Report to:
Jacobs Group (Australia) Pty Ltd

AGL Gas Import Jetty Project
Crib Point, Western Port

Assessment of effects of cold-water discharge on marine ecosystem

FINAL

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AGL Gas Import Jetty Project

Assessment of effects of cold-water discharge on marine ecosystem at Crib Point

EXECUTIVE SUMMARY

AGL Wholesale Gas Limited (AGL) is proposing to develop a Liquefied Natural Gas (LNG) import facility, utilising a Floating Storage and Regasification Unit (FSRU) to be located at Crib Point on Victoria's Mornington Peninsula. The project, known as the "AGL Gas Import Jetty Project" (the Project), comprises:

- The continuous mooring of the FSRU at the existing Crib Point Jetty, which will receive LNG carriers of approximately 300m in length
- The construction of ancillary topside jetty infrastructure (Jetty Infrastructure), including high pressure gas unloading arms and a high pressure gas flowline mounted to the jetty and connecting to a flange on the landside component to allow connection to the Crib Point Pakenham Pipeline Project.

The FSRU will be continuously moored to receive LNG cargos from visiting LNG carriers, store the LNG and re-gasify it as required to meet demand for high pressure pipeline natural gas.

Regasification involves the heating of the -162°C liquefied gas using the ambient heat of seawater in Western Port. A daily volume up to 450,000 m^3 (450 ML/d) (when operating at full capacity) of seawater from Western Port will be pumped at a rate of 5.2 m^3/s through heat exchangers in the FSRU. The discharged seawater temperature will be 7ºC lower than ambient temperature at Crib Point.

AGL engaged Jacobs Group (Australia) Pty Ltd (Jacobs) and their specialist subconsultants to investigate the potential impacts of the seawater intake/discharge arrangements on environmental conditions in Western Port. A series of desktop studies have been undertaken to investigate the hydrodynamics of Western Port and the ecological effects of the seawater intake, the discharge of cooler seawater and the discharge of anti-fouling compounds. The purpose of this report is to examine the effects of the cold-water discharge from the FRSU on the marine ecosystem. The report integrates the near and mid-field hydrodynamic modelling outputs with the existing information on ecosystem characteristics and provides guidance on the impact pathways and extent of effect of the cold-water plume on the marine environment.

This report has been prepared in support of:

- A referral under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act),
- A referral under the Victorian *Environment Effects Act 1978*, and
- Identification of requirements under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act).

The behaviour of the cold-water discharge plume was modelled by CEE (2018) using known and quantified physical fluid dynamics processes, the characteristics of seawater in North Arm of Western Port and tidal current characteristics at Crib Point.

The cold-water discharged from the FSRU heat exchanger will initially be 7°C cooler than ambient but within seconds, the descending plume will be close to the seabed and will have mixed with sufficient surrounding seawater to reduce the temperature.

Relevant information on the nature and distribution of marine ecosystem components in the vicinity of the FSRU was compiled from a range of existing information sources. The modelled behaviour of the discharge showed that the cold-water rapidly descended to depths greater than 12.5 m below the sea surface and demonstrated that marine ecosystem components in water depth less than approximately 12.5 m water depth would not be directly affected in the case of either a single-port or six-port discharge. Consequently, it is concluded that saltmarsh, mangrove, mudflat, intertidal seagrass, subtidal seagrass and channel slope communities and sensitive species that occupy habitats to a water depth of 12.5 m will be unaffected by the direct effects of the cold-water discharge. Hence, a substantial proportion of marine ecosystem habitats and communities will be separated from the effects of cold-water by the physical behaviour of the cold-water discharge.

Species that occupy habitats in water depths greater than 12.5 m in the vicinity of the discharge may be exposed to water temperatures a maximum 0.3°C cooler than ambient within 200 m of the discharge for the preferred six-port discharge. Modelling showed that the extent of the cold-water will depend on a range of tidal and discharge conditions. A single-port discharge temperature differential may extend a maximum of 600 m downstream of the discharge with a maximum width of 240 m, and the cold-water may form a pool on the seabed at low tide during periods of particularly low currents. AGL has adopted a six-port discharge with a resulting temperature differential that reaches within 0.3°C of ambient at a maximum of 200 m downstream of the discharge point with a maximum width of 60 m either side of the discharge. A stable cold-water pool never forms for the six-port discharge. The only location that will be constantly exposed to cool seawater will be the water column and seabed within the fall line of the descending cool plume next to the FSRU.

The biota occupying habitats in water depths greater than 12.5 m depth include the benthic invertebrate fauna that live in (infauna) or on (epibiota) the soft seabed of the channel planktonic plants and animals (phytoplankton and zooplankton) that drift in the tidal currents and fish that swim along the seabed in the deeper parts of the North Arm channel. There are no seagrasses in this area due to insufficient natural light for seagrass photosynthesis. These biota within 200 m upstream and downstream of the discharge and 60 m either side of the discharge may be affected by exposure to cold-water. Exposure of benthic invertebrate community to cold-water will be intermittent as reversals in tidal currents carry the waters up and down the channel. Mobile species in the area may be exposed over a shorter period and may avoid the cooler water by moving higher in the water column or around the water body if affected.

The location with highest exposure to the cold-water discharge will be the seabed in the shipping basin directly beneath the discharge. This will be the location where effect of the discharge on the marine ecosystem is likely to be greatest. Initial dilution and nearfield modelling suggest that the water temperature differential of the discharged seawater of 7°C below ambient at the point of discharge will reduce to 0.8°C below ambient near the seabed for a single-port discharge and 0.3°C below ambient near the seabed for a six-port discharge. The effect of the discharge from the AGL preferred a six -port discharge is unlikely to be detectable at 200 m from the FSRU six-port discharge.

AGL will undertake additional studies to further define the effects within North Arm and to document the distributions of marine ecosystem components in the vicinity of the discharge, which were previously systematically documented more than 40 years ago.

1 INTRODUCTION

1.1 Project overview

AGL Wholesale Gas Limited (AGL) is proposing to develop a Liquefied Natural Gas (LNG) import facility, utilising a Floating Storage and Regasification Unit (FSRU) to be located at Crib Point on Victoria's Mornington Peninsula. The project, known as the "AGL Gas Import Jetty Project" (the Project), comprises:

- The continuous mooring of the FSRU at the existing Crib Point Jetty, which will receive LNG carriers of approximately 300m in length
- The construction of ancillary topside jetty infrastructure (Jetty Infrastructure), including high pressure gas unloading arms and a high pressure gas flowline mounted to the jetty and connecting to a flange on the landside component to allow connection to the Crib Point Pakenham Pipeline Project.

Jacobs Group (Australia) Pty Ltd (Jacobs) was engaged by AGL to undertake planning and environmental assessments for the AGL Gas Import Jetty Project. Jacobs engaged CEE Environmental Scientists and Engineers to define the marine environmental characteristics and identify key potential risks to the marine environment from the development and operation of the Project.

