Hence, over the tide and loading cycles, the initial dilution would vary from 20:1 to 26:1. Further dilution occurs due to the tidal currents, as described in Section 6.0. Nonetheless, the initial mixing due to the high velocity discharge jet arrangement is a substantial part of the total dilution.

7.5.3 Initial Mitigation Measures for Contamination

Initial mitigation measures to avoid and manage contamination and spills from the construction and operation of the FSRU, LNG carriers and equipment involves ensuring that hazardous chemicals storage, handling, usage and disposal meet relevant standards. Initial mitigation measures to minimise the risk of contamination include:

- Ensuring compliance with the Port of Hastings Development Authority (PoDHA) *Safety and Environmental Management Plan* and *Port Operating Handbook*;
- Managing and handling hazardous chemicals and materials in accordance with the relevant legislation and regulations (policies and procedures);
- Minimising the amount of hazardous chemicals and materials stored onsite;
- Selection of hazardous chemicals and materials to include environmental considerations;
- All vessels, routine jetty operations, jetty construction and maintenance must only proceed under relevant *Environment Management Plans (EMPs)* with Standard Operating Procedures (SOPs) for managing and mitigating leaks and spills which comply with the Port Operating Handbook; and
- Vessels must not be cleaned above or below water in harbour without authorisation of the Harbour Master.

7.5.4 Initial Mitigation Measures for Physical Processes

Initial mitigation measures to avoid and manage physical risks on marine habitats and biota from the Project include:

- Ensuring compliance with the PoHDA *Safety and Environmental Management Plan* and *Port Operating Handbook*;

- Ensuring all vessels comply with Port of Hastings navigation requirements;
- Moving vessels only in designated shipping channels and turning basins;
- Ensuring construction and operations EMPs include SOPs for small vessel operations to limit grounding, use of anchors or dragging cable and chains across intertidal banks or through shallow subtidal seagrass beds;
- Following berthing scenarios with tugs as identified in shipping simulations; and
- Ensuring FSRU and LNG carriers are compliant with shipping class and IMO standards.

7.5.5 Initial Mitigation Measures for Biological Disturbance

Initial mitigation measures to prevent and manage biological disturbance risks on marine habitats and biota from the Project include:

- Ensuring compliance with the PoHDA *Safety and Environmental Management Plan* and Port Operating Handbook;
- FSRU and LNG carriers to follow appropriate regulations to prevent introduction of marine pest species;
- FSRU and LNG carriers to be protected with approved antifouling system;
- FSRU and LNG carriers to be inspected by Australian biofouling / IMS inspector;
- FSRU and LNG carriers to be inspected and cleaned at appropriate intervals;
- FSRU and LNG carriers to have ballast water management that complies with all Commonwealth and Victorian requirements; and
- FSRU and LNG carriers to comply with maximum allowed vessel speeds; and comply with operational instructions if encountering a marine mammal.

7.6 Entrainment of Plankton and Other Small Marine Organisms

This section describes the risk assessment for risks ME 1 to ME 9 concerning the effects of entrainment on various Western Port habitats and species groups. According to the risk register, the impacts of entrainment of plankton and other small marine organisms are to be assessed for the following groups of Western Port habitats and species groups:

- Mangroves and saltmarsh;
- Intertidal Mudflat Invertebrate Communities;
- Intertidal and subtidal Seagrasses;
- Benthic subtidal Invertebrate Fauna;
- Pelagic and demersal Fish;
- Plankton;
- Protected Areas (Ramsar);
- Protected Areas (Other); and
- Protected Species.

7.6.1 Use of Seawater by FSRU

Fundamental to the operation of the FSRU is the use of seawater for heat transfer and other purposes, such as for ballast water, firefighting system and freshwater production. Seawater is withdrawn from the surrounding Western Port waters into the FSRU through large inlets on the sides of the FSRU and chlorinated by an electrolytic process before being pumped through a network of pipes, valves and heat exchangers in the vessel.

The seawater intake rates in various modes of operation are listed in Table 6-1, Table 6-2 and Table 6-3 (refer to Section 6.0).

The risks relating to the use of seawater are (1) impingement or trapping of large organisms such as fish or penguins against the intake screening screens; (2) entrainment of plankton and other small organisms in the seawater pumped through the network, with limited survival due to a combination of physical damage and chlorine oxidant damage; and (3) change in primary productivity in Western Port due to effects on plankton.

7.6.2 Initial Risk Ranking – Entrainment

The outcome of the Risk Workshops was a list and preliminary ranking of 53 potential risks. Risks ME1 to ME9 relate to the effects of entrainment on ecological habitats and groups of species, as listed in Table 7-3. The highest initial risk rating identified was medium for fish eggs and larvae during spring. This is because it was expected they would be the most likely to be entrained by the FSRU due to their abundance and their movement past the FSRU on the flood and ebb tides. All other risks were rated as low to very low and required no additional mitigation.

Table 7-3. Initial Entrainment Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 1	Entrainment: Mangroves and Saltmarsh	Negligible	Rare	Very Low
ME 2	Entrainment: Intertidal Mudflat Invertebrate Communities	Minor	Rare	Very Low
ME 3	Entrainment: Intertidal and Subtidal Seagrasses	Negligible	Rare	Very Low
ME 4	Entrainment: Benthic Subtidal Invertebrate Fauna	Minor	Rare	Very Low
ME 5A	Entrainment: Fish Eggs and Larvae (Spring and Summer)	Moderate	Likely	Medium
ME 5B	Entrainment: Fish Eggs and Larvae (Autumn – Winter)	Negligible	Possible	Low
ME 6 NNE	Entrainment: Plankton (NNE Zone)	Negligible	Rare	Very Low
ME 6 NA	Entrainment: Plankton (North Arm)	Minor	Possible	Low
ME 6 WPB	Entrainment: Plankton (Western Port)	Negligible	Rare	Very Low
ME 7	Entrainment: Protected Areas (Ramsar)	Negligible	Unlikely	Very Low
ME 8	Entrainment: Protected Areas (Other)	Negligible	Unlikely	Very Low
ME 9	Entrainment: Protected Species	Minor	Rare	Very Low

7.6.3 Model of Entrainment of Plankton

The hydrodynamic model used to predict entrainment, and the results from the modelling, are described in Section 6.7. Neutrally buoyant particles distributed in the water column were used to simulate the movement of plankton and other small marine organisms. The particles are distributed throughout the zone at the beginning of each simulation. "Entrainment" occurs when a tracked particle enters a small zone beside the FSRU that corresponds to the intake volume of seawater taken in each day through the sea chests.

Particles are tracked for a 28-day period (a full lunar cycle of two neap and two spring tides). Thus, entrainment rates are quoted in terms of "percentage of particles entrained in 28 days" and "average percentage of particles entrained per day". However, the entrainment results are considered in this section in the context of the life cycle of the populations, and other biological stresses and factors influencing population dynamics. The 28-day timeframe can be longer than the time taken to renew plankton populations which is typically 7 to 21 days.

The travel time from the sea chests via the pumps through the pipes and heat exchangers to the discharge ports is a maximum of 5 minutes (other than in ballast water) before discharge. Within a further 3 to 5 minutes after discharge, the dilution of the discharged seawater flow would reduce the chlorine concentration to below the Guideline Value of impact. Only the marine organisms that are more sensitive to chlorine would be affected – others may survive this short-term event. Nonetheless, to provide a conservative risk assessment, it is assumed that all entrained plankton does not survive passage through the FSRU.

As a result of the seawater intake design features described above, the main unavoidable adverse effect of the heat exchanger system is to entrain all small marine organisms (very

small fish, zooplankton and phytoplankton), drifting eggs and larvae in the central part of the water column adjacent to the seawater intake. It is assumed that none of these biota would survive as a result of mechanical damage and exposure to chlorine produced oxidants produced by electrolysis of seawater at the intake, although as noted above, this is a conservative assumption.

The entrained biota comprise a wide range of planktonic plants and animals, larvae and eggs, from a wide range of plant and animal groups. The characteristics of the planktonic community in Western Port was comprehensively sampled during the EES program. Like most marine bays the plankton community comprise holoplankton populations that live their entire lives suspended in the water column and meroplankton that are the propagules or larval stages of larger non-planktonic adults.

Phytoplankton and zooplankton (holoplankton) reproduce in the water column, with different rates of reproduction or turnover between species, seasons and years. The characteristics and duration of the life stages of meroplanktonic invertebrates are highly variable between species. The larval life of species, their settlement and subsequent recruitment to the adult population is a highly complex process which can determine the population abundance and size classes of adults of the species. Seasonal and inter-annual variation in local or large-scale environmental conditions (currents, water temperature, primary productivity) can affect larval recruitment and is a key factor affecting many important ecological community components as well as commercial fisheries species.

Natural physical factors that affect the abundance, turnover and characteristics of phytoplankton and zooplankton communities in tidal bays include water temperature, salinity, light penetration, catchment runoff effects on water quality (such a nutrients, suspended solids, organic material, toxicants) and the natural rate of flushing of the embayment with the adjacent larger water body. If flushing rates are high compared to population replacement rates, then the characteristics of the community in the bay would be similar to that of the larger water body. If flushing rates are low compared to population replacement rates, then there is opportunity for communities that are adapted to local conditions in the bay to develop that are distinct from the adjacent larger water body.

The effects of entrainment in areas of Lower North Arm are therefore primarily assessed in terms of the proportion of seawater that passes through the FSRU over representative time periods compared to the natural rates of variation in the losses of the connected Upper North Arm and Western Entrance to Bass Strait. This enables assessment of the scale of effects of the FSRU operation on the planktonic marine ecosystem in relation to the natural losses to Bass Strait through tidal flushing.

7.6.4 Predictions of Entrainment of Plankton

Hydrodynamic models are widely used to simulate the transport and connectivity of phytoplankton and meroplankton communities within and through small, medium and large-scale marine ecosystems (Barnay et al 2003, Kimmerer et al 2014, Metaxas and Saunders 2009, Swearer et al 2019, Treml et al 2015), and were considered appropriate for holoplankton species in Western Port.

Available information on benthic habitat and plankton distribution show that:

- Marine benthic habitats in terms of planktonic larvae from intertidal and subtidal benthic invertebrates and fish in North Arm are distributed according to water depth and bottom slope;
- The pattern of neap and spring tides drive strong water currents that transport planktonic organisms 4 to 7 km up and down North Arm on a twice-daily cycle;
- The strong tidal currents mix the water column vertically so that vertical stratification or layering due to temperature or salinity is not sustainable over a half tide cycle (6 hours);
- There is a small net circulation around North Arm but the dominant flushing mechanism for Western Port is due to mixing of Bass Strait waters in the main entrance channel and along North Arm;
- The strength of tidal currents is influenced by water depth, with lower currents (and shorter tidal transport distances) in shallower water; and
- The greatest volume flux of water and plankton occurs in the deeper waters of the main channels where currents are stronger and volumes greater.

Based on this information, North Arm was divided into nine zones (with Zone 1 included in Zone 2, refer to Section 6.0) for the purposes of assessing plankton entrainment. The zones are shown in Figure 7-7.

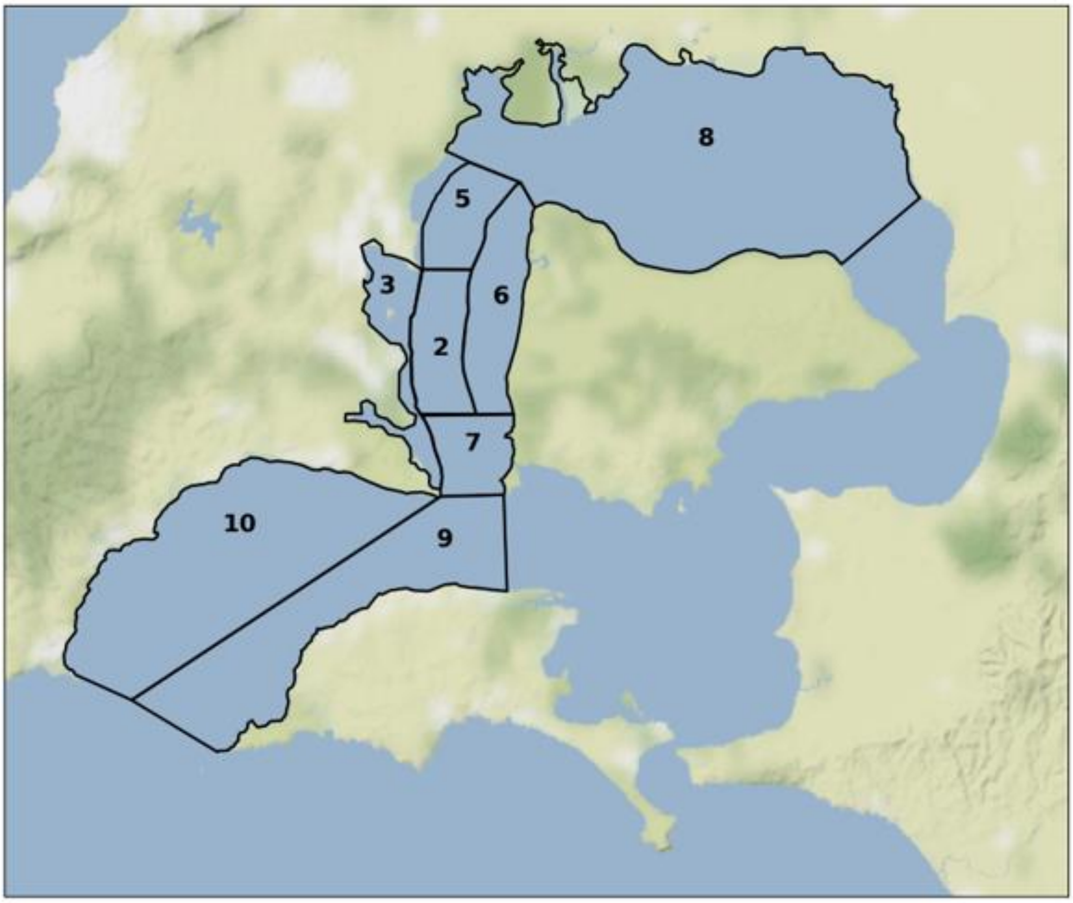


Figure 7-7. Entrainment Model, Zones for Entrainment Calculations

Zone 2 is the 7 km length of North Arm from Stony Point to Long Island Point, centred on the proposed FSRU location, Berth 2 at Crib Point Jetty. The length of this zone approximates the north-south distance travelled during a peak spring tidal excursion. This zone represents the area and body of water most likely to show maximum entrainment of plankton. The western boundary is the model 6 m depth contour along the western shore and the eastern boundary is the model 6 m depth contour on the western side of Middle Spit.

The seabed depths in this zone range from a minimum of 6 m along the lateral boundaries to a maximum of 18 m in the main shipping channel. The zone is approximately 2.5 km wide at Crib Point Jetty. The seabed habitat in Zone 2 comprises unvegetated soft sediments, with sparse or patchy distribution of epifauna. The zone includes the shipping basin which was dredged in the mid-1960s.

Zone 3 is Hastings Bay and Hann's Inlet and includes the shallow and intertidal area including seagrass and mangrove communities extending from the 6 m depth contour to the high tide mark between Sandy Point and Long Island Point.

Zone 5 is the area of water where the deep channel narrows and average water depth shallows from Long Island Point to the top of French Island. The east and west boundaries are the 6 m depth contour.

Zone 6 is the area of shallow water associated with Middle Spit and the channel between Middle Spit and French Island.

Zone 7 is the area southward of a line between Stony Point across North Arm, past the southern end of Middle Spit to the low tide mark on French Island, and the southern extent of North Arm marked by an east-west line between Sandy Point and Tortoise Head on French Island.

Zone 8 is the Upper North Arm, which includes Yaringa Marine National Park and French Island Marine National Park.

Zone 9 includes the deep Western Entrance channel between Middle Bank and Phillip Island and the Exchange Segment north-west of Phillip Island.

Zone 10 is the shallow region of the Western Entrance west of the sand bar and includes the Flinders Aquaculture Fisheries Reserve.

The hydrodynamic model included dispersion of particles released from these zones into and out of East Arm, but for reasons of model run-time efficiency did not release particles in East Arm.

7.6.5 Results of Model Predictions of Entrainment

Table 7-4 lists the results of the particle model in terms of (1) the entrainment rate over periods of 7, 14 and 21 days, and the fate of the remaining particles, in terms of (2) the percentage of particles remaining in the zone; (3) the percentage of particles flushed from the zone to Bass Strait during the period and (4) the percentage of particles flushed from the zone to other zones.

The results for Zone 2, for example, show that after 7 days, 0.31 % of the particles in the zone have been entrained, 38 % remain in this zone, 3 % have been flushed to Bass Strait and 59 % have dispersed to other zones in Western Port (to the north, south and east). With increasing time, there is more entrainment, a higher proportion is flushed to Bass Strait and fewer particles remain in this zone. After 21 days, the results for Zone 2 show that 0.63 % of

the particles in the zone have been entrained, only 20 % remain in this zone, 22 % have been flushed to Bass Strait and 57 % have dispersed to other zones in Western Port.

Table 7-4. Summary of Entrainment Model Predictions (for Peak Open Loop Flow)

Duration, days	Entrainment in period	Remaining in Zone	Flushed to Bass Strait	Elsewhere in Western Port
Zone 2				
7	0.31%	38 %	3 %	59 %
14	0.52%	24 %	11%	64 %
21	0.63%	20 %	22%	57 %
Zone 3				
7	0.13%	33 %	20 %	47 %
14	0.21%	21 %	26 %	53 %
21	0.29%	19 %	32 %	49 %
Zone 5				
7	0.01%	18 %	0 %	82 %
14	0.08%	10 %	2 %	88 %
21	0.19%	7 %	15 %	78 %
Zone 6				
7	0.02%	55 %	2 %	43 %
14	0.04%	41 %	4 %	55 %
21	0.07%	40 %	12 %	48 %
Zone 7				
7	0.10%	17 %	18 %	65 %
14	0.16%	9 %	32 %	59 %
21	0.21%	8 %	46 %	46 %
Zone 8				
Duration, days	Entrainment in period	Remaining in Zone	Flushed to Bass Strait	Elsewhere in Western Port

7	0	81 %	2 %	17 %
14	0.04%	72 %	5 %	23 %
21	0.09%	65 %	7 %	28 %
Zone 9/10				
Duration, days	**Entrainment in period**	**Remaining in Zone**	**Flushed to Bass Strait**	**Elsewhere in Western Port**
7	0.01%	26 %	61 %	13 %
14	0.03%	17 %	75 %	8 %
21	0.04%	11 %	82 %	7 %

The results in Table 7-4 shows that:

- The rate of entrainment depends on how close the zone is to the FSRU. Zone 2, which contains the FSRU shows the highest rate of entrainment (0.63 % after 21 days or about 0.03 % per day). Zones 9/10, which cover the western entrance close to Bass Strait have a very high rate of flushing (82 % after 21 days) but a very low rate of entrainment (only 0.04 % after 21 days or less than 0.002 % per day).
- The rate of flushing to Bass Strait depends on how close the zone is to Bass Strait. Zones 9/10, in the western entrance have a very high rate of flushing (82 % after 21 days) while plankton in Zone 8, in the north of the Bay, is predicted to be flushed at a very slow rate (only 7 % after 21 days). This finding shows the hydrodynamic basis for plankton counts being higher in the north of the Bay (where the flushing rate is low) than near the western entrance (where the flushing rate is high).
- There is a general flushing process operating at all times along the axis of the North Arm, with plankton populations from the north of the Bay being gradually flushed to Bass Strait.
- There is a high rate of mixing from one zone to other adjacent zones. For Zones 2, 3, 5, 6 and 7 as a group (the North Arm zones), 59 % of the particles were mixed into other zones within 7 days. This result shows there is substantial mixing between different parts of Western Port, and any loss of plankton in one zone would be quickly made up by plankton mixing in from adjacent zones.
- For the North Arm zones as a whole, the rate of entrainment is 0.22 % after 14 days or 0.40 % after 28 days. This corresponds to an additional mortality rate of 0.014 % per day.
- The actual rate of entrainment for North Arm is very small relative to natural mortality.
- The rate of entrainment is less at lower production rates. Peak open loop production is anticipated to occur for one month per year. For the remainder of the time, gas production rate is anticipated to operate at two-thirds of the peak rate (average production). Flows for peak and averaged open loop and for closed loop are listed in Table 6-1 (refer to Section 6.0).
- Table 7-5 shows the entrainment rates at 7, 14 and 21 days for the three production modes. It can be seen that the entrainment would be 34 % lower for average production compared to peak production (in open loop mode). Closed loop mode would be 60 % lower compared to peak production in open loop operation. Entrainment rates for 28 days are shown in Figure 7-7.

Table 7-5. Summary of Entrainment Model Predictions for Various Production Rates

Zone & period	Peak Open Loop, 471,000 m^3/d	Average Open Loop, 315,000 m^3/d	Closed Loop, 187,000 m^3/d
Zone 2	**Entrainment**	**Entrainment**	**Entrainment**
7	0.31 %	0.21 %	0.13 %
14	0.52 %	0.35 %	0.21 %
21	0.63 %	0.42 %	0.25 %
Zone 3	**Entrainment**	**Entrainment**	**Entrainment**
7	0.13 %	0.08 %	0.05 %
14	0.21 %	0.14 %	0.08 %
21	0.29 %	0.19 %	0.12 %
Zone 5	**Entrainment**	**Entrainment**	**Entrainment**
7	0.01 %	0.01 %	0
14	0.08 %	0.06 %	0.03 %
21	0.19 %	0.12 %	0.08 %
Zone 6	**Entrainment**	**Entrainment**	**Entrainment**
7	0.02 %	0.01 %	0.01 %
14	0.04 %	0.03 %	0.02 %
21	0.07 %	0.05 %	0.03 %
Zone 7	**Entrainment**	**Entrainment**	**Entrainment**
7	0.10 %	0.07 %	0.04 %
14	0.16 %	0.10 %	0.06 %
21	0.21 %	0.14 %	0.08 %
Zone 8	**Entrainment**	**Entrainment**	**Entrainment**
7	0	0	0

14	0.04 %	0.03 %	0.02 %
21	0.09 %	0.06 %	0.04 %

Zone 9/10	Entrainment	Entrainment	Entrainment
7	0.01%	0.01%	0.01 %
14	0.03%	0.02%	0.01 %
21	0.04%	0.03%	0.02 %

Table 7-6 lists the North Arm entrainment rate predictions for durations from 1 to 28 days, and for the three production modes. The entrainment assessment is based on the seawater intake flows and entrainment rates for the peak month (shown in yellow highlight) and is therefore conservative on an annual basis. The green highlight indicates the other modelled scenarios for which entrainment predictions were developed.

Table 7-6. Summary of North Arm Entrainment Rate Predictions

North Arm	Peak Production open loop	Average Month open loop	Closed loop	Loss to Bass Strait
Number of Days	Entrainment	Entrainment	Entrainment	Flushed from Zone 2
1	0.04 %	0.03 %	0.02 %	0.4 %
7	0.13 %	0.08 %	0.05 %	2.7 %
14	0.22 %	0.14 %	0.09 %	7 %
21	0.30 %	0.20 %	0.12 %	18 %
28	0.40 %	0.27 %	0.16 %	26 %

7.6.6 Ecological Considerations - Seasonality

The plankton community in Western Port is described in Section 5. The community comprises a range of very small plants (phytoplankton), small animals (zooplankton), fish eggs and fish larvae that drift with the strong and turbulent tidal currents along the main deeper channels and in the weaker currents over the subtidal and intertidal areas. As shown in Figure 7-8, the plankton community in 2019 was seasonal, with highest abundances in early spring and summer and lowest abundance in autumn and early winter. The seasonal pattern is the result of the linkage of biological and ecological processes with seawater temperature, daylength and nutrient inputs.

7.6.7 Spatial Distribution of Plankton Communities

The composition and distribution patterns of plankton in North Arm, and Western Port generally is an important consideration in assessing the effects of entrainment. Studies have shown that North Arm plankton communities have higher abundance, but lower species numbers than Bass Strait and Port Phillip communities (Section 5).

However, the species present in Western Port are relatively common throughout south-eastern Australian coastal marine communities.

The composition of the phytoplankton and zooplankton communities in Lower North Arm documented in 2019 differed from the communities documented by others in Bass Strait and Port Phillip Bay, but appears to be very similar to the communities in North Arm as established in the 1970s and in East Arm as established in the 1970s and 1980s.

The results of the plankton studies described in Section 5 indicate a gradient in the characteristics of the permanent phytoplankton and zooplankton community from a phytoplankton community dominated by benthic and small chain-forming diatoms, with a focussed zooplankton group of copepod (*Acartia* spp) in the far north and north east of Western Port, to a more diverse community in the Western Entrance with relatively low numbers of *Acartia spp* and small diatoms. This gradient is similar in pattern to the East Arm zooplankton gradient evident from Corinella to Cowes made about 35 years ago (Kimmerer and McKinnon 1987a).

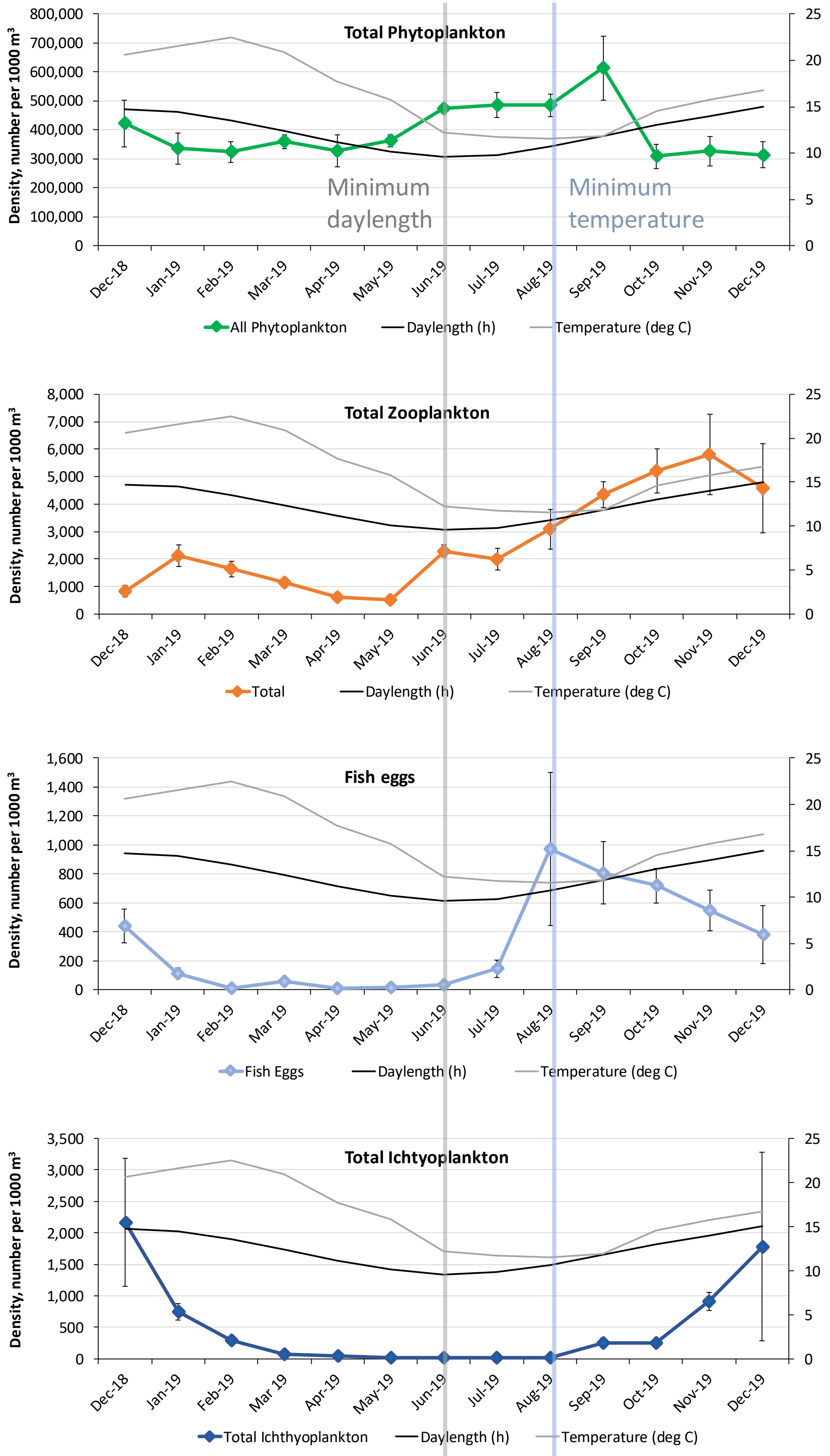


Figure 7-8. Change in Plankton Abundance from Dec 2018 - Dec 2019

An important survey in October 2019 for the EES replicated the gradient of zooplankton distribution from north to south in East Arm documented previously (Kimmerer and McKinnon 1987a) and showed a simultaneous gradient from north to south in Lower North Arm (Figure 5-75, refer to Section 5).

The combined effect of strong tidal currents and high levels of suspended solids in North and East Arms of Western Port appear to be the cause of the difference between their communities with those of Bass Strait and Port Phillip. The plankton gradient is likely to be due to the change in water quality as the clearer Bass Strait water penetrates into North and East Arms and results in (1) dilution of the suspended solids and biota from the north of the Bay towards Bass Strait, (2) dilution of the relatively high concentrations of *Acartia* from the north of Western Port with the lower concentrations in Bass Strait and (3) supply of open coast plankton from the larger plankton source of Bass Strait.

Figure 7-9 illustrates that there are higher suspended solids levels at Corinella in East Arm compared to the other EPA monitoring sites. As discussed in Section 5, there are also higher nutrient concentrations at Corinella, and the chlorophyll-a concentration at Corinella is three times that in North Arm, indicating substantially greater plankton productivity in response to the nutrient input, and despite the higher suspended solids level.

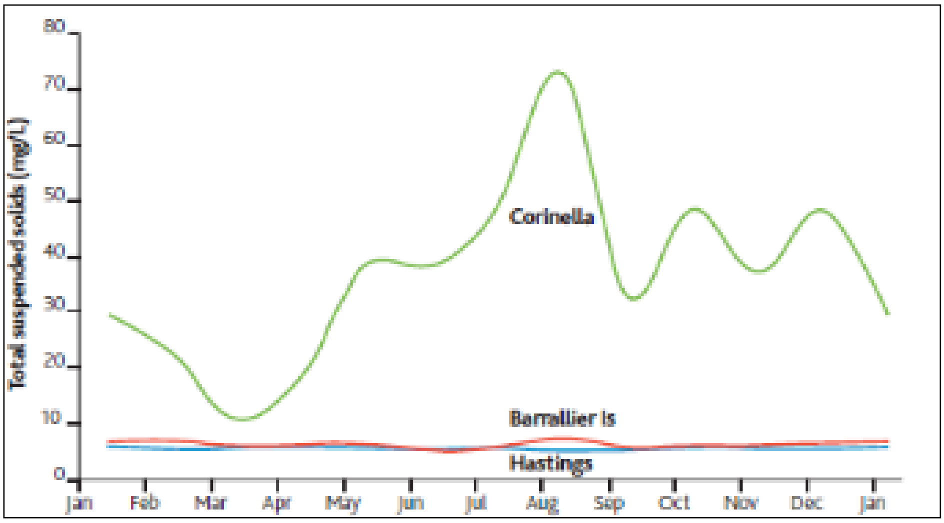


Figure 7-9. Suspended solids concentrations at EPA monitoring sites in Western Port

Source: Melbourne Water 2011

This pattern is consistent with the concept of core plankton populations in northern and north eastern Western Port extending eastward from the northwest tip of French Island to Corinella, which is conceptually shown in Figure 7-10. The core northern Western Port plankton population region is separated from Bass Strait by transitional regions in the Lower North Arm, Rhyll Segment and Western Entrance. Plankton populations at any point along the transitional zones vary substantially in the short-term due to natural patchiness and tidal cycles, in the medium-term due to seasonal changes and in the long-term due to natural changes in the character of the semi-independent core regional populations. Transition zones of ecological change between different environmental conditions are known as **ecotones.**

The identification of these planktonic ecotones in Lower North Arm and wider Western Port community are fundamental to understanding the potential effects of entrainment of plankton at Crib Point from the proposed operation of an FSRU. The plankton zones identified here are consistent with the Western Port segments identified from multidisciplinary studies in the 1974 Western Port Bay study and the Victorian Waters Policy 2018 (also shown in Figure 7-10).

The concept of planktonic ecotones in Western Port may affect the distribution patterns of benthic plants and animals that reproduce by larval dispersal.

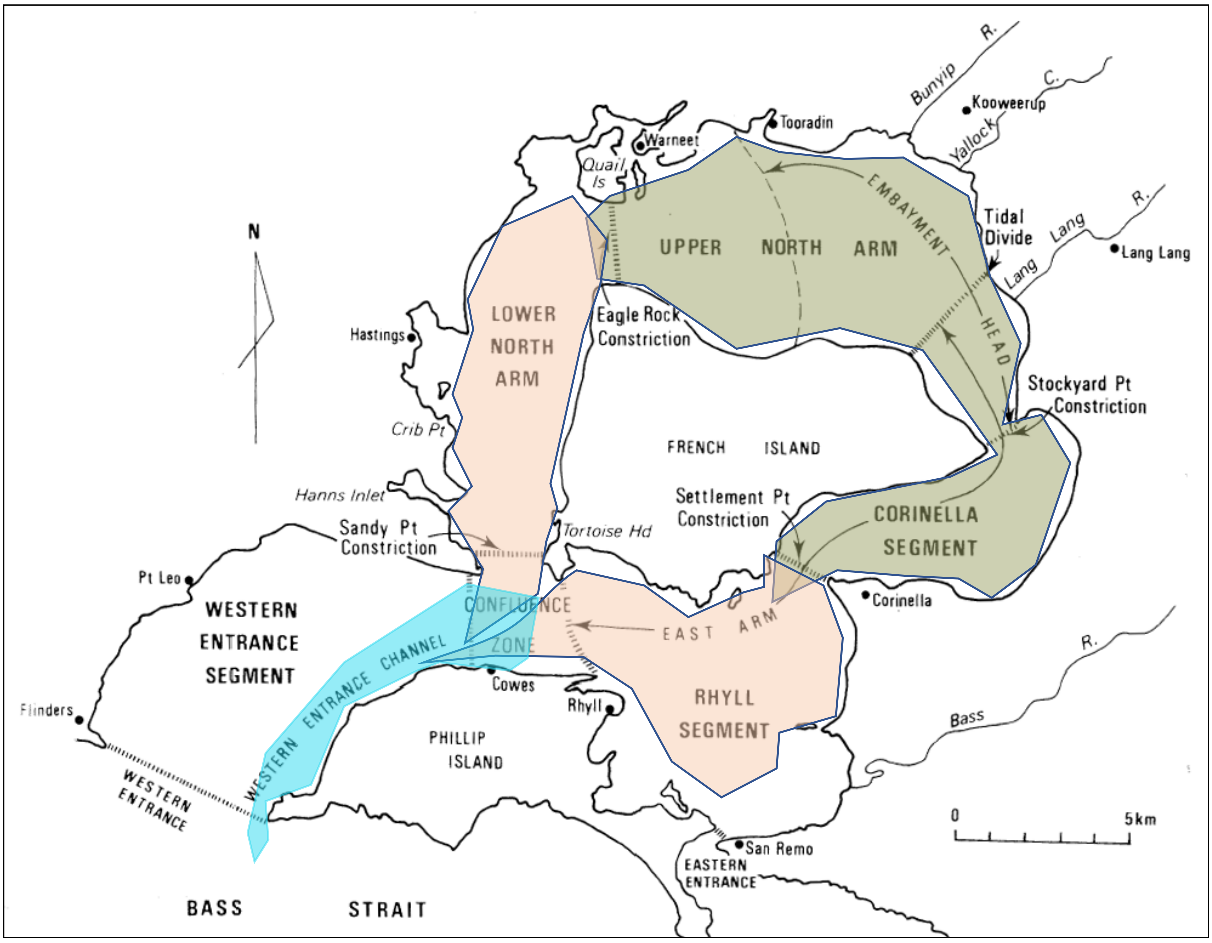


Figure 7-10. Plankton Population Zones and Ecotones in Western Port

Blue = Bass Strait Zone Brown = North to East Zone Pink = Ecotones

The assessment on entrainment risks is based on the environmental factors that influence the plankton population characteristics and dynamics of the plankton community in Lower North Arm based on 12 months of plankton data from Lower North Arm, fundamental processes in plankton biology, known hydrodynamics of Western Port, and hydrodynamic models of particle entrainment simulating drifting neutrally buoyant plankton.

7.6.8 Habitats in Western Port

The distribution of habitats in Western Port is another consideration in assessing entrainment. There is a wide range of durations in the life cycles of marine benthic organisms that inhabit these habitats. Many biota have eggs, and one or a series of larval stages. Life cycles may be confined within the adult, with offshore recruiting immediately with the proximity of the adult, while others have increasingly dispersed intermediate stages between gamete production and recruitment to reproductive adulthood. Some intertidal invertebrates and fish, such as gobies and pipefish, that inhabit mangrove, mudflats and seagrass habitats may produce eggs and larvae that disperse in the water column. Their fate would depend on the duration that the egg or larvae remain in the water column and their ability to locate their preferred settlement habitat and preferred depth.

Those with longer larval periods and limited ability to maintain position are likely to disperse more widely and settle in suitable habitat at greater distances from their origin (Figure 7-11). Those with short or no planktonic larval periods are unlikely to disperse far in a single generation, but may hop increasingly further distances over subsequent generations. The ecology of recruitment, colonisation and succession is a complex and interlinked processes.

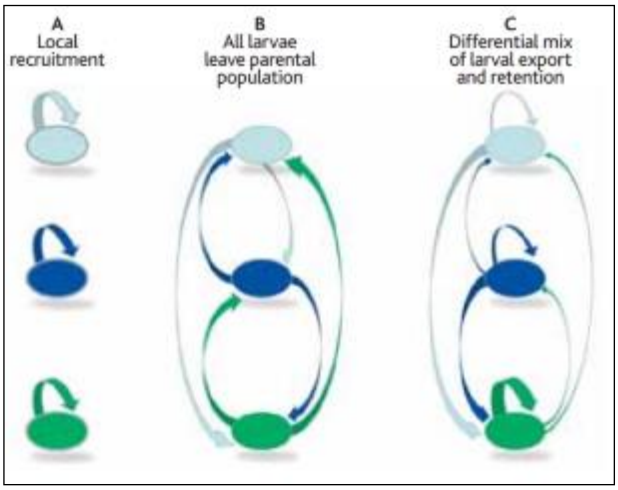


Figure 7-11. Models of benthic invertebrate larval dispersion

Source: Melbourne Water 2011

7.6.9 Assessment of Entrainment Risks to Biota

Table 7-7 lists the dispersal patterns and typical duration for larvae from various biological groups. The groups highlighted in green are unlikely to be entrained, those highlighted in yellow may be entrained and the groups highlighted in purple (phytoplankton and zooplankton, and planktonic fish larvae) are most likely to be entrained.

Table 7-7. Planktonic Dispersal Patterns and Duration

Biological group	Planktonic dispersal	Duration/Replacement
Saltmarsh	Negligible planktonic dispersal	Not applicable
Mangrove	Buoyant seedling	Months
Seagrasses	Benthic seeds, benthic propagules, buoyant propagules	Months (Larkum et al 2006)
Benthic	Eggs: Brood, benthic, broadcast	Day to week
Invertebrates	Larvae: Benthic, planktonic, pelagic	Days to month (Thorson 1960)
Fish and squid	Eggs: Brood, benthic, buoyant, planktonic	Days to 2 weeks (Jenkins 2019)
	Larvae: Benthic, planktonic, pelagic	Weeks to months
	Juvenile: Benthic, surface, pelagic, demersal,	Weeks to months
Plankton	Phytoplankton	Hours to days (CSIRO 1996)
	Zooplankton	3 to 30 days (K&M 1985)

Green: Rare or unlikely to be entrained due to (a) confined retention within habitat (brood) or ability to maintain vertical position in the water column (benthic, buoyant, demersal) and therefore rare or unlikely to pass within 'Entrainment zone' (HydroNumerics 2019).

Yellow: Possible potential be entrained depending of degree of development and strength of independent lateral movement if pass within 'entrainment zone'

Purple: Likely potential to be entrained if pass within 'entrainment zone'

The allocation of the groups' likelihood of entrainment is based on their planktonic biology, possibility of passing within the entrainment zone of the intake, the zones of Western Port they occupy, their duration as plankton, their individual replacement time by reproduction, and the natural proportion of loss from the zone to other parts of Western Port or to Bass Strait (Table 7-4).

7.6.10 Mangroves and saltmarsh

The closest saltmarsh and mangrove communities to the FSRU proposed location are located in Zone 3. ***Saltmarshes*** are rarely inundated and the plants or associated community members do not rely on planktonic dispersion for continuation of the community. There is no realistic pathway for entrainment to affect the saltmarsh community.

Mangroves in Western Port are the white (or grey) mangrove *Avicennia marina*, which produce elongate fruit that float when they fall from the tree. These buoyant propagules are viable for long periods as they float freely at the water surface where they travel with the net forces of sea-surface winds and surface currents. These floating propagules are highly unlikely to be entrained in a seawater intake located more than 2 m below the water surface. Any small amount of floating propagules to be entrained would have a negligible consequence on mangrove distribution.

The likelihood of entrainment of saltmarsh or mangrove vegetation seeds or fruit is **rare**. The proportion of any saltmarsh or mangrove vegetation seeds or fruit entrained in relation to the total population would be **negligible**. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence result in a risk rating of **Very Low**.

7.6.11 Intertidal mudflat Invertebrate Communities

Benthic invertebrate communities in the soft seabed of the mangroves and bare mudflats of Lower North Arm comprise a rich and diverse mixture of burrowing biota from a wide range of intertidal biological groups including burrowing worms, crustaceans, molluscs, echinoderms and many others. Within these groups, there is a wide range of reproductive strategies. Many include larval dispersal. Larval dispersal and recruitment involve diverse, multistage strategies with a range of larval periods and larval behaviour.

Intertidal larvae may be susceptible to entrainment if their dispersal strategy takes them within the entrainment zone of the FSRU. The larvae that are mixed through the water column in the strong currents of the main Lower North Arm channel are likely to originate from 'broadcast' spawners that release eggs or larvae into the pelagic environment to spread over wide areas before settling on suitable seabed and recruiting into further benthic larval or adult stages (Rumril 1990). The reproductive strategy of broadcast spawners is generally characterised by producing massive numbers of eggs and larvae to overcome the high natural mortality and low likelihood of recruitment to reproductive adulthood.

In these biota, females may release millions to hundreds of millions of eggs per spawning (Thorson 1961). Some develop into larvae that survive to settle back into suitable habitat. Most die from a range of natural factors. Average mortality rates due to biological factors of 23 % per day for intertidal benthic planktonic larvae have been suggested (Pechenik and Levine 2007) to the stage of settlement.

Table 7-8 shows an estimate of natural mortality for invertebrate larvae using a mortality rate of 23 % per day with no allowance for loss by advection. For comparison, the entrainment in the peak month (refer to Table 7-6) for North Arm as a whole is 0.22 % after 14 days or 0.40 % after 28 days. It is apparent that natural mortality is two orders of magnitude higher than entrainment.

Table 7-8. Mortality for Invertebrate Larvae

Days	Loss due to mortality (at 23% per day)*	Loss due to Entrainment	Loss due to Flushing
0	0	0	0
1	23 %	0.04 %	2 %
7	84 %	0.13 %	9 %
14	97.4 %	0.22 %	15 %
21	99.6 %	0.30 %	26 %
28	99.9 %	0.40 %	40 %

* As suggested by Pechenik and Levine (2007).