1.2 Purpose of this report

This report integrates the near and mid-field modelling outputs as documented in the report 'Plume Modelling of Discharge from Floating Storage and Regasification Unit' (CEE 2018a) with the existing information on ecosystem characteristics and provides guidance on the impact pathways and extent of effect of the cold-water plume on the marine environment.

This report has been prepared in support of:

- A referral under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act),
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2 HEAT EXCHANGE DISCHARGE MODEL

The FSRU will be located at the southern end of Crib Point Jetty, in the shipping basin approximately 500 m offshore from the inshore seagrass beds (Figure 1). Cool seawater from the FSRU heat exchanger will be discharged to the main channel of North Arm.

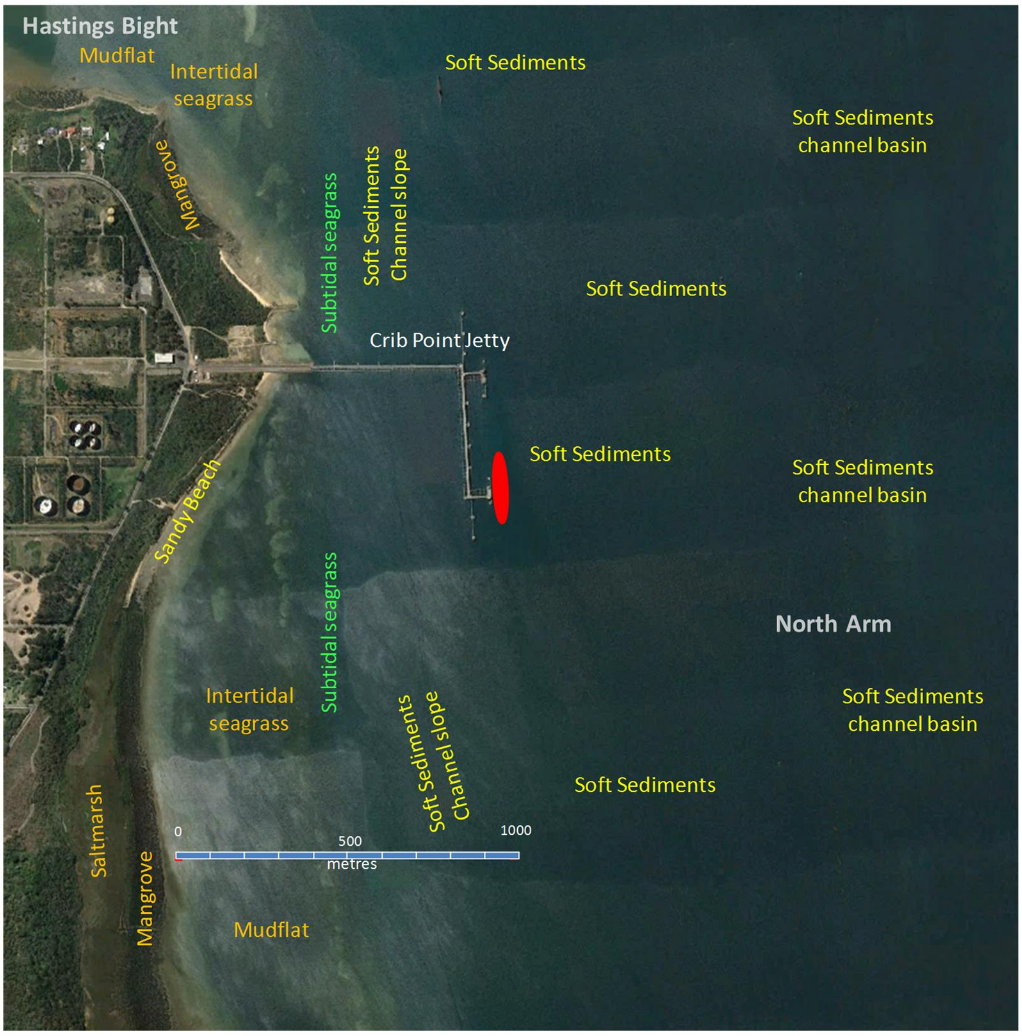


Figure 1. Natural marine ecosystem components at Crib Point
(Position of FSRU shown in red)

The behaviour of the cold-water discharge from the FSRU is discussed in CEE's 'Plume Modelling of Discharge from Floating Storage and Regasification Unit (2018a). The general behaviour of the cold-water discharge from the FSRU is shown in Figure 2.

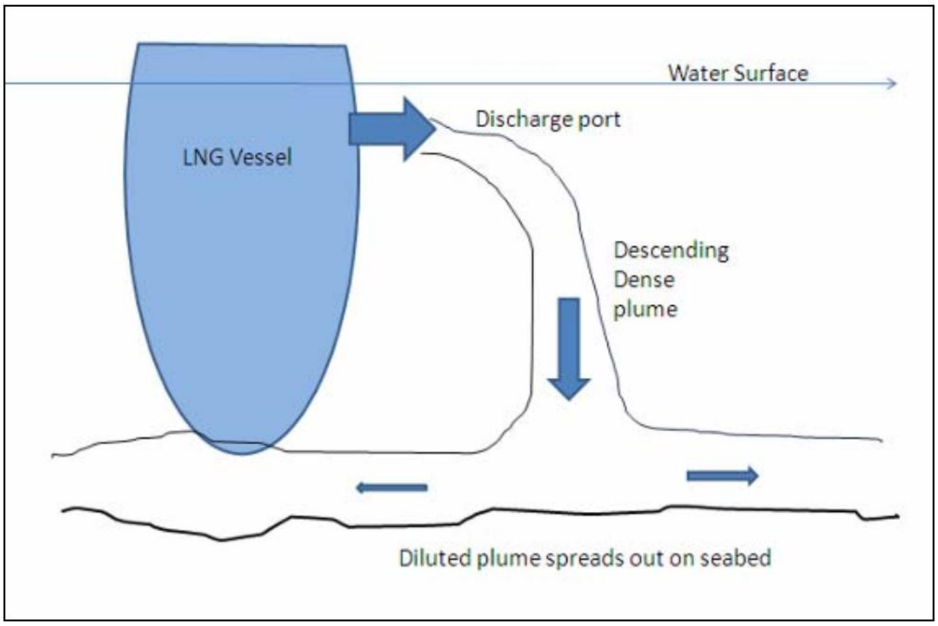


Figure 2. Behaviour of cold-water discharge from FSRU at Crib Point
(showing a single point discharge for simplicity, CEE 2018a)

The plume of water starts from the discharge ports on the FSRU and discharges at 7°C cooler than the adjacent seawater and is therefore more than 1 kg/m^3 more dense than ambient seawater.

The plume descends to the seabed, diluting on the way due to shear between the descending plume and the adjacent seawater. The initial dilution during the descent increases marginally at times of stronger tidal current. During periods of relatively low tidal currents, the cold-water plume reaches the seabed and spreads over the seabed in the shipping basin.

The cold-water layer is denser than the surrounding ambient seawater and, in the absence of strong tidal currents may form a pool that tends to move with weak tidal currents and downhill, with the thickness above the seabed getting smaller as the pool spreads. Stronger tidal currents push along the surface of the cold-water pool and further erode the thickness of the cold-water layer.

2.1 Factors affecting formation of a cold-water plume on seabed

Modelling (CEE 2018a) included consideration of the following factors that affect the temperature, thickness, extent and stability of the plume:

- Number of discharge ports
  - one and two port outlet options were modelled as a conservative case, with a six-port option to demonstrate the effect of increased dilution through a multiport discharge
- Angle of discharge ports
  - Three angles modelled
- Depth of water
  - Variable 1 = tidal range at Crib Point, Variable 2 = draft of vessel at different loads
- Discharge rate
  - Initial dilution for three flows was modelled: 150,000 kL/day; 300,000 kL/day; 450,000 kL/day
- Bathymetry

- dredged basin, natural slopes and features outside dredged basin
- Tidal current strength
  - Tidal current strength has only a minor effect on the initial dilution of the cold-water plume as the plume descends toward the seabed, but considerably effects the thickness, spatial extent and duration of cold-water layer on the seabed
  - Initial dilution was modelled at slack water
  - Layer formation and stability was modelled over an average flood tide (rising tide and currents travelling northward).

2.2 Key outputs of plume modelling

The key outputs of plume modelling from CEE (2018) are:

- Initial dilution of a 450,000 kL/day (5.2 m^3/s) discharge through
  - Single outlet at slack water resulted in a dilution at the seabed of:
    - 8:1 at low water and 10:1 at high water
  - Dual-port outlet at slack water resulted in a dilution at the seabed of:
    - 10:1 at low water and 12:1 at high water
  - Four-port outlet at slack water resulted in a dilution at the seabed of:
    - 15:1 at low water and 17:1 at high water
  - Six-port outlet at slack water resulted in a dilution at the seabed of:
    - 20:1 at low water 23:1 at high water

- The corresponding difference in temperature between the cold-water field on the seabed and the surrounding ambient seawater at high tide would be:
  - -0.8°C for the single port discharge
  - -0.7°C for the dual port discharge and
  - -0.45°C for the four-port discharge and
  - -0.3°C for six port discharge.

- The field from the single discharge will form a stable pool of cool water on the seabed at currents speeds less than 0.13 m/s for approximately 1 hour either side of the turn of the tide. The stable pool of cold-water (up to 0.8°C below ambient) will intermittently form and extend:
  - north of the discharge point during flood tides and south during ebb tides
  - up to 900 m from the discharge point depending on tide height and ambient currents
  - 250 m east and west of the discharge point.

- The field from a six-port discharge could occasionally form a temporary, unstable cold-water layer (up to 0.3°C below ambient) within approximately 200 m of the discharge at slack water during some low tides. More ports than six will produce greater initial dilution and smaller temperature differentials at the seabed.

- Cold-water plumes from all options modelled (one outlet to six-port outlet) will descend to the seabed with sufficient momentum to form a detectable local depression in the seabed.

2.3 Environmental syntheses of discharge model outputs

Figure 3 and Figure 4 show the maximum extent of the cold-water plumes for one port and six port discharge options based on the model outputs, which assume a relatively flat seabed in the area of the pool.

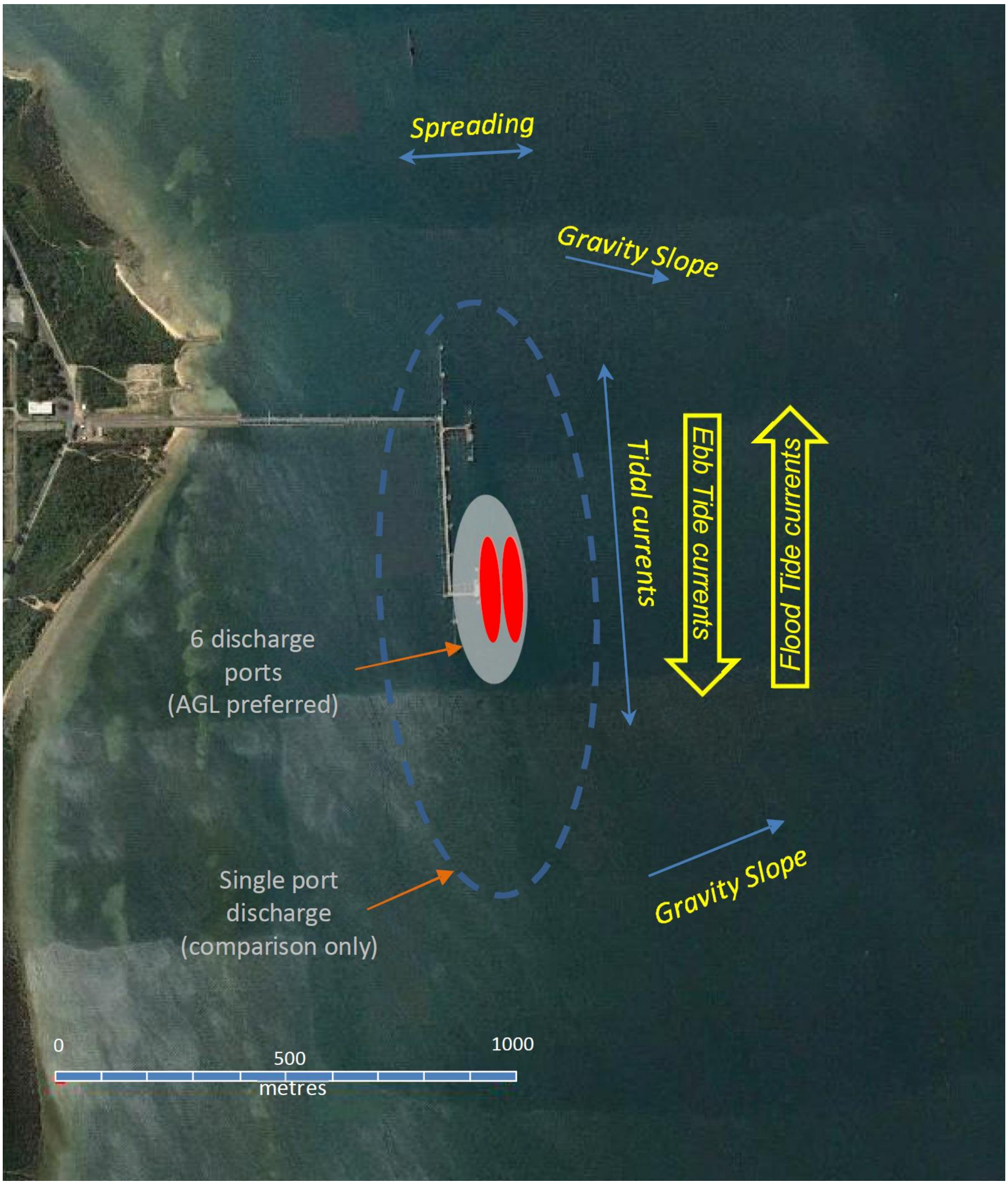
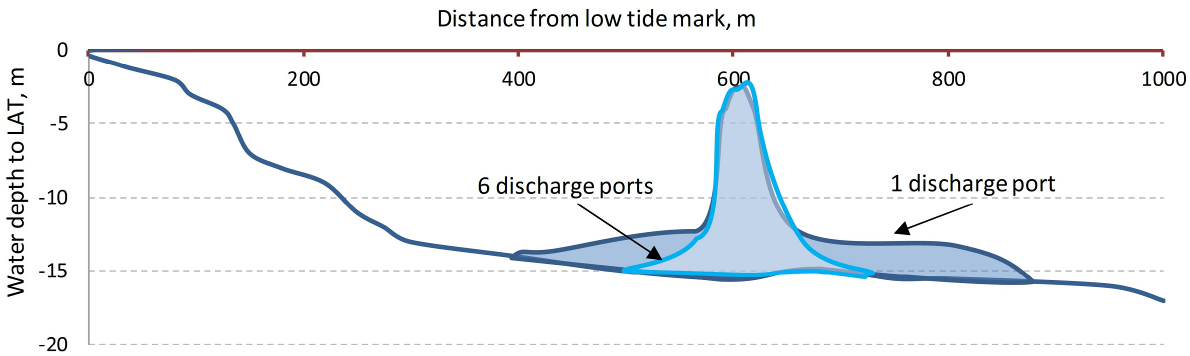