Table 7-8 shows that the rate of production required by females in the source population to overcome natural mortality over one month is millions. Such is the life cycle in pelagic spawning benthic marine invertebrates in general. In North Arm, there is an additional stress as tidal currents carry larvae away from suitable habitat and into Bass Strait where they are lost from the system (the flushing component is listed in Table 7-4 and Table 7-8).

The natural mortality and flushing rates are naturally overcome by the reproductive strategies of broadcast swarmers reproducing in very large numbers in this environment. Broadcast spawners occur in Western Port as shown by the episodic occurrence of high numbers of

polychaete, crab zoea and macrura (shrimp) larvae collected in Lower North Arm in 2019. In these cases, the additional mortality from entrainment by FSRU would be very small compared to the overall combined level of loss from natural mortality and advection.

The particle model shows that particles from individual zones mix into other zones within days. Table 7-4 shows that for larval periods of one week or more, pelagic larvae from other model zones would have mixed across the entire Lower North Arm ecotone. Hence the pool of larvae near the FSRU would include influences from the Upper North Arm/Corinella community and the Bass Strait community. The consequence of entrainment on any particular species would be very small.

Other intertidal benthic invertebrate recruitment strategies reduce the requirement for high numbers of dispersive eggs and larvae, minimise exposure to predation and maximise the chances of remaining in suitable habitat conditions. For intertidal benthic species, recruitment strategies are less likely to involve dispersion processes that take eggs and larvae away from the intertidal zone into the broader pelagic environment. There are many combinations of processes, all of which result in lower risk of mortality in the pelagic environment. These strategies also reduce the likelihood of being entrained. The origin of the species entrained would be widespread so the consequence for any particular species originating from any particular location would be very small.

The intertidal benthic species in Lower North Arm are widespread in Western Port and Bass Strait. There is continuity of habitat for subtidal species throughout south-eastern Australia and continuity of generations of larvae throughout the ranges, including ‘rare’ species (Poore et al 2019).

The intertidal benthic invertebrate fauna in Western Port is an unusual mixture, compared to Port Phillip Bay or Bass Strait. This is due primarily to the range and arrangement of the physical habitats and the large tidal range in Western Port. This would not be affected in any way by entrainment. Any effect of entrainment on intertidal invertebrate’s species abundance or distribution would be classed as ***rare*** and the consequence would be ***minor*** within the proximity of the FSRU seawater intake and negligible to the wider Western Port community. The risk rating is therefore **Very Low***.*

7.6.12 Intertidal and Subtidal Seagrasses

The closest intertidal and subtidal seagrasses to the FSRU proposed location are located in Zones 3 and 6. Seagrasses release seeds and vegetative propagules. The seeds disperse over the seabed with wave action and seabed currents in much the same way as sediment is transported. Larger propagules drift along the seabed with currents, or sometimes float at or near the surface with other seagrass flotsam. The propagules are fully independent plants and may remain functional for long periods while drifting, before they take root in a preferred shallow subtidal or intertidal seabed.

Heterozostera nigricaulis and *Zostera muelleri* seeds tend to remain relatively close to their source while propagules can be transported many kilometres by tidal currents. There is likely to be an interconnection of all seagrass in Lower North Arm through dispersion of propagules.

The seawater intake on the FSRU would be located at least 3 m above the seabed and 2 m below the sea surface, reducing the likelihood of entraining propagules dispersing along the sea surface or seabed. The seawater intake would be remote from the source of drifting the seagrass propagules, where propagule concentrations are highest. The likelihood of entrainment of intertidal and subtidal seagrass propagules is ***rare***. The consequence to

Western Port seagrass populations and species is therefore ***negligible***. Thus, the risk rating is **Very Low**.

7.6.13 Subtidal Benthic Invertebrate Communities

Subtidal benthic invertebrate communities in the soft seabed of subtidal channel habitats of Lower North Arm comprise a rich and diverse mixture of burrowing biota from a wide range of biological groups including burrowing worms, crustaceans, molluscs, echinoderms and many others. Within these groups, there is a wide range of reproductive strategies. Some include larval dispersal. Larval dispersal and recruitment involve diverse, multistage strategies with a range of larval periods and larval behaviour.

Subtidal larvae may be susceptible to entrainment if their dispersal strategy takes them within the entrainment zone of the FSRU. The larvae that are mixed through the water column in the strong currents of the main Lower North Arm channel are likely to originate from 'broadcast' spawners that release eggs or larvae into the pelagic environment to spread over wide areas before settling on suitable seabed and recruiting into further benthic larval or adult stages (Rumril 1990). The reproductive strategy of broadcast spawners is generally characterised by producing massive numbers of eggs and larvae to overcome the high natural mortality and low likelihood of recruitment to reproductive adulthood.

In these subtidal biota, females may release millions to hundreds of millions of eggs per spawning (Thorson 1961). Some develop into larvae that survive to settle back into suitable habitat. Most die from a range of natural factors.

The rate of production required by females in the source population to overcome natural mortality over one month is millions. Such is the life cycle in pelagic spawning benthic marine invertebrates in general. In North Arm, there is an additional stress as tidal currents carry subtidal larvae away from suitable habitat and into Bass Strait where they are lost from the system (the flushing component is listed in Table 7-4 and Table 7-8).

The natural mortality rate and flushing rate are naturally overcome by the reproductive strategies of broadcast swarmers reproducing in very large numbers in this environment. Broadcast spawners occur in Western Port as shown by the episodic occurrence of high numbers of polychaete, crab zoea and macrura (shrimp) larvae collected in Lower North Arm in 2019. In these cases, the additional mortality from entrainment by FSRU would be very small compared to the overall combined level of loss from natural mortality and advection.

The particle model shows that particles from individual zones mix into other zones within days. Table 7-4 shows that for larval periods of one week or more, pelagic larvae from other model zones would have mixed across the entire Lower North Arm ecotone. Hence the pool of larvae near the FSRU would include influences from the Upper North Arm/Corinella community and the Bass Strait community. The consequence of entrainment on any particular species would be very small.

Other subtidal benthic invertebrate recruitment strategies reduce the requirement for high numbers of dispersive eggs and larvae, minimise exposure to predation and maximise the chances of remaining in suitable habitat conditions. For subtidal benthic species, recruitment strategies are less likely to involve dispersion processes that take eggs and larvae away from the subtidal zone into the broader pelagic environment. There are many combinations of processes, all of which result in lower risk of mortality in the pelagic environment. These strategies also reduce the likelihood of being entrained. The origin of the species entrained would be widespread so the consequence for any particular species originating from any particular location would be very small.

The subtidal benthic invertebrate fauna in Western Port is an unusual mixture, with different proportions and distributions of species present compared to Port Phillip Bay or Bass Strait. This is due primarily to the range and arrangement of the physical habitats and the large tidal range in Western Port. The range and arrangement of the physical habitats would not be affected in any way by entrainment. Any effect of entrainment on subtidal invertebrate's species abundance or distribution would be classed as ***rare*** and the consequence would be ***minor*** within the proximity (shipping basin) of the FSRU seawater intake and negligible to the wider Western Port community. The risk rating is therefore **Very Low**.

7.6.14 Pelagic and Demersal Fish Eggs and Larvae

The discussion of pelagic and demersal fish in this section is largely taken from Jenkins 2019. Most marine fish are highly fecund, and mortality rates of eggs and larvae are size-dependent, with the highest mortality rates occurring in the youngest stages (Peterson and Wroblewski 1984 in Jenkins 2019). Mortality rates of marine larvae are most commonly estimated using the "catch curve" method that quantifies the decrease in larval abundance with increasing age (or length as a proxy for age) from ichthyoplankton samples (Pepin 2016 in Jenkins 2019). Estimates based on species in the northern hemisphere are variable, but for typical larvae approximately 5 mm in size (i.e. most of the larvae collected in this survey), the mortality rates are between 10 % and 60 % per day (Bailey and Houde 1989; Houde 2008 in Jenkins 2019).

For larvae of equivalent length to King George Whiting post-larvae of approximately 15 to 20 mm in length (which are several months old before reaching Western Port), mortality estimates range from 5 % to 30 % per day (Bailey and Houde 1989; Houde 2008 in Jenkins 2019). In the case of larvae of pipefish, *Stigmatopora* sp., that are released into the water column at a length of approximately 30 mm, the expected mortality rate of larvae of this length would be in the order of 5 % per day. These estimates are assumed to be applicable to larval mortality for fish species in Western Port, although fish such as King George Whiting and Grayling have substantially longer larval durations. Whiting originate from remote spawning populations outside Western Port (South Australia and western Victoria) or at least Upper North Arm and East Arm. Grayling spawn in coastal river systems in central and eastern Victoria.

Many fish species have a pelagic larval duration in the order of one month from hatching through various stages, sizes and degree of motility to life as free-swimming juveniles or selection of referred benthic habitat or depth, so this is a relevant conservative time scale to initially consider the effects of entrainment. A conservative estimate of mortality over the larval phases (2 – 10 mm length) of 10 % per day (see above), thus approximately 95 % would die over the course of 28 days, if they do not grow to a larger size or settle to suitable habitat in that time. Thus, the additional mortality from entrainment into the FSRU would be small compared to the overall level of mortality. As noted previously, a high proportion of larvae in Lower North Arm of Western Port would be dispersed into other parts of Western Port within two weeks and larvae would have grown considerably over this two week period, (representing half their larval-life span) and may then be capable of maintaining position relatively to preferred benthic habitat or seabed depth.

King George Whiting post-larvae in Western Port are larger (15-20 mm). King George Whiting spawn in South Australia and Western Victoria and have larval periods of 3 to 5 months (Jenkins 2003). Larvae drift along the open coast for months before entering Victorian bays including Western Port, where they settle in seagrass beds or other suitable habitat close to where they are delivered by currents (Jenkins et al 2000, 2003, 2015). For these larger, older post-larvae, a lower conservative level of mortality of 5% per day could be assumed. In this case, approximately 75 % of King George Whiting post-larvae could die over 28 days which

may be a conservative estimate of the time it would take these motile post-larvae (see below) to find, and settle into seagrass habitat by travelling through Lower North Arm after arriving from Bass Strait and passing suitable settlement habitat in the Western Entrance. The same analysis would be relevant to pipefish, *Stigmatopora* sp. larvae which could also be assumed to have a mortality rate of 5% per day based on size at release into the water column. There is, of course, considerable uncertainty in these estimates, because there is wide variation in the estimated mortality and larval behaviour at a given size/age amongst species, and as mortality rates of larvae have not been directly measured for any species in Western Port. In the case of Grayling, King George whiting and some pipefish, it is likely that larval and post-larval behaviour and swimming ability would substantially reduce the likelihood of entrainment by the FSRU seawater intake, as discussed below.

The hydrodynamic modelling assumes that larvae are dispersed passively by currents. The analysis of spatial distributions of larvae in this study tends to support this, with relatively even spatial distributions of larvae from most families throughout the Lower North Arm. There are notable exceptions, for example, the field collection data shows that syngnathid larvae were more abundant at the edges of the main channel (W10 and E10), than within the channel (B2 and C1) where the FSRU is proposed to be located. This pattern is consistent with release of syngnathid larvae mainly from seagrass beds along the shallower margins of the Lower North Arm. This distributional pattern further reduces the likelihood of this group of pipefish larvae being entrained in the FSRU seawater intake.

Larval behaviour can alter passive dispersal and affect the assumptions of the modelling, as well as giving options for reducing the impacts of entrainment. For example, King George Whiting post-larvae are known to show strong diurnal vertical migration behaviour; during daylight they are concentrated near the water surface but at night they are randomly dispersed through the water column (Jenkins *et al.* 1998). Because the seawater intake for the FSRU would be at least 2 m deep, it is less likely that Whiting post-larvae would be entrained during daylight hours compared to at night.

As well as vertical migration, whiting post-larvae, like most older stage larvae and post larvae, are capable of horizontal swimming that can alter passive dispersal. As discussed in Section 5, whiting post-larvae in Port Phillip were found to occur closer to shore than predicted by modelling passive dispersal, most likely due to directed swimming (Jenkins *et al.* 1999). Hence, like syngnathids, it is likely that most whiting post-larvae entering Western Port migrate along the shallow waters where suitable subtidal seagrass habitat is distributed as they do in Port Philip (Jenkins et al 1999), rather than throughout the mid-depths of the main channel where the FSRU seawater intake is proposed to be located and where sampling was focused. This is consistent with the absence of whiting larvae from the depths of the seawater intake position as indicated by the results of the stepped tows from 2 m below the surface to 2 m above the seabed in the central channel sites during the EES studies.

In terms of the depth of the FSRU seawater intake, it should also be noted that pelagic fish eggs tend to be positively buoyant and would tend to accumulate near the surface, potentially reducing the rate of entrainment, although this depends on the strength of turbulent mixing.

Snapper eggs and larvae were not present in any of the samples collected from Lower North Arm. This is consistent with present understanding that snapper do not breed in Western Port and that Port Phillip Bay is the main breeding area for snapper stocks in Victoria west of Wilsons Promontory. The swimming ability of larger larvae means other fish present in Lower North Arm may be able to avoid the FSRU seawater intake depending on the intake velocity. The Project specifications allow for a maximum intake velocity of 0.15 m/s at the seawater intake screening screen. The sustained swimming speed that King George Whiting post-larvae

can maintain for 2 hours is only 0.06 m/s (Jenkins and Welsford 2002). However, the burst speed they are capable of to avoid danger such as predators is unknown. Larvae of temperate fish species were found to increase swimming ability rapidly from hatching to the end of the larval stage (Clark *et al.* 2005). The larger pre-settlement larvae were capable of swimming at speeds of up to 0.2 m/s (Clark *et al.* 2005). Thus, larger, older fish larvae may be able to avoid the FSRU seawater intake by active swimming.

Risk to Fish Eggs and Larvae During Different Seasons

As discussed in Section 5, plankton sampling showed that fish eggs were most common in late winter (August), reduced through spring to early summer (December) and were low in autumn and winter. As mentioned previously, Western Port is a nursery area for fish and this is one of the Ramsar criteria for its status as a Ramsar site. Hence, entrainment risk to this seasonal factor or value (fish egg and larval presence) is considered in seasonal terms.

Risk to Fish Eggs and Larvae in Spring and Summer

Over the spring-summer seasons, there was typically 30 to 100 fish eggs per 100 m^3 of seawater. Eggs were reasonably uniformly distributed through North Arm although numbers were lower in the central area of the main channel. This indicates sources of eggs are the shallower areas at the sides of the channel, and the Middle Spit. At Crib Point Jetty Berth 2, there were 50 fish eggs per 100 m^3 of seawater.

Pelagic eggs are usually buoyant. Hence, if the seawater intake on the FSRU is at least 2 m below the water surface (even at low tide) the relative risk of entraining floating eggs is reduced. This mitigation measure has been recommended for incorporation in the FSRU, as described in Section 7.5.1 and would reduce the rate of entrainment for some species, but not for all species as demonstrated by the catch of eggs in the stepped tows. Unfortunately, present scientific methods cannot distinguish the adult species of most planktonic eggs. Some species larvae and eggs may be less susceptible to entrainment due to behaviour and distribution, but others would not be mitigated by the planned configuration of the FSRU seawater intake (Section 7.5.1).

A wide range of fish larvae were collected in the ichthyoplankton samples at Crib Point Jetty Berth 2 and around North Arm. Fish larval numbers for most groups were strongly seasonal, with numbers increasing from Spring (from September), peaking in November and December and reducing through summer as they transform into free swimming forms or recruit to preferred habitats away from the waters of the main channel. Over the spring-summer seasons, there was typically 20 to 100 fish larvae per 100 m^3 of seawater.

The potential effects of entrainment on fish larvae and fish eggs would be highest over spring and summer given the strong seasonal pattern in ichthyoplankton abundance. Spring and Summer also coincide with the period when larvae of most of the ecologically important, fishing and conservation species are in the water column.

The entrainment for evenly distributed passive particles depends on the rate of intake of seawater, the duration of the life cycle of particular passive eggs and larvae and the period for their development to non-passive juveniles over their larval duration. Considering the typical range of mortality (around 10 % per day), the extra effect of flushing from North Arm to other parts of Western Port and Bass Strait (around 1 % per day) and the development of the larvae from free-drifting, relatively passive larvae to maintaining position in relation to benthic habitat or depth or actively swimming pelagic juveniles within 28 days, it is considered that 14 days is the appropriate period to assess the effects of entrainment in Lower North Arm on the passively drifting period of these meroplankton.

The entrainment rate for North Arm at various seawater intake rates is listed in Table 7-6. At the peak intake rate the entrainment is 0.22 %, which corresponds to a significant reduction in numbers of fish larvae and eggs. There is potential for some fish larvae and eggs may be entrained and the likelihood is therefore ***likely***.

Most fish only produce eggs and larvae at this time of year in particular areas according to the preferred breeding habitat and environmental condition preferences of the adults. The high concentrations present and the restricted habitats they prefer are not widespread in Victoria. Hence, at the peak intake rate, the consequence of reduced recruitment success during spring and summer is classed as ***moderate***. According to the risk matrix in Section 4.0 a likelihood of likely and moderate consequence results in a risk rating of **Medium*.***

Alternatively, at the reduced (average) intake rate the entrainment is 0.14 %, which corresponds to a small reduction in numbers of fish larvae and eggs. There is potential for some fish larvae and eggs to be entrained and the likelihood is therefore ***possible.*** At the peak intake rate, the consequence of reduced recruitment success during spring and summer is classed as ***minor***. According to the risk matrix in Section 4.0 a possible likelihood and minor consequence results in a risk rating of **Low.**

Risk to Fish Eggs and Larvae in Autumn and Winter

Few fish larvae and eggs are present in the waters of Lower North Arm in autumn and even fewer over winter. The likelihood of that a significant proportion would be entrained in this period is ***possible***. The species that are present are common throughout Western Port and Victoria and are highly fecund. Hence, the proportion of the total number of larvae and eggs entrained would be small. The consequence of entrainment is therefore ***negligible***. According to the risk matrix in Section 4.0, a possible likelihood and negligible consequence results in a risk rating of **Low*.***

Mitigation Measure – Limit Regasification Discharge in Spring and Summer

The entrainment consequence ratings, with a particular focus on fish larvae, are shown in Table 4-4 and their development is described in Section 4.5.4. A more stringent consequence was defined for the fish breeding months in spring and summer with a less stringent consequence for months outside the principal fish breeding season. The implications of the consequences as developed above are:

- Risk rating for peak regasification intake flow of 471,000 m3/d is **Medium**;
- Risk rating for average regasification intake flow of 315,000 m3/d is **Low*.***

Consequently, an additional mitigation measure was recommended for this project with a flow limit of 315,000 m^3/d imposed for the spring and summer seasons, which are the times when there is a high abundance of fish larvae in Western Port.

The entrainment rates are calculated as an average over a 14-day period. Thus, the flow limit of 315,000 m^3/d should be applied as a 14-day average. This means that if there is a day in any fortnight with high gas demand, necessitating a short period of high gas production by the FSRU (noting that gas is delivered into the Victorian network in 4-hour time periods), it must be compensated by an equal period of low gas production (below the average) so that the 14-days average discharge remains below 315,000 m^3/d.

In summary, in spring and summer, the average discharge from the regasification process (including the freshwater generator and seawater discharge filter) must be below 315,000 m^3/d in any 14-day period.

7.6.15 Plankton

The plankton community of Lower North Arm is subject to a gradient of exchange and flushing processes between the larger plankton community of Upper North Arm/Corinella Segment (North North East (NNE) Community) and the smaller (but variable) Bass Strait plankton community as discussed in Section 7.6.7.

A gradient zone is ecologically known as an ecotone, which shares the characteristics of the communities that it separates. The distribution of the characteristics is dependent on a range of physical, chemical and ecological factors. In the case of Western Port, the key factor affecting the development, character and permanence of the NNE Community is the high nutrient and suspended solids content of the waters in this region which affects the penetration of light into the water column and the conversion of this light to biomass by the primary producers.

The high suspended solids concentration is due to resuspension of the sediments on the extensive intertidal mudflats in the north and northeast of Western Port. The loss of intertidal seagrasses in the early 1980s may be a contributing factor to the high suspended solids levels in the Upper North Arm/Corinella Segment (NNE area). However, zooplankton studies in the early 1970s indicate that the zooplankton in Lower North Arm were similar in the unusual dominance by the copepod *Acartia*, as they were in the EES studies in 2019, so relatively high suspended solids due to erosion catchment inputs and resuspension across the mudflats may have been a condition that affected plankton characteristics in the upper bay prior to the extensive loss of seagrasses in the late 1970s early 80s.

Another factor determining the extent and character of the NNE Community is the nature of exchange of Bass Strait water around Western Port. Although tidal currents are strong in the Western Entrance and Lower North Arm, flushing of the segments with Bass Strait water takes progressively longer with distance from Bass Strait. Previous hydrodynamic models (Hinwood, Kimmerer and McKinnon) indicated the flushing time for the NNE of Western Port was several months. This is sufficient for phytoplankton and zooplankton populations adapted to high levels of suspend solids to sustain themselves locally.

Phytoplankton number and biomass is determined by growth rate and grazing pressure. Growth rates for phytoplankton are often measured as the population doubling time (or generation time) – the time taken for the population to double given light and nutrients are non-limiting. Doubling times for phytoplankton in nearby Port Phillip Bay were estimated in the Port Phillip Bay Environmental Study (PPBES) (Parslow and Murray 1997) at between 0.5 days and 0.8 days.

Freshwater inputs (which carry essential nutrients for phytoplankton including nitrogen, phosphorus and silica) to most of Western Port are small, with two-thirds on the nitrogen and phosphorus being discharged from the catchment into the NNE area of Western Port.

The small inputs of freshwater from the Western Port catchment (to date) and generally low-nutrient status of Bass Strait waters means that Western Port is considered nutrient limited most of the time (Holland *et al* 2013). However, analysis of salinity and flow inputs from the northern streams of Western Port (Cardinia Creek to Lang Lang River – refer to Figure 5-9, Section 5) show that the nutrient input correlates better than seawater temperature with the observed re-commencement phytoplankton population growth in May and June, and with an increase in proportion of flagellates from May to September. The increase in phytoplankton growth is the assumed trigger of the timing of observed increase in zooplankton growth.

The phytoplankton populations in Lower North Arm characterised by the EES studies in 2019 comprised a high proportion of small, chain forming diatoms that are characteristic of high turnover populations and variable environmental conditions (Brett 2019). This is different from Port Phillip Bay where phytoplankton populations are characteristic of clearer waters, with substantially less turbulent mixing. Hence, the characteristics of the NNE area phytoplankton enable them to maintain a core population in the local conditions of the NNE area and, to some extent, the weeks to months of residence time in the Lower North Arm.

It is apparent from Figure 5-42 (refer to Section 5), and the above discussion, that phytoplankton populations in Lower North Arm rapidly respond to the changing natural marine environmental conditions. The rapid growth rate of these organisms allows them to quickly take advantage of increases in limiting resources (nutrients and light) and ecological space. This characteristic enables phytoplankton 'blooms' to occur in some locations such as Port Phillip Bay, although no blooms occurred in the 2019 EES studies in Lower North Arm. In blooms, phytoplankton respond by increased number of the particular taxa that are best adapted to the conditions of the local. These changes are usually apparent from the monthly data, and the responses are expected to progress within days (CEE 2016).

Plankton populations, like many biological populations, are distributed patchily. Added to this spatial patchiness is the transport of these patches back and forth by the tidal currents of Western Port. So, there would be variations in any planktonic species or group at a particular location over relatively short periods, which was recognised in the design of the EES program (2020b). In Zone 2, the modelled entrainment rate for one day is 0.08 % and over seven days is 0.31 %.

These entrainment percentages are very small for a group of organisms reproducing at rates in excess of 100 % per day, as well as rapidly adapting to ambient conditions. Hence, the net response of the plankton community in the Lower North Arm may be conservatively represented by entrainment over Lower North Arm in one week. The corresponding entrainment for Lower North Arm in 7 days of 0.13% is very small, and not likely to be detectable in the context of natural variation in plankton populations or the factors that influence them.

The flushing rates shown in Table 7-4 demonstrate the long residence time in Zone 8 of the hydrodynamic model. Zone 8 comprises approximately two thirds of NNE area. The data in Table 7-4 show that after 28 days, 60 % of the seawater volume in Zone 8 remains there, and 31 % has mixed to other parts of Western Port. Only 9 % has flushed to Bass Strait after one month. The waters from Zone 8 gradually mix down North Arm and eventually into Bass Strait. This mixing process causes biota from Zone 8 to continually add to the biota population near Crib Point, which is closer to Bass Strait and thus has a faster flushing rate.

The EES monitoring program demonstrated a decreasing gradient in the concentration of NNE characteristic phytoplankton composition from the higher abundance at northern sites to a lower abundance in the south. Even so, the phytoplankton community in the south of North Arm remained strongly identifiable as linked with the NNE characteristic composition. The composition changed more rapidly into the confluence zone with East Arm and the Western Entrance and further along the Western Entrance.

The zooplankton population of Lower North Arm was characterised by similar species as Bass Strait and Port Phillip Bay, but was substantially different in species proportions and was lower in diversity. The key difference between Lower North Arm and Bass Strait and Port Phillip was the numerical and ecological dominance of the zooplankton community by *Acartia spp*.

As discussed previously, these two species are very difficult to separate taxonomically and appear to occupy the same ecological position, so they are treated as a single entity, *Acartia spp*. *Acartia spp* is widely distributed in south-eastern Australia. It is a common coastal species and is usually in highest abundance in coastal embayments and estuaries with high turbidity. Zooplankton studies of East Arm and Western Entrance in the 1980s found it to be so predominant and ecologically influential on other zooplankton and the phytoplankton food source that it became the key focus of analysis (Kimmerer and McKinnon 1985, 1987i, ii, iii,1990).

The EES studies found the zooplankton conditions in 2019 to be similar to those in East Arm in the 1980s. Hence, the large NNE area is identified as the core population centre for zooplankton populations (or permanent resident fauna, Ketchum 1954) extending into Lower North Arm and the Rhyll Segment of Western Port (Figure 7-10).

Plankton populations in Lower North Arm including at Crib Point appear, therefore, to be most strongly influenced by flushing from their northern source population (NNE area) rather than from the southern population (Bass Strait). This suggests that they are more influenced by environmental factors affecting the north and northern catchment of Western Port compared with those in Bass Strait. This is confirmed by the annual seawater temperature records at Crib Point Jetty for the EES that show the influence of summer heating and winter cooling of the shallow northern waters on the bottom seawater temperatures at Crib Point. It should be noted that the seawater temperature records also show episodic intrusions of Bass Strait waters into Lower North Arm, which would affect the composition of the plankton community in Lower North Arm in terms of source water and ecological responses to weeks of lower or higher seawater temperatures in Lower North Arm compared to the populations in the NNE area.

Relevant facts about *Acartia spp* from 1980s and other studies:

- *Acartia* and all zooplankton populations in East Arm are food limited;
- Acartia is omnivorous: grazes on phytoplankton, preys on small copepod adults; preys on copepod larvae including its own (cannibalism), captures and ingests organic particles;
- Adult populations overlap;
- Females are reproductive throughout the year;
- Females produce up to 12 eggs per day;
- *Acartia* broods' eggs, some released as diapause and settle to sediments for later development;
- Acartia adult replacement rate was from 30 to 3 days (3 %/day to 33 %/day) in East Arm;
- Replacement rate depends on food availability and seawater temperature, which affects reproduction; and
- Mortality rate of adults is about 6 % per day excluding advection.

The natural range of increase or decrease in the adult *Acartia* population resulting from adult replacement rate of 3 to 30 days and the mortality rate of 6% per day can be calculated. The comparative rate including entrainment for the population core area (Zone 8), the vicinity of the FSRU seawater intake (Zone 2) and the whole of Lower North Arm (which does not include Zone 8) can be included for comparison with the natural rate of change for the minimum, mean, maximum and intermediate natural recruitment rates. Adults replace themselves at least every 30 days, so the 28-day entrainment rates can be used for key entrainment Zones and the whole of Lower North Arm as shown in Table 7-9.

Table 7-9. Predicted *Acartia* population growth: Natural and 28-day entrainment for Zones 2, 8 and whole of Lower North Arm

		Natural Growth	Zone 8	Lower North Arm	Zone 2
FSRU Entrainment, % per 28 days		0	0.15	0.40	0.79
Recruitment, % / day		Growth, %			
Minimum	3	57.4	59.2	62.0	66.0
=Mortality	6	0	96	89	80
Mean x 0.5	9	230	220	205	185
Mean	18	2,330	2,300	2,200	1,960
Mean x 1.5	27	20,800	20,100	19,000	17,300
Maximum	33	80,600	78,000	73,800	67,700

Negative growth<100 Zero growth Positive growth>100

Table 7-10 shows that the minimum replacement rate is half the mortality rate, so the *Acartia* would naturally decline over 28 days at the minimum replacement rate with further reduction due to entrainment.

The natural mortality rate (6 %) is one third of the mean replacement rate, and near one-fifth of the maximum replacement rate. Natural growth at this rate is zero, but there is a low-level negative growth (that is, population decline) over 28 days proportional to the rate of entrainment when the FSRU is operating at full production in open loop.

The monthly natural population increase ramps up between the mean and maximum replacement, with factors of increase of greater than 20 to more than 800 per month.

Acartia can naturally respond dramatically to environmental conditions in Lower North Arm within one month of change. It is mainly limited by food availability and seawater temperature, with natural advection having an increasing effect as distance from the core population in Zone 8 increases and proximity to Bass Strait increases.

Most of the factors affecting the natural mortality of *Acartia* affect the other zooplankton populations, except that *Acartia* feeds on them as well. At high population density, *Acartia* dominates the zooplankton community. It is grazing heavily on phytoplankton and preying on other zooplankton. But it may also be preyed on by other planktonic members, such as chaetognaths (predatory planktonic worms) and jellyfish. Many of these predators are only obvious in peak growth periods.

Entrainment by the FSRU effectively removes a small proportion of the plankton community. It is not selective in relation to most holoplankton species in Lower North Arm. Hence, plankton species diversity or the portion of species is not directly affected. The FSRU returns the plankton to the marine environment as organic matter either living or non-living. There is no change to the organic carbon load, nutrient concentration or salinity (in an environmentally significant sense). Hence, the discharged plankton re-join the ecosystem and are processed by microbial and planktonic cycles (Figure 7-12).

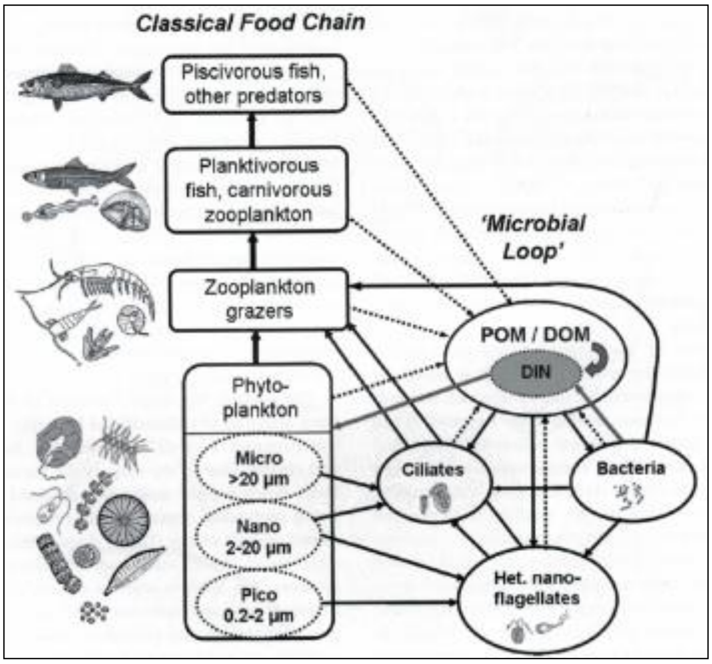


Figure 7-12. Planktonic Food Chain

The EES studies have shown that, while the key plankton species are commonly found throughout south-eastern Australia, the proportions of the key species in northern and eastern Western Port make the community ecologically distinct from those in the adjacent Bass Strait and Port Phillip Bay. The core area of the Western Port plankton community extends along the Upper North Arm (north of French Island) and into the Corinella Segment. Transitional zones (ecotones) between the Western Port plankton community and the Bass Strait Community are described in the Lower North Arm and along the French Island side of the Rhyll segment. The southeast side of the Rhyll segment is likely to be relatively more productive that other parts of Western Port as discussed in following sections.

Risk to Western Port Plankton in Core NNE Area

Hydrodynamic modelling of entrainment shows that the FSRU is relatively remote from the core area of the NNE Community and the modelled entrainment rate was very low. Hence, the likelihood of entrainment adversely affecting the core population is ***rare.*** The core NNE area is large, with a long residence time. The plankton population replacement rates in this area are likely to be at the high end of the distribution due to the higher nutrient concentrations in this area relative to elsewhere in Western Port. Hence, the consequence of entrainment is ***negligible.*** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence result in a risk rating of **Very Low**.

Risk to Plankton in Lower North Arm

Hydrodynamic modelling of entrainment shows that the Lower North Arm zone (where the FSRU is proposed to be located) had a rate of entrainment of 0.4% per month during peak operating conditions. Entrainment in Lower North Arm would occur whenever the FSRU is operating. Thus, the likelihood of the risk occurring across the entire area of Lower North Arm is ***possible*****.** Lower North Arm is relatively large with an ecological gradient along the length from the core area in the north to the confluence zone in the south, with a corresponding flushing rate (with Bass Strait) of months in the north and weeks in the south, to weeks in the confluence zone and days in the Western Entrance. The area would be continuously replenished from the core area in the north on about a monthly basis. Hence, the consequence

of entrainment is ***minor*****.** According to the risk matrix in Section 4.0, a possible likelihood and minor consequence result in a risk rating of **Low***.*

Risk to Plankton in Western Port

Hydrodynamic modelling of entrainment shows that the FSRU is relatively remote from the core area of the Western Port plankton community and from the eastern and south-eastern parts of Western Port. Hence, the likelihood of the risk occurring throughout Western Port is ***rare*****.** Western Port is a large area relative to the volume of seawater that may be entrained. Other physical and ecological factors are more important in determining the characteristics of the plankton community over Western Port as a whole. Hence, the consequence of entrainment over the whole of Western Port is ***negligible*****.** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence result in a risk rating of **Very Low***.*

7.6.16 Protected Species and Areas

Protected Areas – Ramsar Site

As discussed above, entrainment is largest in the zones close to Crib Point and much smaller for the distant zones. Given the minor level of entrainment even at Crib Point and the large volume of water and long residence time in the distant zones, the consequence of entrainment on the adult population of plankton in the Western Port Ramsar site as a whole is ***negligible***. According to the risk matrix in Section 4.0, an unlikely likelihood and negligible consequence result in a risk rating of **Very Low***.*

Protected Areas – Marine National Parks and other Protected Areas

Entrainment is largest for the zones close to Crib Point and negligible from the Marine National Parks and other protected areas. Thus, the consequence of entrainment on the adult population of plankton in Marine National Parks is ***negligible***. According to the risk matrix in Section 4.0, an unlikely likelihood and negligible consequence result in a risk rating of **Very Low***.*

Protected Species - Ghost Shrimps

Two species of ghost shrimps (*Eucalliax tooradin* and *Michelea microphylla*) may occur in Lower North Arm of Western Port. No adults of either species were found Lower North Arm during targeted investigations during the EES studies. It is suggested that Lower North Arm represents a small part of the physical habitat range and that they may be found more commonly in other locations or more suitable habitat (Poore et al 2019). Hence, the rarity of these two ghost shrimp species represents either the sparseness of their natural population or no sampling their more common location or habitat (Poore et al 2019). The likelihood of listed threatened species of ghost shrimp larvae being entrained is ***rare***. The consequence of entrainment of listed threatened species of ghost shrimp on their population is ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence result in a risk rating of **Very Low***.*

Protected Species - Australian Grayling

Adult Australian Grayling populations occur in the freshwater parts of the Bunyip River, Lang River and Cardinia Creek, are possibly in the freshwaters of the Bass River. As discussed in Section 5 larvae drift downstream and enter Western Port from April to July with a peak in May (Koster and Dawson 2010; Koster *et al.* 2013; 2018). Larvae then undergo a period of marine residency for four to five months before returning upstream as young juveniles from September to December (Crook *et al.* 2006; Koster *et al.* 2019). It is not known whether larvae remain in Western Port or are dispersed offshore over the period of marine residency (Crook *et al.* 2006). Flushing periods in the Lower North Arm and Western Entrance as indicated by the modelling are short relative to the four to five month larval and juvenile period of Grayling in the marine environment. Hence, this and the lack of Grayling juveniles in samples from March to September, indicate that it is unlikely that significant proportions of Grayling larvae disperse or remain in Lower North Arm. However, the low flushing rates in the north, northeast and Rhyll segments of Western Port suggest that it is possible that larvae and juveniles could spend significant periods there.

Salinity data and physical processes show that freshwater discharges from the northern Western Port streams disperse into the Eastern Arm of Western Port. Eggs are not viable in the marine environment, hence there is no risk of entrainment of viable eggs being entrained. No early larvae of Australian Grayling were identified in the ichthyoplankton sampling program in Lower North Arm over the thirteen-month period of monthly sampling. Hence, the likelihood of Australian Grayling eggs and early larvae being entrained is **unlikely.** Given the large volume of water and long residence time in East Arm and the low likelihood of even a small proportion of larvae being transported back into Lower North Arm, the consequence of entrainment on the adult population is ***minor***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence result in a risk rating of **Low.**

Hydrodynamic modelling indicates that seawater entering the Confluence Zone from the Western Entrance is deflected towards the eastern side of Lower North Arm. Once in Lower North Arm, north going currents are stronger on the eastern side. A late larval Australian Grayling individual was caught during the ichthyoplankton sampling program in Lower North Arm in September when it was likely returning to freshwater habitat in Upper North Arm. Hence, the likelihood of Australian Grayling late larvae or juveniles being entrained is ***possible*****.** As the larger proportion of returning Australian Grayling late larvae or juveniles would follow the easier migratory current paths and freshwater cues into the East Arm the consequences are ***minor***. According to the risk matrix in Section 4.0, a rare likelihood and minor consequence result in a risk rating of **Low.**

Biota Associated with Jetty Structures

The FSRU would be 60 m offshore from the main Crib Point Jetty but hydrodynamic modelling shows that the temperature and chlorine impact zones extend over part of the Crib Point jetty. The hydrodynamic model predicts that the colder water would be in the lowest 2 m of water (and possibly a shallower layer on the seabed under the jetty as there has been an accumulation of sediment under the jetty). The predicted temperature reduction is about 0.6 deg C for less than an hour per half tide cycle (Figure 6-21) in the worst month but within the 0.5 deg C limit for the other 11 months (Figure 6-22). The predicted chlorine residual under the jetty is well under 6 ug/L and generally under 2 ug/L (Figure 6-38). These results show a negligible effect due to chlorine residual and an occasional and very minor effect due to temperature changes.

The likelihood of an effect under the jetty is ***almost certain*****.** However, within this area the alteration of benthic communities and ecological processes is considered to be ***negligible***.

According to the risk matrix in Section 4.0, an almost certain likelihood and negligible consequence results in a risk rating of **Low**.

7.6.17 Summary of Entrainment Risks

Table 7-10 provides a summary of the risk assessment for entrainment as described in the sections above. It can be seen that risks ME1 to ME9 are rated as low or very low.

Table 7-10. Summary of Entrainment Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 1	Mangroves and Saltmarsh	Entrainment of seeds into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 2	Intertidal Mudflat Invertebrate Communities	Entrainment of larval biota into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Minor	Rare	Very Low
ME 3	Intertidal and Subtidal Seagrasses	Entrainment of seeds and propagules into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 4	Subtidal Invertebrate Fauna	Entrainment of eggs and larvae into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Minor	Rare	Very Low
ME 5 A	Fish eggs and larvae Spring-Summer	Entrainment of fish eggs and larvae into FSRU over Spring-Summer	Design of intake, velocity and screens on FSRU.	In spring/summer, limit regasification flow to less than 310,000 m^3/d	Minor	Possible	Low
ME 5 B	Fish eggs and larvae Autumn-Winter	Entrainment of fish eggs and larvae into FSRU over Autumn to Winter	Design of intake, velocity and screens on FSRU.	Risk is low and does not require further mitigation	Negligible	Possible	Low
ME 6 NNE	Plankton in NNE Zone	Entrainment of plankton into FSRU in NNE Zone	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 6 North Arm	Plankton in North Arm	Entrainment of plankton into FSRU in North Arm	Design of intake, velocity and screens on FSRU.	Risk is low and does not require further mitigation	Minor	Possible	Low
ME 6 WPB	Plankton in Western Port	Entrainment of plankton into FSRU in Western Port	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 7	Protected Areas (Ramsar)	Entrainment impact on values of the Ramsar Site	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Unlikely	Very Low
ME 8	Protected Areas (Other)	Entrainment impact on values of the Marine National Parks and other protected areas	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Unlikely	Very Low
ME 9	Protected Species	Entrainment effect on listed protected species present within Western Port	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Minor	Unlikely	Low

7.7 Temperature Change

This section describes the risk assessment of changes in seawater temperature caused by the FSRU operations.

7.7.1 Temperature Changes in FSRU Discharge

During **open loop operation** of the FSRU, the seawater that is taken in by the vessel for the regasification process is discharged approximately 7°C cooler than the ambient seawater temperature. During peak production, the FSRU discharges 468,000 m^3/d of cooler seawater through six discharge ports on the starboard (east) side of the vessel (refer to Table 6-1, Section 6.0). The FSRU has other minor flows such as the freshwater generator and seawater filter (refer Table 6-1. Section 6.0) and intermittent flows (refer Table 6-3, Section 6.0) during open loop operation. However, these additional flows are much less than the regasification discharge and are not discharged cooler than ambient seawater. Thus, the minor and intermittent flows were not included in the temperature assessment.

During **closed loop operation**, the seawater for the heat exchangers is recirculated through the FSRU. Thus, the main seawater discharges for this operation mode come from the boilers

and other processes on board totalling a maximum of 187,000 m^3/d. The discharge volumes for each of the closed loop sources and corresponding temperature differences are listed in Table 6-2 (refer to Section 6.0).

The flows for closed loop operation are significantly less than for open loop operation resulting in a smaller area being potentially impacted by the seawater discharge plume.

Closed loop operation also has intermittent flows which occur mainly when an LNG carrier is docked adjacent to the FSRU (refer to Table 6-3, Section 6.0). However, these discharges are at ambient temperature and thus are not included in the closed loop temperature assessment.

7.7.2 Initial Risk Ranking – Temperature Change

The outcome of the Risk Workshops was a list and preliminary ranking of 53 potential risks as shown in Table 7-2. Risks ME10 to ME19 relate to the effects of cooler seawater from the FSRU discharge on ecological habitats and groups of species, as listed in Table 7-11. The highest initial risk ratings identified was 'medium' for plankton. This is because it was expected plankton would have the most exposure to the cooler seawater as they would travel past the FSRU on the flood and ebb tides in great abundance. All other risks were rated as low to very low and thus, required no additional mitigation.