Figure 3. Maximum horizontal extent of cold-water fields (concept)
One outlet and six-port discharge port options



LAT (Lowest Astronomical Tide): the lowest tide level which can be predicted to occur under any combination of astronomical conditions.

Figure 4. Maximum extent of cool water field cross-section (concept)
One outlet and six-port discharge port options

Figure 5 shows that, while the seabed is relatively flat, there are gentle variations of 1 m to 2 m that are likely to affect the shape of the cold-water pool as it spreads beyond the footprint of the descending plume.

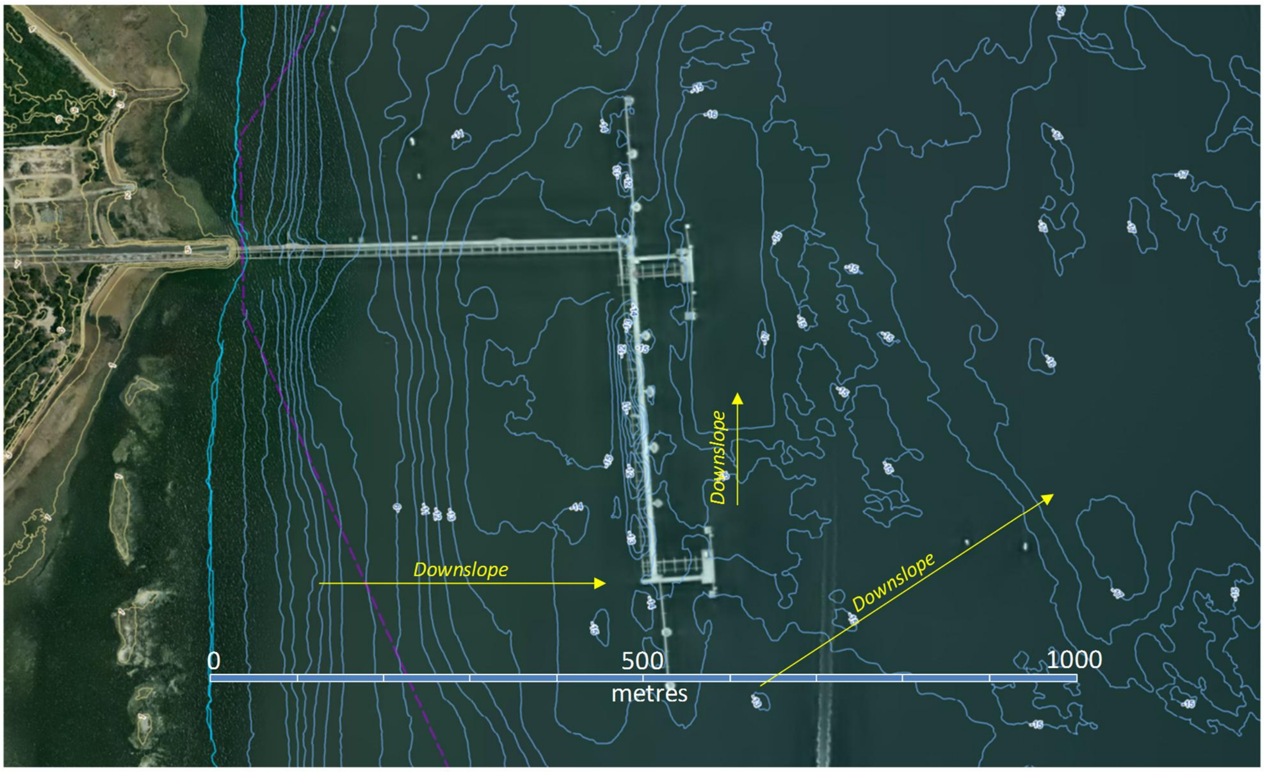


Figure 5. Detailed bathymetry at Crib Point Jetty head

The models for the one-port discharge and the six-port discharge demonstrate the consequences of discharge configuration on plume characteristics and the potential extent of environmental effect. Increasing the number of discharge ports at appropriate spacing increases the mixing rate of the cold-water and reduces the temperature differential between the cold-water plume and the surrounding ambient seawater. More than six ports would produce greater initial dilution and smaller temperature differentials at the seabed.

Monthly seawater temperature measurement at EPA water quality monitoring site 709 located in the main channel approximately 2 km north of Crib Point typically ranges between 11°C and 22°C over the year. Water temperature measured at Long Island Point in March 2016 varied naturally by 0.3°C over a 4-hour period (CEE data). Hence a 0.3°C temperature difference over a relatively small area appears within the range of short term-natural variation.

Further assessment of short-term and long-term variations in seawater temperature at Crib Point would provide further context for assessment of the effect of temperature differentials resulting from the heat exchanger seawater discharge on marine ecosystem components in the temperature differential footprint.

2.3.1 AGL preferred option: six-port discharge

The AGL preferred design for discharge of the cold seawater is through a six-port discharge arrangement, instead of the alternate single (or double) discharge port/s. This optimises dilution of the discharge and results in a smaller temperature difference closer to the discharge point being an area approximately 200 m north and south and 60 m east and west of the discharge point, representing a total seabed area of approximately 5 ha. No cold-water pool is expected to form on the seabed at any stage of the tide with the six-port discharge.

2.3.2 Recommended Baseline Monitoring

Seawater temperature monitoring will document natural short-term variations in temperature and the actual extent of temperature differences and dispersion paths of the cold-water discharge. This will inform the potential effect of the cold-water discharge on the marine ecosystem of North Arm. Ambient monitoring at Crib Point in the next stage of assessment will further inform the understanding of the significance of the predicted temperature difference with natural short-term variations at different tides and seasons.

3 MARINE ECOSYSTEM ASSESSMENT

Western Port is a diverse but compact marine environment. It comprises vast intertidal mudflats with saltmarsh, seagrass and mangrove habitats as well as steep subtidal sloping banks with seagrass and deep channels that connect the north of the bay with the oceanic waters of Bass Strait in the south (CEE 1995, CEE 2009, EPA 1996, Melbourne Water 2011, Ministry for Conservation 1975).

The ecosystem components associated with the habitats are closely connected by their relatively close spatial proximity and the strong tidal currents that transport water back and forth through the channels and over and off the intertidal flats. The distribution of marine habitats in the vicinity of Crib Point Jetty is shown in Figure 6, and the marine communities associated with the habitats are shown in Figure 7.

Figure 6. Natural marine ecosystem components at Crib Point

The habitat distribution (Figure 6) and conceptual model of the marine ecosystem in the vicinity of Crib Point (Figure 7) show that the FSRU is at least 400 m from intertidal and nearshore marine ecosystem components. It is located in an area of the channel characterised by plankton and pelagic marine species in the water column and invertebrate species and demersal fish associated with the soft seabed around the jetty.

As discussed in Section 2.3, water temperature in North Arm varies seasonally from approximately 11°C to 22°C over the year and over tidal periods of hours as tides water cover the tidal flats and drain back into the cannels. Marine communities in the vicinity of Crib

Point are therefore accustomed to seasonal changes in seawater temperature. Natural seasonal patterns in seawater temperature combined with other seasonal queues such as day length, light intensity, salinity and tides are important factors affecting all marine ecosystem processes in Western Port.

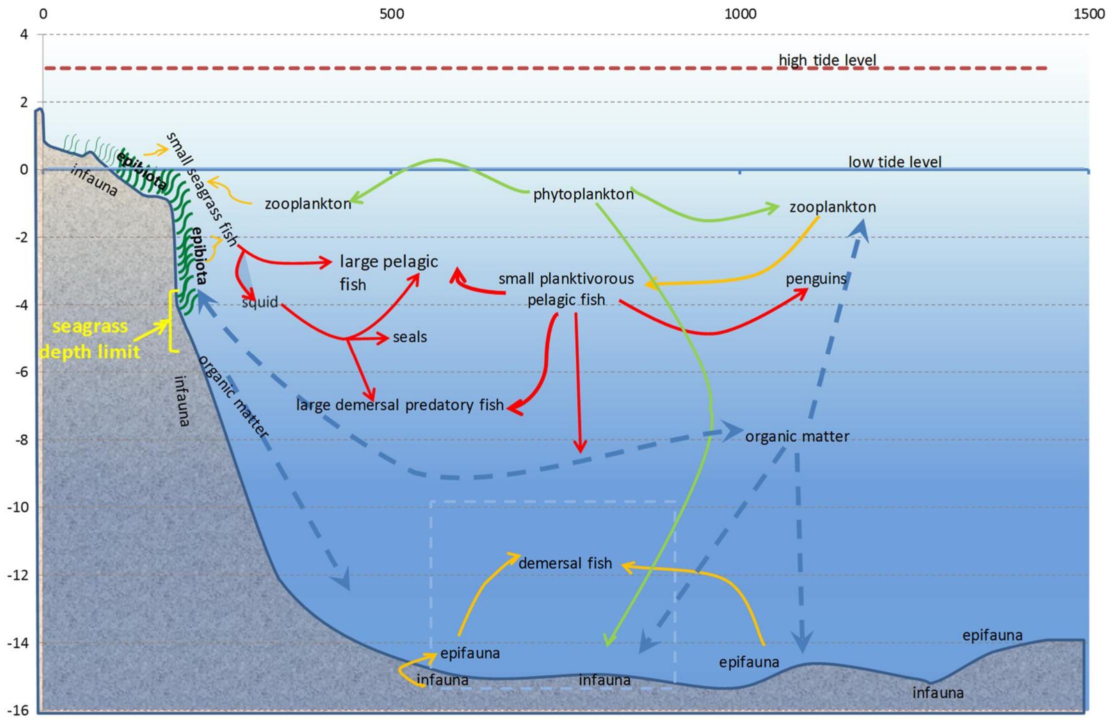


Figure 7. Conceptual model of Western Port marine ecosystem in Crib Point area
(Derived from CEE 2009)

The characteristics of the marine communities in Western Port were most recently described in Melbourne Water's review "Understanding the Western Port Environment" in 2011. Much of the large-scale information on the distribution of invertebrates (see Section 3.2.1), fish and zooplankton in Western Port is based on systematic ecosystem sampling in the 1970s for the Western Port Bay Study (Coleman et al 1978, Ministry for Conservation 1975), more than 40 years ago. Seagrass distribution and limits have been studied more recently for the Port of Hastings Development Authority and a range of local scale monitoring programs and academic projects have investigated species or communities at a local scale. The outcomes of the cold-water plume dispersion modelling enable an assessment of potential effects of the cold-water discharge on targeted marine ecosystem components as discussed below.

3.1 Extent of possible effect on marine ecosystem

As discussed previously, the cold-water from single/dual discharge ports from the FSRU would rapidly descend to the seabed and spread as discussed in the previous sections. Habitats in water depths less than 12.5 m deep will be unaffected by the discharge, except for those planktonic and pelagic species in direct contact with the descending cold-water discharge and those marine communities associated with the jetty piles within the trajectory of the descending cold-water discharge. The extent of possible effect of the cold-water discharge from one and six-port discharge options on marine communities in the Crib Point vicinity is shown in Figure 8.

The figure indicates that effects of the cold-water discharge may occur on the soft seabed community of the channel (at water depths greater than 12.5 m), within the possible footprint of the intermittent, cooler-than-ambient field of water. The maximum temperature difference from ambient within this area may be 0.8°C for single or dual discharges, while it is less than 0.3°C for most of the area with a six-port discharge.