Table 7-11. Initial Cooler Seawater Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 10	Cooler seawater - Mangroves and Saltmarsh	Negligible	Rare	Very Low
ME 11	Cooler seawater - Intertidal Mudflat Invertebrate Communities	Negligible	Rare	Very Low
ME 12	Cooler seawater - Intertidal and Subtidal Seagrasses	Negligible	Rare	Very Low
ME 13	Cooler seawater - Benthic Subtidal Invertebrate Fauna	Negligible	Almost Certain	Low
ME 14	Cooler seawater - Pelagic and Demersal Fish	Negligible	Almost Certain	Low
ME 15	Cooler seawater - Plankton	Minor	Almost Certain	Medium
ME 16	Cooler seawater - Subtidal Reef	Negligible	Rare	Very Low
ME 17	Cooler seawater - Protected Areas (Ramsar)	Negligible	Rare	Very Low
ME 18	Cooler seawater - Protected Areas (Other)	Negligible	Rare	Very Low
ME 19	Cooler seawater - Protected Species	Negligible	Possible	Low

Risks ME20 to ME29 relate to the effects of warmer seawater from the FSRU discharge on ecological habitats and groups of species, as listed in Table 7-12. The highest initial risk ratings identified was 'medium' for plankton. This is because it was expected plankton would have the most exposure to the warmer seawater as they would flow past the FSRU on the flood and ebb tides in great abundance. All other risks were rated as low to very low and thus, required no additional mitigation. The risks for warmer seawater discharge are very similar to the cooler seawater discharge as they have similar impact. However, some of the initial risks are lower as the size and extent of the warmer seawater plume is far smaller than the cooler seawater plume and thus, less likely to have a negative impact.

Table 7-12. Initial Warmer Seawater Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 20	Warmer seawater - Mangroves and Saltmarsh	Negligible	Rare	Very Low
ME 21	Warmer seawater - Intertidal Mudflat Invertebrate Communities	Negligible	Rare	Very Low
ME 22	Warmer seawater - Intertidal and Subtidal Seagrasses	Negligible	Rare	Very Low
ME 23	Warmer seawater - Benthic Subtidal Invertebrate Fauna	Negligible	Rare	Very Low
ME 24	Warmer seawater - Pelagic and Demersal Fish	Negligible	Almost Certain	Low
ME 25	Warmer seawater - Plankton	Minor	Almost Certain	Medium
ME 26	Warmer seawater - Subtidal Reef	Negligible	Rare	Very Low
ME 27	Warmer seawater - Protected Areas (Ramsar)	Negligible	Rare	Very Low
ME 28	Warmer seawater - Protected Areas (Other)	Negligible	Rare	Very Low
ME 29	Warmer seawater - Protected Species	Negligible	Rare	Very Low

7.7.3 Natural Temperature Variation

Section 5 describes existing conditions in Western Port with respect to seawater temperature at Crib Point. Over 2019, seawater temperature varied from a maximum of 24°C in February to 11°C in August. In most months, the seawater temperature varied by 2°C or more in a day or so, in response to the large-scale hydrodynamic processes in Bass Strait, or diurnal variations in daily temperature (refer to Figure 7-13).

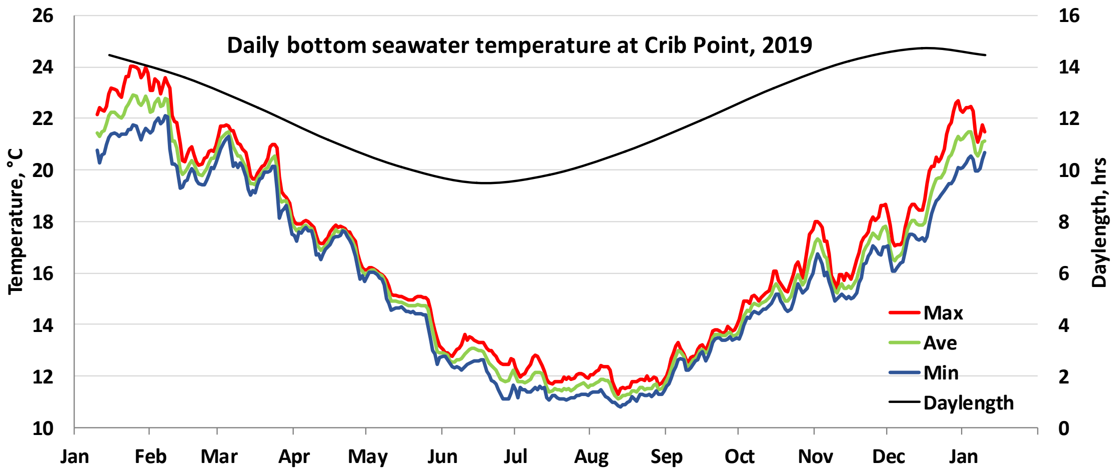


Figure 7-13. Daily Seawater Temperature at Crib Point Seabed

The magnitude of the daily variation in seawater temperature at Crib Point over the year 2019 is shown in Figure 7-14. In summer, biota can experience seawater temperature variations of up to 2^{o}C.

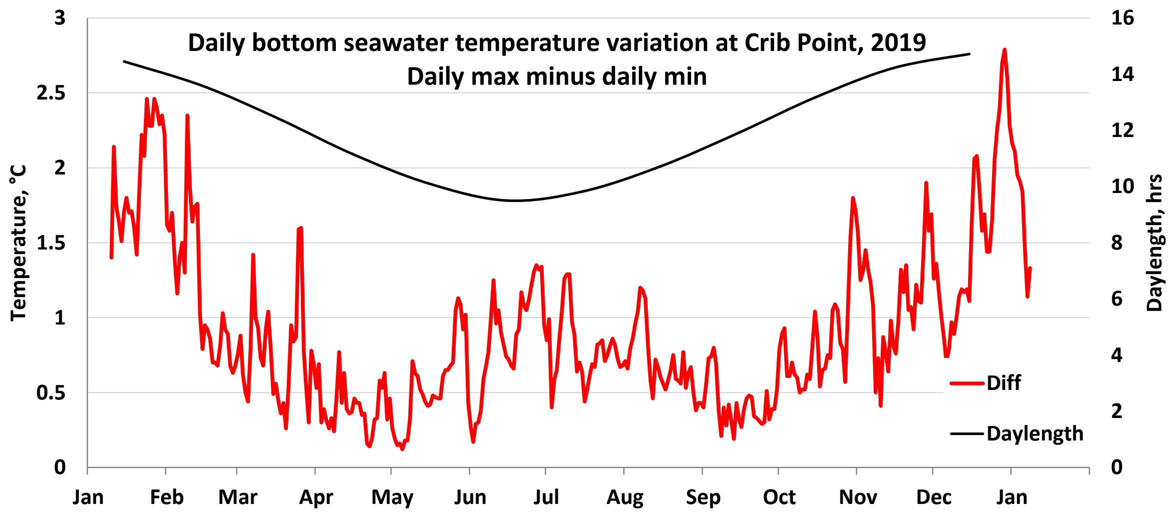


Figure 7-14. Daily Variation (max – min) in Bottom Seawater Temperature

7.7.4 Guideline Value for Temperature Variation

The 25th percentile and 75th percentile temperature change values were calculated from the collected data for half tidal (6 hour), full tidal (12 hour) and 24-hour time periods in Table 7-13. There is negligible increase between the 6-hour and 12-hour periods and only a small increase to the 24-hour period. This confirms that the 6 to 12-hour temperature variations are most likely due to the solar heating and cooling of shallow water and exposed mudflats and thus, the mixing of seawater of different temperatures. The data show that the marine biota in North Arm are accustomed to large seasonal and short-term variations in seawater temperature.

Table 7-13. Range of Seawater Temperature Variation at Crib Point

Exposure Duration	25th percentile	75th percentile	Range (25% - 75%)
6-hours	0.37°C	0.88°C	0.5°C
12-hours	0.37°C	0.85°C	0.5°C
24-hours	0.48°C	1.00°C	0.5°C

The Guideline Value used to assess temperature change was based on the interquartile range difference that was calculated in Table 7-13. For each of the exposure durations, the range was calculated to be 0.5 °C. Thus, the overall Guideline Value for temperature variation at Crib Point is **0.5°C.**

7.7.5 FSRU Operating Scenarios

Table 7-14 summarises the temperature predictions of the regional model for the various conditions and flow patterns in the proposed operation of the FSRU.

- When there is no LNG carrier unloading (FSRU only), in open loop mode, average operation would occur for 90 % of the year and peak operation would occur for 10 % of the year.
- Unloading LNG carriers occurs for 12 % (40 days) of the year, and normal operations (either peak or average production) occur for 88 % of the year.

Table 7-14. Summary of Results for Temperature Predictions

Frequency over year	Description of scenario	LNG Carrier Presence	Area above Guideline Value (0.5°C)	Location
88 %	Peak or average operation in open loop	None	0.7 ha	Under and near FSRU
	Peak or average operation in closed loop	None	0.2 ha	Under and near FSRU
12 %	Peak or average operation in open loop	LNG carrier present	20 ha	Under and near the two vessels
	Peak or average operation in closed loop	LNG carrier present	0.3 ha	Under and near the two vessels

7.7.6 Modelled Variation in Seabed Temperature Over Time

Figure 7-15 shows the modelled variation in seabed temperature with time over a 28 days cycle, at sites north, south, east and west of the FSRU. The largest temperature anomaly (the temperature difference from ambient seawater due to the heat exchanger discharge) corresponds to slack water when cooler seawater accumulates in a pancake on the seabed, as described in Section 6.0. The peak anomaly is greatest on the seabed beneath the discharge ports, but is seldom more than 0.5°C at 340 m north and is always less than 0.5°C different from ambient seawater at 340 m south, 200 m west and 200 m east of the FSRU seawater discharge.

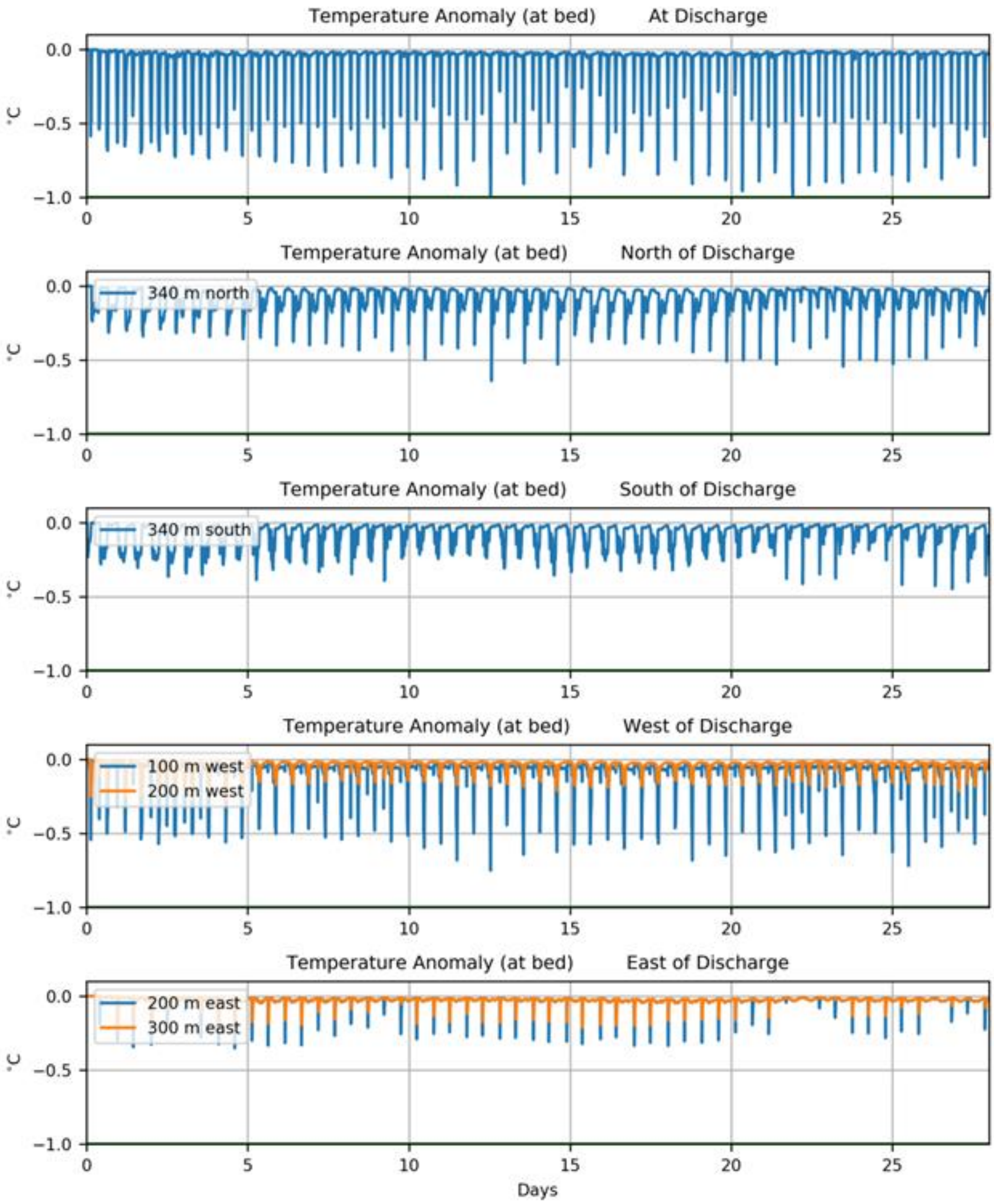


Figure 7-15. Modelled Variation in Seabed Temperature Over Time

When an LNG carrier is unloading, it obstructs the high velocity discharge jets in open loop mode. This reduces seawater discharge dilution in the tidal currents and causes more accumulation of partly-diluted discharge under the two vessels (FSRU and LNG carrier) at slack water. In open loop, the pool extends over an area on the seabed of about 360 m north/south and 200 m east/west. However, this size of the pool on the seabed is reduced with lower flow rates (Figure 7-16).The extent of the cooler seawater pancake is larger when an LNG carrier is moored next to the FSRU, as illustrated in Figure 7-16 for peak production and one-third production.

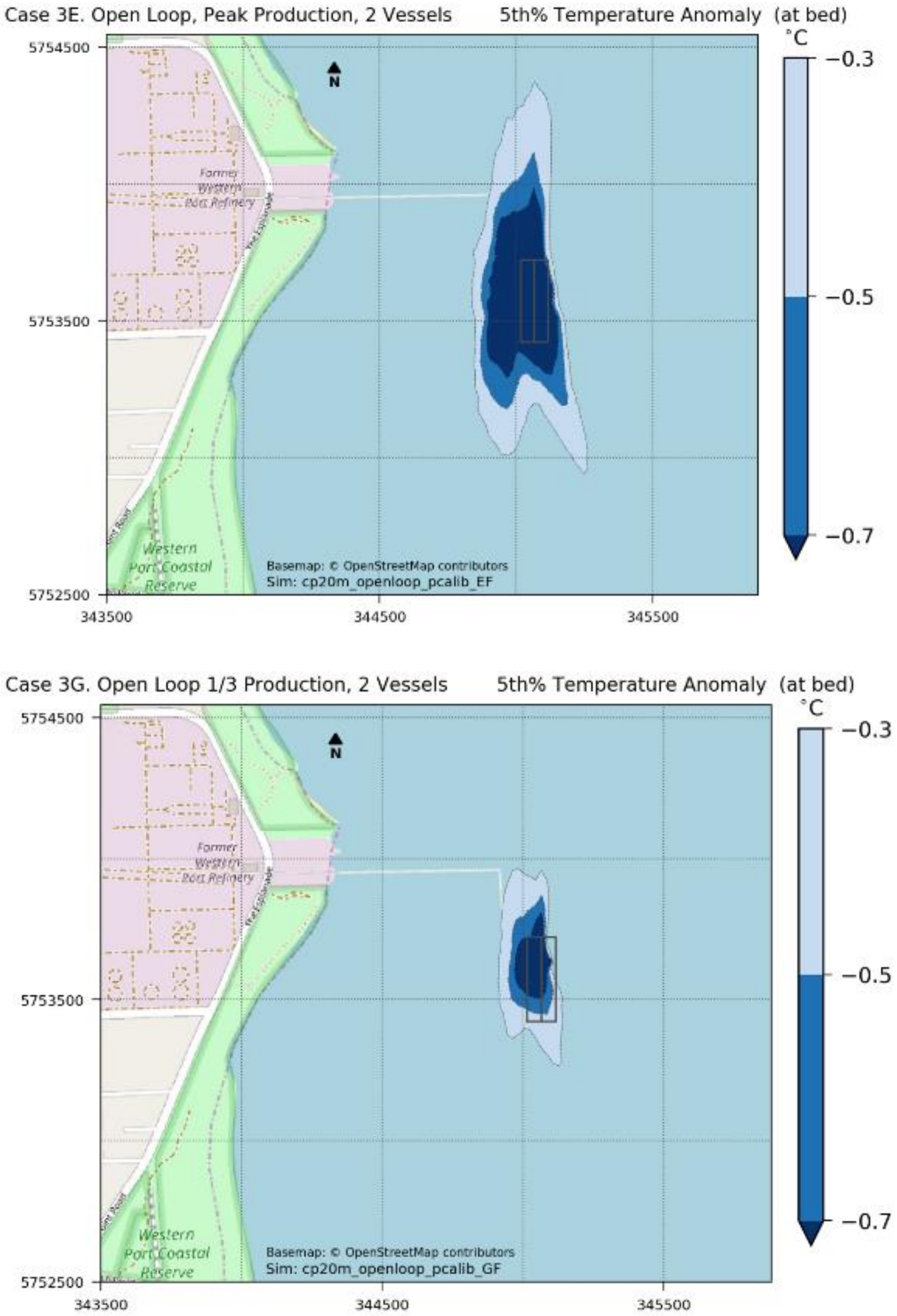


Figure 7-16. Examples of Seabed Temperature Distribution in Open Loop Production

7.7.7 Summary of Zone with Temperature Variation Exceeding 0.5 deg C

When there is an adjacent LNG carrier, a pool of cooler seawater forms under the FSRU and LNG carrier for a short period every slack water. The pool is then eroded and mixed as the tidal currents strengthen during the ebb or flood tide following the slack water events. There is reduced dispersion during these events, and the extent of the pool with temperature change of more than 0.5°C from ambient seawater is increased, as shown in Table 7-14.

Considering the various modes of operation and the sequence of neap and spring tides, Figure 7-17 shows the area above the temperature Guideline Value. This area encompasses all the seabed and water column in which the tidally-averaged cooler seawater level could exceed 0.5°C. The area above the temperature Guideline Value encompasses an area of approximately 20 ha, all of which is within the defined Port Zone and also within the area that was dredged or altered by previous construction and presence of the Crib Point Jetty.

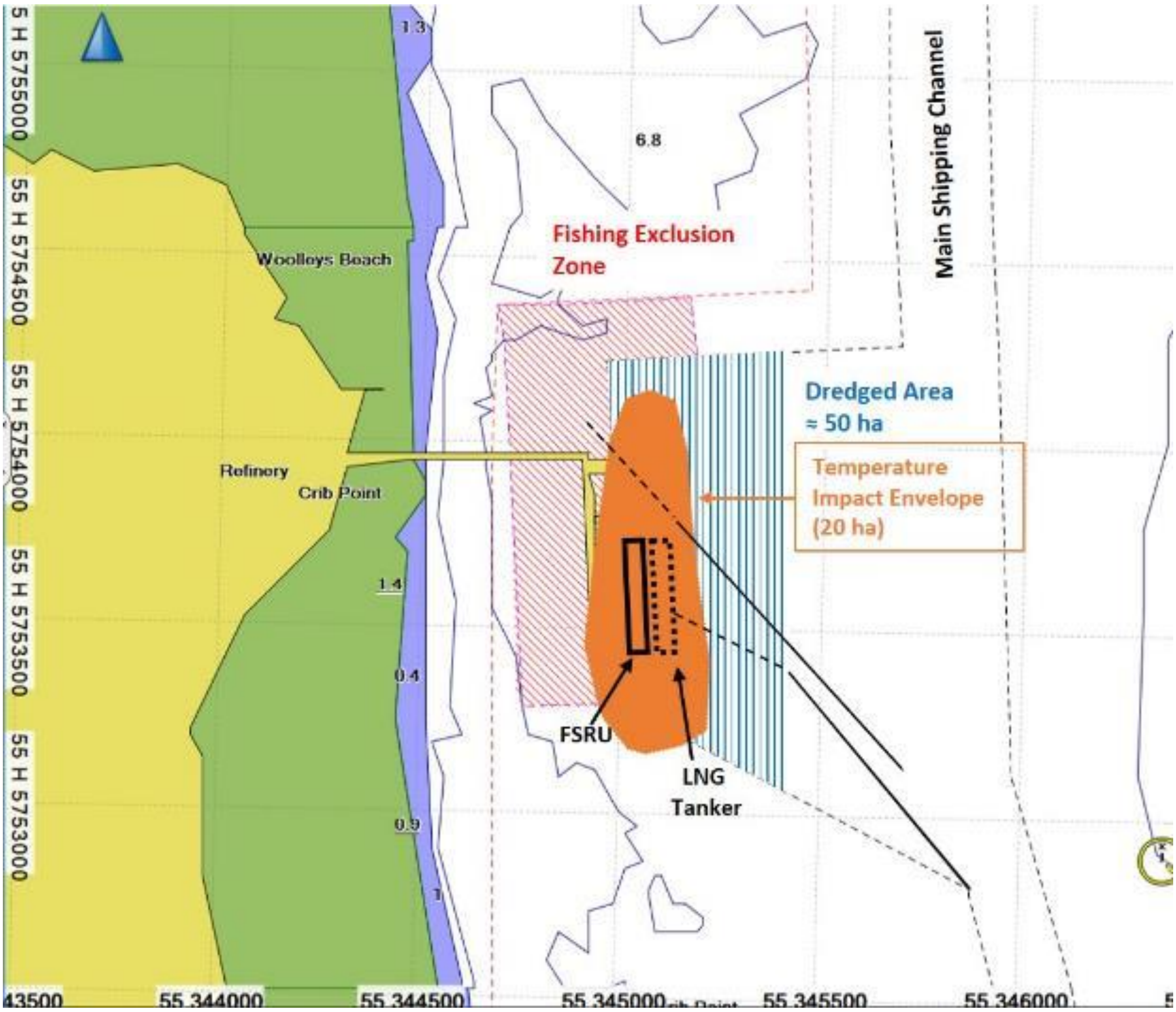


Figure 7-17. Area above Temperature Guideline Value

7.7.8 Extent of Impact of Cooler Seawater

A key outcome from the modelling and assessment of temperature change risks on the marine environment is that the extent of significant temperature change above the Guideline Value is limited to 20 ha in the Port Zone. Figure 7-17 shows that the area above the temperature Guideline Value extends for approximately 600 m north/south and 350 m east/west, and is under and near the FSRU and the LNG carrier. The seabed biota under the two vessels would be affected by the shading caused by the two vessels, changed hydrodynamic conditions due to the presence of the vessels and by local scour due to the discharges and berthing and departure of the LNG carriers (refer to Section 6.0).

Figure 7-18 and Figure 7-19 show the area above the temperature Guideline Value in a wide context, firstly showing the area in the context of the width of Lower North Arm (Figure 7-18) and secondly showing the area in the context of the whole of Western Port (Figure 7-19). In Figure 7-18 and Figure 7-19, the area above the temperature Guideline Value shows the area in which the temperature change exceeds the Guideline Value of 0.5°C difference from ambient seawater.

On this basis, Table 7-15 summarises the likelihood of a detectible temperature change reaching various Western Port habitats and species groups.

Table 7-15. Likelihood of Significant Temperature Change in various Western Port habitats and species groups

Habitats / species groups	Assessment Outcome	Reasoning
Mangroves	No impact	No temperature change reaches mangroves
Seagrasses	No impact	No temperature change reaches seagrasses
Seabirds	No impact	Easily avoid area with temperature change
Migratory birds	No impact	Migratory birds easily avoid area of temperature change.
Penguins and seals	No impact	No temperature change reaches areas used by penguins and seals. Can easily avoid area.
Fish	No impact	Some avoidance reaction in local area near FSRU. (refer to Section 7.7.13)
Zooplankton	Minor Impact	Refer to Section 7.7.14. cooler seawater risk to Plankton
Plankton	Minor Impact	Refer to Section 7.7.14. cooler seawater risk to Plankton

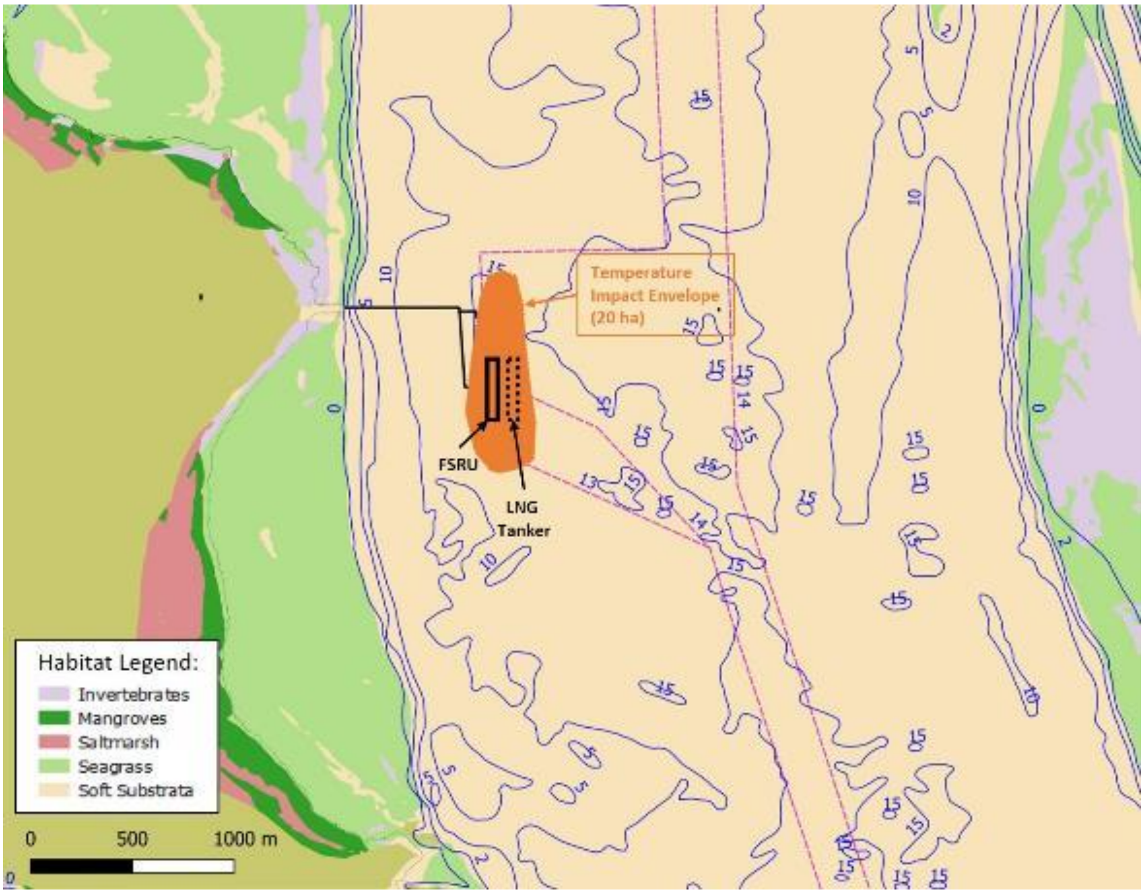


Figure 7-18. Area above Temperature Guideline Value in Lower North Arm

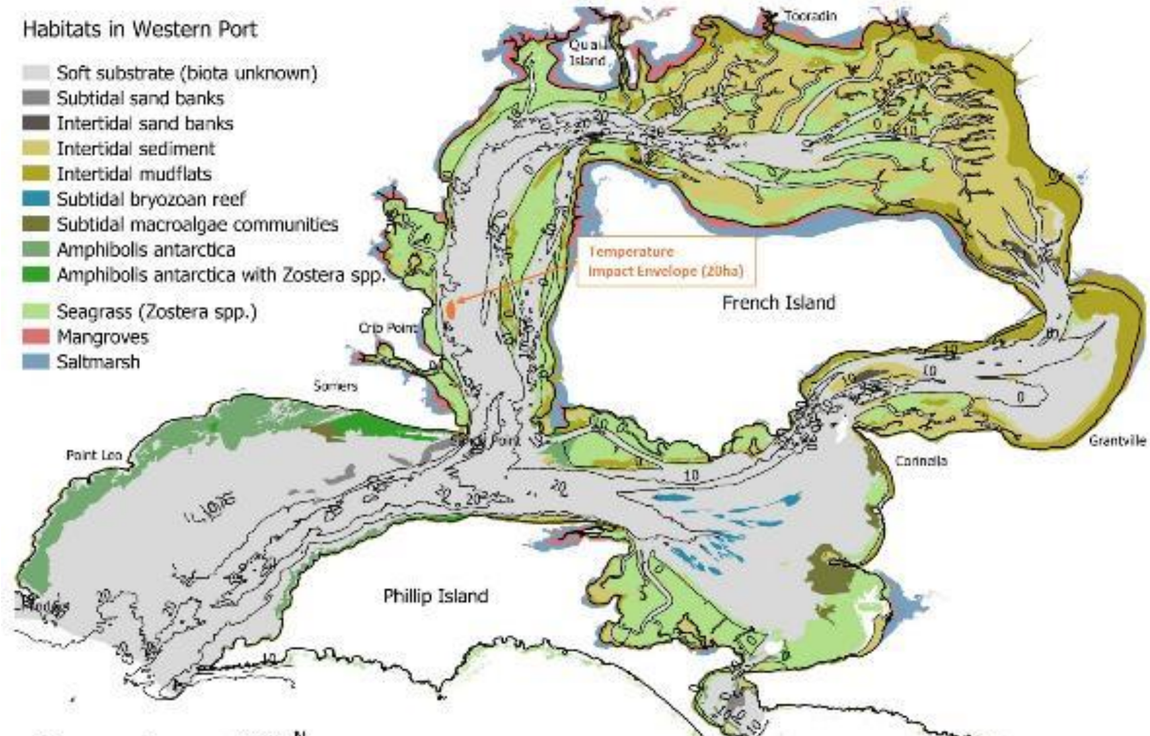


Figure 7-19. Area above Temperature Guideline Value in Western Port

7.7.9 Cooler Seawater Risk: Saltmarsh and Mangrove Community

The nearest saltmarsh and mangrove vegetation along the southern shore of the Port of Hastings is approximately located above the mid-tide mark, approximately 1 km from the proposed FSRU location (refer to Section 5). The area above the temperature Guideline Value would be remote from saltmarsh and mangroves. Thus, the likelihood of cooler seawater reaching the mangrove or saltmarsh habitats is ***rare*****.** If cooler seawater was to reach the mangrove and saltmarsh vegetation, the concentration would be well below any Guideline Value and the consequence would be ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low*.***

7.7.10 Cooler Seawater Risk: Intertidal Mudflat Invertebrate Communities

The nearest intertidal benthic communities are approximately 500 m west of the FSRU (refer to Figure 5-22, Section 5). The nearest boundary of area above the temperature Guideline Value would be relatively remote from the intertidal areas and, in open loop discharge, the discharge sinks to the seabed and can only reach the intertidal mudflat habitats and associated invertebrate communities after substantial vertical mixing. Thus, temperature differential in the intertidal mudflats would be within natural ambient levels.

The likelihood of cooler seawater concentrations reaching intertidal mudflat habitats and associated invertebrate communities is ***rare*****.** Due to the distance of intertidal habitats from the FSRU any temperature change that would reach them would be so low that they would be well below the Guideline Value. Thus, the consequence was ***negligible*****.** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low*.***

7.7.11 Cooler Seawater Risk: Intertidal and Subtidal Seagrasses

The closest seagrass habitats to Crib Point Jetty is approximately 450 m to the west of the FSRU at approximately 1.5 m depth (Section 5). The nearest boundary of the area above the temperature Guideline Value would be relatively remote from the nearest seagrass habitats and, in open loop discharge, the discharge sinks to the seabed and can only reach the depths less than 10 m after substantial vertical mixing. Thus, temperature differential in the seagrass habitats would be within natural ambient levels.

The likelihood of cooler seawater reaching seagrass habitats is ***rare*****.** Due to the distance of seagrass habitats from the FSRU any temperature change would be negligible. Thus, the consequence was ***negligible*****.** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low.**

7.7.12 Cooler Seawater Risk: Benthic Subtidal Invertebrate Fauna

The total area of soft seabed in Western Port is approximately 360 km^2. As discussed in Section 5. the subtidal seabed habitats is predominantly soft sediments but is variable over even small distances due to relatively small-scale variation in bed form, proportion of shell material and other seabed surface features as demonstrated by towed video investigations. Invertebrate epifauna and infauna diversity and abundance are generally lower in bare areas compared to seagrass areas (Edgar et al 1994).

Figure 5-32 shows the distribution of seabed habitats along towed video transects T3 and T8 that run for 890 m and 880 m respectively along the approximate north-south axis of the cold-water plume dispersion pathway. The figure shows that the habitat along the pathway is relatively homogeneous "sand/shell with benthic invertebrates" where the FSRU and LNG carrier would be moored. The visible evidence of benthic invertebrates was predominantly epibiota sparse sea urchins, tube worms, lamp shells and bryozoans, the entrances of burrows (probably the common Bass yabby *Trypaea australiensis* see CEE 2019e) were patchy. Transects T2 and T1 indicate that this habitat continues offshore, where benthic invertebrates (in particular the lamp shell *Magellina flavescens*) becomes common from approximately 400 m offshore from Berth 2 as shown on north-south transect T5 in Figure 5-34.

The relative homogeneity of the seabed on the video transects along and transverse to the dispersion pathway in the berth area is likely due the dredging of the area in the 1960s. Observation of the subsurface seabed during ghost shrimp investigations in the Berth 2 area found that the seabed was "unconsolidated shellgrit and fine material was underlain by stiff grey clay that was less than 150 m from the seabed surface" (CEE 2019e). This is possibly explained as a layer of soft sediments (sand and shell) that have accumulated over the predominantly clay bed in the dredged zone near the jetties which provides a relatively homogenous habitat for infauna and epibiota in the shipping basin (refer to Section 5.8.3).

The infauna of the subtidal seabed at Crib Point Jetty comprise polychaetes ("bristle worms") as the most abundant class, closely followed by crustaceans and molluscs. On average, 110 animals were found in each litre of sediment. More infauna were found near the Jetty (100 – 300/L sediment) than at reference sites elsewhere in North Arm (10 – 120/L sediment). It is well-known that a major influence on infauna community composition is habitat characteristics (Gray 1960). The plots of habitat distribution in Lower North Arm (Figure 5-31 and CEE 2019e) show that the variation in soft seabed habitat would result in variation in infaunal community composition around Lower North Arm, including the differences observed in infauna between the dredged area at Crib Point and most non-dredged areas throughout Western Port.

Factors other than the cold-water discharge would affect environmental conditions on the seabed in the berth area. Operation of the proposed FSRU would result in shading caused by the two vessels, changed hydrodynamic conditions due to the presence of the vessels and local scour due to the discharges and tug-assisted berthing and departure of the LNG carriers as well as a zone of cooler seawater from the heat exchanger discharge (refer to Section 7.10). There would also be a minor increase in the quantity of non-living organic material from plankton damaged in the passage through the FSRU heat exchangers.

The effects on seabed fauna would be due to the combined effects of these processes. A possible interpretation is that the benthic community would be altered by the shading and local scour, and that the extra effects of temperature may be small after these changes.

Figure 7-17 shows the spatial extent of the predicted area of temperature difference greater than 0.5°C from ambient seawater. The area above the temperature Guideline Value occupies an area of approximately 20 ha and encompasses the 3 ha of seabed under and around the FSRU and LNG carrier that may be affected by shading and physical effects. The perimeter of the area represents the boundary of effect on seabed biota from the combined physical and cooler seawater effects of the Project. Within this area, greatest effect would be expected within the footprint of the two vessels, with reducing effect on the habitat and biota as frequency of exposure due to tidal currents and the temperature differential decreases along the seawater discharge plume pathways. A gradient of effect on the seabed biota may be expected over the 20 ha, with greatest effect under the FSRU to no detectable effect at the boundary of the area above temperature Guideline Value.

As discussed above, the benthic species present in the dredging-modified soft seabed habitat at Crib Point Jetty (Berth 2) are widely represented throughout the 36,000 ha of soft seabed in Lower North Arm, as discussed in Section 5, and are likely to be distributed widely throughout the coastal environment of Victoria (e.g. Poore 2019). The proportion of the species at any particular location is dependent on the natural characteristics of the seabed at that location, which is patchy at small spatial scales (metres to tens of metres) but relatively homogeneous at larger scales (hectares and kilometres).

Thus, likelihood of an effect within the 20-ha area above the temperature Guideline Value is ***almost certain*.** However, within this area the magnitude of effect would be variable along dispersion gradients, as discussed above. The alteration of benthic communities, benthic ecological processes and nutrient and carbon cycles outside the 20-ha area above the temperature Guideline Value (which is characterised by modified habitat) within the context of Lower North Arm or Western Port as a whole is considered to be ***negligible***. According to the risk matrix in Section 4.0, an almost certain likelihood and negligible consequence results in a risk rating of **Low*.***

7.7.13 Cooler Seawater Risk: Pelagic and Demersal Fish

Pelagic and demersal fish species move around in Western Port and therefore some would be in the vicinity of the proposed FSRU location where they could have direct contact with the cooler seawater plumes as they dilute and spread out on the seabed.

Experience at power station and desalination plant outlets is that fish are attracted to the discharge plumes by a combination of the food particles contained in the discharge and the disturbance created by the high velocity jets in the discharge. These attractions often overcome the avoidance reaction that fish may have with warmer or cooler water. Although the discharge plumes extend over a very small area in the context of Western Port, the potential for contact for some fish with the discharge is rated as ***almost certain***.

Given these observations, coupled with the knowledge that fish are very mobile and have the opportunity and ability to move quickly away from the discharge area, indicate that most fish would not be exposed to the discharge for extended periods (or only be their preference), and therefore the consequence of the risk is rated as ***negligible.*** According Cooler Seawater Risk: Plankton

Field sampling of zooplankton and phytoplankton in North Arm established that plankton are abundant and widely distributed through Western Port and around Crib Point (refer to Section 5). The highest plankton counts occur in the north-east and east zones of Western Port as these zones have long residence times (or a low rate of flushing to Bass Strait). The Upper North Arm and East Arm receive approximately two-thirds of all nutrient inputs to Western Port (from the Bunyip River, Lang River and Cardinia Creek).

Even at low tide, Western Port has a surface area of 52,300 ha and a volume of 9,090,000 m^3. Thus, the 20-ha encompassed by the area above the temperature Guideline Value constitutes only 0.03 % of the area of Western Port, or 0.3 % of the area of Lower North Arm (refer to Table 5-2, Section 5). Thus, the area of cooler seawater is very small compared to the extent of North Arm or Western Port.

The assessment of the impact of plankton being entrained into the seawater cooling systems on the FSRU is described in Section 7.6. This section addresses the environmental risk to the plankton populations in Western Port due to water temperature changes. The field studies described in Section 5 showed that plankton populations have a similar composition throughout Western Port. According to the results of the particle studies, the populations in

different segments of Western Port are intermixed in a period of one to three weeks. The north-east and east segments seem to be the major source of the plankton populations that move through North Arm to Bass Strait.

As discussed in Section 7.6, plankton populations are carried with the water currents and the general (non-entrained) plankton population would be exposed to the cooler seawater temperatures in the plume for a short period (typically a few minutes). A change of less than 7°C from ambient seawater temperature for a few minutes is unlikely to change the daily cycle of metabolic or feeding processes of plankton at any time of the year.

The likelihood of direct contact of some plankton with cooler seawater discharge is rated as ***almost certain***. The proportion of plankton that are likely to come into contact is very small and the effect on those plankton may be temporary slowing of metabolic processes at worst resulting in a consequence rating of ***negligible***. According to the risk matrix in Section 4.0, an almost certain likelihood and negligible consequence results in a risk rating of **Low**.

7.7.14 Cooler Seawater Risk: Subtidal Reef and Jetty Biota

The main examples of subtidal reefs in Western Port are at Eagle Rock and Crawfish Rock, located approximately 12 km north of Crib Point Jetty (refer to Section 5).

Crib Point Jetty is an artificial structure with similar flora and fauna attributes to other jetties in Lower North Arm. As an artificial structure, the risk of the Project to biota that may inhabit the jetty is not assessed here. The biota on the south section of Crib Point Jetty are within the area above the temperature Guideline Value and may show some response to the cooler seawater discharge, for example, as a change in the composition of the attached or sedentary communities on the Jetty. The effect would decrease with distance along the Jetty (to the north). It is highly unlikely that the biological communities at other jetties in Lower North Arm would show any detectable effect.

Given the distance between the boundary of the area above the temperature Guideline Value and the subtidal reef at Eagle Rock and Crawfish Rock the likelihood of these habitats being exposed to a temperature differential due to the discharge is rated as ***rare*** (effectively zero). The large distance between the FSRU and the subtidal reef at Eagle Rock and Crawfish Rock means that several tidal cycles would be involved in transport of any water from Crib Point Jetty to Eagle Rock and Crawfish Rock with substantial further mixing and thermal exchange with the atmosphere and larger water thermal-mass. Therefore, the consequence is rated as ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low**.

7.7.15 Cooler Seawater Risk: Protected Areas (Ramsar)

Western Port is listed under the Ramsar convention as an area of significant importance as it meets the majority of the Ramsar criteria for designation. Western Port contains a large number of Wetland Habitat types recognised under the Ramsar Convention including:

- Marine subtidal aquatic beds; such as seagrass beds;
- Rocky marine shores; such as the intertidal and subtidal rocky reefs;
- Estuarine Waters; such as the (limited) areas around the mouths of the rivers and creeks that drain into Western Port;
- Intertidal mud, sand or salt flats; such as the extensive vegetated and unvegetated mud and sand flats, with large numbers of waterbirds;
- Intertidal forested wetlands; such as the extensive fringing mangroves around the north and west shores of Western Port, including near Crib Point. The White Mangroves

(*Avicennia marina*) found in Western Port are the most southerly mangroves in the world; and

- Intertidal mud, sand or salt flats; such as the extensive vegetated and unvegetated mud and sand flats, with the associated waterbirds.

Given the relatively small area of the area above the temperature Guideline Value and the low to very low risks it presents to the ecosystem components of Lower North Arm, the likelihood of the cooler seawater discharge affecting the Ramsar values of Western port is ***rare***.

The effects of the cooler seawater discharge are confined to the marine ecosystem components around the existing operating Crib Point Jetty, with negligible consequences to roosting and feeding habitats of waterbirds and wading birds (intertidal mudflat, seagrass, mangrove and saltmarsh habitat and associated communities). The FSRU would not add or remove nutrients or organic constituents, or affect suspended solids loads to or in Western Port. No alteration in the food supply for intertidal birds is expected. All of the affected waters are part of the declared and operating Port of Hastings, are used by approximately 150 commercial vessels per year and many more recreational vessels during the period of occupation by most migratory bird species. In this context, the consequence of the cooler seawater discharge from the FSRU is assessed as ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low**.

7.7.16 Cooler Seawater Risk: Protected Areas (Other)

Western Port has several Marine National Parks with the closest to Crib Point being the Yaringa Marine National Park approximately 12 km away.

Given the distance between the area above the temperature Guideline Value and the subtidal reef at Yaringa the likelihood of there being any effect from the cooler seawater discharge on the subtidal reef is rated as ***rare*** (effectively zero). The large distance between the FSRU and the subtidal reef at Yaringa means that several tidal cycles would be involved in transport of any water from Crib Point Jetty to Yaringa with substantial further mixing and thermal exchange with the atmosphere and larger water thermal-mass. Therefore, the consequence is rated as ***negligible*****.** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low**.

7.7.17 Cooler Seawater Risk: Protected Species

There are several protected species that have potential to come within the vicinity of Crib Point Jetty including whales, turtles, fish and infauna such as the ghost shrimp. Most of these protected species are not expected to be close to the FSRU and any contact with the area above the temperature Guideline Value is likely to be for very limited periods of time.

The potential presence of the FFG Act listed ghost shrimp *Michelea microphylla* in the vicinity of Crib Point Jetty was investigated during the EES studies. No individuals of *Michelea microphylla* were found and it was concluded that Western Port is not likely to represent the most optimal environment for this species (Poore 2019). The likelihood of individuals of this species being exposed to cooler seawater discharge is ***unlikely*** and the effect of the exposure to a very small proportion of the population of this species is rated as ***negligible***. According to the risk matrix in Section 4.0, a combination of unlikely likelihood and negligible consequence results in a risk rating of **Very Low**.

The FFG Act and Commonwealth listed Australian Grayling fish are most likely to migrate to and from the freshwater habitats or Western Port and Bass Strait via the East Arms, rather than Lower North Arm. The likelihood of exposure of this species to the cooler seawater discharge is therefore ***possible*****,** but with **negligible** effect on the Western Port populations**.**

According to the risk matrix in Section 4.0, a combination of possible likelihood and negligible consequence results in a risk rating of **Low**.

Individuals of species such as whales, turtles and sharks are reported to be in the vicinity of Crib Point on a few occasions each year for a short period. As a result, they would have very low exposure time, and can minimise their exposure simply by swimming away. Thus, the likelihood of impact on protected species is rated as **unlikely.** Because the species are listed as protected, any impact could be seen as detrimental but these are large animals so the effects of a short exposure are expected to be negligible in terms of general health. As there a very low chance of impact on populations of these species, the consequence is rated as ***negligible***. According to the risk matrix in Section 4.0, a combination of unlikely likelihood and negligible consequence results in a risk level of **Low**.

Thus, a combined risk for protected species with the potential to come within the vicinity of Western Port is derived with a likelihood of ***unlikely*** and a consequence of ***negligible*** which give a residual risk rating of **Low**.

7.7.18 Summary of Cooler Seawater Risks

Table 7-16 provides a summary of the risk assessment as described in the sections above. It can be seen that risks ME10 to ME19 are rated as low or very low.

Table 7-16. Summary of Cooler Seawater Discharge Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 10	Mangroves and Saltmarshes	Cooler seawater discharge plume alters the natural mangrove and saltmarsh habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 11	Intertidal Mudflat Invertebrate Communities	Cooler seawater discharge plume alters natural intertidal mudflat invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 12	Intertidal and Subtidal Seagrasses	Cooler seawater discharge plume alters the natural intertidal and subtidal seagrass habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 13	Benthic Subtidal Invertebrate Fauna	Cooler seawater discharge plume alters natural benthic subtidal invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is low and does not require further mitigation	Negligible	Almost Certain	Low
ME 14	Pelagic and Demersal Fish	Cooler seawater discharge plume affects local fish species near FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is low and does not require further mitigation	Negligible	Almost Certain	Low
ME 15	Plankton	Cooler seawater discharge plume affects local Plankton as they float past the FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	In spring/summer, limit regasification flow to 315,000 m^3/d	Negligible	Almost Certain	Low
ME 16	Subtidal Reef	Cooler seawater discharge plume alters subtidal reef habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 17	Protected Areas (Ramsar)	Cooler seawater discharge plume impacts values of the Ramsar site	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 18	Protected Areas (Other)	Cooler seawater discharge plume impacts values of marine parks and other protected areas	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 19	Protected Species	Cooler seawater discharge plume impacts on listed protected species	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is low and does not require further mitigation	Negligible	Possible	Low

7.7.19 Warm Water Discharge

The identified risks for warmer seawater discharge are the same as for the cooler seawater discharge risks listed in Table 7-16. However, due to the much smaller volume of warmer seawater that is discharged into Western Port waters compared to when the FSRU is operating in open loop there is a lower chance of any nearby sensitive receptors being impacted. All of the associated risks for warmer seawater are ranked as either very low or low, indicating that warmer seawater discharges are not likely to have any significant impact on the surrounding environment of North Arm. The results of the risk assessment are shown in Table 7-17.

Table 7-17. Summary of Warmer Seawater Discharge Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 20	Mangroves and Saltmarshes	Warmer seawater discharge plume alters the natural mangrove and saltmarsh habitats	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 21	Intertidal Mudflat Invertebrate Communities	Warmer seawater discharge plume alters natural intertidal mudflat invertebrate communities	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 22	Intertidal and Subtidal Seagrasses	Warmer seawater discharge plume alters the natural intertidal and subtidal seagrass habitats	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 23	Benthic Subtidal Invertebrate Fauna	Warmer seawater discharge plume alters natural benthic subtidal invertebrate communities	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 24	Pelagic and Demersal Fish	Warmer seawater discharge plume affects local fish species near FSRU	High velocity discharge to increase dilution	Risk is low and does not require further mitigation	Negligible	Almost Certain	Low
ME 25	Plankton	Warmer seawater discharge plume affects local plankton as they float past the FSRU	High velocity discharge to increase dilution	In spring/summer, limit regasification flow to less than 315,000 m^3/d	Negligible	Almost Certain	Low
ME 26	Subtidal Reef	Warmer seawater discharge plume alters subtidal reef habitats	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 27	Protected Areas (Ramsar)	Warmer seawater discharge plume impacts values of the Ramsar site	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 28	Protected Areas (Other)	Warmer seawater discharge plume impacts values of marine parks and other protected areas	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 29	Protected Species	Warmer seawater discharge plume impacts on listed protected species	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

7.8 Chlorinated Seawater Discharge

This section describes the risk assessment for risks ME30 to ME40 concerning the effects of chlorine produced oxidants (CPO) in the seawater discharge on various Western Port habitats and species groups. The impacts of the chlorinated discharge are to be assessed for the following groups of Western Port habitats and species groups:

- Mangroves and saltmarsh:
- Intertidal Mudflat Invertebrate Communities;
- Intertidal and subtidal Seagrasses;
- Benthic subtidal Invertebrate Fauna;
- Pelagic and demersal Fish;
- Plankton;
- Protected Areas (Ramsar);
- Protected Areas (Other); and
- Protected Species.

7.8.1 Use of Chlorine by FSRU

A fundamental part of the operation of the FSRU is the use of chlorine to control biofouling in the pipes, pumps and heat exchangers. The chlorine is produced by electrolysis of seawater at the seawater intake, before the seawater is pumped through the network of pipes, valves and heat exchangers in the FSRU. The concentration of chlorine produced oxidants (CPO) convert back to natural salts through natural chemical processes during passage through the heat exchanger, as described in Section 6.0. The residual levels of CPO (as chlorine) at the point of discharge for the various modes of operation of the FSRU are listed in Table 7-18. The reduction in CPO concentration and toxicity continues after release into the marine environment (refer to Section 6.0).

For all seawater discharges except ballast water, the concentration of CPO as chlorine at the point of discharge is 100 µg/L (0.1 mg/L), the maximum chlorine concentration assured by the FSRU supplier. Ballast water undergoes longer storage, and there is more chlorine decay, so the concentration of CPO in the ballast discharge is taken as 21 µg/L.

Table 7-18. Chlorine Concentration in Seawater Discharge for Various Modes of Operation of FSRU

Operation	Chlorine, µg/L
Open Loop	
Peak Rate	All 100 µg/L (47 kg/day)*
Average Rate	All 100 µg/L (32 kg/day)*
Closed Loop	
Peak	All 100 µg/L (18 kg/day)*
Intermittent Flows	
Ballast	21 µg/L (1 kg/d)*
Miscellaneous	100 µg/L (0.1 kg/day)*

** indicates the discharge in kg/day*

The quantity of chlorine or CPO discharged is estimated to be 47 kg/d at peak production open loop operations, 32 kg/d at average production open loop operations and 19 kg/d with closed

loop operations. On the days when there is an LNG carrier unloading LNG to the FSRU, there is an extra discharge of 0.6 kg/d from the fire water (firefighting system) and about 1 kg/d from the ballast water system.

As explained further in Section 7.8.4, the chlorine in CPO quickly converts through a series of reactions back to natural seawater salts sodium and chloride. Bromine products created in the reaction of chlorine back to chloride convert back to their natural seawater salt, bromide, so there is no long-term accumulation of chlorine or related products in the seawater.

7.8.2 Initial Risk Ranking – Chlorinated Seawater

The outcome of the Risk Workshops was a list and preliminary ranking of 53 potential risks as shown in Section 7.4. Risks ME30 to ME40 relate to the effects of chlorinated seawater on Western Port habitats and groups of species, as listed in Table 7-19. The highest initial risk ratings identified was 'medium' for plankton. This is because it was expected they would have the most exposure to the cooler seawater as the they would flow past the FSRU on the flood and ebb tides in great abundance. All other risks were rated as low to very low and thus, required no additional mitigation.

Table 7-19. Initial Chlorinated Seawater Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 30	Chlorinated Seawater: Mangroves and Saltmarsh	Negligible	Rare	Very Low
ME 31	Chlorinated Seawater: Intertidal Mudflat Invertebrate Communities	Negligible	Rare	Very Low
ME 32	Chlorinated Seawater: Intertidal and Subtidal Seagrasses	Negligible	Rare	Very Low
ME 33	Chlorinated Seawater: Benthic Subtidal Invertebrate Fauna	Negligible	Almost Certain	Low
ME 34	Chlorinated Seawater: Pelagic and Demersal Fish	Negligible	Almost Certain	Low
ME 35	Chlorinated Seawater: Plankton	Minor	Almost Certain	Medium
ME 36	Chlorinated Seawater: Subtidal Reef	Negligible	Rare	Very Low
ME 37	Chlorinated Seawater: Protected Areas (Ramsar)	Minor	Rare	Very Low
ME 38	Chlorinated Seawater: Protected Areas (Other)	Negligible	Rare	Very Low
ME 39	Chlorinated Seawater: Protected Species	Negligible	Possible	Low
ME 40	Chlorinated Seawater: Accumulation in the Food Chain	Negligible	Possible	Low

7.8.3 Purpose of Chlorine Dosing

Seawater contains a variety of microscopic organisms including bacteria, phytoplankton zooplankton and the eggs, larvae and propagules of larger plants and animals. The larvae of a variety of invertebrates may settle on the internal surfaces of pumps and pipes that transport seawater through ships, power stations and desalination plants.

It is common for seawater to be chlorinated to prevent establishment of biological growth on these internal surfaces that may restrict or obstruct flows through seawater pumps and pipe networks as shown in Figure 7-20. (Boudjellaba et al 2016, Jenner and Wither 2011, Satpathy et al 2010, Taylor 2006).

Chlorine is a strong oxidant that dissolves in water and rapidly hydrolyses to the hypochlorite ion and hypochlorous acid (not hydrochloric acid) that are also effective oxidants. Sodium hypochlorite solution can be added to water intakes to prevent biological growth in pipe networks, but most commonly in seawater intakes for desalination plants and coastal power stations.

Chlorine produced oxidants (CPO) are created by the electrolysis of seawater at the intake (Apetroaei et al. 2018, Jenner and Wither 2011). This removes the need to manufacture, transport, store and handle liquid or gaseous chlorine and is a relatively simple, efficient and economical process.

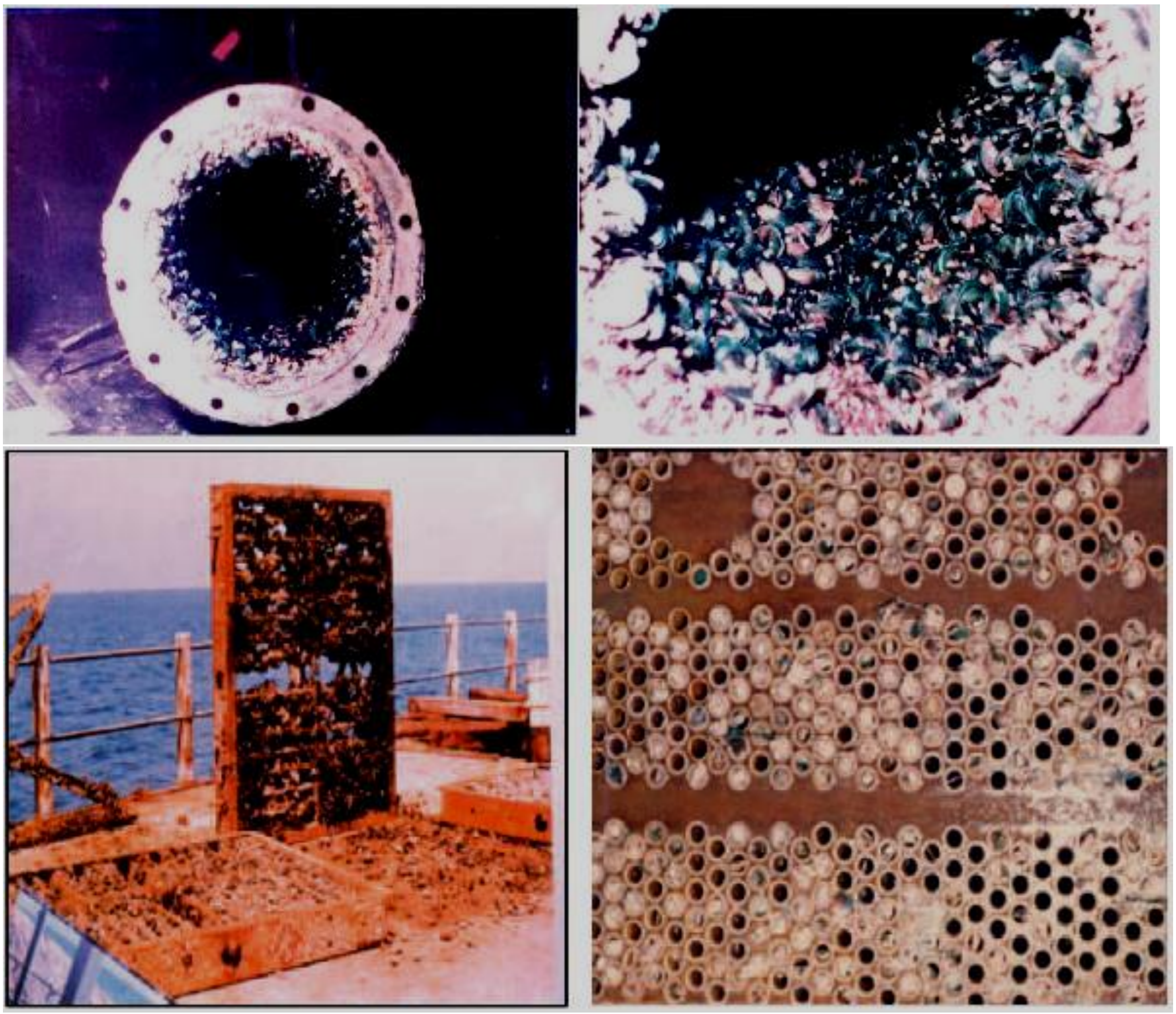


Figure 7-20. Biofouling of Seawater Intake Pipe, Screen and Heat Exchanger (by mussels and barnacles)

Source: Satpathy et al 2010

7.8.4 Production of Chlorine Produced Oxidants from Seawater

As a preface to the assessment of marine impacts arising from residual chlorine in the seawater discharge, it is useful to clarify how chlorine products are formed from seawater and how these products return almost entirely to seawater, or are volatilised to the atmosphere.

Seawater taken into the FSRU for all purposes passes through an electrolysis cell that converts the sodium chloride (NaCl) naturally present in seawater to sodium and chlorine ions (Na^+ and Cl^-). The generation of chlorine from electrolysis of seawater results from a series of steps involving the initial creation of chlorine gas (Cl_2) from the chloride ions (Cl^-) naturally present in high concentration in seawater.

$$2Cl^- + 2H_2O \rightarrow Cl_2 + H_2 + 2OH^-$$

The chlorine dissolves in the seawater and instantaneously dissociates to hypochlorous acid (HOCL) and hypochlorite ion (OCl^-). The hypochlorite ion 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, while the chlorine component of the hypochlorite has returned to the original chloride ion.

$$OCl^- + Br^- \rightarrow OBr^- + Cl^-$$

This series of reactions is rapid and almost complete within 10 seconds (Jenner et al 1997). Bromine is a weaker oxidant than chlorine, but is effective in disinfecting saltwater swimming pools or preventing biofouling in heat exchangers. 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 supplies 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 – 3 µg/L as a result of natural production by a range of marine micro-algae and macro-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.

As shown in Figure 7-21, CPO concentration reduces rapidly over time due to inorganic reductive 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 reduction 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.

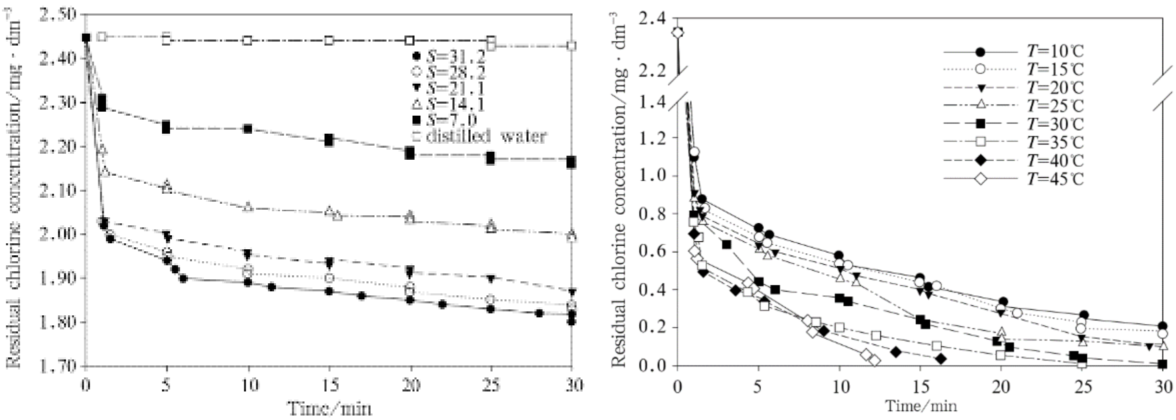


Figure 7-21. Reduction in CPO Concentration with Time

Source: Zeng *et al* 2009

The electrolysis process on the FSRU would produce an initial CPO concentration of 500 µg/L. This concentration would decay rapidly in the pipe network to less than 200 µg/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 100 µg/L.

Thus, all near-field and regional model predictions are based on a chlorine concentration of 100 µg/L in all seawater discharges except ballast water, which has a residual chlorine concentration averaging 21 µg/L.

The model calculations assume the mass of chlorine is conserved in the hours after discharge, although in practice there is subsequent reduction in CPO mass and concentration due to chemical reaction and volatilisation. However, initial dilution processes are substantially quicker in the short period after discharge while chemical 'decay' occurs over a longer period. Decay processes in seawater would result in total loss of CPO from the initial production over a period of one to two days from decay in well-mixed aerobic seawater (CEE 2018b, Saeed *et al* 2015, Water Technology 2017) as occurs in Western Port.

It should be noted that small biota in the FSRU pipes are subjected to a continuous dose of chlorine in the range of 100 to 500 µg/L (depending on the position 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.

7.8.5 Chlorinated Seawater Discharge Rate

The peak rate discharges and chlorine loads are summarised in Table 7-18. As described in Section 5, the average seawater discharge rate is approximately two-thirds of the peak rate. However, as the peak rate is proposed to continue for a month or more each winter (when gas use is highest), this risk assessment is based on the peak rate of seawater discharge.

The FSRU can operate in open loop mode (once-through seawater flow) or closed loop mode (recirculating seawater flow with boilers operating). In open loop mode, there is a higher rate of discharge and the cooler seawater is discharged at high velocity through six horizontal ports on the side of the vessel. In closed loop mode, there is a lower rate of discharge (refer to Table 7-18) and the warmer seawater is discharged at high velocity through several pipes on the rear corners of the FSRU. A description of the resulting flow and dilution patterns is presented in Section 6.0.

The risk assessment is based on the worst-case distribution of chlorine in open loop and closed loop operations.

As listed in Section 7.8.1, for all flows except ballast water, the level of CPO in the discharges is taken as 100 µg/L. Ballast water undergoes longer storage, and there is more chlorine decay, so the level of CPO in the ballast discharge is taken as 21 µg/L,

7.8.6 Limit or Guideline Value for Chlorine in the Marine Environment

The maximum acceptable chlorine level or Guideline Limit is obtained by consideration of SEPP Waters, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZ Guidelines) and a CSIRO report specifically addressing the chlorine limit in marine waters (CSIRO 2019).

SEPP Waters (2018)

Discharges from Scheduled Premises to the aquatic environment in Victoria are regulated by the Environment Protection Authority (EPA) under SEPP Waters 2018. SEPP Waters lists Environmental Quality Indicators and Objectives that are required to be met to protect 'Beneficial Uses' of Victoria's aquatic environments, and assigns levels of protection for various water bodies depending on their natural characteristics.

SEPP Waters lists Western Port as a sub-Segment of Victoria's Marine and Estuarine segment. The SEPP Waters further divides the Western Port sub-Segment into:

- Entrances and North Arm, where the FSRU is proposed to be sited, which are considered largely unmodified; and
- East Arm which is considered slightly to moderately modified.

The SEPP Waters also refers to the ANZECC Guidelines for levels of potential toxicants that are considered appropriate to protect aquatic ecosystems at the level assigned to that water body.

The New EP Act is set to come into effect on 1 July 2020, and substantially amends 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 current legal framework for assessment and approval of a wastewater discharge under the Environment Protection Act 1970, requires consistency with the State Environment Protection Policy (Waters) 2018 (SEPP (Waters)).

In the context of the transition to the New EP Act and the assessment of the operation of the FSRU as a development licence, the SEPP (Waters) has been referred to as indicative guidance regarding the approach to assessment of risks of seawater discharges from the FSRU.

ANZECC Guideline for Chlorine

The ANZECC Guidelines have been developed and refined over years of scientifically rigorous processes, review and consultation. The ANZ Guidelines provide generic trigger values (Default Guidelines Values) and procedures to develop site-specific Guideline Values for the protection of aquatic ecosystems.

The ANZECC Guidelines and an associated document (Warne et al 2015) define the procedure to develop Guideline Values 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 Guideline Values for the possible short-term discharge of chlorine produced oxidants to the marine environment at Western Port.

The ANZECC Guidelines have a chronic Guideline Value for chlorine in freshwater of 3 µg/L (ANZECC/ARMCANZ, 2000), but no value for marine waters had been published.

CSIRO Report on Chlorine Guideline Value

CEE contracted CSIRO to finalise development of the Default Guideline Value for chlorine, applicable to marine waters in Western Port, that provided 99 % species protection (CSIRO, 2019).

The conclusions of the CSIRO report may be summarised as follows:

- Because of the natural, relatively rapid conversion of toxic chlorine produced oxidants and trihalomethanes (as chlorine) from seawater electrolysis back to harmless natural salts in the marine environment, CSIRO considered that long-term exposure of biota to chlorine in the marine environment was not possible in the broader environment and therefore a short-term Default Guideline Value for chlorine was appropriate.
- Where the concentration is relatively consistent over time with continuous exposure, for 99 % species protection, the Default Guideline Value for chlorine (CPO) is 2 µg/L.

- Where the concentration is *intermittent or variable* over time, such as the tidally varying conditions in the North Arm of Western Port, for 99 % species protection, the Guideline Value for chlorine (CPO) is 6 µg/L.

Hence, for this assessment, a Guideline Value of 6 µg/L is used for chlorine, based on averaging chlorine exposure over a 12-hour tidal cycle.

The tidal excursion of waters on North Arm ranges from 4.3 km on the average neap tide to 7.2 km on the average spring tide. Thus, all sites in the tidal channels of North Arm are considered to experience intermittent chlorine exposure over a 12-hour tidal cycle and the Guideline Value of 6 µg/L applies to the average chlorine exposure over 12 hours.

7.8.7 Summary of Predictions for Chlorine Modelling – Peak Operation

This section summarises the chlorine predictions of the regional model for the various conditions and flow patterns in the proposed operation of the FSRU.

In Section 6.0, and the HydroNumerics report on regional hydrodynamic modelling that underlies the Section, a wide range of discharge and flow scenarios are examined. For all discharge scenarios, the key features of the resulting plumes are as follows:

- The travel path depends entirely on the tidal water movement. In ebb tides, the plumes formed from the seawater discharges are carried to the south, in flood tides, the plumes are carried to the north. There is considerable dilution (reducing the chlorine concentration from 100 µg/L to less than 5 µg/L within about 40 m from the point of discharge).
- At slack water, the tidal currents are weak and there is less dilution, with the seawater discharge pooling beside and under the FSRU until the pool is carried away and diluted in the following tidal cycle. In open loop mode, the pool extends over an area on the seabed of about 160 m north/south and 150 m east/west. The time-averaged chlorine concentrations exceed 6 µg/L in the footprint of the pool.
- In closed loop mode, at slack water, the pool extends over an area on the seabed of about 100 m north/south and 100 m east/west. The time-averaged chlorine concentration exceeds 6 µg/L in the footprint of the pool. The pool for closed loop mode is smaller than for open loop mode because the discharge rate of seawater and chlorine is 60 % lower, and the discharge is warm, which aids dispersion due to the extra dilution produced by buoyant rise.
- When an LNG carrier is unloading, it obstructs the high velocity discharge jets in open loop mode. This reduces dilution in the tidal currents and causes more accumulation of partly-diluted seawater discharge under the two vessels (FSRU and LNG carrier) at slack water. In open loop mode, the pool extends over an area on the seabed of about 360 m north/south and 200 m east/west. The time-averaged chlorine concentration exceeds 6 µg/L in the footprint of the pool.
- The effect of the parallel LNG carrier is less for closed loop mode, because the discharge ports are at the rear of the FSRU. Even so, when an LNG carrier is unloading, there is reduced dilution and a pool of partly-diluted seawater discharge under the two vessels (FSRU and LNG carrier) at slack water. In closed loop mode, the pool extends over an area on the seabed of about 200 m north/south and 150 m east/west. The time-averaged chlorine concentration exceeds 6 µg/L in the footprint of the pool.

These outcomes with associated frequencies are set out in Table 7-20. Note that the frequencies in the table assume 40 LNG Carriers per year each moored for up to 36 hours. Without an LNG carrier adjacent, the time-averaged chlorine level is less than the Guideline

Value of 6 µg/L at all sites in the regional model. There would be a small zone in the water column next to the discharge ports where higher chlorine levels would occur over a short distance.

With an LNG carrier unloading to the FSRU, there is a zone under and adjacent to the two vessels in which the Guideline Value would be exceeded. The estimated dimensions of the zone in which the chlorine concentration exceeds 6 µg/L is shown in Table 7-20.

Table 7-20. Summary of Results for Chlorine Predictions

Frequency over year	Description of scenario	LNG Carrier presence	Area of seabed exceeding 6 µg/L	Location
73 %	Peak or average operation in open loop	None	None	Complies
	Peak or average operation in closed loop	None	None	Complies
17 %	Peak or average operation in open loop	LNG carrier present	5 ha	Under and near FSRU
	Peak operation in closed loop	LNG carrier present	0.2 ha	Under and near the two vessels

7.8.8 Predictions for Chlorine Modelling – Reduced Rate Operations

The size of the pool of higher chlorine levels is smaller at a lower rate of discharge.

In closed loop mode, the discharge remains the same whatever the level of production, and so does the zone of impact. Even so, the size of the zone of impact for closed loop mode is smaller than for one-third open loop mode.

Table 7-21. Summary of Chorine Results for Various Operation Modes

Operating mode	Description of scenario	LNG Carrier presence	Area of seabed exceeding Guideline Value (6 µg/L)	Location
Open Loop	Peak operation	LNG carrier present	5 ha	Under and near the two vessels
	2/3 peak operation (average rate)	LNG carrier present	2 ha	Under and near the two vessels

Operating mode	Description of scenario	LNG Carrier presence	Area of seabed exceeding Guideline Value (6 µg/L)	Location
	1/3 peak operation (1 regas train)	LNG carrier present	1 ha	Under and near the two vessels
Closed Loop	Closed loop (all rates of production)	LNG carrier present	0.2 ha	Under and near the two vessels

7.8.9 Duration of Chlorine Exposure

As illustrated in Figure 7-22, marine organisms that enter the FSRU pipe network with the seawater would be subjected to a short-term dose of chlorine that varies from at 500 µg/L at the inlet chlorinator to 100 µg/L at the outlet over a maximum passage duration of five minutes (other than in ballast water) before being discharged. Marine organisms that might attach to the walls of the heat exchange and pipe network are continuously exposed to a constant dose of chlorine as long as they are fixed to the walls.

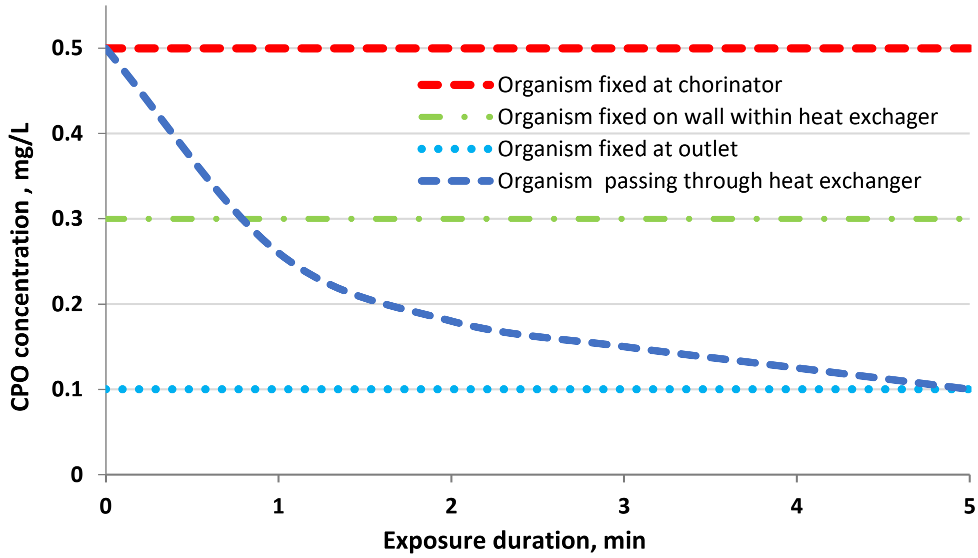


Figure 7-22. Chlorine Exposure on FSRU – Inlet to 5 minutes

As shown in Figure 7-23, a marine organism suspended in the tidal currents and passing the discharge ports would experience a chlorine concentration reducing from 100 µg/L at the outlet to less than 10 µg/L after about 5 minutes, because of the dilution of the seawater discharge plumes as they mix with the surrounding seawater. The chlorine concentration continues to decrease with time due to subsequent dilution. Only organisms sensitive to a low level and short duration of exposure to chlorine would be affected during the passage through the FSRU or in the discharge plume - others would survive this short-term event. Nonetheless, a precautionary approach must be followed in determining the potential effects from use of chlorine to control biofouling in the FSRU.

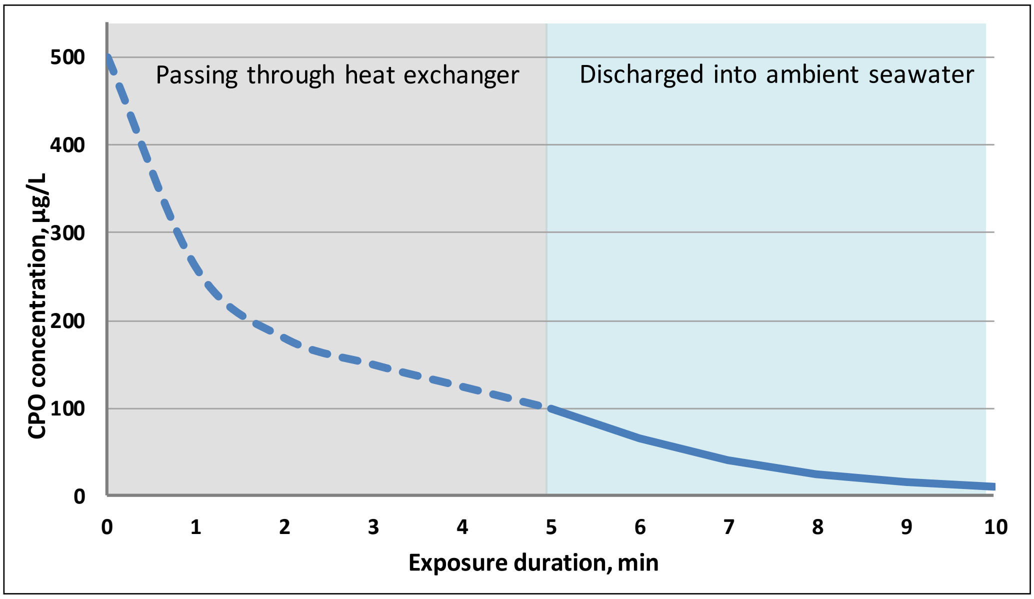


Figure 7-23. CPO Exposure Inlet to 10 Minutes including after Discharge

The risk and impacts on marine organisms and communities due to chlorine produced oxidants is directly related to the concentration, duration and frequency of exposure to chlorine. The net effect on phytoplankton populations is the result of the integrated exposure profile. The exposure to chlorine is either continuous (e.g. on the seabed immediately below the discharge ports) or intermittent (every 6 hours, in response to the cycle of tidal currents), as illustrated in Figure 7-24.

Thus, the analysis of exposure should focus on the relationship between (1) duration of exposure to a stress of a particular level and (2) response to that stress. This pattern of intermittent and variable exposure is well known for various environmental stressors including nutrients, toxic effluents, pesticides, metals and light reduction (Belgers et al 2011, Brock et al 2010, Brock 2013, CEE 2014, 2019, CSIRO 2019, EFSA 2016, Handy 1994)

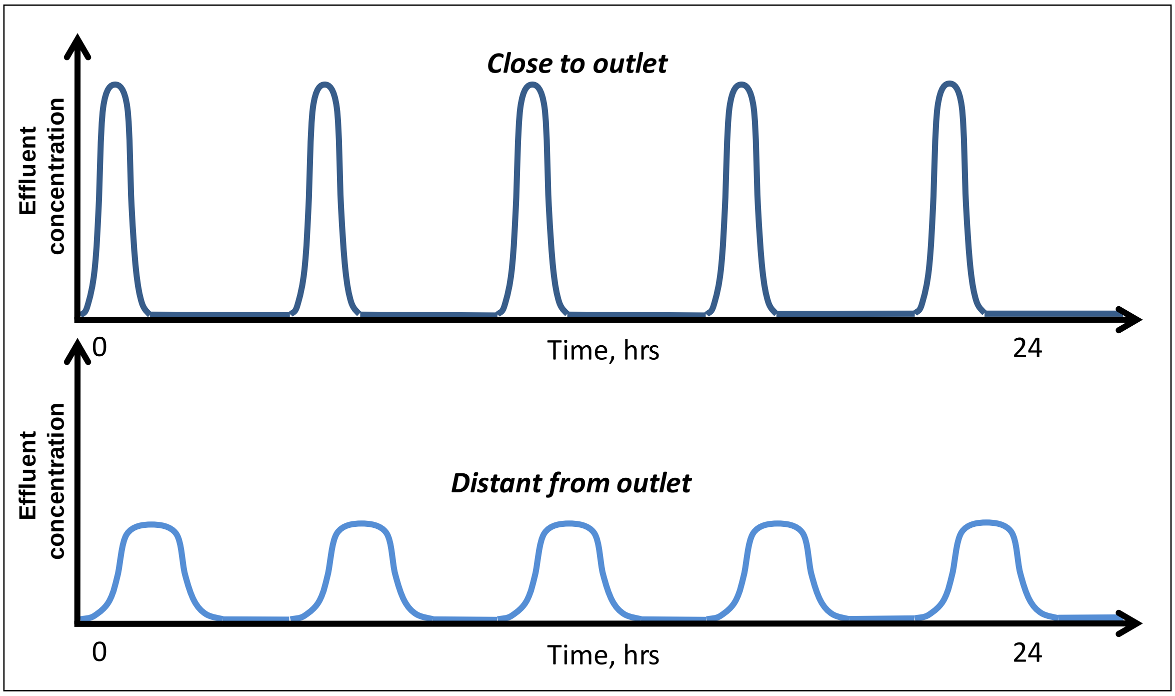


Figure 7-24. Exposure of benthic marine biota to intermittent chlorine in seawater discharge

7.8.10 Risk Assessment for Marine Biota Near the FSRU – FSRU Only

As listed in Table 7-20, for open loop operations (or closed loop) and when there is no adjacent LNG carrier (FSRU only), the tidally-average chlorine concentration exposure of marine organisms near the FSRU is less than 6 µg/L. The predicted chlorine concentrations at sites on the seabed next to the FSRU, at 340 m north, 340 m south, 100 m and 200 m west, and 200 m and 300 m east are plotted in Figure 7-25. The following peak concentrations can be seen in the figure:

- Tidally-averaged chlorine concentration on the seabed is 2 to 2.3 µg/L
- Tidally-averaged chlorine concentration at 340 m north is 1.5 to 2 µg/L
- Tidally-averaged chlorine concentration at 340 m south is 1.2 to 2 µg/L
- Tidally-averaged chlorine concentration at 100 m west is 1.5 to 2 µg/L
- Tidally-averaged chlorine concentration at 200 m east is 0.5 to 1 µg/L.

All of the chlorine concentrations are well below the Guideline Value of 6 µg/L. There are short-term events of chlorine concentrations above 6 µg/L in weak currents at slack water but these are more than compensated for by the low chlorine concentrations through the majority of the tide cycle, making the time-averaged chlorine concentration under 6 µg/L.

It also can be seen in Figure 7-25 that because of the continued dilution over time, there is no long-term accumulation of chlorine in Western Port, even in the vicinity of the FSRU.

The model of chlorine dispersion does not include decay as the decay of chlorine products do not accumulate over time, but disperse and return to the original chloride and bromide salts with 1 to 2 days. Because there is rapid chemical change, and because of exchange of waters between the project area and the remainder of the bay (and ultimately with the ocean), the cumulative effects of the FSRU on chlorine concentrations in the project area and more broadly over the remainder of the bay are expected to be negligible.

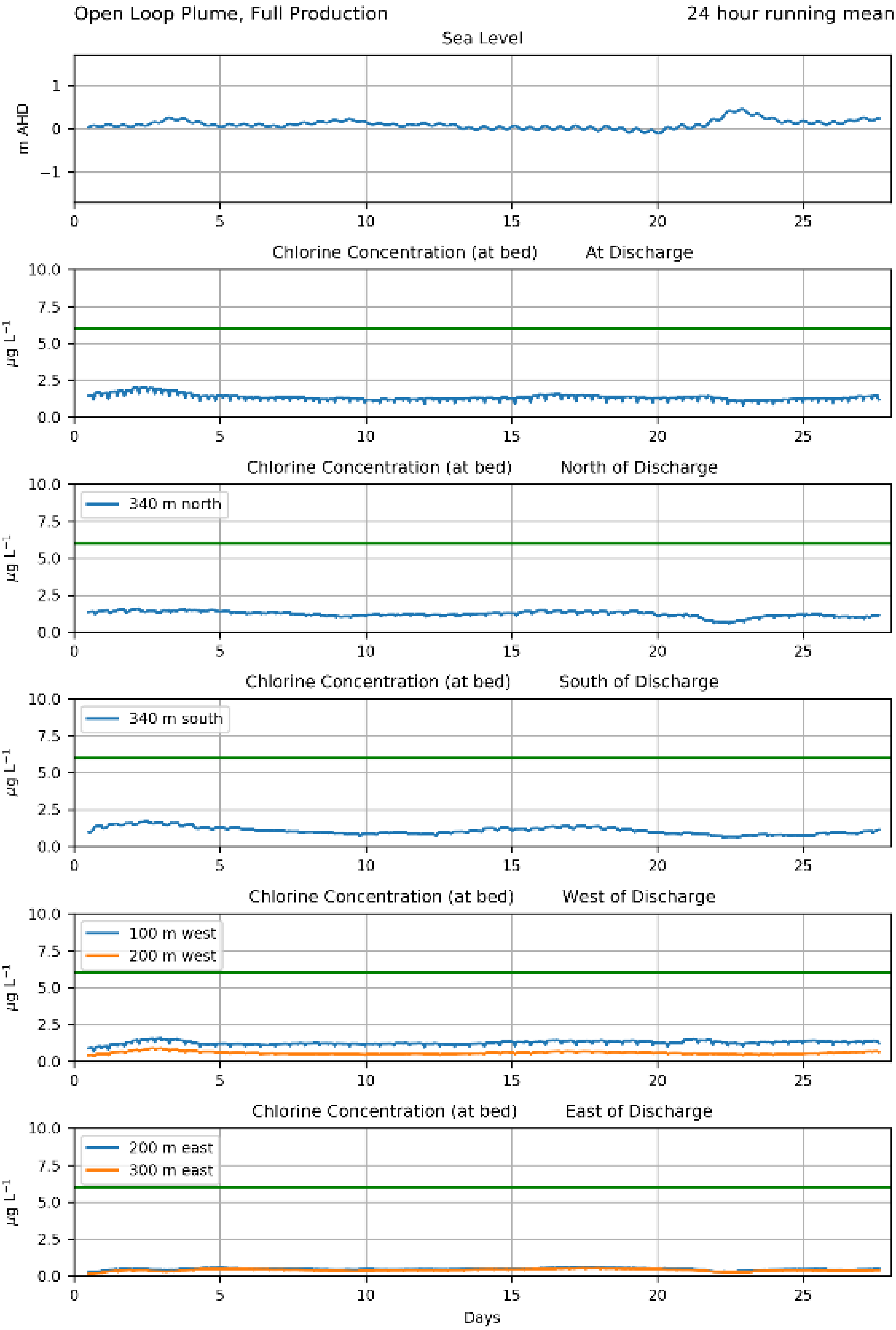


Figure 7-25. Time Series Plots of Tidally-averaged Chlorine Concentration over 28 days

7.8.11 Risk Assessment for Biota Near the FSRU – FSRU With LNG Carrier

As listed in Table 7-20, when there is an LNG carrier moored adjacent to the FSRU, a pool with more elevated chlorine concentrations forms under the FSRU and LNG carrier every slack water. The pool is then eroded and mixed as the tidal currents strengthen during the ebb or flood tide following the slack water events. There is reduced dispersion during these events, and the extent of the pool with > 6 µg/L time-averaged chlorine concentration is listed in Table 7-20.

Considering the various modes of operation and the sequence of neap and spring tides, Figure 7-26 shows the area above chlorine Guideline Value. This area encompasses all the seabed and water column in which the tidally-averaged chlorine concentration could exceed 6 µg/L. The area encompasses approximately 5 ha, all of which is in the defined Port of Hastings and also within the area that was dredged (or the adjacent area altered by the Crib Point Jetty construction).