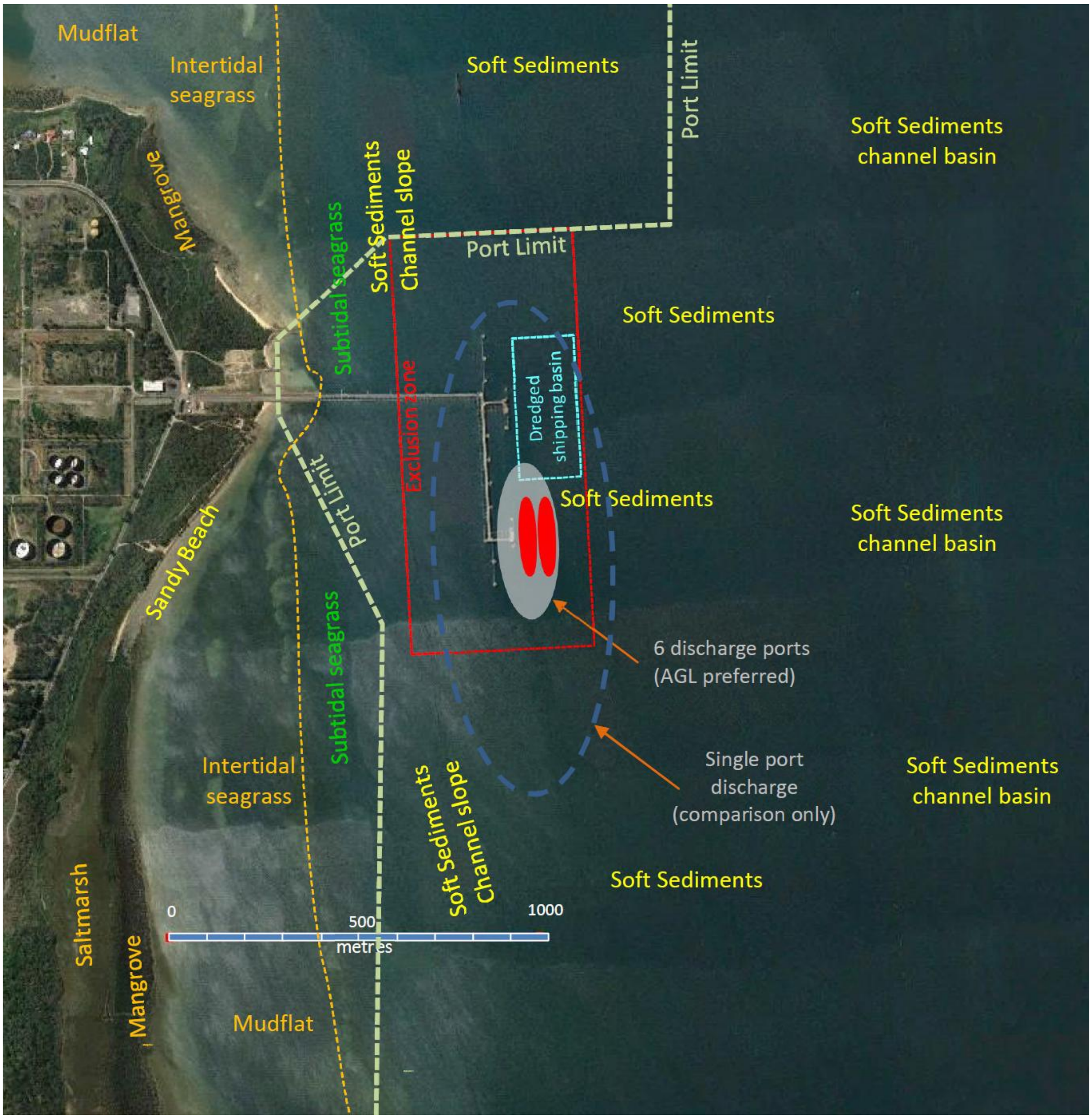


Figure 8. Marine characteristics and extent of temperature difference on seabed

Soft seabed communities on the steeper, western channel slopes will not be affected by the cold-water discharge. Subtidal seagrass, intertidal seagrass, intertidal mudflat, mangrove and saltmarsh communities will not be affected by the cold-water discharge. Planktonic and demersal communities close to the seabed may be exposed to small temperature differences during the time (<1 hour) they swim past or drift past the jetty with the tidal currents.

3.2 Marine communities potentially affected

The soft seabed communities within the cold-water footprint (Figure 8) are likely to comprise:

- Infauna - sparse but diverse populations of invertebrates that live in the fine sandy, silty seabed of the channel floor, such as polychaetes, crustaceans and molluscs;
- Epifauna - invertebrates that live on the surface of the seabed and;
- Demersal fish - mobile fish that live on or close to the seabed.

3.2.1 Infauna

Most of the area potentially affected by the cold-water footprint is soft seabed in the deeper channel area at water depth greater than 12.5 m. This habitat is characterised by the infauna community of burrowing invertebrates. This community was characterised during sampling for the Western Port Bay Study of 1973/74 (Coleman et al 1978). There has been localised sampling at some sites near jetties since then at BlueScope and Long Island Point, but no widespread surveys of the channel.

The infaunal communities in Western Port during the Western Port Bay Study 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 9). 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 percent of all stations sampled.

The characteristics of infaunal communities were divided into two general groups, in spite of the eleven different sampling strata. It was found that 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 percent, and (2) the fine sand and mud assemblage – with mud contents generally greater than 20 percent. 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 North Arm channel were 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 was characterised by the polychaete worms *Amaeana* and *Mediomastus* and bivalve molluscs *Tellina* and *Katelysia*.

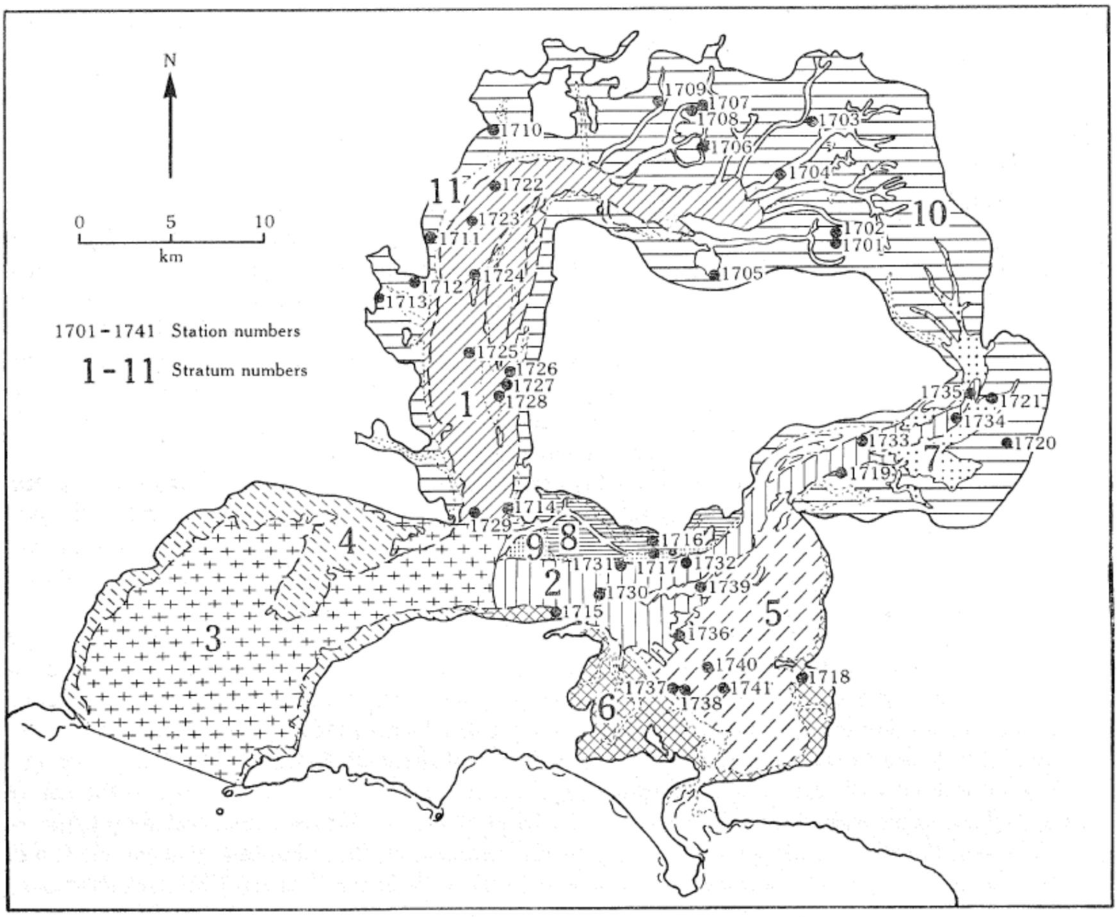


Figure 9. Infauna sampling strata and sites - Westernport Bay Environmental Study
(Source Coleman *et al* 1978)

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 sample site in the Crib Point shipping basin was given particular mention from the 1973/74 sampling. The assemblage at the site was found to have very low diversity of polychaetes, crustaceans and molluscs, and very low abundance of polychaetes and molluscs. Only one crustacean species, *Apseudes*, was abundant. The low diversity and abundance of infauna at this site was attributed to ‘recent’ dredging (Coleman et al 1978).