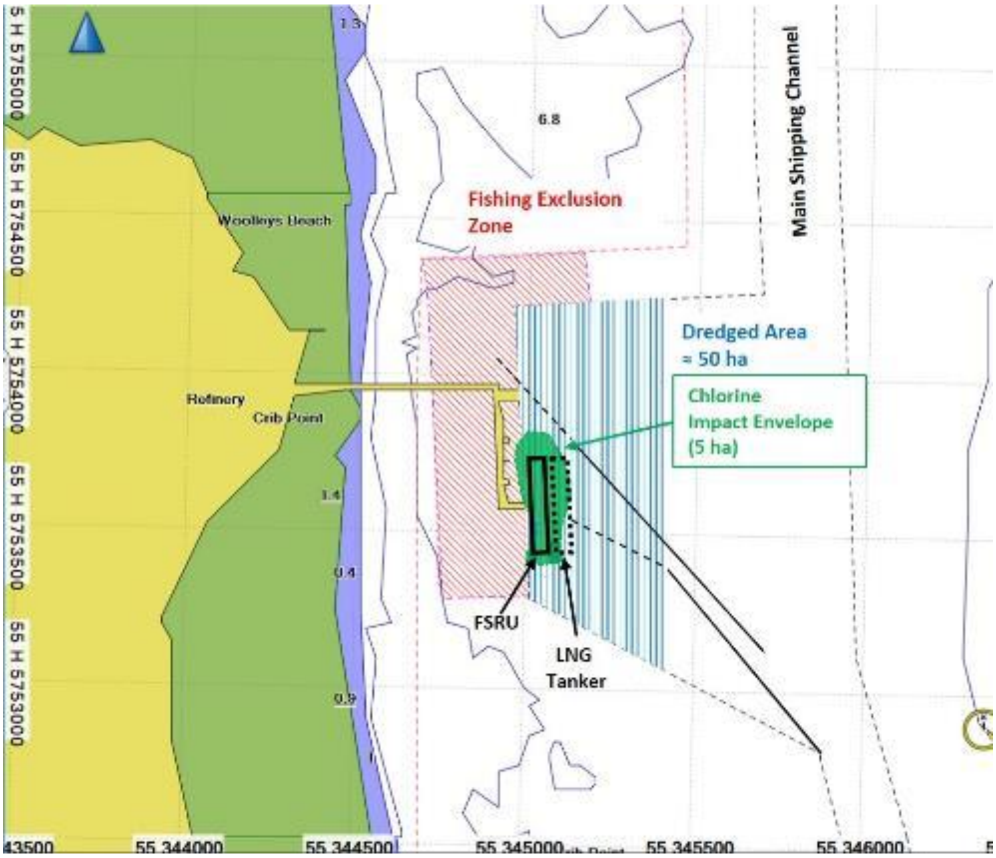


Figure 7-26. Area above Chlorine Guideline Value – Crib Point

7.8.12 Exposure Graph

The hydrodynamic model predicts that for most of the volume within the area above chlorine Guideline Value, the chlorine concentration ranges from zero to 12 µg/L, depending on the stage in the tide cycle. There is a small part of the zone, extending from the discharge ports to the adjacent seabed, where higher chlorine concentration occurs. Exposure to the higher chlorine concentration occurs for marine biota entrained into the plumes during the dilution phase.

The extent of impacts of short bursts of chlorine on marine organisms and communities is directly related to the concentration and duration of exposure. Exposure over a short period (say 5 minutes) may not cause significant adverse responses but exposure to the same level of stress over a long period may cause chronic adverse effects.

Figure 7-27 plots the toxicity results from the recent CSIRO review of chlorine as a function of time. The time scale is logarithmic, in hours. The concentration scale is logarithmic, in µg/L.

The blue diamonds in the graph show the results of tests from CSIRO's review (CSIRO 2019) on different species over different durations. The lowest effect was at 21 µg/L for a 96-hour test. The green squares show the CSIRO Guideline Values for chlorine of 6 µg/L for intermittent tidally-averaged exposure (taken as 12 hours) and of 2 µg/L for long-term consistent exposure. The dashed orange line is the lower envelope of the test results.

The green and orange triangle shows the envelope chlorine concentration corresponding to 5-6 minutes exposure (0.1 hours), which is around 100 µg/L. As the worst-exposed biota would go from zero up to 100 µg/L and down to 10 µg/L in 5 minutes, the test data in Table 7-24 suggest that the effect would be minor. It is not possible to say that there would be no effect, but on the evidence available, the effect would be minor to negligible.

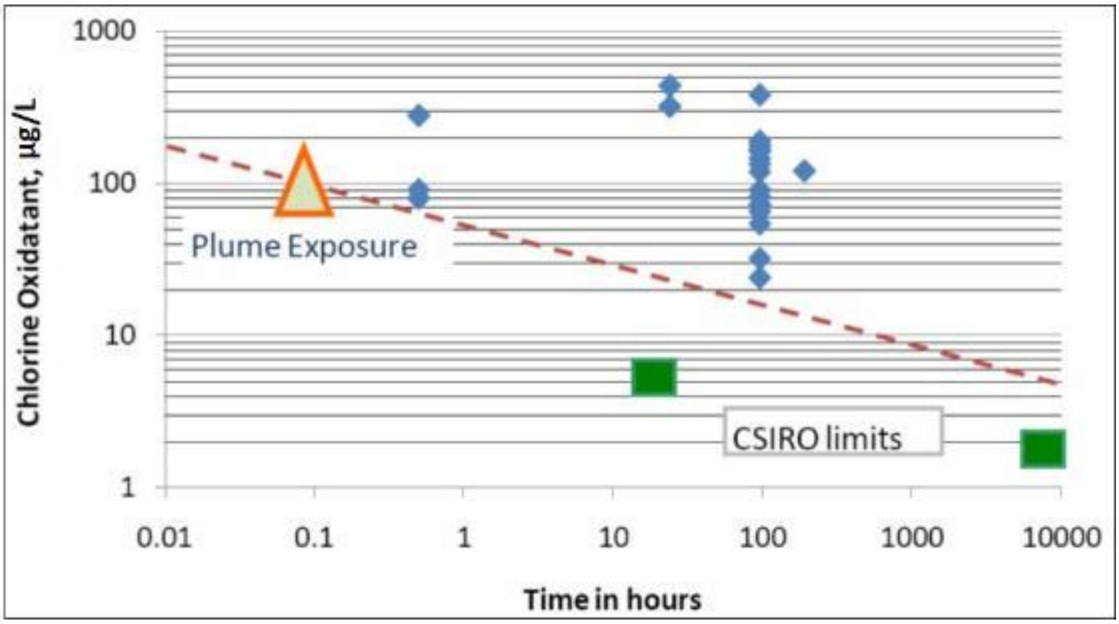


Figure 7-27. Chlorine Toxicity Results as Function of Duration of Exposure

7.8.13 Findings of Risk Assessment for Chlorine

The main outcomes from the modelling and assessment of chlorine risks on the marine environment are as follows.

- In normal open (or closed) loop operations without an LNG carrier (FSRU only), the chlorine concentrations at all locations averaged over a 12-hour tidal cycle are less than the Guideline Value of 6 µg/L.
- When there is an LNG carrier moored next to the FSRU, chlorine concentration under and beside the two vessels exceed to Guideline Value.
- Figure 7-26 shows the predicted chlorine impact CPO potential effects area which encompasses all the seabed and water column in which the tidally-averaged chlorine concentration could exceed 6 µg/L. The area encompasses approximately 5 ha, all of

which is in the defined Port of Hastings and also within the area that was dredged (or the adjacent area altered by the Crib Point Jetty construction).

- The assessment of the effects of short-term exposure to low chlorine concentrations in the diluting plumes indicate that the effect would be minor to negligible. The entrainment assessment is based on the assumption that all plankton and other biota travelling through the FSRU seawater systems are destroyed by the chlorination process (conservative assumption). The entrainment assumption may be an over-estimate, which would more than compensate for any under-estimate of the post-discharge effects.
- The risk of bioaccumulation of chlorine (or bromine) as THMs in the marine food chain is assessed as **low** (refer Section 7.8.25).

7.8.14 Extent of Impact of Chlorine

A key outcome from the modelling and assessment of chlorine risks on the marine environment is that the extent of chlorine above the Guideline Value is limited to 5 ha in the Port Zone. Figure 7-26 shows that the area of chlorine above the Guideline Value extends for approximately 300 m north/south and 160 m east/west, and is mostly under the FSRU and the LNG carrier. The seabed biota in the area also would be affected by the shading caused by the two vessels and also by the local seabed scour due to the discharges (refer to Section 7).

Figure 7-29 and Figure 7-30 show the area of chlorine above the Guideline Value in a wider context, firstly showing the area in the content of the width of North Arm and secondly showing the area in the context of the whole of Western Port. In this context it shows the area in which chlorine exceeds to Guideline Value of 6 µg/L, and a strip extending 3 km north and south along the main channel of North Arm would encompass the area in which chlorine concentration could (occasionally) be detected at 2 µg/L.

On this basis, Table 7-22 summarises the likelihood of chlorine reaching various environmental segments.

Table 7-22. Likelihood of Significant Chlorine Reaching Environmental Segments

Habitats and Species Groups	Assessment Outcome	Reasoning
Mangroves and saltmarsh	No impact	No chlorine reaches mangroves and saltmarsh
Seagrasses	No impact	No chlorine reaches seagrasses
Seabirds	No impact	Easily avoid area with chlorinated seawater
Migratory birds	No impact	Migratory birds easily avoid area of potential chlorine impact.
Penguins and seals	No impact	No chlorine reaches areas used by penguins and seals. Can easily avoid area.
Fish	Negligible impact	Some avoidance reaction in local area near FSRU. However, time-averaged chlorine concentration meets Guideline Value. See discussion on entrainment of fish embryo in Section 7.6.14
Zooplankton	Limited Impact	Refer to Section 7.8.20. chlorinated seawater risk: plankton
Plankton	Limited Impact	Refer to Section 7.8.20. chlorinated seawater risk: plankton

To provide a basis for comparison, Figure 7-28 shows the Crib Point Berths with the FSRU,

LNG carrier at berth 2 and a petroleum carrier at berth 1. It also is possible to have vessels using berth 3, which is on the east-/west jetty inshore of Berth 1.

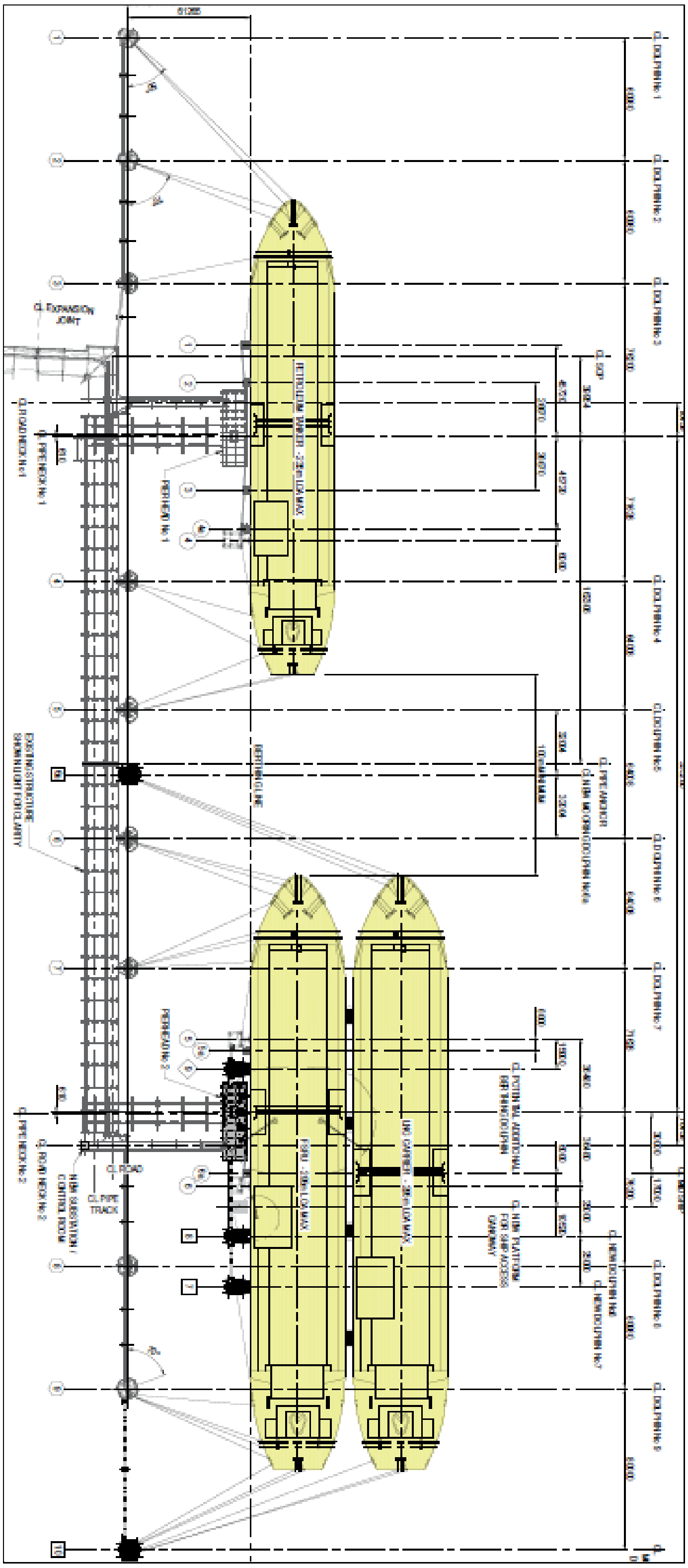


Figure 7-28. Extent of Vessels at Crib Point Jetty

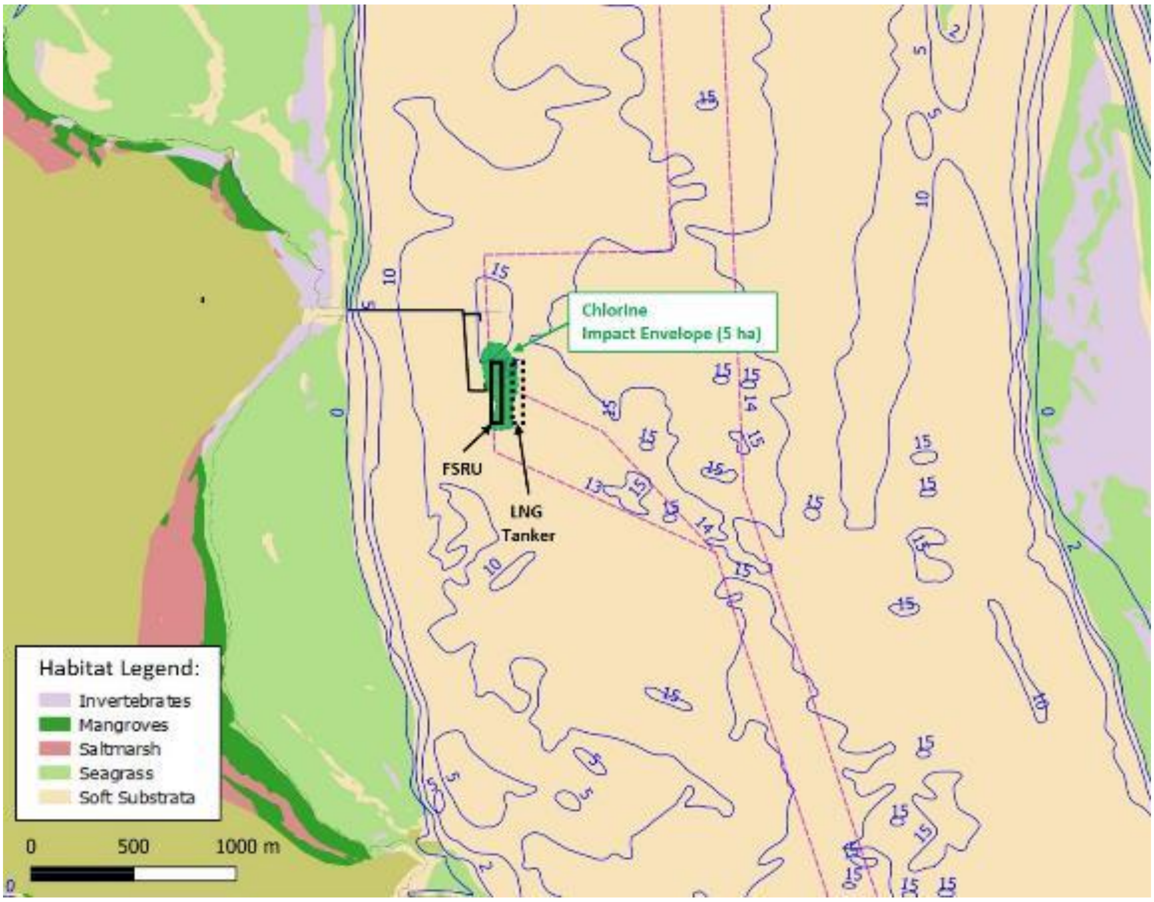


Figure 7-29. Area above Chlorine Guideline Value – North Arm

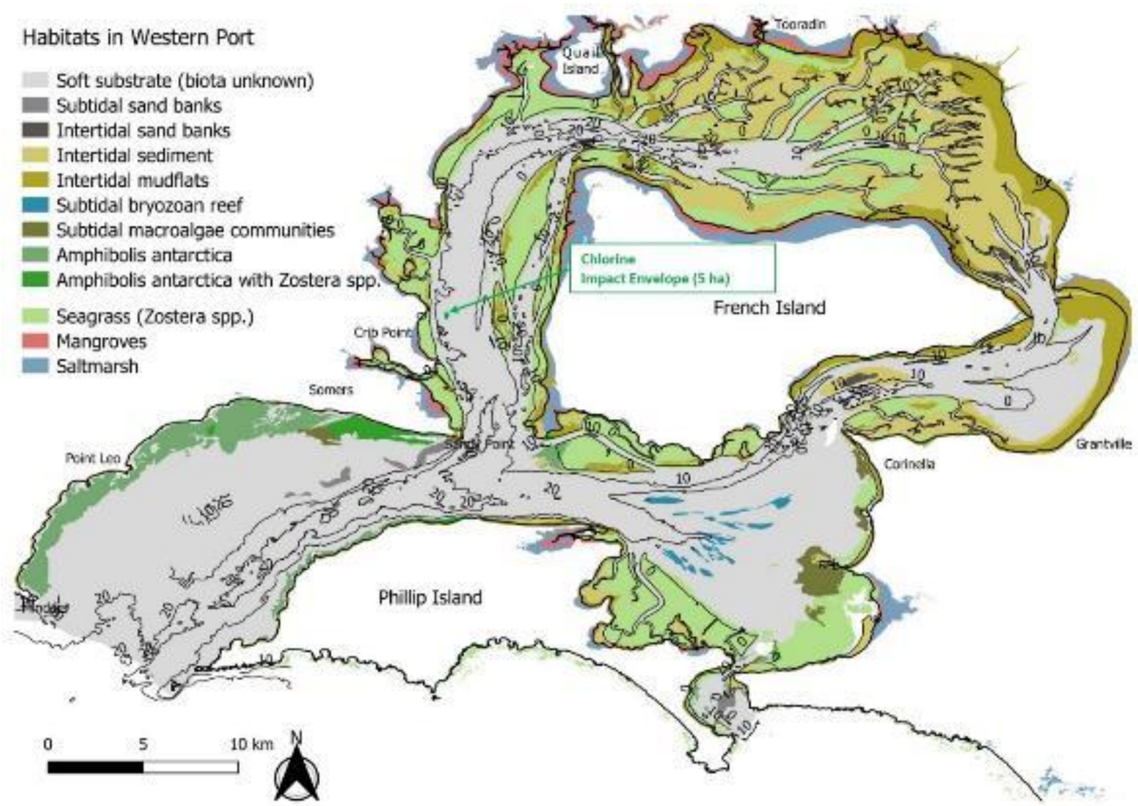


Figure 7-30. Area above Chlorine Guideline Value – Western Port

7.8.15 Chlorinated Seawater Risk: Saltmarsh and Mangrove Community

The nearest saltmarsh and mangrove vegetation along the southern shore of the Port of Hastings is approximately located above the mid-tide mark, approximately 1 km from the proposed FSRU location (Section 5). The nearest boundary of CPO potential effect would be remote from saltmarsh and mangroves (Figure 7-29). Thus, the likelihood of CPO concentration exceeding the Guideline Value in the mangrove or saltmarsh habitats is ***rare*.** If the discharge seawater was to reach the mangrove and saltmarsh vegetation, the concentration of CPO would be well below any Guideline Value due to dilution and chemical conversion to natural seawater constituents and the consequence would be ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low.**

7.8.16 Chlorinated Seawater Risk: Intertidal Mudflat Invertebrate Communities

The nearest intertidal benthic communities are approximately 500 m west of the FSRU (refer to Figure 5-22, Section 5). The nearest boundary of CPO potential effect would be relatively remote from the intertidal areas and, in open loop discharge, the discharge sinks to the seabed and can only reach the intertidal mudflat habitat and associated invertebrate communities after substantial vertical mixing. Thus, the likelihood of CPO concentration exceeding the Guideline Value in the intertidal mudflat habitats is ***rare*.** If the discharge seawater was to reach the intertidal mudflat habitats, the concentration of CPO would be well below any Guideline Value due to dilution and chemical conversion to natural seawater constituents, and the consequence would be ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low*.***

7.8.17 Chlorinated Seawater Risk: Intertidal and Subtidal Seagrasses

The nearest intertidal and subtidal seagrass habitats are approximately 450 m west of the FSRU at approximately 1.5 m depth (refer to Figure 5-22, Section 5). The nearest boundary of CPO potential effect would be relatively remote from the intertidal areas and, in open loop discharge, the discharge sinks to the seabed and can only reach the intertidal and shallow subtidal seagrass habitats and associated communities after substantial vertical mixing.

Thus, the likelihood of CPO concentration exceeding the safe Guideline Value in intertidal and shallow subtidal seagrass habitats is ***rare*.** If the discharge seawater was to reach the intertidal and shallow subtidal seagrass habitats, the concentration of CPO would be well below any Guideline Value due to dilution and chemical conversion to natural seawater constituents, and the consequence would be ***negligible***. According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low*.***

7.8.18 Chlorinated Seawater Risk: Benthic Subtidal Invertebrate Fauna

The total area of soft seabed in Western Port is approximately 360 km^2. As discussed in Section 5, the natural subtidal invertebrate community in sediment habitats is variable over even small distances due to relatively small-scale variation in sediment particle size, seabed form and seabed surface features. Invertebrate diversity and abundance are generally lower in bare areas compared to seagrass areas.

The infauna of the subtidal seabed at Crib Point Jetty comprise polychaetes (“bristle worms”) as the most abundant class, closely followed by crustaceans and molluscs. On average, 110 animals were found in each litre of sediment. More infauna were found near the Jetty (100 – 300/L sediment) than at reference sites elsewhere in North Arm (10 – 120/L sediment) This is possibly explained by the layer of soft sediments (sand and shell) that have accumulated over the predominantly clay bed in the dredged zone near the jetties which provides a relatively homogenous habitat for infauna and epibiota in the shipping basin (Section 5.8.3).

There would be a 3-ha zone of chlorinated seawater from the heat exchanger discharge, as discussed in Section 6.0. There would also be an increase in the quantity of non-living organic material from plankton damaged in the passage through the FSRU heat exchanger. The effects on infauna would be due to the combined effects of these processes and the shade under the vessels, local changes in currents above the seabed and the effects of tugs berthing and manoeuvring the LNG carriers.

Figure 7-29 shows the spatial extent of the predicted area of CPO concentration above the Guideline Value. The area occupies approximately 5 ha and encompasses the 3 ha of seabed under and around the FSRU and LNG carrier that may be affected by shading and physical effects (refer to Section 7.10). The area of CPO concentration above the Guideline Value is within the larger, 20 ha area of temperature change exceedance.

Within this 5-ha area, the greatest combined effect would be expected within the footprint of the two vessels, with reducing effect on the habitat and biota as frequency of exposure to CPO concentration and temperature change decreases and the magnitude of the effects decrease along the discharge plume pathways.

The effects of the temperature differential would extend from the 5-ha area above the chlorine Guideline Level to the 20-ha area above the temperature Guideline Value. The gradient of combined effect on the seabed biota is likely to be non-linear over the 20 ha, with greatest effect under the FSRU and within the boundary of the 5-ha area above the chlorine Guideline Value to no detectable effect at the boundary of the 20-ha area above the temperature Guideline Value.

The species present in the dredging-modified soft seabed habitat at Crib Point Jetty (Berth 2) are widely represented throughout the 36,000 ha of soft seabed in Lower North Arm as discussed in Section 5, and are likely to be distributed widely throughout the coastal environment of Victoria (e.g. Poore 2019). The proportion of the species at any particular location is dependent on the natural characteristics of the seabed at that location, which is patchy at small spatial scales (metres to tens of metres) but relatively homogeneous at larger scales (hectares and kilometres). Brachiopods, as an example, are most abundant in North Arm well to the east of the area above chlorine Guideline Value, and thus are unlikely to experience an impact (as noted in Section 5, brachiopods are widely distributed from NSW to Tasmania).

Thus, likelihood of an effect within the 20-ha area above combined chlorine and temperature Guideline Values is ***almost certain*.** However, within this area the magnitude of effect would be variable along dispersion gradients as discussed above. The alteration of benthic communities, benthic ecological processes and nutrient and carbon cycles outside the 20-ha area (which is characterised by modified habitat) within the context of Lower North Arm or Western Port as a whole is considered to be ***negligible***. According to the risk matrix in Section 4.0, an almost certain likelihood and negligible consequence results in a risk rating of **Low*.***

7.8.19 Chlorinated Seawater Risk: Pelagic and Demersal Fish

Pelagic and demersal fish species move around in Western Port and therefore some would be in the vicinity of the FSRU where they could have direct contact with the chlorinated seawater plume as it dilutes and spreads out on the seabed.

As discussed in the initial mitigation measures, the seawater intake has been designed with a low, horizontal velocity to minimise the possibility of fish impinging on the screens or being entrained into the FSRU.

Experience at power station and desalination plant outlets is that fish are attracted to the discharge plumes by a combination of the food particles contained in the discharge and the disturbance created by the high velocity jets. These attractions overcome the reservations that fish could be expected to have with warmer or cooler water. Although the discharge plumes extend over a very small area in the context of Western Port, the potential for contact of fish with the seawater discharge is rated as ***almost certain***.

Given these observations, coupled with the knowledge that fish are very mobile and have the opportunity and ability to move quickly away from the seawater discharge, the consequence of the risk is rated as ***negligible.*** According to the risk matrix in Section 4.0, an almost certain likelihood and negligible consequence results in a risk rating of **Low**.

7.8.20 Chlorinated Seawater Risk: Plankton

Field sampling of zooplankton and phytoplankton in North Arm established that plankton is abundant and widely distributed through Western Port and around Crib Point (refer to Section 5). The highest plankton counts occur in the north-east and east zones of Western Port as these zones have long residence times (and consequently a low rate of flushing to Bass Strait) and receive approximately two-thirds of all nutrient inputs to Western Port (from the Bunyip River, Lang River and Cardinia Creek).

Even at low tide, Western Port has a surface area of 52,300 ha and a volume of 9,090,000 m^3. Thus the 5-ha encompassed by the area above the chlorine Guideline Value constitutes only 0.01 % of the area of Western Port, or 0.07 % of the area of Lower North Arm (refer to Table 5-2, Section 5). Thus, the zone of chlorine impact is very small compared to the extent of North Arm or Western Port.

The assessment of the impact of plankton being entrained into the FSRU is described in Section 7.6. This section addresses the environmental risk to the plankton populations in Western Port, as a whole. The field studies described in Section 5 showed that plankton populations have a similar composition throughout Western Port. According to the results of the particle studies, the plankton populations in different zones of Western Port are intermixed in a period of one to three weeks. The north-east and east zones seem to be the major source of the plankton populations that move through North Arm to Bass Strait.

Application of the toxicity exposure results shown above (refer to Figure 7-23) to plankton indicates that the general (non-entrained) plankton population is exposed to chlorine products for up to 5 minutes and the test data in Figure 7-27 suggest that the effect would be negligible in a population sense, as only a tiny proportion of the plankton population are exposed and only a small proportion of them might be affected.

The likelihood of direct contact is rated as ***almost certain***. Only a tiny amount of plankton are predicted to be impacted by the seawater discharge compared to the high abundance in North Arm and Western Port resulting in a consequence rating of ***negligible.*** According to the risk matrix in Section 4.0, a possible likelihood and moderate consequence results in a risk rating of **Low**.

7.8.21 Chlorinated Seawater Risk: Subtidal Reef

The main examples of subtidal reefs in Western Port are at Eagle Rock and Crawfish Rock, located approximately 12 km north of Crib Point Jetty.

Given the distance between the area above the chlorine Guideline Value and the subtidal reef at Crawfish Rock the likelihood of there being any effect from the chlorinated seawater discharge on the subtidal reef is rated as ***rare*** (effectively zero). The large distance between the FSRU and the subtidal reef at Eagle Rock and Crawfish Rock means that several tidal cycles would be involved in the travel time, and residual chlorine would have dispersed and decayed to zero before it reached the rock. Therefore, the consequence is rated as ***negligible*****.** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low*.***

7.8.22 Chlorinated Seawater Risk: Protected Areas (Ramsar)

Western Port is listed under the Ramsar convention as an area of significant importance as it meets the majority of the Ramsar criteria for designation. Western Port contains a large number of Wetland Habitat types recognised under the Ramsar Convention including:

- Marine subtidal aquatic beds; such as seagrass beds;
- Rocky marine shores; such as the intertidal and subtidal rocky reefs;
- Estuarine Waters; such as the (limited) areas around the mouths of the rivers and creeks that drain into Western Port;
- Intertidal mud, sand or salt flats; such as the extensive vegetated and unvegetated mud and sand flats, with large numbers of waterbirds;
- Intertidal forested wetlands; such as the extensive fringing mangroves around the north and west shores of Western Port, including near Crib Point. The White Mangroves (*Avicennia marina*) found in Western Port are the most southerly mangroves in the world;
- Intertidal mud, sand or salt flats; such as the extensive vegetated and unvegetated mud and sand flats, with the associated waterbirds.

Given the distance between the area above the chlorine Guideline Value and the various habitat types recognised under the Ramsar convention, the likelihood of there being any effect from the discharge of chlorinated seawater on the subtidal reef (for seagrass, estuarine areas, intertidal mud flats, intertidal forested wetlands, salt marshes and mangroves) is rated as ***rare****.* The FSRU is not adding or removing and nutrients or organic constituents to Western Port and there is not expected to be any alteration in the food supply for birds using intertidal areas.

The only part of the Ramsar area that is potentially affected by the proposal is the waters of North Arm within the area above the chlorine Guideline Value. All of these waters are part of the declared and operating Port of Hastings, are used by approximately 150 commercial vessels each year, including for the import and export of petroleum products, and the seabed is subject to periodic dredging. In this context, the consequence of any additional impact is assessed as ***minor***. According to the risk matrix in Section 4.0, a rare likelihood and minor consequence results in a risk rating of **Very Low*.***

7.8.23 Chlorinated Seawater Risk: Protected Areas (Other)

Western Port has several Marine National Parks with the closest to Crib Point being the Yaringa Marine National Park approximately 12 km away.

Given the distance between the area above the chlorine Guideline Value and the subtidal reef at Yaringa the likelihood of there being any effect from the chlorinated seawater discharge on the subtidal reef is rated as ***rare*** (effectively zero). The large distance between the FSRU and Yaringa means that several tidal cycles would be involved in the travel time, and residual chlorine would have dispersed and decayed to zero before it reached the rock. Therefore, the consequence is rated as ***negligible*****.** According to the risk matrix in Section 4.0, a rare likelihood and negligible consequence results in a risk rating of **Very Low***.*

7.8.24 Chlorinated Seawater Risk: Protected Species

There are several protected species that have potential to come within the vicinity of Crib Point Jetty including whales, fish and infauna such as the ghost shrimp *Michelea*. Most of these species are not expected to be close to the FSRU and any contact with the area above the chlorine Guideline Value is likely to be for very limited periods of time.

The potential presence of the FFGA listed ghost shrimp *Michelea microphylla* in the vicinity of Crib Point Jetty was investigated during the EES studies. No individuals of *Michelea microphylla* were found and it was concluded that Western Port is not likely to represent the most optimal environment for this species (Poore 2019). The likelihood of individuals of this species being exposed to the chlorinated seawater discharge is ***unlikely*** and the effect of the exposure to a very small proportion of the population of this species is rated as ***negligible***. According to the risk matrix in Section 4.0, a combination of unlikely likelihood and negligible consequence results in a risk rating of **Very Low***.*

The FFGA and Commonwealth listed Australian Grayling fish are most likely to migrate to and from the freshwater habitats or Western Port and Bass Strait via the East Arms, rather than Lower North Arm. The likelihood of exposure of this species to the chlorinated seawater discharge is therefore ***possible*****,** but with ***negligible*** effect on the Western Port populations**.** According to the risk matrix in Section 4.0, a combination of possible likelihood and negligible consequence results in a risk rating of **Low***.*

Individuals of marine species such as whales and sharks are reported to be in the vicinity of Crib Point on a few occasions each year for a short period. As a result, they have very low exposure time. Thus, the likelihood of impact on these protected species is rated as **possible**. Because the species are listed as protected, any impact could be seen as detrimental but these are large animals so the effects of a short exposure are expected to be negligible in terms of general health. As there a very low chance of impact on populations of these species, the consequence is rated as ***negligible*****.** According to the risk matrix in Section 4.0, a combination of possible likelihood and negligible consequence results in a risk rating of **Low***.*

7.8.25 Bioaccumulation of Chlorine

As discussed previously, electrolysis of seawater results in chlorine produced oxidants that are mostly bromine based. Subsequent reactions between CPO and ammonia in seawater and organic matter may produce bromamines or trihalogenated methanes respectively.

Bromamines may only form from the reaction between CPO with ammonia, if CPO and ammonia concentrations are sufficiently high. It was estimated that ammonia concentrations would need to exceed 10 µg/L and chlorination at 1 mg/L for bromamines to be formed in significant amounts (Sugam and Helz, 1977). Long-term EPA seawater quality monitoring in Western Port (1990 to 2013) shows that annual average concentrations of ammonia in North Arm are consistently less than 10 µg/L, and beyond the area above the chlorine Guideline Value, average CPO would be at a concentration at least thirty times lower than the 100 µg/L at the discharge ports. CSIRO (2019) concluded that there is negligible potential for significant quantities of chloramines or bromamines to be formed in the chlorinated seawater discharge from the FSRU. This is consistent with the findings elsewhere that bromamines do not register on lists of CPB produced in chlorination of seawater (Abdel-Wahab 2110 Boudjellaba et al 2016, Jenner and Wither 2011, Satpathy et al 2010).

The halogenated (chlorinated or brominated) organics chlorine-produced by-products (CPB) that are formed by reaction of CPO with dissolved organic matter in seawater are trihalo methanes (THM). The amount produced is less with lower concentrations of chlorine and also is less with short duration of exposure, but represent approximately 6% of the CPO produced, and tribromomethane (bromoform, $CHBr_3$) represents more than 90 % of the CPB produced from initial chlorination (Abdel-Wahab 2110, Boudjellaba et al 2016, Jenner and Wither 2011, Satpathy et al 2010). These are of low toxicity: according to the US EPA, chloroform is not particularly toxic to algae and diatoms, with a 72-hr EC10 in the range of 3,600 to 10,000 µg/L.

Marine biological processes have evolved that naturally synthesise the dissolved chloride and bromide salts into various chlorine and bromine oxidants and brominated compounds (Abdel-Wahab 2110 Boudjellaba et al 2016, Jenner and Wither 2011, Satpathy et al 2010). Many marine red and brown alga naturally produce bromoform (this can be observed by storing those algae in a sealed container and opening it hours later). The bromoform produced by alga is a substrate for a range of natural processes, many are intended to reduce the rate of bacterial infection on the alga. These biologically produced chemicals are components of the natural halogen cycle in the marine environment (Figure 7-31).

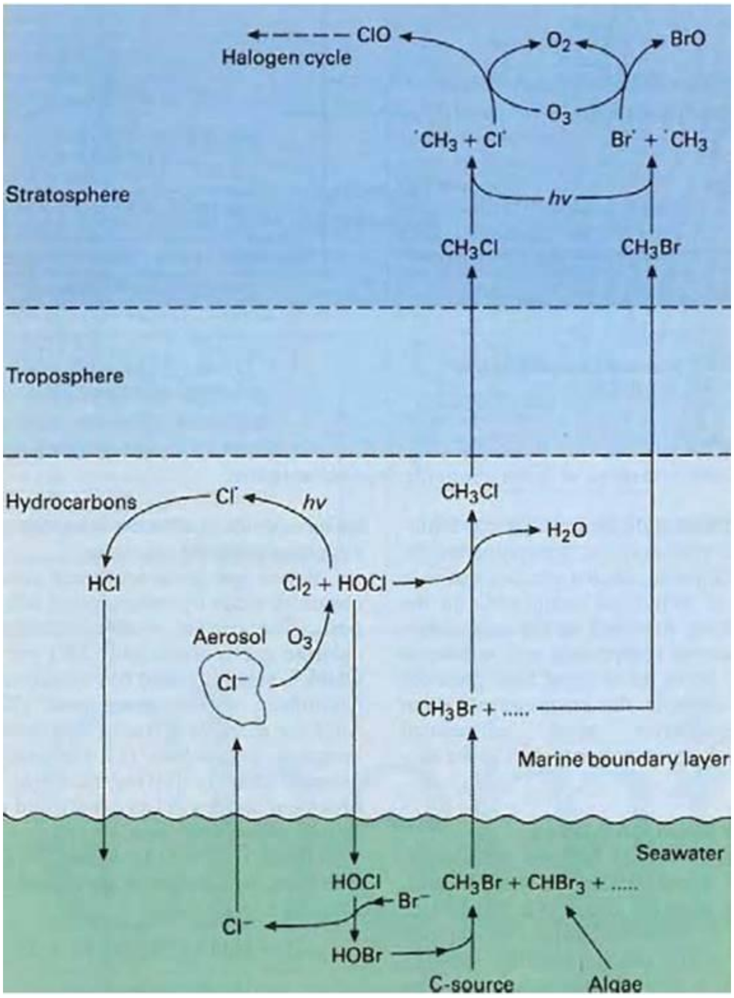


Figure 7-31. Natural halogen cycle in the marine environment

Source: Hoekstra and De Leer 1995, in Jenner and Wither 2011

Background bromoform concentrations in marine waters on seagrass beds are reported to be in the range of 1 to 3 µg/L (Heohn et al, 1977) and 0.5 to 2.2 µg/L in bay waters distant for chlorine sources (Boudjellaba et al 2016). Bromoform is volatile and has a short half-life in water and biological tissue. It may be found in slightly higher concentrations in some biota close to chlorinated seawater discharges (e.g., Boudjellaba et al 2016), however bromoforms are depurated by natural processes so that concentrations reduce to natural concentrations within 2 days of removal from the area of high concentration (Jenner and Wither 2011). The generally low concentration of bromoform presence in low natural concentrations in seawater and biological tissue as a widely produced naturally produced organic chemical in the marine environment (Figure 7-31) confirms that natural physical (volatile), chemical (oxidation breakdown) and biological (oxidation and depuration) processes prevent accumulation of these chemicals.

Predictions from the hydrodynamic modelling described in Section 6.0 show residual chlorine would be diluted to a low concentration close to the FSRU. Thus, THM would form in the short period between the seawater intake and discharge at a low rate because of the low chlorine concentrations and short reaction time. As described above, the likely fate of these THM is decay and volatilisation. The potential for short-term accumulation in the marine food chain is assessed as ***possible***. The concentrations would be below any Guideline Value and the consequence would be ***negligible***. According to the risk matrix in Section 4.0, a possible likelihood and negligible consequence results in a risk rating of **Low*.***

7.8.26 Summary of Chlorinated Seawater Risks

Table 7-23 provides a summary of the risk assessment as described in the sections above. It can be seen that risks ME30 to ME40 are rated as low or very low.

Table 7-23. Summary of Chlorinated Seawater Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 30	Mangroves and Saltmarsh	Chlorinated seawater from discharge plume alters the natural mangroves and saltmarsh habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from mangroves and saltmarsh so risk does not require further mitigation	Negligible	Rare	Very Low
ME 31	Intertidal Mudflat Invertebrate Communities	Chlorinated seawater from discharge plume alters natural intertidal mudflat invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from mudflats so risk does not require further mitigation	Negligible	Rare	Very Low
ME 32	Intertidal and Subtidal Seagrasses	Chlorinated seawater from discharge plume alters the natural intertidal and subtidal seagrass habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from seagrasses so risk does not require further mitigation	Negligible	Rare	Very Low
ME 33	Benthic Subtidal Invertebrate Fauna	Chlorinated seawater from discharge plume alters natural benthic subtidal invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Very small zone affected so risk does not require further mitigation.	Negligible	Almost Certain	Low
ME 34	Pelagic and Demersal Fish	Chlorinated seawater from discharge plume affects local fish species near FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Low risk so does not require further mitigation	Negligible	Almost Certain	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 35	Plankton	Chlorinated seawater from discharge plume affects local plankton as they float past the FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	In spring/summer, limit regasification flow to less than 315,000 m^3/d	Negligible	Almost Certain	Low
ME 36	Subtidal Reef	Chlorinated seawater from discharge plume alters subtidal reef habitat	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from subtidal reef so risk does not require further mitigation	Negligible	Rare	Very Low
ME 37	Protected Areas (Ramsar)	Chlorinated seawater from discharge plume impacts values of the Ramsar site	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from Ramsar wetland habitats so risk does not require further mitigation	Minor	Rare	Very Low
ME 38	Protected Areas (Other)	Chlorinated seawater from discharge plume impacts values of marine parks and other protected areas	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from marine parks so risk does not require further mitigation	Negligible	Rare	Very Low
ME 39	Protected Species	Chlorinated seawater from discharge plume impacts on listed protected species	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value away from segment so risk does not require further mitigation	Negligible	Possible	Low
ME 40	Bioaccumulation of Chlorine	Chlorine produced oxidants bioaccumulating in species in the food chain	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Dilution reduces chlorine concentrations at ambient levels, so risk does not require further mitigation	Negligible	Possible	Low

7.9 Contamination by Leaks and Spills Management

All coasts and estuaries are sensitive to spills of oil, diesel, other liquid fuels and other chemicals. Western Port is particularly sensitive because of the large intertidal mudflats, fringing mangroves, seagrass close to the water surface at low tide and the importance of the coastal areas to birdlife.

Western Port has been used for the import and export of petroleum products since the 1960s when BP established a petroleum facility at Crib Point. The main existing imports and exports from the Port of Hastings include crude oil, liquid petroleum gas (LPG), steel and unleaded petrol (ULP). The port distributes crude oil, petrol and condensate from Bass Strait to coastal markets, and to Mobil and Viva refineries in Melbourne and Geelong via a pipeline from Hastings to Altona. Some crude oil tankers visiting Western Port have Deadweight tonnage (DWT) up to 100,000 DWT, which is the total capacity of the ship's cargo (crude oil), fuel, ballast water, provisions and crew. The assessment of the risk of spills from the Project recognises the context of the special characteristics and sensitivities of Western Port and the existing risk profile and historical importance.

Spills and leaks of contaminants can occur through the construction and operation of the facilities, or from operations on the FSRU or LNG carrier. Faults or damage to equipment and facilities can cause spills. These types of minor spills and leaks occur with similar vessels and operations and commonly involve very small quantities in contained areas (bunded work areas, workshops, equipment operational areas), are quickly identified and managed with documented standard operating procedures (SOPs) and generally cause minimal damage to the surrounding environment, if those spills reach it.

7.9.1 Initial Risk Rating – Contamination

The outcome of the Risk Workshops was a list and preliminary ranking of potential risks as shown in Section 7.4. Risks ME41 to ME44 relate to the effects of contamination, as listed in Table 7-24. All of the risks are rated as low with the exception of Risk ME43 (medium). However, further mitigation measures to be implemented during construction and operation would lower the likelihood or consequence ratings further.