The major finding of the infauna study was that the greatest influence on infauna characteristics was the composition of the seabed. Two major community groups were distinguished on this basis: ‘clean medium sand’; and ‘fine sand and mud’. Infauna at sites close to each with the same sediment character tended to be similar. The study concluded that the strongest similarities were between strata 5, 6, 8 and 10, which comprise fine to medium sediments in the east of the Bay. The next strongest similarities were between strata 1, 2 and 7: strata 1 and 2 comprise deeper sites in channels on both sides of the Bay; whereas stratum 7 represents shallow sites of medium to fine sediments in the east of the Bay.

3.2.1.1 Potential Extent of Channel Infauna Community

The area of potential effect from the cold-water discharge is located within stratum 1, which is an extensive area of approximately 70 km^2 extending nearly 30 km from Sandy Point in south of North Arm to Bourchier Channel in the northeast (Figure 9). The maximum area of seabed that is potentially affected by the cold-water pool in the conservative one port discharge model is defined by the 0.7 km^2 ellipse shown in Figure 8. In this case, the potential effect of the cold-water on infauna represents less than 1 % of the channel community of North Arm or 0.11% of Western Port. The installation of six-discharge ports on the FSRU will decrease the temperature difference to a maximum of -0.3°C from ambient within close proximity of the FSRU, which is likely to be within the range of natural local-scale seawater temperature variation in North Arm.

Registration no	Location	Stn no	Latitude	Longitude	Depth	Date	No of specimens
MoV J16722	Swan Bay, near Edwards Point		38°14´S	144°39´E	2	1982	1
MoV J302	Western Port, off Crib Point	CPBS-N 11	38°20.23´S	145°13.28´E	5	31 Mar 1965	2 (paratypes)
MoV J303	Western Port, off Crib Point	CPBS-?	?	?	?	1965	1
MoV J301	Western Port, off Crib Point	CPBS-N 11	38°20.23´S	145°13.28´E	5	31 Mar 1965	1 (holotype)

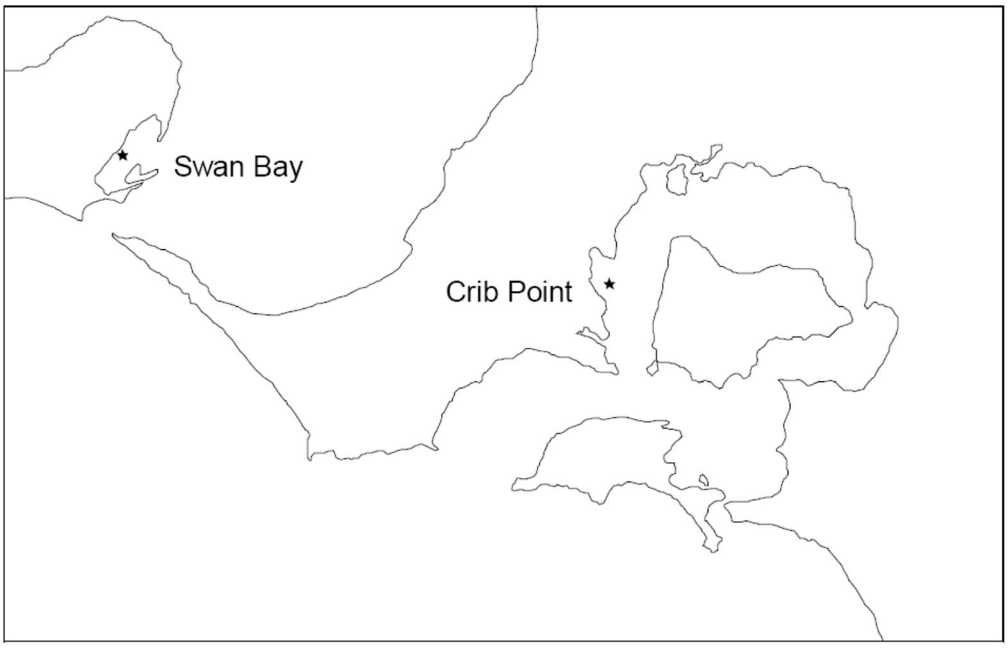


Figure 10. Distribution of ghost shrimp C*alliax tooradin*
(O'Hara and Barmby 2000)

3.2.1.2 Potential Effect on Channel Infauna Species – species of concern

The channel infauna community includes two species listed in the Flora and Fauna Guarantee Act. Both species are small ghost shrimps: *Calliax tooradin* (formerly *Eucalliax tooradin*) and *Michelea microphylla*. The burrowing clam *Neotrigonia margaritacea* is not listed but is known as a "living fossil" and therefore is a species of interest to some marine biologists.

The ghost shrimp *Calliax tooradin* is known only from a total of five individuals. Four were collected subtidally in grab samples offshore from Crib Point in 1965 and since then have not been recorded in Western Port (Figure 10). The habitat where it was found at Crib Point comprised fine sand in 5 m water depth. Its potential dependence on seagrass is not known, but it has also been recorded from sediments among seagrasses at shallower depth in Swan Bay (Figure 10). Based on its depth range (5 m depth or less) from the few individuals collected, this species may be unlikely to be affected by the cold-water discharge due to the physically restricted depth range of the cold-water field (>12.5 m) and the relatively small temperature differential resulting from a multi-port discharge. There is some uncertainty in the actual depth range of this species due to the small number of records of this species.

The ghost shrimp *Michelea microphylla* is known from only one specimen collected in sandy gravel in 19 m water depth offshore from Crib Point in 1965 (Figure 11). It is very rare as it was not found in any other samples in the 1965 survey and has not been found in anywhere else since 1965, including the comprehensive infauna sampling program for the Western Port Study in the 1973/74 (Coleman et al 1978). The only known individual of this species was collected in depth range and location that may be affected by the cold-water discharge. The potential for impact (if any) on this species will be substantially reduced by the discharge of heat exchange seawater from the FSRU via a multi-port discharge arrangement.