Table 7-24. Initial Contamination Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 41	Contamination - Hazardous chemicals, hazardous materials or waste spill / leaks (Construction)	Minor	Possible	Low
ME 42	Contamination - Hazardous chemicals, hazardous materials or waste spill / leaks (Operation)	Minor	Possible	Low
ME 43	Contamination - Spills from vessels	Major	Unlikely	Medium
ME 44	Contamination - from Hull and Propeller cleaning	Minor	Possible	Low

7.9.2 Sources of Contamination

Spill from Break in Hydraulic Hose

Breaks in hydraulic hoses typically involves the release of relatively small volumes of hydraulic fluid. According to the Material Safety Data Sheet (MSDS) for hydraulic fluid, it has a 96-hour lethal concentration 50 (LC50) of more than 1000 mg/l (*Oncorhynchus mykiss*) and a 48-hour median effective concentration (EC50) of more than 1000 mg/l (*Daphnia magna*)[1]. If a spill of hydraulic fluid did occur, given the rapid dilution of hydraulic fluid in currents underneath the jetty there could be a very localised effect. 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 described above.

Small Diesel Spill

Small diesel spills typically involve the release of three to 30 litres of diesel. No diesel spill has exceeded three litres at the Port of Hastings in recent years (pers comms Strategy Manager, PoHDA, May 2020). According to the Material Safety Data Sheet (MSDS) for diesel fluid, it has a:

- 72-hour effective loading rate resulting in 50 per cent effect (EL50)of 22 mg/L for algae
- 72-hour EL50 of 65 mg/L for fish
- 48-hour EC50 of 210 mg/L (Daphnia).

Diesel is more toxic than hydraulic fluid. If a spill of diesel did occur, a localised effect at the site of the spill would be expected. In a typical tidal current, or even with surface spreading and local wind mixing, the diesel would disperse within 10 minutes over an area of 30 m^2 and

[1] The median effective 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.

a depth of 2 metres, with a resulting concentration of 500 mg/L. This concentration is below the range of toxic effect for a short time event. Overall, the effects of a spill of diesel would be localised and short term and, although undesirable, would not result in a significant regional impact.

Large Spills of Diesel or Fuel Oil

Large spills of diesel or bunker as a result of a collision (with a reef or another vessel) would have more potential for widespread effects than the smaller spills described above. For a trading ship entering port (the equivalent of the LNG situation), the DNV review identified the most likely spill as less than one tonne, the 85 % spill as 10 tonnes and the 90 % spill as 30 tonnes. The Asia-Pacific Applied Science Associates (APASA) oil spill model assessed spills of 200 tonnes of heavy fuel oil at McHaffie's Reef on Phillip Island and two scenarios of 66 tonnes of diesel from Long Point Jetty. The APASA model examined the effects of these assumed spills under tidal currents and northerly winds (during winter) and southerly winds (during summer).

Diesel spreads rapidly over the surface. Some evaporates, but most mixes into the water column with ambient turbulence. Heavy fuel oil spills also spread over the water surface but evaporate slowly and tend to form a sticky surface emulsion of oil, entrained water and floatables. Thus, compared to a spill of diesel, heavy fuel oil spills would cause more adverse effects on intertidal mudflats and seagrass, and also on intertidal mangroves. 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 several kilometres.

The assessment of risk considers the consequence of a large spill (described above) and the likelihood of a large spill occurring. The FSRU and LNG carriers are not transporting crude oil or refined oil products and have very limited volumes of bunker fuels or marine diesel onboard as they are primarily powered by boil-off gas from their own cargo. This reduces the consequence of a spill substantially from oil or petroleum transport tankers which are the basis of historical concerns about an oil spill in Western Port.

While the FSRU is in regasification operation, the generators would run on gas and the liquid fuel consumption would be very low - mainly related to pilot fuel for the generators running on gas, maintenance activities, and as back-up fuel in case of short duration upsets in the fuel gas management system supplying gas to the generators. Provided that there is sufficient LNG in the tanks onboard the FSRU, the liquid fuel demand onboard the FSRU may be a few hundred tonnes per year. Hoegh (an international FSRU operator) advised AGL that, as an example, a FSRU in their fleet took on 600 tonnes of bunker fuel once over a five-year period.

Hoegh has also advised AGL that LNG carriers that would visit Western Port to supply LNG to the FSRU are powered by gas and could carry similarly small volumes of diesel fuel as discussed above. 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 1,800 tonnes. Normally the tanks are less than half full. Taking account of the spread of storage tanks, it is assumed that only one tank would be ruptured.

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 or fuel oil 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.

LNG Spill

LNG spills are not a potential threat to the Ramsar values of Western Port as natural gas (methane) rises and dissipates to the atmosphere in the event of a spill and does not form a slick on the water. As such, an LNG spill would not adversely affect the natural values of Western Port such as mangroves and seagrass. The potential safety risks associated with an LNG spill are discussed in the EES Technical Report K *Safety, hazard and risk assessments*.

7.9.3 Assessment of Contaminant Spills During Construction

The construction phase of the Project involves minor works on the Crib Point Jetty over a short period. Thus, potential spills could arise from (1) breaks in hydraulic hoses or (2) spill of diesel in refuelling.

The FSRU would be constructed and equipped at an offshore site and must be inspected prior to departure for Western Port. There would be some installation work once the FSRU is berthed prior to start-up. This would include mounting the seawater intakes to the hull of the FSRU and fastening the marine loading arm (MLA) connection.

The only marine construction in the Project would be fitting the Jetty Infrastructure (including MLAs and gas piping) on the Crib Point Jetty to transfer gas from the FSRU to facilities on the shore. This would involve construction over a short period involving jetty works, vehicles and workboats and associated hydraulic fluids, lubricants and diesel.

A *Construction Environmental Management Plan* (CEMP) would be required for all construction activities. The CEMP would be risk-based, including identification description of contaminant sources and impact pathways. The CEMP would include prevention, management, minimisation and actions relating to potential impacts of spills/leaks on the environment during construction.

Jetty Infrastructure construction and maintenance would only proceed with EMPs approved by the Harbour Master, and pursuant to a Marine and Coastal Act consent. The FSRU would operate as a licensed Scheduled Premise under the *Environment Protection Act 1970* (Vic) and related Policies. In this case, the Works Approval Application should include relevant Environment Management Plans with SOPs for managing and mitigating leaks and spills which must be approved the EPA.

Thus, the likelihood for contamination due to leaks or spills of significant quantity is ranked as ***unlikely.*** Any spills are most likely to be small to negligible and contained before reaching the marine environment. The consequence for any spill on the marine environment is ranked as ***minor.*** According to the risk matrix in Section 4.0, an unlikely likelihood and minor consequence results in a risk rating of **Low*.***

7.9.4 Assessment of Contaminant Spills During Operations including FSRU and visiting LNG carriers

The risk of contamination by spills / leaks from the FSRU and LNG carriers would be the same as any similar vessels visiting Australian ports, but considerably less than oil and fuel tankers. Crib Point Jetty presently operates as a fuel and fuel oil unloading facility, with tankers arriving approximately every fortnight. Long Island Point approximately 6 km north of Crib Point is a gas and oil facility that stores gas, liquefied petroleum gas (LPG) and oil in bulk tanks on land.

LPG and oil are exported from Long Island Point via carrier ships that pass Crib Point on a frequent schedule.

Australia is the fifth largest user of commercial shipping in the world with more than 18,000 vessels from 600 overseas ports visiting Australia's 65 major ports each year. Records of spills in Port of Hastings provide a local basis for assessing the potential frequency and magnitude of spill events. Over the last three years, there have been an average of 2.5 notified spills per year at the Port of Hastings, all involving small quantities (less than five litres) of diesel or unleaded petrol (mostly from containers knocked over). No major spills have occurred from shore facilities or offshore. No spills from commercial vessels have occurred.

Based on a review published by DOE in 2018, the pollution issues of greatest concern involve (1) discharge of ballast water contaminated by marine pests; (2) antifouling paints; (3) disposal of sewage, debris and litter; (4) oil spills and chemical spills, (5) sludge spills.

Ballast Water

Ballast water for the FSRU would be managed in accordance with current Port of Hastings protocols and the *Australian Ballast Water Management Strategy.* The FSRU would initially arrive to Western Port full of LNG and therefore would not be carrying ballast. It would be taking on ballast water from Western Port once in operation, so there is no risk of extra marine pests being introduced to Western Port in FSRU ballast water. LNG Carriers also would arrive full of LNG with no ballast water and take in ballast water in Western Port. The anti-fouling paints would meet the requirements of MARPOL and the *Maritime Environment Protection Committee* of the *International Maritime Organization.* TBT in anti-fouling paints has been banned in Australia for over a decade.

Antifouling and propeller cleaning

The anti-foul coating on the FSRU would be selected to permit in-water cleaning in Western Port before the vessel reaches Australian waters. The vessel that operates as an FSRU must have a documented history to demonstrate that undesirable external coatings such as TBT have never been applied to the vessel. The FSRU, as a long-stay vessel, must be regularly, cleaned of marine growth, antifouling systems renewed or restored, and inspected by a qualified inspector. The antifouling coating system applied should be suited to long periods of inactivity in inshore waters. The vessel should also depart for Australia as soon as possible after hull maintenance is complete.

The hull and propeller would accumulate growth over the period of its operation at Crib Point and would be inspected and cleaned to remain seaworthy. Hull and propeller cleaning are only permitted within the Port of Hastings by permission of the Harbour Master.

Permitted work would be carried out by qualified commercial divers in accordance with AMSA Guideline 9/2017 "*Biofouling and In-water Cleaning* (Department of Agriculture, 2015)*".* Large cleaning debris would be taken to shore for disposal. It is noted that strong tidal currents at Crib Point may affect the efficiency of hull cleaning and collection of removed biological debris.

Biofouling on delivery carriers should be managed in accord with the IMO biofouling management guidelines, including each vessel having a ship-specific biofouling management plan and biofouling record book that are followed, maintained and regularly updated. Port stays in both the export and import ports should be minimised, and arrival-on-time logistics practised to avoid queuing prior to loading or unloading.

The likelihood for release of contaminants during hull and propeller cleaning operations is ranked as ***unlikely.*** Any releases are likely to be small to negligible; the consequence is

ranked as ***minor.*** According to the risk matrix in Section 4.0, an unlikely likelihood and minor consequence results in a risk rating of **Low*.***

Sewage, debris and litter

Sewage, oily water waste, debris and litter would be collected and stored on-board the FSRU and taken onshore to a licenced treatment facility for disposal by licenced contractors. There would be dedicated containers on the vessels for solid wastes (e.g. plastics, packaging, paper).

Sludge

Operation of the FSRU would generate wastes including sludge from various activities. it is expected that up to 25 t of sludge would be generated per month from marine diesel oil and lube oil purifiers, as well as oil residue from drain, drip trays, oil separators and sludge units from ongoing operation of the FSRU. This sludge and waste oil would be collected by a licenced contractor and disposed of at a licenced facility for treatment and reuse/disposal by a licenced contractor.

Waste management procedures would be developed and implemented for the operation of the FSRU to appropriately manage sludge. Sludge and other forms of waste generated by the FSRU would be managed in accordance with Environment Protection (Industrial Waste Resource) Regulations 2009 (see mitigation measure MM-C10 in EES Technical Report E: *Contamination and acid sulfate soils impact assessment*). The risk of sludge and other waste streams impacting on the Ramsar site is considered low.

The likelihood for contamination due to leaks or spills of significant quantity from the above sources is ranked as *unlikely****.*** Any spills are most likely to be small to negligible and contained before reaching the marine environment, especially in the context of other existing shipping and coastal industrial activities in Western Port.

Oil spills and chemical spills

Most oil spills from marine vessels result from accidents in re-fuelling. The FSRU would mostly be powered by LNG and, as such, there is not sufficient oil on board to cause a moderate to large oil spill and so is not subject to this risk. Any oil spills would be managed by PoHDA and Australian Maritime Safety Authority (AMSA) and there is a comprehensive AMSA spill management plan for Western Port.

Potential spills during operations that are assessed could arise from breaks in hydraulic hoses, for example in manoeuvring the marine loading arms or LNG transfer pipelines, spills of bunker oil or diesel fuel from FSRU or LNG carrier; and a spill of LNG.

For Australia as a whole, DNV estimated in 2011 that there are six oil spills of one tonne or more each year in Australia, with a slight downward trend over time. However, most spills are from small commercial vessels and shore-based processes. In the 40 years between 1970 and 2010, there were seven oil spills in a port with the estimated quantity ranging from 25 tonnes to 407 tonnes and the average quantity being 230 tonnes (DNV report to AMSA, 2011).

There is some potential for spills to occur during the bunkering of diesel fuels onto the FSRU from fuel supply vessels, although as noted earlier, bunkering of fuels may occur at intervals greater than 5 years. On the FSRU, drip trays are fitted under the bunkering manifolds and the fuel tanks are equipped with high level alarms to prevent overfilling. A crew member is posted on the liquid manifold during the bunkering who would immediately stop fuel transfer in case a leak was detected, or in any other scenario where the transfer should be stopped.

All hose connectors are fitted with dry-break couplings to prevent fuel losses during connection or disconnection of fuel hoses during bunkering.

The scuppers in the manifold area are plugged during bunkering operation to prevent any spilled liquid from draining to the sea. During the bunkering operation, oil spill pollution prevention equipment is placed near the bunkering manifold in case a leak should occur. The FSRU vessels being considered for the Project have procedures and checklists for bunkering operations, and dedicated risk assessments (safe job analysis and toolbox talks) are carried out onboard prior to each bunkering operation. Guidelines for ship to ship bunkering operations are found in the Oil Companies International Marine Forum (OCIMF) Ship to Ship Transfer Guide for Petroleum, Chemicals and Liquefied Gases. PoHDA approval would also be required for any bunkering operation, and it would need to be conducted in accordance with the Port Operating Handbook.

As outlined in Section 7.9.2, the small volumes of diesel fuel onboard the FSRU and visiting LNG carriers, combined with the mitigations of fuel being stored in multiple smaller tanks and the fact that LNG vessels are double hulled means the likelihood of a major spill is considered highly unlikely.

The FSRU would operate under an *Operations Environment Management Plan* (OEMP) which considers the Port of Hastings guidelines and regulations and is consistent with the *Victorian Marine Safety Act 2010* and the *Marine Regulations 2012*. Only minor quantities of fuels and chemicals would be stored and used on the FSRU, in containers within bunded storages. The FSRU is moored in relatively calm waters, so there is little potential for accidental spillage, other than due to human mistake.

Spills and incidents with the potential to have consequences on human safety are discussed in EES Technical Report K: *Safety, hazard and risk assessments*.

LNG carriers use natural gas from their own cargo in their engines, unlike other ship such as oil tankers, container ships or bulkers that carry and burn large amounts of marine distillate or heavy fuel oils in their engines.

Because LNG carriers use boil-off gas from the cargo as their primary source of fuel; they carry only relatively small quantities of bunker fuels. They carry small stores of marine diesel onboard because the self-ignition temperature of natural gas used in the engines is too high to ignite the natural gas. They use the diesel as “pilot fuel” in the combustion process. Typically, the amount of pilot fuel used is below one percent of the energy used by the engine.

In addition, LNG carriers are double hulled. There is no single point on the vessel where bunkers (or the LNG cargo) are in direct contact with the outer “skin” of the vessel. For a significant loss of fuel oil to occur, the outer and inner hull of the vessel would have to be breached at the exact point where the bunkers are stored on the vessel. In the unlikely event of this happening, there are also multiple bunker tanks meaning it would be improbable for a full complement of bunkers to be lost.

Therefore, the smaller amount of oil onboard LNG ships means the risk of an oil spill is much lower, and it is also highly unlikely due to their double hull construction.

Furthermore, if there were a loss of containment in one tank, the ship’s crew would react quickly and transfer bunkers into remaining good tanks, to minimise any loss. If there was LNG spill, natural gas (methane) rises and dissipates to the atmosphere and therefore cannot form a slick on the water.

When in transit to and from Crib Point beyond North Arm towards Flinders and the entrance to Western Port, the vessels are under the control of a pilot and every LNG carrier would be escorted by tugboats. The Harbour Master has advised that only one-way traffic would be permitted while an LNG Carrier was transiting through this section. While in North Arm, the Harbour Master only allows one vessel at a time while in transit under tug. Thus, the risk of a collision with another vessel is negligible.

On the basis of the above, the risk of a vessel collision associated with the FSRU and visiting LNG carriers resulting in a spill of diesel fuel is considered rare. An Environment Management Plan relating to the FSRU's EPA operating licence must include an Environmental Management Plan (EMP) to minimize and manage potential spills to the marine environment. In addition, the FSRU would have a comprehensive Emergency Response Plan, with documented response procedures and appropriate equipment readily available.

The likelihood for contamination due to leaks or spills of significant quantity from vessels to occur is ranked as ***rare.*** The consequence for a spill is ranked as ***major.*** According to the risk matrix in Section 4.0, a rare likelihood and major consequence results in a risk rating of <u>Medium</u>.

Nonetheless, recognizing the special sensitivity of the Western Port environment to oil spills, an assessment of consequences has been made for a credible spill of 30 tonnes of diesel over a period of three hours from a breached diesel storage tank on an LNG carrier near McHaffie's Reef. This corresponds to rupture at the centre of a partly full tank with crew response in an hour and corresponds to the 90 per cent spill recorded in similar situations from similar vessels. It is considered the credible diesel spill event from an LNG carrier normally using LNG as fuel.

According to the hydrodynamic model developed by Hydrodynamics for this assessment, tidal currents in the western entrance channel range over any three hours from 0.1 to 0.8 m/s. Diesel spilled into marine waters would spread over the surface, evaporate (loss of about 40 per cent over 10 hours) and mix vertically down into the water column. Using published evaporation and dispersion rates, the indicative diesel concentration would be around 100 mg/L at 100 metres distance, 5 mg/L at 500 metres, 0.7 mg/L at 5 kilometres and 0.1 mg/L at 10 kilometres distance. Approximately half the diluted diesel would be flushed to Bass Strait within 24 hours and the remainder would spread around Phillip Island and, to a limited extent, into North Arm.

In the unlikely event of a spill during operation, major short term impacts would be expected on the biota in the water column and on the shoreline of Phillip Island within a distance of about 5 km either side of the spill (based on the short term EC50 of 1 to 100 mg/L for most marine biota). Minor short term effects are expected within a distance of 10 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.

The likelihood for contamination due to leaks or spills of significant quantity from vessels to occur is ranked as ***rare.*** The consequence for a spill is ranked as ***major.*** According to the risk matrix in Section 4.0, a rare likelihood and major consequence results in a risk rating of <u>Medium</u>***.***

7.9.5 Managing a Potential Spill

In the event of a spill, and in accordance with the prevailing International Maritime Organisation (IMO) Marpol requirements, all vessels are equipped with a Shipboard Oil Pollution Emergency Plan (SOPEP) which provides guidance to the crew onboard on the measures to

be taken if an oil pollution incident has occurred or is likely to occur. The SOPEP address various scenarios such as transfer system leaks, tank overflow, fuel tank / hull leaks from penetration and the like and also contains an overview of the oil spill response equipment available onboard the vessel. Monthly oil pollution prevention drills are typically carried out onboard an FSRU, potentially involving deployment of onboard response equipment depending the scenario being rehearsed. The risk of spills and leaks during FSRU operation would be managed with documented standard operation procedures (SOPs) and by ensuring compliance with the Port of Hastings Development Authority Safety and Environmental Management Plan and Port Operating Handbook (see mitigation measure MM-ME05).

Emergency management and response in the event of a spill or leak, would be a component of the emergency management structure implemented at Crib Point under the Port of Hastings Development Authority (PoHDA) Emergency Management Plan. The PoHDA SEMP identifies the requirement that operators of the Gas Import Jetty Works shall develop an emergency plan that is consistent with the PoHDA Emergency Management Plan. The FSRU would also require an EPA Works Approval and would operate pursuant to an operating licence for a scheduled activity under the Environment Protection Act 1970. It would operate under operating licence conditions and Environmental Management Plans approved by EPA.

7.9.6 Summary of Contamination Risks

Table 7-25 provides a summary of the risk assessment as described in the sections above. It can be seen that risks ME41, ME42 and ME44 are rated as low, and ME43 rated as medium.

Table 7-25. Summary of Contamination Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 41	Hazardous chemicals, hazardous materials or waste spill / leaks (Construction)	Accidental spills or leaks from chemicals, materials or waste streams into Western Port during construction	Correct handling, usage, storage and disposal of chemicals and wastes, compliance with the Port Operating Handbook.	Compliance with the construction environment management plan, regulations or policies	Minor	Unlikely	Low
ME 42	Hazardous chemicals, hazardous materials or waste spill / leaks (Operation)	Accidental spills or leaks from chemicals, materials or waste streams into Western Port during operation	Correct handling, usage and storage of chemicals and compliance with the Port of Hastings Handbook.	Compliance with the operations environment management plan, regulations or policies	Minor	Unlikely	Low
ME 43	Spills from Vessels	Spills or leaks of fuel, oil or other chemicals from the FSRU or LNG carriers.	Correct handling, usage, storage and disposal of chemicals and wastes, compliance with the Port Operating Handbook.	Compliance with the operations environment management plan, regulations or policies	Major	Rare	Medium
ME 44	Contamination from Hull and Propeller Cleaning	Release of contaminants from FSRU hull and propeller cleaning processes	Correct handling, usage, storage and disposal of chemicals and wastes, compliance with the Port Operating Handbook.	Compliance with the operations environment management plan, regulations or policies	Minor	Unlikely	Low

7.10 Physical Processes

There are several potential risks that relate to physical processes that could impact on Western Port from the operation of FSRU and LNG carriers, including seabed scour, vessel grounding and light spill.

7.10.1 Initial Risk Rating – Physical Processes

The outcome of the Risk Workshops was a list and preliminary ranking of 53 potential risks as shown in Section 7.4. Risks ME45 to ME48 relate to the effects of physical processes, as listed in Table 7-26. All of the risks are rated as low. However, further mitigation measures to be implemented during construction and operation would lower the likelihood or consequence ratings further.

Table 7-26. Initial Physical Processes Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 45	Physical risk - Seabed Scour (FSRU)	Minor	Likely	Medium
ME 46	Physical risk - Seabed Scour (LNG carriers and Tugs)	Minor	Likely	Medium
ME 47	Physical risk - Vessel Grounding	Negligible	Likely	Low
ME 48	Physical risk - Light Spill	Negligible	Almost Certain	Low

A further physical process risk due to the presence of the FSRU is that the area of seabed in Western Port under the FSRU would be shaded. This risk was not identified in the original risk assessment but was recognized later and is assessed here.

The zone of seabed shaded consistently by the moored FSRU (and intermittently by the LNG carrier) is about 3 ha. There are no benthic plants on this area of seabed as there is already insufficient light. The maximum depth of seagrass is described in Chapter 5. Infauna in the shaded areas under the FSRU would adjust within weeks and the change in infauna communities due to shading is considered minor to negligible. The same shading occurs under the 13 existing operational jetties in Western Port.

The shaded zone is 60 m offshore from the main Crib Point jetty (apart from Berth 2) as shown in Figure 7-36 and shading of macroalgae and invertebrates under the jetty is not physically possible.

It should be noted that the seabed in the shipping basin (including Berth 2) was dredged in the mid-1960s. Marine biological studies documented in Section 5 show that the modified seabed in the shipping basin is uniform in character and the composition of the invertebrate infauna and epibiota community is also relatively uniform throughout the shipping basin compared to the patchiness elsewhere in North Arm (as described in Chapter 5).

7.10.2 Physical Processes Risk: Seabed Scour – FSRU

The FSRU would be moored at Berth 2 of the existing Crib Point Jetty. The channel to the Jetty and a turning basin for Berths 1 and 2 has been dredged by the PoDHA to a minimum depth of 13 m (relative to chart datum) as described in Section 5. There is local scour next to

jetty piles (up to 1 m depth) and also an accumulation of sediment in between groups of piles. Thus, the FSRU would be moored in an area where the seabed has already been dredged and disturbed to create a port and jetty.

The hydrodynamic modelling shows there would be a local increase in tidal current velocity underneath the FSRU due to the restriction to flow caused by the vessel (50 m wide and an up to 12 m deep, in a total water depth of about 14 m at low tide). Thus, local scour is expected under the FSRU, increasing the local depth by about 0.5 m. This scour would occur in the month after mooring of the FSRU and remain relatively stable thereafter.

Near-field modelling showed that in closed loop operations the three discharge jets at the rear of the FSRU would scour a hole about 1.2 to 1.5 m deep, and about 8 m in diameter. A similar scour hole would be created where the ballast water jet impinges on the seabed. These scour holes would form within hours after commencing discharge. They would partly refill in the periods between discharge as flow is not ongoing but natural movement of sediment is ongoing.

The seabed in the shipping basin was dredged in the mid-1960s. Marine biological studies documented in Section 5 show that the modified seabed in the shipping basin is uniform in character and the composition of the invertebrate infauna and epibiota community is also relatively uniform throughout the shipping basin compared to the patchiness elsewhere in North Arm. Any areas of seabed scour are remote from the intertidal areas or subtidal seagrass communities. Protected species were not found in the area and are unlikely to occur in the shipping basin. Hence, seabed scour is likely to have minimal effect on biodiversity values in North Arm.

Marine sediments near Berth 1 are contaminated in places, but not at Berth 2. The seabed scour processes near Berth 2 related to the FSRU and LNG carrier operation would not disturb or transport the contaminated sediments that occur near Berth 1.

The consequences of the expected local seabed scour are assessed as ***negligible***, as very small quantities of sediment are involved, there would be a brief local increase in turbidity but no large scale or long-term increase, and Western Port benthic biota are adapted to relatively strong currents. The likelihood for seabed scour is ranked as ***likely.*** According to the risk matrix in Section 4.0, the combination of likely occurrence and negligible consequence results in a risk rating of **Low**.

7.10.3 Physical Processes Risk: Seabed Scour – LNG carriers and Tugs

The mooring of the FSRU and LNG carriers would be assisted by tugs. When operating at high power, the propeller wash from the tugs is expected to increase the shear velocity at the seabed for 100 m to 300 m behind a tug by 0.3 m/s to 0.4 m/s (Hatch 2011), sufficient to raise a turbidity plume behind the tug. As peak tidal currents at Crib Point range up to 0.8 m/s, the extra seabed scour caused by tug operation is considered to be very small. Any eroded sediment would settle back to the seabed within the defined Port area.

The seabed in the shipping basin was dredged in the mid-1960s. Marine biological studies documented in Section 5 show that the modified seabed in the shipping basin is uniform in character and the composition of the invertebrate infauna and epibiota community is also relatively uniform throughout the shipping basin compared to the patchiness elsewhere in North Arm. Any areas of seabed scour are remote from the intertidal areas or subtidal seagrass communities. Protected species were not found in the area and are unlikely to occur in the shipping basin. Hence, seabed scour would have minimal effect on biodiversity values in North Arm.

The consequences of the expected local seabed scour due to tug operations is assessed as ***negligible***, as very small quantities of sediment are involved, there would be a brief local increase in turbidity but no large scale or long-term increase, and Western Port has a naturally mobile seabed. The likelihood for seabed scour is ranked as ***likely.*** According to the risk matrix in Section 4.0, the combination of likely occurrence and negligible consequence results in a risk rating of **Low*.***

7.10.4 Physical Processes Risk: Vessel Grounding

Large vessel grounding occurs infrequently. The ***Searoad Mersey*** grounded when trying to leave Grassy Harbour at low tide on 30 October in 2015. In the same year the ***Maesk Garonne*** grounded at the entrance of Fremantle Harbour while under the control of the pilot when the tugs did not arrive as scheduled. Fortunately, in both cases the vessels were refloated on the following flood tide, there was no damage and no spills or leaks.

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 oil Carriers *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 2006, ATSB 2008, ATSB 2016).

None of the vessel groundings that have occurred in previous years have been in Western Port.

LNG carriers would be under control of a local pilot and would be assisted by tugs before entering Western Port and during their outward passage. LNG carriers during passage would draw more than 12 m water depth. The shipping lanes less than 12 m depth comprise bare sand from the Fairway Buoy at the entrance to Western Port to Crib Point Jetty. Vessels using Western Port have defined speed limits, which are intended to reduce the risks to vessel navigation including grounding.

The seabed along the shipping channel is unvegetated as it is too deep 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 North Arm.

Nonetheless, the likelihood of an LNG carrier grounding in Western Port over a long period (say 25 years) is classified as possible. The likelihood of the FSRU grounding is classified as rare, as the FSRU would come and go rarely.

The consequences of an LNG carrier grounding on the edge of the channel is assessed as ***negligible***, as the vessel can be retrieved on the following high tide and the risk of storm damage to a large vessel is minimal. In summary, the likelihood of vessel grounding is ranked as ***possible***. According to the risk matrix in Section 4.0, the combination of a likelihood of possible and negligible consequence results in a risk rating of **Low*.***

7.10.5 Physical Processes Risk: Light Spill

The recently released Commonwealth Draft National Light Pollution Guidelines for Wildlife (DEE, 2019) provide discussion mostly specific to marine turtles, seabirds and migratory shorebirds.

Potential risks of light spill to seabirds and migratory shorebirds are discussed in EES Technical Report B: *Terrestrial and freshwater biodiversity impact assessment*.

The Commonwealth Guidelines discuss light pollution effects on turtles in relation to breeding and behaviour of hatchlings. As discussed previously, adult turtle visitation to Western Port is ***rare*** and the presence of hatchlings is impossible. The effects on breeding and hatchling behaviour is therefore ***negligible*** and the risk of light spill to turtle populations is rated **Very Low**.

This section discusses the potential for light spill effects on marine biota in relation to the addition of light sources on the FSRU to existing sources of light in Western Port and marine biota in the Western Port waters.

Artificial lighting has the potential to affect marine fauna, bats and birds by altering visual cues for orientation, navigation or other purposes, resulting in behavioural responses, which can alter natural distribution and dependencies. As discussed above, lighting is well-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, encourages predatory fish behaviour and may assist penguins, which are visual predators, to catch fish at night.

There is existing lighting along the 440 m length of Crib Point Jetty from the shore causeway to the jetty head, as well as existing lighting along the 400 m of the jetty head that includes Berth 1 and Berth 2. Additional lighting may be required at Berth 2 for the operations of unloading LNG and the moored FSRU would require safety lighting at night.

Minimum lighting is required on the vessels for safety purposes and for navigation purposes. 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 13 jetties around Western Port (Flinders, HMAS Cerberus, Stony Point, Crib Point, Long Island Point, BlueScope, Corinella Ferry Terminal, San Remo, New Haven, Rhyll, Rhyll Boat Ramp, Cowes and Carrierston) that cause light spill on the water surface. An example of Cowes Jetty is shown in Figure 7-32.

Figure 7-32. Light Spill at Cowes Jetty

There are approximately 100 elevated lights on jetties around Western Port. Taking account of the beam radius, proportion of the beam on the water surface, it is estimated that the surface area of the Bay that is illuminated by light spill is 10,200 m^2. This is only 0.0014 % of the surface area of Western Port.

The additional light spill contributed by the FSRU is shown in the light spill calculation report (AECOM, 2019) as 4,500 m^2. Other vessels using PoH may illuminate a similar area when in port. Even so, with the FSRU in operation, the total area of water surface subject to light spill would be 0.002 % of the surface area of Western Port.

The waters of North Arm at Crib Point are characterised by high turbidity from suspended solids and low light penetration relative to Bass Strait. Hence, the extent of light transmission from the sea surface into the water column from night-lighting at Berth 2 would be limited in extent and depth.

As the increase of existing night-lighting into Western Port is unavoidable with the FSRU being constantly docked at Crib Point Jetty. The likelihood of the risk occurring is ranked as ***almost certain.*** As the rise of illuminated area is very small, and the potential effects in that small area are minor, the consequence of the additional light in the context of other sources of light can be ranked as ***negligible.*** According to the risk matrix in Section 4.0, an almost certain likelihood and negligible consequence results in a risk rating of **Low**.

7.10.6 Summary of Physical Processes Risks

Table 7-27 provides a summary of the risk assessment as described in the sections above. It can be seen that risks ME45 to ME48 are rated as low.

Table 7-27. Summary of Physical Processes Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 45	Seabed Scour (FSRU)	Alteration of the seabed due to FSRU increasing seabed current and encouraging seabed scour	Proposed FSRU location in dredged area of Port of Hastings	Compliance with the environment management plan and regulations or policies	Negligible	Likely	Low
ME 46	Seabed Scour (LNG carriers and Tugs)	Alteration of the seabed from higher velocity water movement from tug propellers	Operations in defined port area, within dredged channel and turning basin. PoHDA maintaining berth at depth of 13 m	Compliance with the environment management plan and regulations or policies	Negligible	Likely	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 47	Vessel Grounding	Unplanned grounding of FSRU or LNG carriers impacting shallow waters habitats and communities	Complying with the Port Operating Handbook, class and IMO / AMSA standards	FSRU is continuously moored in Crib Point Jetty (Berth 2). LNG carriers will be under the control of experienced captain or pilot, stay in dredged channel and within speed limit.	Negligible	Possible	Low
ME 48	Light Spill	Extra light from FSRU and intermittently from the LNG carriers	Limiting lights to the number for safe operations. Reducing direct light spill where possible subject to meeting navigation and vessel safety standards.	Risk is low and does not require further mitigation	Negligible	Almost certain	Low

7.11 Biological Disturbance

With the up to 40 LNG carriers coming and going from Western Port Bay each year, there are risks to marine ecosystem from pathways such as introduction of marine pest species, aggregation of marine life due to increases in food supply or habitat, and the risk of whale strike by an LNG carrier.

7.11.1 Initial Risk Rating – Biological Disturbance

The outcome of the Risk Workshops was a list and preliminary ranking of 53 potential risks as shown in Section 7.4. Risks ME 49 to ME 53 relate to the effects of biological disturbance, as listed in Table 7-28. All of the risks are listed as low. However, further mitigation measures implemented during construction and operation would lower the likelihood or consequence ratings further.

Table 7-28. Initial Biological Disturbance Risk Assessment

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 49	Biological Disturbance – Marine Pest Introduction- FSRU	Moderate	Unlikely	Low
ME 50	Biological Disturbance – Marine Pest Introduction- LNG carrier	Moderate	Unlikely	Low
ME 51	Biological Disturbance – Aggregation of Marine Fauna	Negligible	Almost Certain	Low

Risk ID	Risk name	Risk Rank		
		Conseq	Likelihood	Risk
ME 52	Biological Disturbance - Whale Strike	Minor	Unlikely	Low
ME 53	Biological disturbance – Underwater noise from FSRU operations	Minor	Unlikely	Low

7.11.2 Biological Disturbance Risks: Marine Pest Introduction – FSRU

Mobilisation of the FSRU from an external port to Crib Point has a potential to introduce marine pest species to Western Port, which could be attached to the vessel or present in ballast water. The FSRU is planned to have a single entry to Western Port.

It is standard practice that prior to entry to Australian waters as a long residence vessel, the FSRU would be dry-docked, cleaned of marine growth, antifouling systems renewed or restored, and inspected by a qualified inspector. The antifouling coating applied should be suited to long periods of inactivity in inshore waters. The vessel should also depart for Australia as soon as possible after hull maintenance is completed (Lewis 2019).

During its delivery voyage to Australia, the FSRU must manage ballast water in accordance with Australian and international ballast water management requirements by either deep sea exchange or, preferably, operation of an approved Ballast Water Treatment system to treat any ballast water to be discharged in Australian waters.

Port Phillip has been populated by a high number of introduced marine pests for decades. There is a great number of commercial vessel and recreational exchanges between Port Phillip and Western Port bays every year. Hence, there are many opportunities for introduced marine species in Port Phillip to be transferred to Western Port every year. Yet the number and extent of introduced species in North Arm of Western Port compared to Port Phillip is small. This suggests that North Arm is not a suitable environment for many of the introduced species present in Port Phillip. If this is not the case, then the likely source of introduced species to Western Port is from Port Phillip, with a similar consequence to the marine ecosystem as occurred in Port Phillip (Lewis 2019).

Thus, the likelihood of the FSRU causing introduction of marine pests compared with other existing or future vectors is rated as ***rare.*** Given that Western Port is a Ramsar site, the introduction of marine pest species that may cause impacts to the natural flora and fauna of the bay is given a consequence of ***moderate***. According to the risk matrix in Section 4.0, a rare likelihood and moderate consequence results in a risk rating of **Low**.

7.11.3 Biological Disturbance Risks: Marine Pest Introduction – LNG Carriers

There may be up to 40 LNG carriers per year, which creates a greater potential to introduce marine pests than the single trip of the FSRU. The following controls and processes would be employed when possible in order to minimize or eliminate the risk of introducing pests:

- Carriers will have appropriate antifoul coating to prevent the encrusting of biota on the hull;
- International vessels will empty ballast water in accordance with the latest version of the Australian Ballast Water Management Requirements (DAWR, 2017);
- If an IMP 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*

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 Western Port.

Thus, the increased likelihood for LNG carriers to cause marine pest introduction to Western Port in relation to the existing likelihood from other existing vectors is rated as ***rare.*** Given that Western Port is a Ramsar site, the introduction of other species that may cause impacts to the natural flora and fauna of the bay is given a consequence of ***moderate***. According to the risk matrix in Section 4.0, a rare likelihood and moderate consequence results in a risk rating of **Low***.*

7.11.4 Biological Disturbance Risks: Aggregation of Marine Fauna

Like the outlets from power stations and desalination plants, the seawater discharge from the FSRU would contain food that is easily caught by marine species. This form of food along with the attraction of the water disturbance created by the discharge jets, and the adjacent habitat provided by the FSRU may result in an accumulation of fish around the discharge. Similar aggregations are recorded at the discharges of the Eraring, Vales Point and Munmorah power stations in NSW (DPI NSW website, 2018), the Calliope power station in Queensland (Parks QLD, 2014) where a boat ramp has been provided for recreational fishing, at the Hunter Valley offshore outfalls (Hunter Water, 2017) and at the discharges of desalination plants. The cooling water discharge from the Newport Power Station in the mouth of the Yarra River is known as “the Warmies”. Anglers aggregate at this location when the power station is operating to fish for pelagic predatory fish that aggregate to feed on easy prey that have been incapacitated by passage through the (unchlorinated) power station heat exchanger. Thus, the likelihood of marine fauna aggregation near the FSRU is rated as ***almost certain.***

A vessel exclusion zone extends for 100 m from the FSRU and any moored LNG carriers. Thus, there would not be any recreational or commercial fishing within this zone, which means that the fish aggregation would be untouched, except for natural predation. On this basis, the consequence to marine fauna is rated as ***negligible***. According to the risk matrix in Section 4.0, the combination of almost certain likelihood and negligible consequence results in a risk rating of **Low***.*

7.11.5 Biological Disturbance Risks: Whale Strike

Whale Distribution

Humpback Whales and Southern Right Whales visit Western Port during their seasonal migrations between summer feeding in the productive Southern Ocean and winter breeding in the warmer coastal Australian waters. Killer Whales have been reported around the seal colony at the western entrance of the bay. Western Port is not recognised as an aggregation point or breeding area for any of these whale species and most whale visits to Western Port Bay are usually the result of general wandering from the main migration paths (CEE, 2018).

The Two Bays project of 2014 to 2017 compiled whale sightings by the Victorian Dolphin Research Institute and Wildlife Coast Cruises. The results are shown in Figure 7-33. Humpback Whale sightings in the western entrance were the most common, but a few whales were recorded in North Arm as far as the Long Island Point Jetty. Southern Right whales are less common in the Bay and were along the western entrance and south of French Island. A

whale, probably a Southern Right, was sighted at Crib Point Jetty in 2019. Killer whales have mostly been spotted around the western-most tip of Phillip Island.

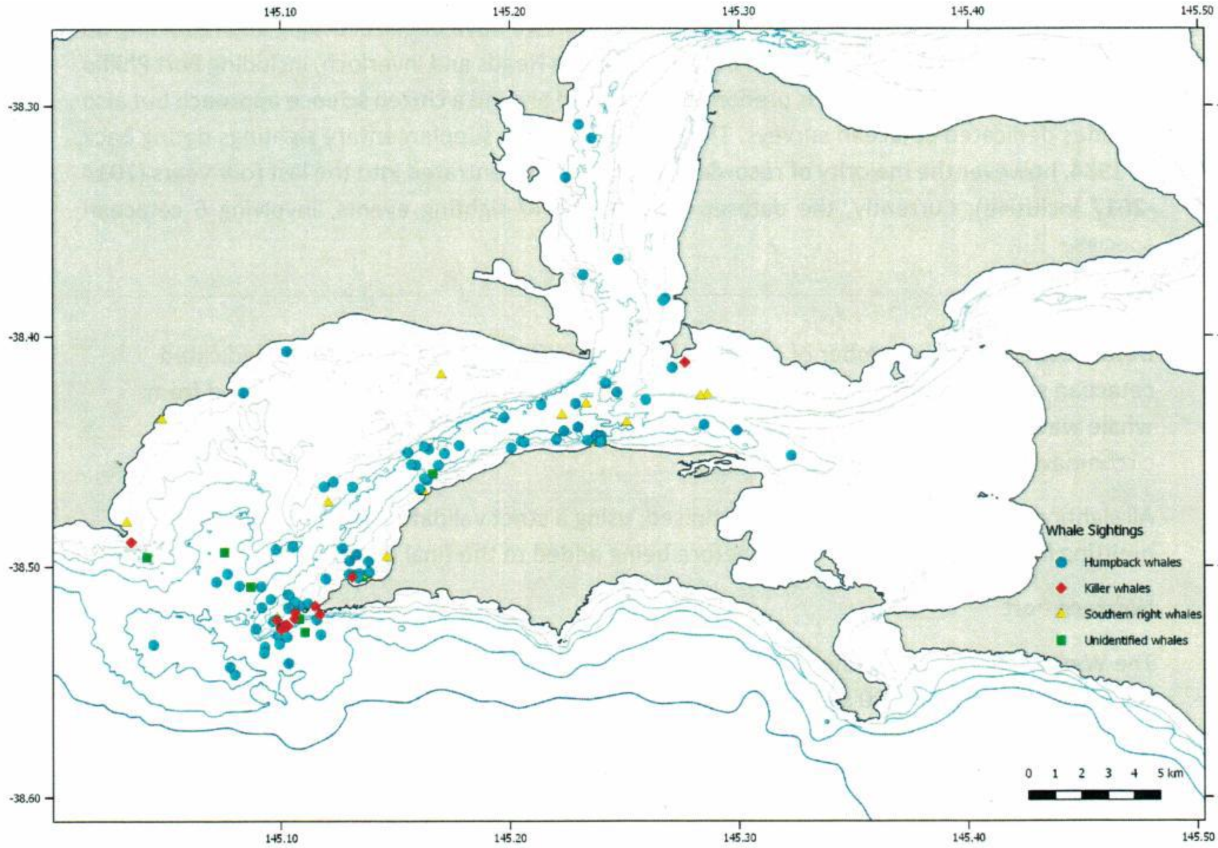


Figure 7-33. Whale Sightings in Western Port – 2014-2017

Figure 7-34 shows aggregation sites for whales around Australia and the annual migration paths. The aggregation sites are along the coast of Western Australia and Queensland. Humpback whales have migratory paths that extend north and south along the east and west coasts of Australia from the Southern Ocean. Bass Strait is a regular part of the whale migratory path but is not a breeding area. South Right Whales are found around Bass Strait seasonally as they migrate to the warmer water of southern Australia to calve. The main sighting points for Southern Right whales in Bass Strait are from Port Campbell to Portland along the western end of the Strait.

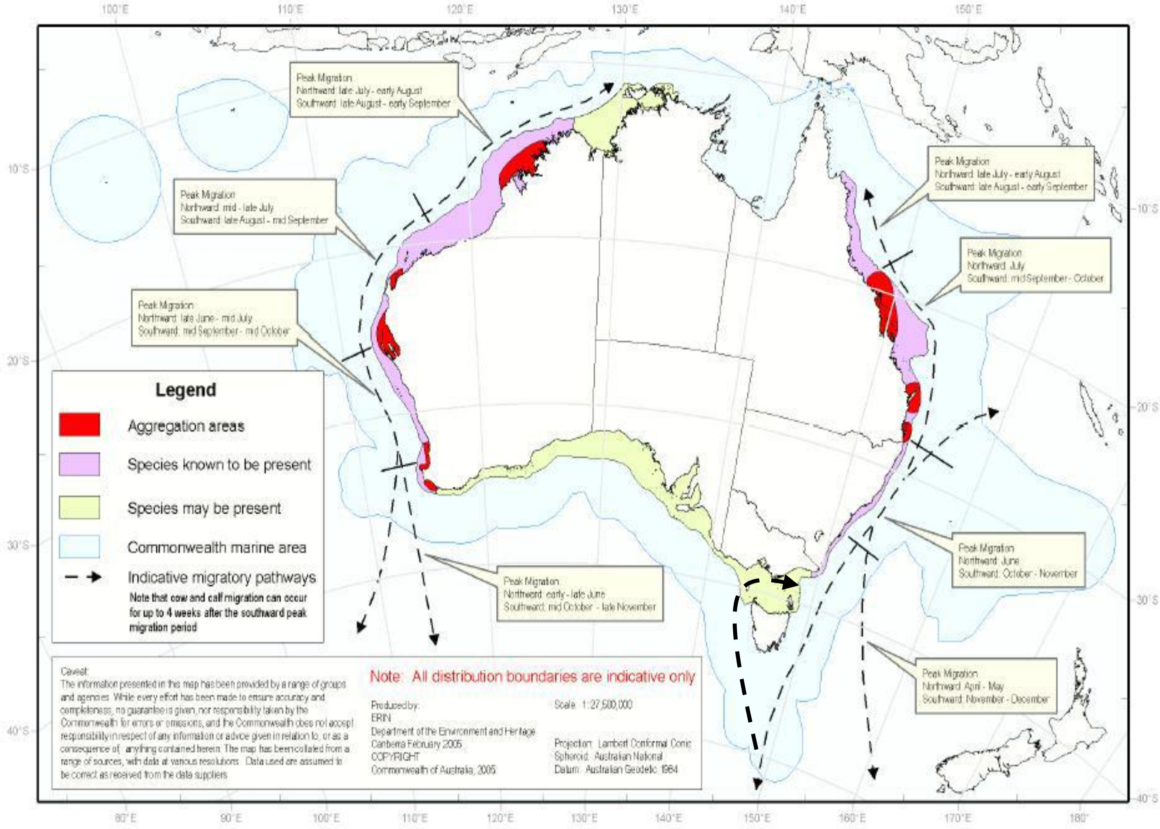


Figure 7-34. Whale Migratory Paths and Aggregation Sites

Vessel Movement in Bass Strait

Figure 7-35 shows the main shipping routes through Bass Strait. Melbourne and Geelong are the two major ports in Victoria, with several other minor ports including Portland, Port Welshpool and the Port of Hastings in Western Port.

Melbourne is the largest port in Australia and has approximately 3,500 vessels using the port each year. Major shipping routes to and from Melbourne extend east and the west, as shown in Figure 7-35. There also are twice-daily vessel travel between Melbourne and Burnie and Melbourne and Devonport. In summary, there is around 7,000 vessel movements in Bass Strait from operations of the Port at Melbourne.

In contrast, the Port of Hastings currently has around 150 vessel movements per year. The number of LNG carriers are predicted to increase from 12 per year at commencement of the Project to about 40 per year, depending on gas demand. The LNG carriers correspond to an additional 80 vessel movements in Bass Strait.

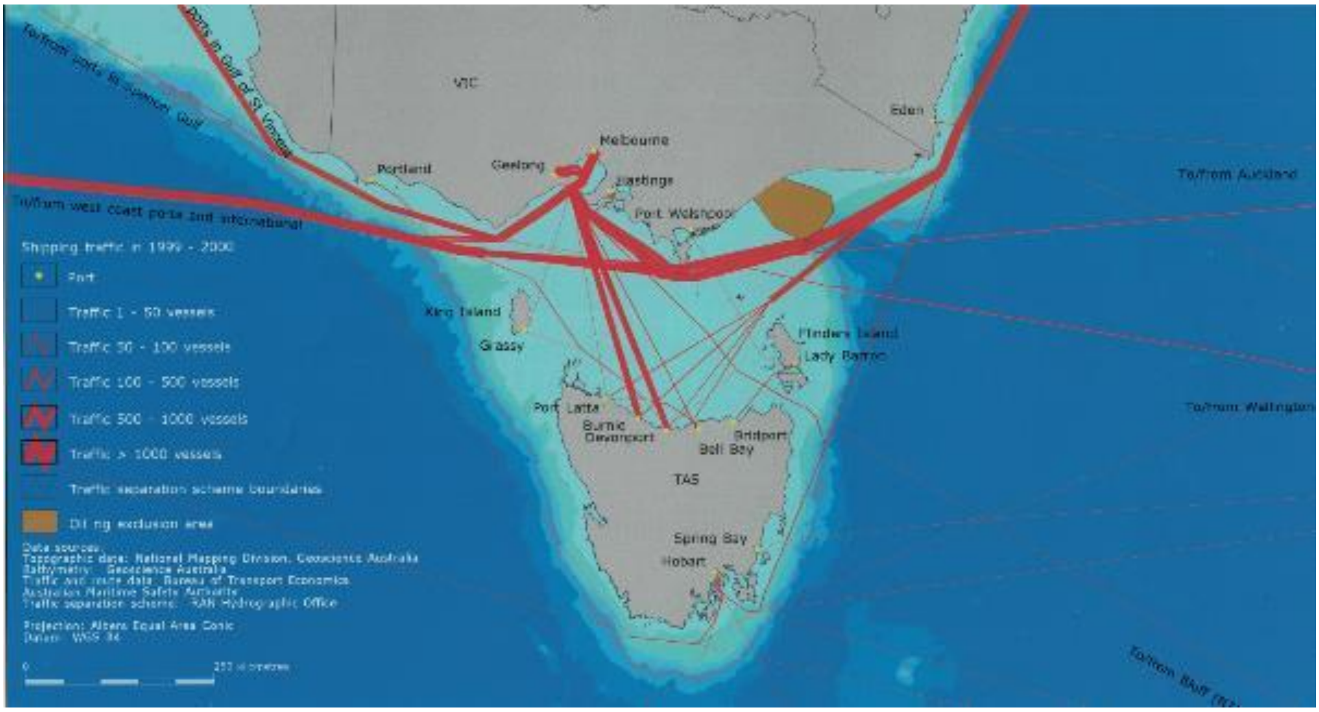


Figure 7-35. Main Commercial Ship Vessel Routes through Bass Strait

Whale strike

Information on whale strikes show that 89 % of events when a whale is seriously injured or killed occur when the vessel is travelling at a speed greater than 14 knots (DoEE, 2016). The Port of Hastings has speed restrictions on vessels in the main shipping channel which effectively reduces the risk of whale strike incidents.

Records of whale strike events show that small vessels such as recreational fishing boats are the leading cause of whale strike in Australian waters. Large vessels, such as the proposed LNG Carriers, are the vessel type with the lowest recorded number of whale strikes, even less than vessels used for tourist whale watching (DoEE, 2016). LNG carriers and other bulk carriers are responsible about 20 % of whale strikes.

There have been approximately 42 reported incidents of vessels in Australian waters striking Humpback Whales from 1997 to 2015 (Peel et al, 2016). That corresponds to an average of 2.3 whale strikes per year. As there were an average of 60,000 commercial vessel movements in Australia per year, the risk of a whale strike by a commercial vessel was approximately 1 in 100,000 vessel movements. The proposed up to 40 LNG carriers per year would have a combined 1 in 2,500 risk of a whale strike.

Operations of LNG carriers would be in accordance with Part 8 of *the EPBC Regulations (Interacting with Cetaceans and Whale Watching)*. The risk would be further reduced by having a 9-knot maximum speed between buoy 31 and buoy 35 in Western Port.

A few whales visit Western Port during their seasonal migrations. These same whales are at risk of whale strike from thousands of ships and recreational vessels in Bass Strait waters and tens of thousands of vessels in Australian waters generally. The increase in likelihood of strike of whales resulting from the addition of up to 40 LNG carriers to the existing and future shipping traffic in these areas is not significant.

Whales within Western Port are mostly seen in the Western Entrance channel. These represent a small proportion of the stocks of any species, but individuals are at risk from vessel strike. However, as there are variably small numbers of whales during the migratory months and less than four LNG carriers per month (less than 8 LNG carriers/hour) present in the Western Entrance channel, the likelihood of one of the LNG carriers seriously injuring or killing a whale is ***unlikely.***

The consequence to the population of any whale species of an LNG carrier strike is ***minor*** (for the whale population). According to the risk matrix in Section 4.0, the combination of rare likelihood and minor consequence results in a risk rating of **Low**.

Underwater noise from FSRU operations

A separate assessment of the potential impacts of underwater noise generated by FSRU operations on marine fauna receptors has been carried out and is appended to this report at Annexure I (Underwater noise impact assessment).

The findings of this impact assessment conducted by Jasco can be summarised as follows. The planned operations of the FSRU at Berth 2 would contribute to the soundscape in this port area 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 white sharks or Australian grayling) and little penguins are at risk from the planned operations as the Gas Import Jetty.

7.11.6 Summary of Biological Disturbance Risks

Table 7-29 provides a summary of the risk assessment as described in the sections above. It can be seen that risks ME49 to ME53 are rated as low and very low.

Table 7-29. Summary of Biological Disturbance Risks

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 49	Marine Pest Introduction- FSRU	FSRU introducing marine pest species when it arrives to Western Port	FSRU has appropriate antifouling system, is cleaned, inspected and follows relevant regulations	Compliance with the environment management plan and regulations or policies	Moderate	Rare	Low
ME 50	Marine Pest Introduction- LNG carrier	LNG carriers introducing marine pest species when entering Western Port	LNG Carriers have appropriate antifouling system, and are cleaned, inspected and follow relevant regulations	Compliance with the environment management plan and regulations or policies	Moderate	Rare	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 51	Aggregation of Marine Fauna	Increased food supply from damaged biota and increased light causes unnatural marine fauna aggregation.	Exclusion zone around FSRU	Policing of exclusion zone	Negligible	Almost certain	Low
ME 52	Whale Strike	LNG Carriers collide with whales	FSRU and LNG carriers will comply with the maximum allowed vessel speeds and comply with operational instruction if a marine mammal is encountered.	No additional mitigation measures identified	Minor	Unlikely	Low
ME 53	Underwater noise from FSRU operations	Underwater noise generated by operation of the FSRU causes injury or disturbance to marine biota	Risk is low and does not require mitigation	Initial risk was low and so no further mitigation was needed	Minor	Unlikely	Low

7.12 Potential Accumulated Impacts of Key Risks

It is important to understand how the effects of the Project would interact with the marine environment over time to assess potential for accumulated impacts. The accumulated impacts has been assessed for the four key issues of the FSRU operation: (1) the discharge of cooler seawater from the regasification process, (2) the discharge of chlorinated seawater generated by electrolysis in the FSRU, (3) entrainment of plankton by the two main seawater intake sea chests on either side of the FSRU and (4) physical changes. The assessment uses the modelled predictions for when the FSRU is operating in open loop regasification mode.

7.12.1 Cooler Seawater Discharge

As described in Section 6.0, the cooler seawater discharges from the FSRU are rapidly mixed at times of medium to strong tidal currents, but accumulate as a pool on the seabed under the vessel(s) for the period over slack water. Once the currents increase with the flood and ebb tides, the discharge plumes disconnect from the pool and return to a mixed stream at mid-depth, while the pool on the seabed is eroded and mixed vertically and laterally. The pool of cooler seawater can only form at slack water and is eroded by the currents between successive slack water events. Thus, pooling would extend for less than the hour. When pooling does not occur, the plumes are effectively diluted and do not reach the seabed. Therefore, cooler seawater cannot accumulate over a long period but as series of short-term events every slack water.

The regional model predictions show that there is no continual cooling of waters at the seabed in the Project Area. At the bay-wide scale, heat fluxes are dominated by exchanges with the ocean and the atmosphere (on diurnal and seasonal cycles and during events such as storms) so that the dispersed cooler seawater has a local effect but a negligible large scale or cumulative effect on the seawater temperature in the remainder of the bay.

Assuming the cooler seawater mixes over an area of 8 km north/south by 1.5 km east/west, a seawater temperature reduction of 0.015^{o}C in the waters within this zone would alter the heat balance to increase input to the extent necessary to balance the FSRU cooler seawater input. This is approximately equal to the annual increase in seawater temperature due to global warming (0.015^{o}C per year).

7.12.2 Chlorine Produced Oxidants in Seawater Discharge

The electrolysis of natural salts in seawater to prevent biological growth in the FSRU piping results in chemicals known as chlorine produced oxidants (CPO) and trihalomethanes (THM). The toxicity of chlorine derived chemicals in seawater includes CPO and THM, but by convention is measured as the concentration of CPO in terms of chlorine concentration. THM are produced in much smaller quantities than CPO and are much less toxic than CPO.

The CPO that are discharged from the FSRU are diluted and ultimately decay by chemical changes (back to their natural state as chloride and bromide ions) and by escape to the atmosphere (as chlorine, bromine and bromoform which convert water, carbon dioxide and natural salts). The modelling of CPO dispersion as reported in Section 6.0 conservatively assumed that there is no natural decay in the short-term (days) and therefore, the predicted impact area affected by CPO concentrations above the Guideline Value is marginally larger than it would be if a decay factor was applied.

CPO are dispersed and diluted to concentrations less than 6 µg/L in the vicinity of the FSRU and to much lower concentrations elsewhere in Lower North Arm. There would be negligible chlorine in the Western Port beyond Lower North Arm. The CPO created by electrolysis of seawater returns to the chloride (as part of sodium chloride) in seawater in a day or so.

THM and CPO are also produced naturally by marine plants including seaweeds and phytoplankton. They are non-cumulative and are part of the natural marine environment halogen cycle, which naturally regulates CPO and THM concentrations in the marine environment through a series of physical, chemical and biological processes. There is no potential for long-term accumulation of CPO or THM derived chlorine in Western Port.

7.12.3 Entrainment

The plankton found in Western Port and in the vicinity of Crib Point mostly have life cycles between one and three weeks although in cooler weather the life cycle could be a month or more. As there is an average flushing period for the Western Port waters of about 28 days, the plankton in Lower North Arm are replaced in the Bay approximately each month (refer to CEE, 2019). The seawater intake of the FSRU has the potential to entrain plankton from throughout the North Arm and Western Entrance to the Bay. However, as the plankton reproduce very quickly and are continuously flushed out of the Bay and replaced, the entrainment of plankton for a particular month does not affect plankton abundance in the following month. Thus, the effects of entrainment occur over a time scale of weeks and not months or years.

As discussed, Lower North Arm is considered an ecotone between the distinct planktonic community in the Upper North Arm, which are characterised by elevated water column suspended solids concentrations and the open coastal plankton communities of the Western Entrance and Bass Strait, which are characterised by relatively clear waters.

The intake of the FSRU has the potential to entrain holoplankton (permanently planktonic) and meroplankton (seasonal or short-term egg and larval plankton) from throughout the Lower North Arm and, to a much smaller extent, the Upper North Arm and Western Entrance of the bay. However, as the holoplankton reproduce quickly and are continuously flushed out of the bay by tidal exchange and are replaced, the entrainment of plankton for a particular month does not affect plankton abundance in the following month as the seasonal cycle of natural influences (temperature, light, nutrients, food) progress. Even with a catastrophic loss of plankton in Lower North Arm from some short-term perturbation, it is likely that the populations would regrow by re-seeding from the adjacent populations in Upper North Arm and Bass Strait - if the topographic, hydrodynamic, water temperature and water quality (e.g. nutrient conditions) were not permanently altered. This is demonstrated from the similarity in the composition of the zooplankton community, particularly the abundance and seasonal patterns in the keystone zooplankton species *Acartia* spp, in Western Port over the past 50 years.

Meroplankton (including fish and invertebrate larvae) that are most susceptible to entrainment are largely the eggs and larvae of adults that produce huge numbers of eggs and larvae that disperse widely the marine environment. These groups have high natural mortality (death) and loss (transport from suitable environment) rates and, consequently, a low recruitment rate to the adult population. Even the relatively short-term members of the meroplankton are dispersed widely in the strong tidal currents of Western Port. The pools of the adult population for these species are widely dispersed in terms of a single generation and even further in terms of subsequent generations. The proportion of entrainment from these much larger population pools is far less than assessed for the individual zones in this report and even smaller with consideration of population generations. At this level, the on-going considerations of larger scale environmental change outweigh the effects of operation of the FSRU.

Human population pressures are catchment-wide (Melbourne Water 2011) and extend over marine regions. Natural pressures on marine populations (annual variations, long-term changes in climate and sea-level) result in corresponding variations in the marine ecosystem of Western Port (e.g. Morrongiello and Jenkins 2016). Human activities in the catchment affect water quality and topography in Western Port. Fishing pressure on populations affects adult, juvenile and larval populations of targeted fish species (at least). Increased vessel transport spreads exotic species and disease widely over regions. Accelerated climate change results in changes to bioregional boundaries resulting in warm water species extending ranges into previous cool water systems and cool-water species becoming rare or extinct. The cumulative effect of the operation of the FSRU at Crib Point could be assessed against this background of present ecosystem change. However, it is beyond the scope of this report to address this societal-level assessment.

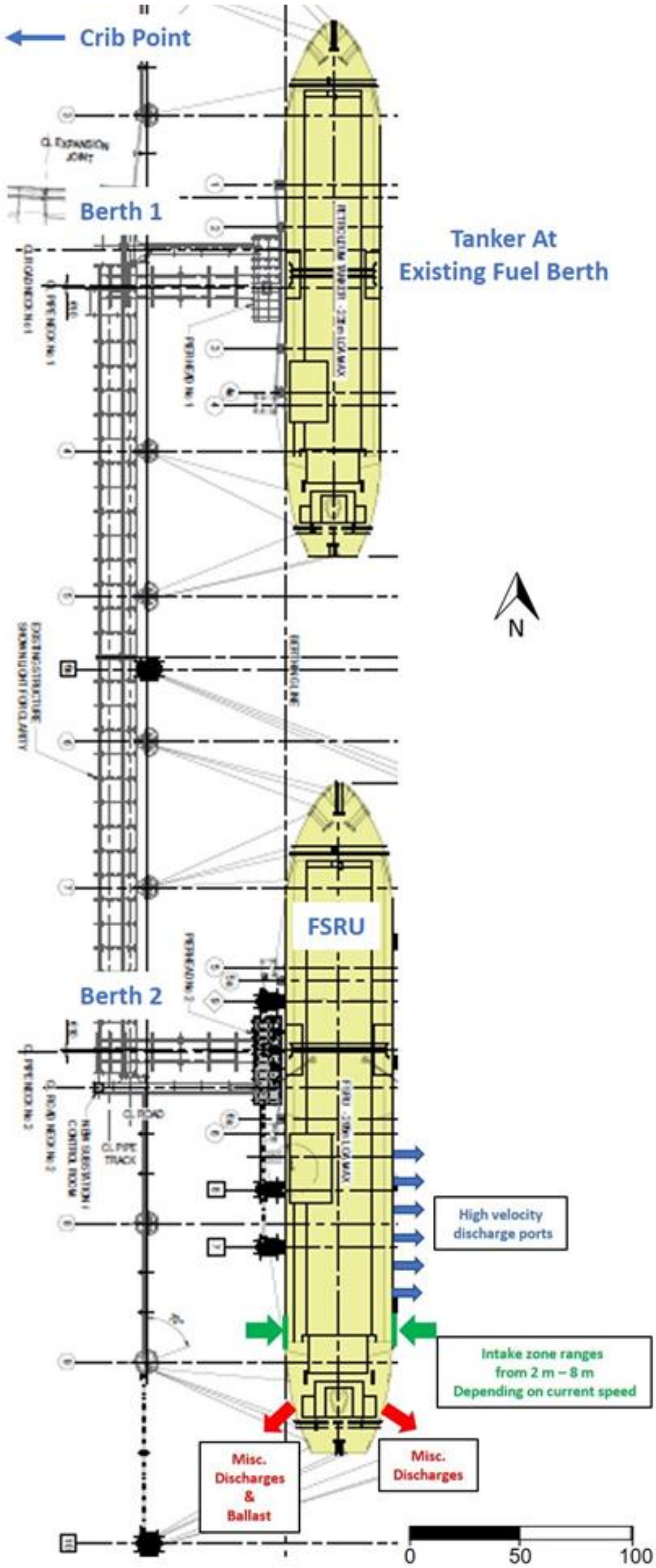


Figure 7-36. Location of FSRU at Berth 2 and Adjacent Vessel at Berth 1

7.12.4 Physical Changes

As described in Section 7.10, local scour is expected under the FSRU, increasing the local depth by about 0.5 m. This scour would occur in the month after mooring of the FSRU and remain relatively stable thereafter. A scour hole would be created where the ballast water jet impinges on the seabed within hours after commencing discharge. It would partly refill in the periods between discharge.

The scour processes occur in a short period and are then relatively stable. It is noted that there is scour next to jetty piles (up to 1 m depth) and also an accumulation of sediment in between groups of piles. The ripples on the seabed in the main channels show that there is consistent movement of sediment up and down the bay. Sandy Point and Somers Beach show large seasonal variations due to sediment movement and the effect of storms. Scour due to the FSRU operations would be localised and limited, so it does not continue to grow over time.

Any areas of seabed scour are remote from the intertidal areas or subtidal seagrass communities. Protected species were not found in the area and are unlikely to occur in the shipping basin. Hence, seabed scour is likely to have minimal effect on biodiversity values in North Arm.

Another physical change due to the presence of the FSRU is that the area of seabed in Western Port under the FSRU would be shaded. The same shading occurs under the 13 existing jetties in Western Port. The zone of seabed shaded by the FSRU is well offshore from the main Crib Point jetty (apart from Berth 2) as shown in Figure 7-36. Infauna under the FSRU would adjust within weeks to months to the altered physical conditions.

It should be noted that the seabed in the shipping basin (including Berth 2) was dredged in the mid-1960s. Marine biological studies documented in Section 5 show that the modified seabed in the shipping basin is uniform in character and the composition of the invertebrate infauna and epibiota community is also relatively uniform throughout the shipping basin compared to the patchiness elsewhere in North Arm.

8 Conclusion

The potential impacts of the Project on water quality and marine ecology in Western Port have been assessed in this report. The outcomes of this assessment are summarised in this Section. The outcomes include recommended mitigation measures to reduce potential impacts of the Project on the marine environment, and a marine monitoring program to verify that the predicted outcomes are met in practice, or management actions are taken accordingly.

8.1 Impact Assessment Summary

The Project involves mooring and operating a floating storage and regasification unit (FSRU) at Berth 2 of Crib Point Jetty. The FSRU would be approximately 300 m long by 50 m wide with capacity to store 170,000 cubic metres (m^3) of LNG.

LNG would be brought to the FSRU in LNG carriers that would berth alongside the FSRU for 24 to 36 hours, depending on the capacity of the carrier, and transfer the LNG to the FSRU through flexible cryogenic hoses. The FSRU would store the LNG as a liquid and convert the LNG into natural gas by heating the LNG using seawater or gas-fired boilers (a process known as regasification).

Following regasification, the natural gas would be transferred through a gas pipeline along the jetty from the FSRU to the Crib Point Receiving Facility. The Crib Point Receiving Facility would include facilities to inject odorant and nitrogen (as required) into the natural gas. The gas would flow along a new pipeline from Crib Point to Pakenham and enter the Victorian gas network.

8.1.1 Construction Impacts

The key construction activities for the Project relevant to the marine environment include:

- Mooring and commissioning the FSRU at Crib Point Jetty and connecting it to the MLAs prior to operation; and
- Installation of Jetty Infrastructure on the Crib Point Jetty, including MLAs, gas piping mounted to the jetty, electrical and instrumentation equipment and a firefighting system.

Construction activities at Crib Point are minor in extent as the FSRU would be constructed overseas and brought to Western Port ready to operate at the existing Crib Point Jetty (Berth 2). There are no FSRU construction issues to be addressed in this assessment.

Crib Point Jetty was constructed in the 1960s with capacity for docking petroleum product transport vessels and installation of product loading and unloading pipes. The modifications to be made to the existing jetty as part of the project, include: a gas pipeline to be installed on the existing pipe rack and the installation of Marine Loading Arms, and are minor in extent and duration. The jetty has been used for the import and export of petroleum products from the 1960s to present and has an existing pipe rack.

The Port of Hastings Development Authority will continue to be responsible for port operations and for maintenance of the jetty and also will be responsible for maintenance and minor upgrades of port facilities. The Victorian Regional Channels Authority will continue to administer the shipping channel.

8.1.2 Operation Impacts

A detailed investigation was made of the potential risks to the marine environment from the operation of the Project and 53 individual risks were identified and are assessed in this report.

This section summarises the risks, together with the risk pathway, initial and additional mitigation measures, and the residual risk rating after the mitigation measures.

The main risks to the marine environment during the operation of the FSRU are:

- Discharge of chlorine-produced oxidants (CPO) and products from the electrolysis of seawater used to control biofouling in the piping network and heat exchangers on the FSRU;
- Discharge of seawater colder than ambient, and also discharge of seawater warmer than ambient, from alternative modes of operation on the FSRU; and
- Entrainment of plankton and other small biota in seawater taken into the FSRU for warming the LNG from a very cold liquid to a gas at ambient temperature, and other purposes.

8.1.3 Extent of Impacts

A key outcome from the modelling and assessment of chlorine and seawater temperature risks for the marine environment is the extent of the predicted area above the chlorine (CPO) and seawater temperature Guideline Values. These comprise the area in which exceedances of the Guideline Values are predicted to occur. The area above the temperature Guideline Value would cover 20-ha while the area above the chlorine Guideline Value would cover 5 ha. In both cases, the areas extend around the FSRU over an area that is within the defined Port of Hastings.

The 'worst-case' scenario for temperature and chlorine would occur when the FSRU is operating in open loop at peak regasification rate (i.e., all three regasification trains are operating) with the largest seawater discharge rate, and a LNG carrier is berthed adjacent to the FSRU. The LNG carrier obstructs the discharge ports on the starboard side of the FSRU, decreasing the efficiency of mixing of the discharge plumes.

For all discharge scenarios, the predicted extent of the area above temperature and chlorine Guideline Values is limited to the shipping basin and ship berthing areas within the Port of Hastings boundaries. This comprises seabed that has previously been dredged and is regularly subject to sediment resuspension by propeller wash from existing shipping activities at Crib Point jetty.

The area above the chlorine Guideline Value for the worst-case scenario covers the area in which the time-averaged chlorine level is predicted to exceed 6 µg/L. The area extends for approximately 300 m north/south and 160 m east/west from the FSRU discharge ports, over an area of 5 ha. Most of this area is directly under the FSRU and the LNG carrier.

The seabed biota in the area above the chlorine Guideline Value would also be affected by the combined effect of the shading caused by the two vessels (an around of around 3-ha), the local scour due to the discharges and the sediment resuspension due to docking and departures of the LNG carriers and associated tugs (see Section 7) and the change is seawater temperature.

The area above the temperature Guideline Value, where the short-term temperature change is predicted to exceed 0.5°C from ambient, extends for approximately 800 m north/south and 250 m east/west of the FSRU, over about 20-ha under and near the FSRU and the LNG carrier, and adjacent to the jetty of Berth 2 and the adjacent ship turning basin.

Figure 8-1 shows the combined area above the chlorine and temperature Guideline Values in the port area.

Figure 8-2 shows the combined area above the Guideline Values in a wider context, in the context of the width of North Arm.

Figure 8-3 shows the combined area above the Guideline Values in the context of the whole of Western Port. In each of these figures, the outer extent of the predicted areas represents where the Guideline Value for temperature would be exceeded. The area where the Guideline Value for chlorine (0.6 µg/L time-averaged) is predicted to be exceeded is smaller, and contained within the combined areas above temperature and chlorine Guideline Values shown in Figure 8-1 to Figure 8-3.

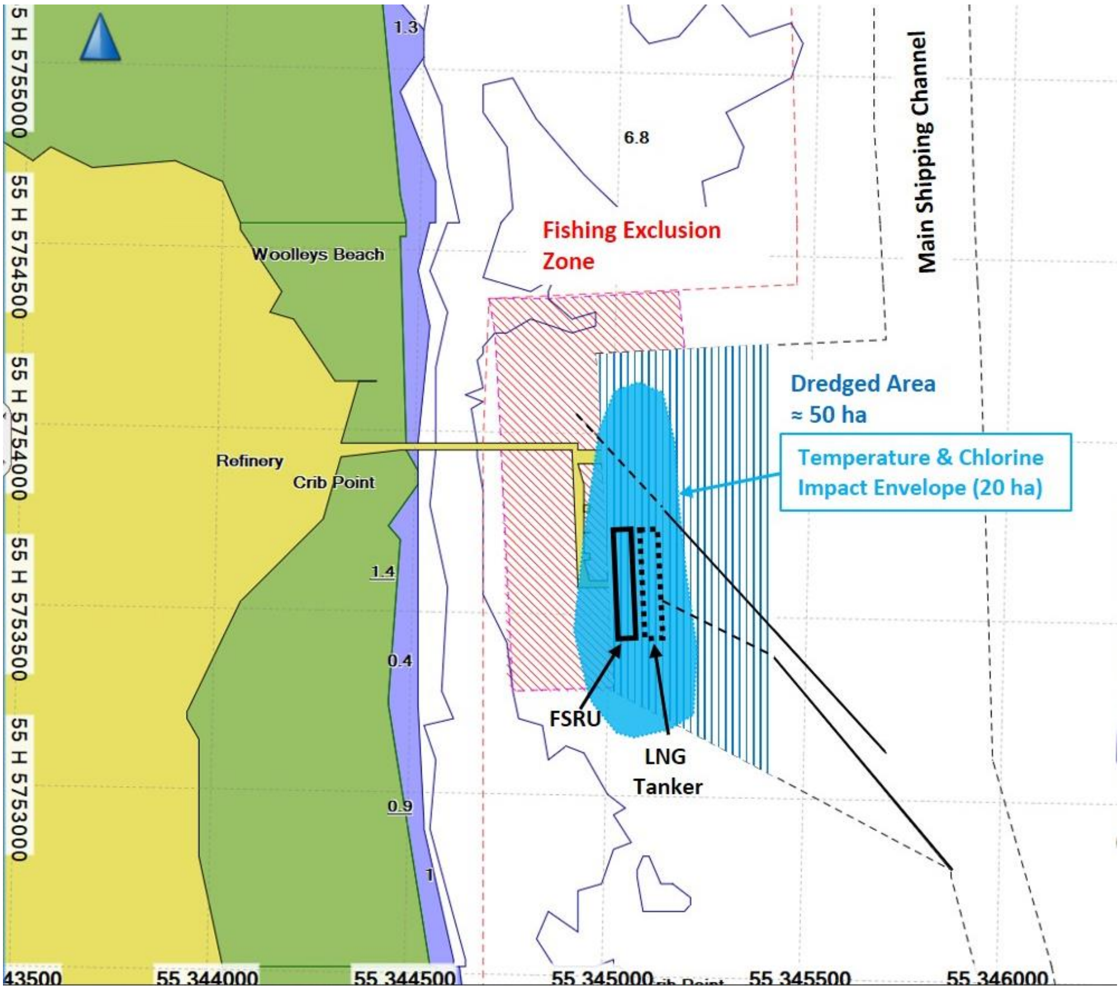


Figure 8-1. Predicted Combined area above Temperature Chlorine Guideline Values in Port of Hastings – 20 ha

It is apparent from Figure 8-1 to Figure 8-3 that the predicted combined areas above the Guideline Values for CPO and temperature differential is localised to the Port area, and well separated from the shallow edges of North Arm, all seagrass and mangrove areas, all of the northern area of Western Port, and all areas used by wading birds.

In summary, in the worst-case scenario, the area of potential impact for residual chlorine and seawater temperature change extends over 20-ha around the proposed FSRU location. Mangroves, saltmarsh, seagrasses, subtidal reefs and waterbirds (including wading birds) are not impacted by the seawater discharge associated with the seawater usage of the FSRU.

Peak gas production is only expected to occur for 30 days per year and typically through winter when gas demand is high. Therefore, the likelihood of operating at peak production

while an LNG carrier is moored alongside the FSRU is only likely to occur a few times a year (if at all).

Table 8-1 summarises the likelihood and consequence ratings of cooler seawater or chlorine affecting various habitats and species groups, to establish a risk rating. These risk ratings are calculated using the worst-case discharge and plume blocking scenario. The likelihood of these impacts occurring would be lower under other modelled scenarios, such as when an LNG carrier is not berthed adjacent to the FSRU and therefore mixing and dilution is more readily achieved, and when the FSRU is operating at lower gas production rates (and therefore the seawater intake and discharge rates are smaller).

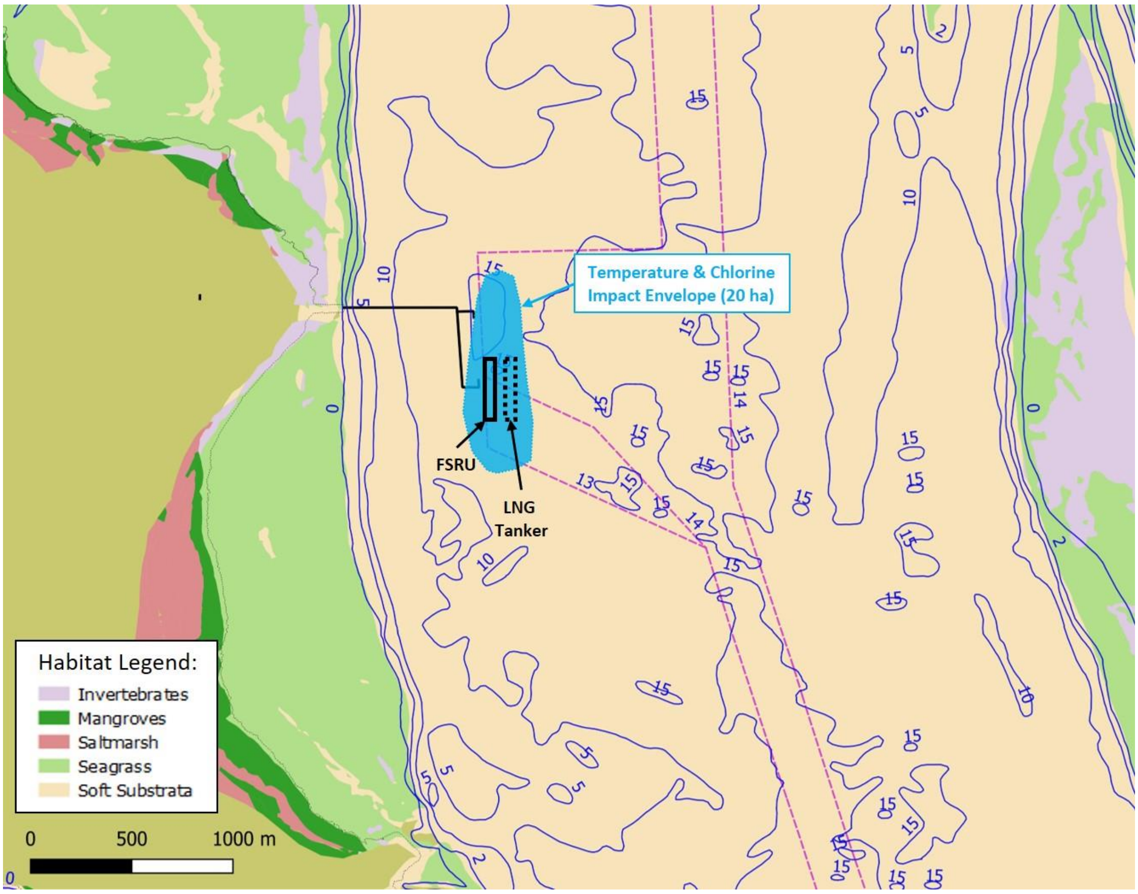


Figure 8-2. Combined 20-ha area above Temperature and Chlorine Guideline Value in North Arm

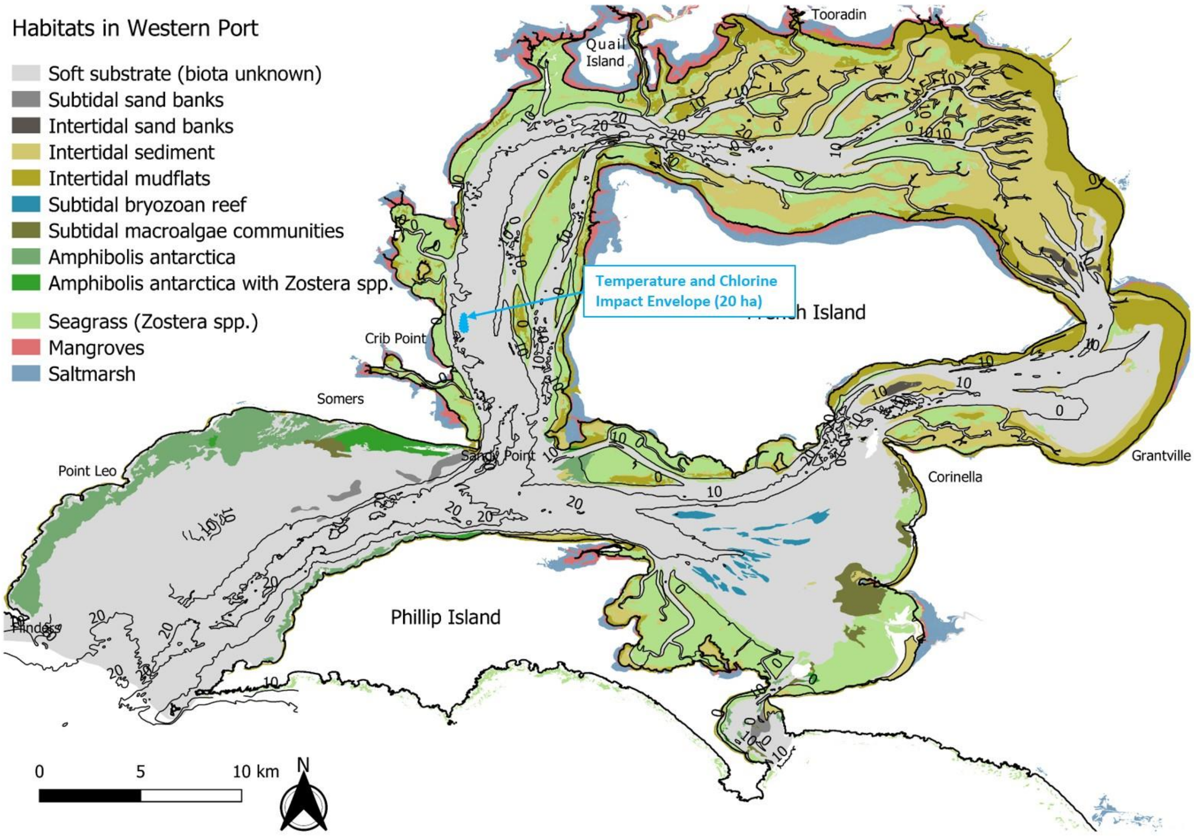


Figure 8-3. Combined area above Temperature and Chlorine Guideline Value in Western Port

Table 8-1. Summary of Impact Assessment for Western Port Habitats and Species

Habitats and Species Groups	Impact assessment outcome	Reasoning - Consequence / Likelihood	Residual Risk
Saltmarsh and mangroves	No impact because cooler seawater and chlorine produced oxidants do not reach mangroves and saltmarsh	The closest area of saltmarsh and mangroves is approximately 420 m from the area above temperature Guideline Value. The likelihood of cooler seawater or residual chlorine reaching the area is rated as **rare** and the temperature difference would be well within any guideline value by the time it reached that area meaning the consequence is rated as **negligible**.	Very Low

Habitats and Species Groups	Impact assessment outcome	Reasoning - Consequence / Likelihood	Residual Risk
Intertidal mudflat invertebrates	No impact because cooler seawater and chlorine produced oxidants do not reach intertidal mudflat zone	The nearest intertidal benthic communities are over 500 m west of the proposed FSRU location. The likelihood of cooler seawater or residual chlorine reaching mudflat habitats is rated as **rare**. Due to the distance of intertidal mudflat habitats from the proposed FSRU location, the temperature difference would be well within any guideline value by the time it reached the habitat, meaning the consequence is rated as **negligible**.	Very Low
Intertidal and subtidal seagrasses	No impact because cooler seawater and chlorine produced oxidants do not reach seagrasses zone	The closest seagrass vegetation is located 450 m to the west of the proposed FSRU location. All seagrass areas are well away from the combined area above temperature and chlorine Guideline Values. The likelihood of cooler seawater or residual chlorine reaching the seagrass vegetation is rated as **rare**. The temperature difference would be well within any guideline value by the time it reached the seagrasses vegetation meaning the consequence is rated as **negligible**.	Very Low
Benthic subtidal invertebrates	No impact for infauna population in North Arm as a whole, but localised impact on infauna within the area above combined Guideline Values in the port area.	Infauna were found near the Crib Point Jetty (100 – 300/L sediment). The benthic habitats and species present at Crib Point Jetty (Berth 2) are widely represented in the Lower North Arm over an area of about 36,000 ha. While the likelihood is rated as **almost certain,** the consequence of alteration of benthic communities (in about 20-ha) due to discharge of cooler seawater and residual chlorine is assessed as **negligible**, in terms of changes to the ecological processes and nutrient and carbon cycles.	Low for infauna in port area Very low for infauna elsewhere in Western Port
Waterbirds	No impact due to localised change in water quality	Waterbirds are widely distributed throughout Western Port. Crib Point is not a significant part of their habitat. Cooler seawater sinks to the seabed and is not accessible to birds. Likelihood rated as **rare** and consequence is rated as **negligible**.	Very Low

Habitats and Species Groups	Impact assessment outcome	Reasoning - Consequence / Likelihood	Residual Risk
Pelagic and demersal fish	Negligible impact on fish populations in North Arm. Potential local effects for fish populations under Crib Point Jetty Berth 2, in conjunction with effects of shading, avoidance or attraction.	Pelagic and demersal fish species move around in Western Port and some will be in the vicinity of the FSRU where they could have direct contact with the cooler seawater and residual chlorine, as the discharge plume dilutes and spreads out. Although the discharge plume extends over a very small area in the context of Western Port, the potential for contact of fish with the discharge is rated as **almost certain**. Given that fish are very mobile and have the opportunity and ability to move away quickly from the discharge area but prefer to stay near the interface of the discharge plumes and ambient seawater, the consequence of the risk is rated as **negligible**.	Low
Plankton	No impact on plankton populations in North Arm. Potential very small effects for plankton populations passing Crib Point Jetty (Berth 2).	Field sampling of zooplankton and phytoplankton in the North Arm established that plankton is abundant and widely distributed through Western Port and around Crib Point. The likelihood of direct contact with the cooler seawater or residual chlorine is rated as **almost certain**. Only a very small percentage of plankton is predicted to be impacted by the seawater discharge compared to the high abundance of plankton in North Arm and Western Port generally resulting in a consequence rating of **negligible**.	Low
Subtidal reef	No impact because cooler seawater and chlorine produced oxidants do not reach subtidal reef	The main examples of subtidal reefs in Western Port are Eagle Rock and Crawfish Rock located approximately 12 km north of Crib Point Jetty. Given the distance, the likelihood of cooler seawater or residual chlorine reaching the subtidal reef is rated as **rare**. The temperature difference and chlorine concentrations would be well within any guideline value by the time it reached the reef, meaning the consequence is rated as **negligible**.	Very Low
Migratory birds	No impact because cooler seawater and chlorine produced oxidants do not reach migratory birds' habitat	Assessment of potential impacts on migratory birds is provided in Biosis Technical Report B: *Terrestrial and freshwater biodiversity impact assessment*. These birds are widely distributed in Western Port and Crib Point Jetty is not a significant part of their habitat. Likelihood of effect is rated as **rare** and consequence is rated as **negligible.**	Very Low

Habitats and Species Groups	Impact assessment outcome	Reasoning - Consequence / Likelihood	Residual Risk
Penguins and seals	No impact as penguins and seals are rarely recorded to be within the vicinity of Crib Point and can actively avoid the cooler seawater and chlorinated water plume	Penguins and seals live mainly at western entrance and feed out to sea. Thus, North Arm is not a significant part of their habitat and any individuals that are within the Crib Point vicinity can actively avoid the discharge plume. Likelihood of effect is rated as **rare** and consequence is rated as **negligible.**	Very Low
Protected Areas (Ramsar)	No impact because cooler seawater and chlorine produced oxidants do not affect the defined Ramsar values	There is a significant distance between the combined area above the temperature and chlorine Guideline Values and the various habitat types recognised under the Ramsar convention. Due to the distance, the likelihood of there being any effect from the seawater discharge on the subtidal reef or seagrass, estuarine areas, intertidal mud flats, intertidal forested wetlands, salt marshes and mangroves is rated as **rare**. The only part of the Ramsar site that is potentially affected by the proposal are the waters of North Arm within the combined area above the Guideline Values. All of these waters are part of the declared and operating Port of Hastings, used by around 125 commercial vessels each year and the seabed is subject to periodic dredging. Therefore, the consequence of any potential impact from the Project is **minor**.	Very Low
Protected areas (Other)	No impact because cooler seawater and chlorine produced oxidants do not affect the Marine National Parks	Western Port has several Marine National Parks with the closest to Crib Point being the Yaringa Marine National Park approximately 12 km away. Given the distance between the combined area above the temperature and Guideline Values and the subtidal reef at Yaringa, the likelihood of there being any effect from the discharge of cooler seawater or residual chlorine on the Marine National Parks is rated as **rare**. The large distance between the FSRU and Yaringa means that several tidal cycles would be involved in the travel time and cooler seawater and residual chlorine would have dispersed and decayed to zero before it reached the protected area. Therefore, the consequence is rated as **negligible**.	Very Low

Habitats and Species Groups	Impact assessment outcome	Reasoning - Consequence / Likelihood	Residual Risk
Protected species	No impact because mobile species can actively avoid the plumes and there are no known listed threatened ghost shrimp present within the area above combined Guideline Values	There are several protected species that have potential to come within the vicinity of Crib Point including whales, turtles, fish and Ghost Shrimp. Ghost Shrimp are rare, and were not found to be within the area above the combined temperature and chlorine Guideline Values in targeted surveys. Larger species are not expected to be close to the FSRU and any contact with the area above the combined Guideline Values is likely to be for very limited periods of time due to their ability to actively avoid the plumes. As a result, they have very low exposure time. The highest likelihood of impact is rated as **possible** and the consequence is rated as **negligible,** due to the low exposure time.	Low

With implementation of the recommended mitigation measures, all the potential risks associated with both cooler and warmer seawater discharges from the FSRU into Western Port are ranked as either very low or low and are not considered to have adverse impacts on the marine environment of Lower North Arm or more widely in Western Port. The effects of the seawater discharge will be localised within 20-ha and would occur within the declared and operating Port of Hastings, which is used by approximately 150 commercial vessels each year and where the seabed is subject to periodic dredging.

8.1.4 Entrainment of Plankton and Other Small Biota

During operation, the FSRU would take in large volumes of seawater from Western Port for the heat transfer process associated with regasification, and for other purposes such as ballast water, firefighting system and freshwater production. The seawater is taken into the FSRU through sea chests on the sides of the FSRU and chlorinated by an electrolytic process before being used on the vessel and discharged through the discharge ports back to Western Port.

The potential adverse effect of seawater intake is entrainment of smaller marine organisms (very small fish, zooplankton and phytoplankton, drifting eggs and larvae) in the central part of the water column adjacent to the intake. The effects of entrainment are assessed in terms of the amount of seawater that passes through the FSRU over representative time periods. This enables subsequent assessment of the scale of effects on the marine ecosystem in relation to the volume of North Arm and the biota most affected according to their planktonic population replacement rate or planktonic larval period.

The effect of entrainment on plankton and other small biota was modelled using a combined mathematic hydrodynamic and particle dispersion model. Model particles simulating planktonic biota were released from various ecological zones in Western Port and were tracked on a daily basis over a 28-day period. (refer to Section 6.0 for a detailed description of hydrodynamic modelling).

The fate of the particles was recorded in terms of:

1. Percentage of particles that were entrained in seawater taken into the FSRU;

2. Percentage of particles dispersed into other ecological zones in Western Port;
3. Percentage of particles flushed to Bass Strait; and
4. Percentage of particles remaining in the ecological zone where they started.

The rate of particle entrainment depends on how close the modelled zone is to the FSRU. The highest predicted rate of plankton entrainment for any modelled zone (0.63% of the total population after 21 days or about 0.03% per day) is from the zone covering the western side of Lower North Arm including Berth 2 at Crib Point Jetty and the proposed FSRU location. This zone does not include the mudflats and near shore waters to 6 m depth which are subject to a different hydrodynamic regime.

In comparison, the zones for the western entrance close to Bass Strait have a very low rate of entrainment (only 0.04% after 21 days or less than 0.002% per day) but have a very high rate of flushing (82 % of the total population after 21 days).

The rate of flushing to Bass Strait depends on how close the zone is to Bass Strait. The plankton in the zone in the north of Western Port are flushed at a very slow rate compared to those closer to Western Port entrances (only 7% after 21 days). This finding shows a hydrodynamic basis for the different plankton species and abundance distribution in the north of Western Port (where the flushing rate is lower) compared to those near the Western Entrance (where the flushing rate is higher).

Plankton populations in the Western Entrance are generally representative of those in Bass Strait. There is always a general plankton transport process operating along the axis of the entire North Arm with plankton populations from the north of Western Port being gradually flushed to Bass Strait. There is a high rate of mixing from zone to zone within 7 days. This result shows that there is substantial mixing between different sectors of Western Port, and that the loss of plankton in one zone would be quickly made up by plankton mixing in from adjacent zones.

Table 8-2 summarises the percentage of particles and, by inference, the percentage of plankton that would be entrained from various zones in North Arm. Entrainment is predicted for various rates of gas production and with the FSRU operating in open loop and closed loop mode. The results are shown for periods up to 28 days. The yellow highlighting shows the predicted entrainment for peak operations in open loop. This modelled scenario has been used for the purposes of assessing potential impact, to present a ‘worst-case’ assessment. The green highlighting indicates other potential operating modes on the FSRU (open loop at a lower gas production rate and closed loop). The blue highlighting shows the predicted loss of small marine biota to Bass Strait via flushing out of North Arm from Zone 2.

For the peak rate of production, the predicted rate of entrainment is 0.22 % after 14 days or 0.40 % after 28 days. This corresponds to an additional mortality rate for plankton of 0.014 % per day (assuming complete loss of survival of all plankton passing through the chlorination process and piping system in the FSRU).

The predicted small loss of plankton due to entrainment would result in a small increase in opportunity for the rest of the population, in terms of available resources. Thus, to a partial extent, there would be a compensating increase in growth rates by the rest of the population to take advantage of the available resources.

Table 8-2. North Arm Entrainment Rate Predictions for Various Production Rates

North Arm	Peak Production open loop 471,000 m^3/d	Average Production open loop 315,000 m^3/d	Closed loop 187,000 m^3/d	Loss to Bass Strait
Number of Days	**Entrainment**	**Entrainment**	**Entrainment**	**Flushed from Zone 2**
1	0.04 %	0.03 %	0.02 %	0.4 %
7	0.13 %	0.08 %	0.05 %	2.7 %
14	0.22 %	0.14 %	0.09 %	7 %
21	0.30 %	0.20 %	0.12 %	18 %
28	0.40 %	0.27 %	0.16 %	26 %

The rate of entrainment for North Arm is small relative to natural mortality. As a result, there would be only a slight reduction in abundance amongst plankton species and also a slight loss of fish eggs and larvae.

Natural mortality rates for plankton and invertebrate larvae vary from about 5 % per day to more than 20 % per day (or up to 50 % to 95 % loss over 14 days). In contrast, the predicted loss due to entrainment is 0.22 per cent over a 14-day period and unlikely to have a significant effect on abundance or the Western Port ecosystem.

The final column of Table 8-2 shows the predicted rate at which particles (and hence plankton) are flushed from Zone 2 (around Crib Point) to Bass Strait over the periods from 1 to 28 days. The longer the duration, the greater the proportion of plankton that are predicted to be flushed from Western Port into Bass Strait. Over 14 days, 7 % of plankton are lost to Bass Strait, while only 0.22 % would be lost due to entrainment.

Bass Strait plankton would be mixed into Western Port waters by the same dispersion and mixing processes that cause the flushing which, to some extent, would compensate for the loss due to natural flushing.

From a comparison of the rate of entrainment of plankton (in the first three columns in Table 8-2) with the rate of flushing to Bass Strait (in the final column), it is apparent that the rate of entrainment is small relative to the rate of flushing – over 14 days the rate of flushing is 32 times the rate of entrainment, and over 28 days the rate of flushing is 65 times the rate of entrainment.

Small Reduction in Primary Production in North Arm

For the peak regasification operating scenario for the FSRU, potential entrainment impacts are predicted to be small relative to natural mortality and flushing, and unlikely to have significant implications on Western Port's ecosystem. There is a small predicted decrease in primary productivity from phytoplankton in North Arm of up to 0.22 % in a peak production month. Predicted entrainment would be less when the FSRU is operating at lower gas production rates (compared to peak production) as less seawater would be drawn in to the FSRU for the regasification process.

There is no loss of organic carbon or nutrients due to entrainment. The organic carbon and nutrients in the plankton entrained would remain in North Arm and would be cycled by bacteria and infauna.

Effect of Gas Production Rate

Table 8-2 lists the North Arm entrainment rate for durations from 1 to 28 days for three modelled gas production modes on the FSRU: (1) peak production, open loop operations; (2) average production, open loop operations; and (3) closed loop operations.

When comparing the modelled scenarios for entrainment, the predicted decrease in plankton productivity in North Arm of Western Port is:

- 0.22 % in the peak production month, open loop operations (generally winter when gas demand is highest);
- 0.14 % in average production months, open loop operations; and
- 0.09 % in months using closed loop mode.

Compared to the entrainment predictions for the peak modelled scenario, entrainment is predicted to be 34 % lower under the average production modelled scenario and 60 % lower when operating in closed loop.

Effect of Entrainment on Fish Eggs and Larvae

The plankton community in Western Port comprises a range of very small plants (phytoplankton), small animals (zooplankton), fish eggs and fish larvae that drift with the strong and turbulent tidal currents along the main deeper channels in North Arm and in the weaker currents over the subtidal and intertidal areas. The sampling program carried out for this assessment indicates that the plankton community in 2019 varied, with higher abundance in early spring and summer and lower abundance in autumn and early winter.

The predicted entrainment effects from the FSRU on fish larvae would be highest in spring and summer when they are present in large numbers, reflecting the strong seasonal pattern in larval and egg abundance. Spring and summer also coincide with the period when larvae that are most important in terms of conservation, fishing and ecological values are in the water.

The FSRU is expected to operate at the average rate of gas production for most months of the year and the rates of entrainment would be lowest in spring and summer (Table 8-2). To ensure that there is not high entrainment in the peak season for larvae, a limit on seawater use for the regasification process (excluding ballast water and minor users) (over any 14-day period in spring and summer) has been recommended as a mitigation measure.

The likelihood that a significant proportion of fish larvae would be entrained in this period is very small. The fish species that are present in North Arm are highly fecund and common throughout Western Port and elsewhere. Fish larvae and juvenile fish also enter Western Port from other breeding and nursery areas via Bass Strait.

8.1.5 Other Impacts

Other predicted effects from the operation of the FSRU are risks involved with normal shipping activities within the Port of Hastings. Port maintenance and shipping activities are managed under existing Port and State regulations. The Port of Hastings within Western Port is a functioning port with approximately 150 commercial vessels per year. These vessels have the same likelihood of effects as the FSRU and LNG carriers for many of the same risk pathways.

8.2 Residual Risk

A marine biodiversity risk assessment has been carried out as part of the EES. The marine biodiversity risk assessment identified potential Project risks and risk pathways, the potential consequences of impacts on marine ecology and the likelihood of these impacts occurring. Appropriate risk mitigation measures and the resulting residual risk rating where then established.

With implementation of the recommended mitigation measures, and based on the outcomes of the assessment of potential impacts in this assessment report, all risks are rated as low or very low, with the exception of Risk ID ME43 (medium). Thus, the outcomes of the proposal would satisfy EES evaluation objectives for marine biodiversity.

Potential marine impacts on Ramsar values, *Environment Protection and Biodiversity Conservation Act 1999* listed threatened species and migratory species are also described in EES Attachment 1 *Matters of National Environmental Significance* to assess Matters of National Environmental Significance. There is considered to be no significant impact on MNES, as described in the EES chapter describing the assessment of MNES for the purpose of the EPBC Act.

The residual risk for each of the identified risks (Section 7) are summarised in Table 8-3. The table shows the initial mitigation for each risk and any additional mitigation measures that were applied to reduce impacts to an acceptable level.

In finalising this report, the proponents and other members of the team (designers, contractors and other specialists) were consulted to ensure the recommended mitigation measures are achievable and compatible with those proposed by other specialists. These recommended mitigation measures have been refined as a result of these discussions and would be incorporated into the Environmental Management Framework (EMF) to provide assurance regarding the environmental performance of the Project.

For risks relating to normal shipping operations, additional mitigation measures include compliance with the existing Port of Hastings Safety and Environmental Management Plan and relevant regulations as prescribed by the Victorian Regional Channels Authority, any other relevant policies and regulations, and adopting an appropriate monitoring program to assess impacts. Marine speed restrictions imposed by Port of Hastings help reduce the chance of whale strike. Policing the exclusion zone around the FSRU would stop overfishing in the fauna aggregation area (fish will aggregate because of their attraction to discharge jets and to the food supply in the discharge).

Table 8-3. Residual Risk and Mitigations

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 1	**Entrainment**: Mangroves and Saltmarsh	Entrainment of seeds into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 2	**Entrainment:** Intertidal Mudflat Invertebrate Communities	Entrainment of larval biota into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Minor	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 3	**Entrainment:** Intertidal and Subtidal Seagrasses	Entrainment of seeds and propagules into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 4	**Entrainment:** Benthic Subtidal Invertebrate Fauna	Entrainment of eggs and larvae into FSRU	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Minor	Rare	Very Low
ME 5 A	**Entrainment:** Fish eggs and larvae Spring	Entrainment of fish eggs and larvae into FSRU over Spring-Summer	Design of intake, velocity and screens on FSRU.	In spring/summer, limit regasification flow to less than 315,000 m^3/d	Minor	Possible	Low
ME 5 B	**Entrainment:** Fish eggs and larvae Autumn-Winter	Entrainment of fish eggs and larvae into FSRU over Autumn to Winter	Design of intake, velocity and screens on FSRU.	Risk is low and does not require further mitigation	Negligible	Possible	Low
ME 6 NNE	**Entrainment:** Plankton in NNE Zone	Entrainment of plankton into FSRU in NNE Zone	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 6 North Arm	**Entrainment:** Plankton in North Arm	Entrainment of plankton into FSRU in North Arm	Design of intake, velocity and screens on FSRU.	Risk is low and does not require further mitigation	Minor	Possible	Low
ME 6 WPB	**Entrainment:** Plankton in WPB as a whole	Entrainment of plankton into FSRU in Western Port	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 7	**Entrainment:** Protected Areas (Ramsar)	Entrainment impact on values of the Ramsar Site	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Unlikely	Very Low
ME 8	**Entrainment:** Protected Areas (Other)	Entrainment impact on values of the Marine National Parks and other protected areas	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Negligible	Unlikely	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 9	**Entrainment:** Protected Species	Entrainment effect on listed protected species present within Western Port	Design of intake, velocity and screens on FSRU.	Risk is very low and does not require further mitigation	Minor	Unlikely	Low
ME 10	**Cooler Seawater:** Mangroves and Saltmarsh	Cooler seawater discharge plume alters the natural mangrove and saltmarsh habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 11	**Cooler Seawater:** Intertidal Mudflat Invertebrate Communities	Cooler seawater discharge plume alters natural intertidal mudflat invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 12	**Cooler Seawater:** Intertidal and Subtidal Seagrasses	Cooler seawater discharge plume alters the natural intertidal and subtidal seagrass habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 13	**Cooler Seawater:** Benthic Subtidal Invertebrate Fauna	Cooler seawater discharge plume alters natural benthic subtidal invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is low and does not require further mitigation	Negligible	Almost Certain	Low
ME 14	**Cooler Seawater:** Pelagic and Demersal Fish	Cooler seawater discharge plume affects local fish species near FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is low and does not require further mitigation	Negligible	Almost Certain	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 15	**Cooler Seawater:** Plankton	Cooler seawater discharge plume affects local Plankton as they float past the FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	In spring/summer, limit regasification flow to 315,000 m^3/d	Negligible	Almost Certain	Low
ME 16	**Cooler Seawater:** Subtidal Reef	Cooler seawater discharge plume alters subtidal reef habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 17	**Cooler Seawater:** Protected Areas (Ramsar)	Cooler seawater discharge plume impacts values of the Ramsar site	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 18	**Cooler Seawater:** Protected Areas (Other)	Cooler seawater discharge plume impacts values of marine parks and other protected areas	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 19	**Cooler Seawater:** Protected Species	Cooler seawater discharge plume impacts on listed protected species	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Risk is low and does not require further mitigation	Negligible	Possible	Low
ME 20	**Warmer Seawater:** Mangroves and Saltmarsh	Warmer seawater discharge plume alters the natural mangrove and saltmarsh habitats	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 21	**Warmer Seawater:** Intertidal Mudflat Invertebrate Communities	Warmer seawater discharge plume alters natural intertidal mudflat invertebrate communities	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 22	**Warmer Seawater:** Intertidal and Subtidal Seagrasses	Warmer seawater discharge plume alters the natural intertidal and subtidal seagrass habitats	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 23	**Warmer Seawater:** Benthic Subtidal Invertebrate Fauna	Warmer seawater discharge plume alters natural benthic subtidal invertebrate communities	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 24	**Warmer Seawater:** Pelagic and Demersal Fish	Warmer seawater discharge plume affects local fish species near FSRU	High velocity discharge to increase dilution	Risk is low and does not require further mitigation	Negligible	Almost Certain	Low
ME 25	**Warmer Seawater:** Plankton	Warmer seawater discharge plume affects local plankton as they float past the FSRU	High velocity discharge to increase dilution	In spring/summer, limit regasification flow to less than 315,000 m^3/d	Negligible	Almost Certain	Low
ME 26	**Warmer Seawater:** Subtidal Reef	Warmer seawater discharge plume alters subtidal reef habitats	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 27	**Warmer Seawater:** Protected Areas (Ramsar)	Warmer seawater discharge plume impacts values of the Ramsar site	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 28	**Warmer Seawater:** Protected Areas (Other)	Warmer seawater discharge plume impacts values of marine parks and other protected areas	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 29	**Warmer Seawater:** Protected Species	Warmer seawater discharge plume impacts on listed protected species	High velocity discharge to increase dilution	Risk is very low and does not require further mitigation	Negligible	Rare	Very Low
ME 30	**Chlorinated Seawater:** Mangroves and Saltmarsh	Chlorinated seawater from discharge plume alters the natural mangroves and saltmarsh habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from mangroves and saltmarsh so risk does not require further mitigation	Negligible	Rare	Very Low
ME 31	**Chlorinated Seawater:** Intertidal Mudflat Invertebrate Communities	Chlorinated seawater from discharge plume alters natural intertidal mudflat invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from mudflats so risk does not require further mitigation	Negligible	Rare	Very Low
ME 32	**Chlorinated Seawater:** Intertidal and Subtidal Seagrasses	Chlorinated seawater from discharge plume alters the natural intertidal and subtidal seagrass habitats	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from seagrasses so risk does not require further mitigation	Negligible	Rare	Very Low
ME 33	**Chlorinated Seawater:** Benthic Subtidal Invertebrate Fauna	Chlorinated seawater from discharge plume alters natural benthic subtidal invertebrate communities	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Very small zone affected so risk does not require further mitigation.	Negligible	Almost Certain	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 34	**Chlorinated Seawater:** Pelagic and Demersal Fish	Chlorinated seawater from discharge plume effects local fish species near FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Low risk so does not require further mitigation	Negligible	Almost Certain	Low
ME 35	**Chlorinated Seawater:** Plankton	Chlorinated seawater from discharge plume effects local plankton as they float past the FSRU	Use 6 discharge ports design and maintain discharge velocity to increase mixing	In spring/summer, limit regasification flow to less than 315,000 m^3/d	Negligible	Almost Certain	Low
ME 36	**Chlorinated Seawater:** Subtidal Reef	Chlorinated seawater from discharge plume alters subtidal reef habitat	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from subtidal reef so risk does not require further mitigation	Negligible	Rare	Very Low
ME 37	**Chlorinated Seawater:** Protected Areas (Ramsar)	Chlorinated seawater from discharge plume impacts values of the Ramsar site	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from Ramsar wetland habitats so risk does not require further mitigation	Minor	Rare	Very Low
ME 38	**Chlorinated Seawater:** Protected Areas (Other)	Chlorinated seawater from discharge plume impacts values of marine parks and other protected areas	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from marine parks so risk does not require further mitigation	Negligible	Rare	Very Low
ME 39	**Chlorinated Seawater:** Protected Species	Chlorinated seawater from discharge plume impacts on listed protected species	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Area above chlorine Guideline Value well away from segment so risk does not require further mitigation	Negligible	Possible	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 40	**Chlorinated Seawater:** Bioaccumulation of chlorine	Chlorine produced oxidants bioaccumulating in species in the food chain	Use 6 discharge ports design and maintain discharge velocity to increase mixing	Dilution reduces chlorine concentrations at ambient levels, so risk does not require further mitigation	Negligible	Possible	Low
ME 41	Hazardous chemicals, hazardous materials or waste spill / leaks (Construction)	Accidental spills or leaks from chemicals, materials or waste streams into Western Port during construction	Correct handling, usage, storage and disposal of chemicals and wastes, compliance with the Port Operating Handbook.	Compliance with the construction environment management plan, regulations or policies	Minor	Unlikely	Low
ME 42	Hazardous chemicals, hazardous materials or waste spill / leaks (Operation)	Accidental spills or leaks from chemicals, materials or waste streams into Western Port during operation	Correct handling, usage and storage of chemicals and compliance with the Port of Hastings Handbook.	Compliance with the operations environment management plan, regulations or policies	Minor	Unlikely	Low
ME 43	Spills from Vessels	Spills or leaks of fuel, oil or other chemicals from the FSRU or LNG carriers.	Correct handling, usage, storage and disposal of chemicals and wastes, compliance with the Port Operating Handbook.	Compliance with the operations environment management plan, regulations or policies	Major	Rare	Medium
ME 44	Contamination from Hull and Propeller Cleaning	Release of contaminants from FSRU hull and propeller cleaning processes	Correct handling, usage, storage and disposal of chemicals and wastes, compliance with the Port Operating Handbook.	Compliance with the operations environment management plan, regulations or policies	Minor	Unlikely	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 45	Seabed Scour (FSRU)	Alteration of the seabed due to FSRU increasing seabed current and encouraging seabed scour	Proposed FSRU location in dredged area of Port of Hastings	Compliance with the environment management plan and regulations or policies	Negligible	Likely	Low
ME 46	Seabed Scour (LNG carriers and Tugs)	Alteration of the seabed from higher velocity water movement from tug propellers	Operations in defined port area, within dredged channel and turning basin. PoHDA maintaining berth at depth of 13 m	Compliance with the environment management plan and regulations or policies	Negligible	Likely	Low
ME 47	Vessel Grounding	Unplanned grounding of FSRU or LNG carriers impacting shallow waters habitats and communities	Complying with the Port Operating Handbook, class and IMO / AMSA standards	FSRU is continuously moored in Crib Point Jetty (Berth 2). LNG carriers will be under the control of experienced captain or pilot, stay in dredged channel and within speed limit.	Negligible	Possible	Low
ME 48	Light Spill	Extra light from FSRU and intermittently from the LNG carriers	Limiting lights to the number for safe operations. Shading to keep light spill on the deck	Risk is low and does not require further mitigation	Negligible	Almost certain	Low
ME 49	Marine Pest Introduction- FSRU	FSRU introducing marine pest species when it arrives to Western Port	FSRU has appropriate antifouling system, is cleaned, inspected and follows relevant regulations	Compliance with the environment management plan and regulations or policies	Moderate	Rare	Low

Risk ID	Risk Name	Risk Pathway	Initial Mitigation	Additional Mitigation	Residual Risk		
					C	L	R
ME 50	Marine Pest Introduction- LNG carrier	LNG carriers introducing marine pest species when entering Western Port	LNG Carriers have appropriate antifouling system, and are cleaned, inspected and follow relevant regulations	Compliance with the environment management plan and regulations or policies	Moderate	Rare	Low
ME 51	Aggregation of Marine Fauna	Increased food supply from damaged biota and increased light causes unnatural marine fauna aggregation.	Exclusion zone around FSRU	Policing of exclusion zone	Negligible	Almost certain	Low
ME 52	Whale Strike	LNG Carriers collide with whales	LNG carriers comply with vessel traffic management plan to avoid whale strike.	Carriers will be under the control of experienced captain or pilot, stay in dredged channel and within speed limit	Minor	Unlikely	Low

8.3 Assessment of Limits of Acceptable Change and Risks to Ecological Character

Table 8-4. Assessment of Risks to Ramsar Limits of Acceptable Change

Critical Components Processes and Services	Limit of acceptable change (LAC) 2010 (KBR, 2010)	Limit of acceptable change (LAC) 2016 (Hale)	Project risk to LAC
Wetland bathymetry	No loss of intertidal mudflat area (270 km^2)	No loss of wetland area or change in bathymetry by the Project.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low
Geomorphology and sedimentation	No LAC set	Only minor local scour. No large-scale change to sedimentation.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low
Marine invertebrates	No LAC met	Minor potential effect over 20-ha in the Port of Hastings area. No effect elsewhere in 36,000-ha of soft sediments in Lower North Arm.	Likelihood= Unlikely Consequence=Negligible Risk of change = Very Low
Flora - seagrass	Total seagrass extent will not decline below 5400-ha for a period of greater than 10 continuous years.	Melbourne Water measured 15 000-ha in 2011 (Holland et al. 2013). No loss of seagrass due to Project.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low
Flora - mangrove	Total mangrove extent will not decline below 900 ha.	The most recent assessment of mangrove extent in Western Port indicates 1700 ha. This represents an increase of 40 % since the time of listing. No loss of mangroves due to Project.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low
Flora - saltmarsh	Total saltmarsh extent will not decline below 850 ha.	No loss of saltmarsh due to Project.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low
Waterbirds	Abundance of waterbirds will not decline	No effect on waterbirds due to Project.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low

Critical Components Processes and Services	Limit of acceptable change (LAC) 2010 (KBR, 2010)	Limit of acceptable change (LAC) 2016 (Hale)	Project risk to LAC
Supports threatened species - birds	Abundance of threatened bird species will not decline	Abundance of threatened bird species will not decline due to Project.	Likelihood= Rare Consequence=Negligible Risk of change = Very Low
Supports threatened species - fish	Australian Grayling continues to be supported in one or more of the catchments draining into Western Port.	Australian Grayling are present, spawning and migrating in Bunyip River (Koster and Dawson 2010). Expected effect is negligible.	Likelihood= Unlikely Consequence=Negligible Risk of change = Very Low

The Critical Components Processes and Services for Western Port Ramsar values are listed in Table 8-4 together with the associated 2010 Limits of Acceptable Change (LACs) (KBR, 2010), the updated 2016 LACs (Hale, 2016) and the corresponding risk of the project to each one. The 2016 assessment was based on a review of recent information against the LAC to Critical Components. The risks of the Project to the LAC are rated in the final column (on the right) of Table 8-4 and is based on the EES risk assessment method (Sections 1.0 to 4.0), risks identified and discussed in Section 7 and an assessment of potential impacts of the proposal to the entire Western Port Ramsar site. In conclusion, the risks of the Project to LACs across the entire Western Port Ramsar site are assessed as Very Low.

8.4 Summary of Mitigation Measures

A series of impact mitigation measures have been developed through the impact assessment process, to limit the extent of adverse effects on the marine environment. There are:

- Seawater intake 2 m below surface and 3 m above seabed;
- Seawater intake velocity in horizontal plane only, speed <0.15 m/s,
- Six high velocity discharge ports, for open loop operations, with a discharge velocity no less than 5 m/s;
- Limit seawater usage in the regasification process in spring and summer to an average of 315,000 m^3/d;
- Manage cleaning and antifouling system in vessels to avoid contamination in Western Port waters or biota;
- Compliance with vessel speed restrictions in Western Port; and
- Ensure chlorine concentration at the discharge point does not exceed 100 µg/L.

8.4.1 Seawater Intake

The design constraints for the seawater intake are that it will be at least 2 m below the water surface (to avoid entraining biota from near the surface) and at least 3 m above the seabed (to avoid entraining biota from near the seabed) and with approximate dimensions of 2.5 m high by 14.5 m long (to keep the seawater intake velocity in the horizontal plane and limit the intake current speed to below 0.15 m/s).

8.4.2 High Velocity Ports

The design constraint for the discharge of seawater in open loop mode is to have the discharge through six ports close to the water surface (but a minimum of 1.5 m below the water surface) at with a minimum spacing along the FSRU of 10 m and discharging horizontally at a minimum velocity of 5 m/s. This will achieve a high initial dilution of the seawater discharge.

8.4.3 Limit Seawater Intake in Spring and Summer

To ensure that a very low percentage of fish larvae are entrained in spring and summer, the rate of seawater intake in spring and summer for regasification operations will be restricted to an average less than 315,000 m^3/d over any 14-day period.

8.4.4 Cleaning and Antifouling system in Vessels

The FSRU is to be cleaned and an antifouling coating applied before it reaches Western Port, to minimise the risk of importing marine pests.

8.4.5 Vessel Speed Restrictions in Western Port

Vessels will be under the control of experienced captain or pilot, and stay in dredged channel within speed limit.

The LNG carriers are to adhere to the VRCA vessel speed requirements to limit the risk of whale strikes.

8.4.6 Limit Chlorine Dose

The seawater electrolysis process will be managed to ensure the concentration of chlorine in the seawater discharge does not exceed 100 µg/L. This can be compared to the chlorine concentration in potable water throughout Australia which is normally in the range of 400 to 800 µg/L.

8.5 Cumulative Impact Assessment

Cumulative impacts of the Project are assessed in this section in relation to:

- Combined temperature and chlorine (in seawater discharge) stresses;
- Combined entrainment, temperature and chlorine (in seawater discharge), vessels shading and seabed scour stresses;
- Combined Project and other port stresses;
- Combined Project and catchment development stresses; and
- Combined Project and climate change stresses.

8.5.1 Combined Temperature and Chlorine Stresses

The chlorine stress is predicted to occur on the seabed and the lower water column over an area of up to 5-ha (during peak operations when an LNG carrier is moored adjacent to the FSRU) while the temperature change stress is predicted to occur on the seabed and the lower water column over an area of approximately 20-ha (under the same ‘worst-case’ modelled scenario). The 5-ha area above the chlorine Guideline Value is within the 20-ha area above the temperature Guideline Value and there will be an overlap of effects.

It is expected that there would be an alteration in the composition of the infauna community within the 5-ha zone of combined stress. Species that are tolerant of the conditions would be present in greater abundance while more sensitive species would be present in lower

abundance. A similar change in composition has occurred on the seabed in Bass Strait from the brine discharge of the Wonthaggi desalination plant, also over a zone of about 5-ha.

The changes would be most apparent in the 3-ha directly under the two vessels (FSRU and LNG carrier) and less apparent, and possibly not measurable in relation to natural variation, in the outer part of the 20-ha combined area above temperature and chlorine Guideline Values.

8.5.2 Combined Entrainment, Temperature, Chlorine, 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 temperature change, CPO, shading and scour of sediments (periodically due to tugs and locally due to the discharged seawater on the seabed), as well as entrainment resulting from seawater intake.

Shading is expected to be a significant stress, as it would reduce the light in the water column and also reduce the biota in the water column occupied by the vessels, thereby potentially reducing the food supply to infauna in the seabed below the vessels. This would be compensated (to the east of the FSRU) by the extra food supply from the effects of plankton damaged in travel through the heat exchangers.

The assessment of entrainment impact in this report is based an assumed zero survival of all plankton passing through the heat exchangers. This may be a conservative assumption, as there is evidence that about half the plankton would survive (Michels, 2010; Ramirez-Duque, 2012; Wang and Lan, 2018). Whether survival is 50 % or zero, there would be a supply of food to the infauna under the discharge ports. Thus, filter feeders (and their predators) are expected to flourish. There would be no loss or addition of organic carbon and nutrients. The overall effect of these combined stresses is expected to be a greater shift in the composition of the infauna community within the 5-ha zone of combined stresses.

8.5.3 Combined Project and Other Port Stresses

The 20-ha area for temperature change extends over Berth 2 and Berth 1 of Crib Point Jetty, where there would be other vessels moored from time to time. Under the Berth 1 vessel, there would be the additional stresses due to shading, tugs and occasional maintenance dredging, and hence a similar response as under the FSRU at Berth 2.

8.5.4 Combined Project and Catchment Development Stresses

In Section 5.1, it was noted that there is rapid urban population growth in the northern parts of the Western Port catchment (Casey Shire and Cardinia Shire) and by the year 2041, the present population in the Western Port catchment is projected to increase from 45,000 persons at present to about 250,000 persons (sum of municipality projections by *id.population*, 2020).

The majority of the runoff from this urban development would drain into the northern part of Western Port. This would exacerbate the already elevated nutrient concentrations in the north-east section of Western Port due to runoff from the existing urban population and agriculture.

The EPA water quality monitoring of Western Port has identified that nutrient concentrations in the north east are approximately twice those near Hastings (e.g. total nitrogen averages 0.25 mg/L near Lang Lang and 0.12 mg/L near Hastings). Some further increase in nutrient concentrations in the north-east of Western Port can be anticipated with possibly a small increase elsewhere in Western Port (responding to dispersion and also the smaller rate of population growth in Hastings and elsewhere on the Mornington Peninsula).

Assuming nutrients are, at times, a factor limiting plankton growth, the higher nutrient levels would permit increased plankton populations, mostly in the north-east of Western Port. The 2013 Melbourne Water report points out that areas with the highest anthropogenic nutrient concentrations in Western Port, such as Watsons Inlet, also have some of the highest seagrass densities (Holland et al, 2013). Thus, urban growth may result in higher plankton and seagrass abundance.

On a bay-wide basis, the extra plankton abundance would compensate (most likely more than compensate) for the loss on plankton due to entrainment. However, the increase in plankton is hypothesized for the north-east of Western Port while the entrainment process occurs at Crib Point. These are widely different zones, with a slow connection from mixing over many tide cycles. In conclusion, it is not considered there is the potential for a significant cumulative impact between the Project and catchment development – these are separate effects in different areas of Western Port.

8.5.5 Combined Project and Climate Change Stresses

Section 5 notes that sea level in Western Port has increased by about 250 mm over the last hundred years due to the warming climate. Thus, climate change has already had a significant impact on the intertidal zones of Western Port.

Steadily increasing sea level and seawater temperature increases over coming decades would have further significant impacts on Western Port, particularly on mangroves, saltmarsh, estuaries and seagrasses. These impacts would mostly occur around the perimeter of Western Port and would be separate from the effects of the Project in the deeper channel near Berth 2 of Crib Point Jetty. There is minimal overlap between the areas impacted by climate change and the predicted combined area above the Guideline Values for the Project. Infauna are unlikely to be affected by rising sea level.

Climate change will result in slightly deeper water at Crib Point Jetty, but would not affect the operation of the FSRU. Deeper water would slightly increase dilution. For example, an increase in MSL of 40 ml (2 mm/yr for 20 years) would increase the dilution of the plumes by about 0.2 %.

As described in Section 7, the regional model predictions show that there is no continual cooling of waters in the Project area or more broadly in Western Port. Assuming the cooler seawater mixes over the tidal excursion of 8 km north/south by 1.5 km east/west, a temperature reduction of 0.015^{o}C in the waters within this zone would alter the atmospheric heat balance to the extent necessary to balance the temperature reduction caused by the FSRU seawater discharge. This reduction in seawater temperature is approximately equal to the annual increase in water temperature due to global warming (0.015^{o}C per year).

Similarly, chlorine is dispersed and diluted to concentrations less than 6 µg/L in the vicinity of the FSRU and to much lower concentrations in North Arm. There would be negligible chlorine from the FSRU in Western Port beyond North Arm. The chlorine created by the electrolysis of seawater returns to the chloride (as part of sodium chloride) in seawater in a day or so, so there is no long-term accumulation of dissolved chlorine or bromine in Western Port. Bromine concentrations would decline due to natural decay processes to the typical ambient background levels of 1 to 3 µg/L.

8.6 Marine Monitoring Program

Monitoring 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 monitoring program will be designed in collaboration with a statistician.

The recommended components of the marine monitoring plan are as follows.

1. **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 any EPA licences) and, if not, provide the trigger for remedial actual (including reducing production).

2. **Plankton Survival Study**. Every quarter for 3 years, collect plankton samples on the seawater intake and discharge of the FSRU and analyze the samples to determine the percentage of zooplankton and fish larvae survival.

   The EES risk assessment is based on the conservative assumption of 100 % loss of small biota that is entrained in the FSRU. The objective of this task is to establish whether a smaller loss might actually occur in practice, so the effect of the Project on primary productivity in North Arm is less than calculated assuming 100 per cent loss, providing a further factor of safety.

3. **Seabed Biota Monitoring in Port Area**. Baseline surveys and post-commissioning surveys every six months for 3 years of benthic fauna abundance, diversity and composition to detect if there are any significant changes to infauna communities in the Port area and further along North Arm.

   The objective is to check whether the impact on infauna is less or more than the impact predicted in the EES from the combined areas of chlorine and temperature change on the seabed near Berth 2 (20-ha).

4. **Water Quality Sampling**. Monitor seawater at six sites down-current of the FSRU and at reference sites to accurately determine chlorine produced oxidants (CPO) concentration and temperature change as a result of FSRU operation. Collect replicate samples for quality control.

   The objective is to check whether the predicted extent of chlorine concentration and the temperature anomaly matches the EES predictions and, if a greater extent, what corrective actual should be taken to limit the extent. The distribution of CPO can be calculated from the measured extent of temperature.

5. **Transplanted Mussel Monitoring**. Every six months for 3 years, deploy 10 sets of mussels at, for example, sites 100 m, 200 m, 400 m, 800 m and 1,500 m north and south of the FSRU. Leave the mussels in place for 21 days. Retrieve mussels and analyze for chlorinated organics.

   The objective is to check whether there is measurable or significant accumulation of chlorinated or brominated organics in biota. Mussels are recognised as an appropriate method to accumulate any collect chlorinated organics (if present) for analysis. If there are elevated levels (e.g. exceeding background levels at reference sites) then a review of chlorination rates and procedures should be undertaken.

8.7 Summary of assessment outcomes

A marine biodiversity risk assessment was carried out to identify Project risks pathways, the potential consequences of impacts on marine ecology, the likelihood of these impacts occurring and appropriate risk mitigation measures.

The construction impacts are minor in extent, duration and severity as the FSRU would be constructed overseas and brought to Western Port ready to operate at the existing Crib Point Jetty and works on the Crib Point Jetty are able to be managed through the application of industry standard measures to ensure the potential for impact is minimised.

The modelling carried out for temperature and chlorine identified that the intermittent presence of an LNG carrier moored alongside the FSRU when LNG is being delivered had the most substantial effect on these factors. This is particularly the case during open loop regasification operations, as the discharge ports for the regasification water are on the starboard side of the FSRU, which is the same side that LNG carriers would moor on.

When there is no LNG carrier moored next to the FSRU, there is a small footprint (approximately 0.7 ha) where a pool of cooler seawater forms on the seabed for a short period at slack water. The pool of cooler seawater lasts for less than an hour before the increase in tidal currents stimulates mixing.

Under the same scenario, the time-averaged chlorine level is less than the Guideline Value for chlorine of 6 µg/L at all sites in the regional model, with only small zone in the discharge plumes (approximately 0.2 ha) that has chlorine levels above the Guideline Value. The discharge plumes would be in the immediate vicinity of the FSRU, which corresponds with the Port of Hastings area at Berth 2 of the Crib Point Jetty.

When an LNG carrier is moored alongside the FSRU, the situation changes considerably. There is a larger footprint (of up to 20 ha) where a pool of cooler seawater forms on the seabed during each slack water, lasting for one to two hours. The size of the pool of cooler seawater decreases as the production rate decreases.

Under the same scenario, the time-averaged chlorine level exceeds the Guideline Value for chlorine of 6 µg/L over an area of 5 ha.

In closed loop regasification operations, and with or without an LNG carrier, there is a small footprint of 0.2 ha of chlorine above the Guideline Value at the rear of the FSRU.

Altogether, the chlorine (CPO) concentration can exceed the Guideline Value at times in an area of up to 5 ha.

It is expected that there would be an alteration in the composition of the infauna community within the 5-ha combined area where the temperature and chlorine guideline values would be exceeded. Species that are tolerant of the conditions would be present in greater abundance, while more sensitive species would be present in lower abundance. The changes would be most apparent in the 3 ha under the two vessels and less apparent, and possibly not measurable in relation to natural variation, in the outer part of the 20 ha area above the temperature Guideline Value. There is predicted to be no effect from temperature or chlorine discharges on saltmarsh, mangroves, seagrass, intertidal mudflats, waterbirds, seals or penguins.

A large flow of seawater would be required to transfer heat to the LNG when the FSRU is operating in open loop regasification mode. The flow of seawater would change depending on the gas production rate that the FSRU is operating at. Over a period of 14 days, 0.22 % of

plankton in North Arm could be entrained through the heat exchangers at the peak gas production rate and 0.14 % at the average gas production rate.

To ensure that entrainment does not present a medium or higher risk in the peak season for fish larvae, a limit on seawater use for the regasification process in spring and summer has been recommended as a mitigation measure. Additional mitigation measures have been defined for the location and size of the seawater intake, and for discharge of the seawater back to Western Port (Refer to Section 7.5). Together these recommended mitigation measures would enable the FSRU to operate in open loop regasification mode all year with a residual risk of potential entrainment impacts on fish eggs and larvae not exceeding low.

Other predicted effects from the operation of the FSRU involve very low risks associated with activities that are equivalent to normal shipping activities occurring within the Port of Hastings

With implementation of the recommended mitigation measures, the assessment of potential impacts in this assessment report rated all residual risks as low or very low. Thus, the outcomes of the proposal would satisfy the relevant EES evaluation objectives for marine biodiversity. There is considered to be no significant impact on MNES, as described in the EES chapter describing the assessment of MNES for the purpose of the EPBC Act.

In summary, it is considered that the Project would not result in unacceptable or long-term impacts to the marine environment of Western Port. The recommended mitigation measures and monitoring programs would avoid and minimise potential adverse effects to native flora and fauna and their habitats, on water quality and the Western Port Ramsar site.

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www.gasimportprojectvictoria.com.au

General and Gas Import Jetty enquiries
1800 039 600
AGLcommunity@agl.com.au

Pipeline enquiries
1800 531 811
cribpointpakenham@apa.com.au