Registration no	Location	Stn no	Latitude	Longitude	Depth (m)	Date	No of specimens
MoV J1263	Western Port, off Crib Point	CPBS-N 52	38°19.92´S	145°13.95´E	19	31 Mar 1965	1 (holotype)

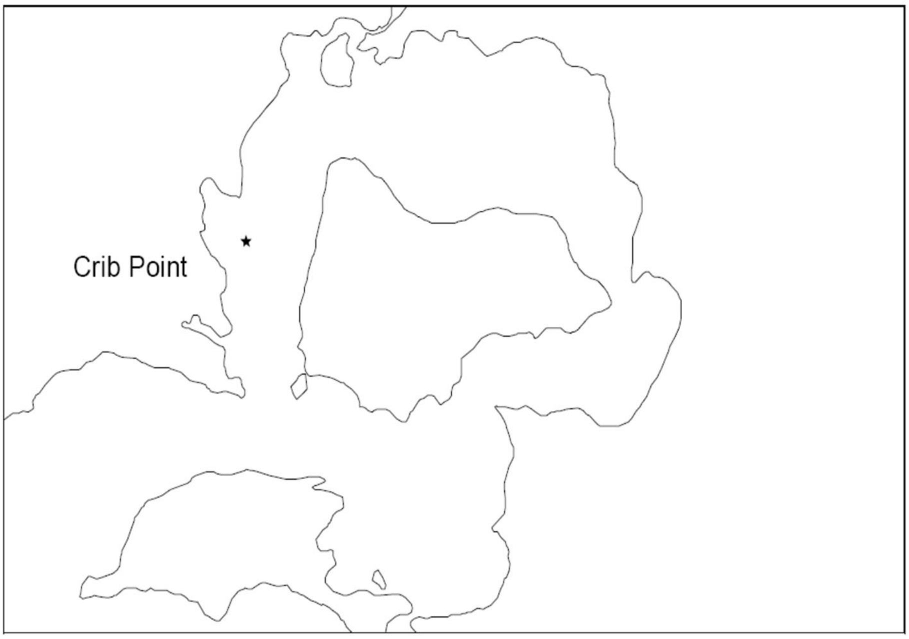


Figure 11. Distribution of ghost shrimp *Michelea microphylla*
(O'Hara and Barmby 2000)

3.2.1.3 Infauna baseline monitoring

Infauna are the most representative ecosystem in the area of the cold-water pool footprint. It is more than 40 years since the infauna of North Arm, including the area that may be affected by the cold-water plume, have been documented. The characteristics of the infauna community in the channel area potentially affected by the cold-water field footprint is uncertain, but may include the FFG listed ghost shrimp *Michelea microphylla* and *Calliax tooradin*. The nature of the infauna community along the potential dispersion pathways and reference locations should be documented through an appropriately designed sampling program including:

- Sediment characteristics;
- Key infaunal community species abundance and distribution;
- Targeted investigation of potential ghost shrimp *Michelea microphylla* and *Calliax tooradin* habitat.

3.2.2 Epifauna

The distribution and abundance of large epibiota of the soft seabed, deeper channels in Western Port is not well documented. Inspections by CEE and other marine scientists over the years (e.g. J E Watson, Marine Science and Ecology, Figure 14) near BlueScope (Figure 12), Long Island Point Crib Point (Figure 13 and Figure 15) and Stoney Point indicate that the epibiota are sparsely distributed over much of the soft seabed or concentrated in high numbers or diverse 'clumps' at particular localities of favourable seabed conditions especially under jetties in North Arm.

Figure 12. Seabed epibiota on channel bottom near Bluescope
(Seabed at all sites was relatively flat with no significant rock outcropping CEE 2008.)

Patches of coarse shell or rubbly material in channels provide relatively stable substrata for attachment and growth of sessile epifaunal animals (epizoic species) and associated mobile epifaunal animals. Sessile epizoic species include the brachiopod *Magellania flavescens* (Figure 13), the solitary ascidian *Pyura stolonifera*, sponges, hydroids and colonial ascidians (Smith *et al.* 1975). *Magellania* and the seapen *Sarcophyllum* can reach densities of 250 per m^2 in suitable habitat, but is not thought to be common elsewhere in Bass Strait (Smith *et al.* 1975). Mobile epizoic species include the gastropod *Sigapatella calyptraeformis*, the sea stars *Nectria ocellata*, *Patiriella brevispina* and *Tosia magnifica*, and the urchin *Goniocidaris tubaria* (Figure 13) (Smith *et al.* 1975). Areas of firmer seabed may exist in the deeper channels that provide sufficient habitat for establishment of patches of sponge communities, while seapens such as *Sarcophyllum* and *Sarcoptilus* inhabit mobile sand waves as well as stable fine sand seabed (Figure 14).

Figure 13. Seabed and epibiota under Crib Point Jetty, Berth 1
Urchin *Goniocidaris tubaria and seastar Nectria ocellata (left); cuttlefish and Magellania flavescens (right)*
(CEE November 2017)

Sarcophyllum sp *Sarcoptilus grandis*

Figure 14. Seapens in lower North Arm
(Photos J Watson May 2009)

Figure 15. Seabed in shipping basin at jetty edge, Berth 1 (northern), Crib Point
(CEE November 2017)

Figure 16. Biota under Stony Point jetty
Red hydroid (left); seastar *Nectria oscellata* (centre) solider crab *Leptomithrax gaimardii* (right)
(March 2009 CEE)

3.2.2.1 Potential Effect on Channel Soft Seabed Epibiota Community

The area of potential effect from the cold-water discharge is located within Stratum 1 of the natural seabed categories identified in the Western Port Bay Environmental Study, as discussed above (Figure 9). The maximum area of seabed and associated soft seabed epibiota that is potentially affected by the cold-water pool from a single-port discharge is defined by the 0.47 km^2 ellipse shown in Figure 8. The area affected by a six-port discharge is substantially smaller as shown in Figure 8. Hence the potential effect of the cold-water represents less than 1 % of the soft seabed epibiota channel community of North Arm. As discussed above, this community has not been systematically surveyed, but is likely to be sparse, patchy and diverse.

3.2.2.2 Potential Effect on Channel Epibiota – biota of concern

There are no listed threatened epibiota likely to occur in the area potential affected by the cold-water discharge. The various shipping jetties in North Arm, including Crib Point Jetty, provide an artificial habitat for relatively high numbers of biota from a range of interesting species as shown in the figures above.

3.2.2.3 Epibiota baseline monitoring

Most species are thought to be distributed widely and populations are not likely to be directly threatened by the proposed discharge. However, there is no existing information on the distribution of epibiota in the shipping basin or channel around the jetty. Hence, a baseline investigation is required to confirm nature of epibenthic biological characteristics in the channel within approximately 1 km of the FSRU.

The most likely effect of the discharge of cold-water at Crib Point Berth 2 is likely to be detectable on the epibiota under the jetty at Berth 2 and less so at Berth 1. These biota are a potential indicator of the extent of the discharge effect on the wider ecosystem and it is recommended that these epibiota should be included in the environmental baseline program to document potential extent of effects of the project on the marine ecosystem of North Arm.

3.3 Ecosystem temperature exposure

The only location that will be constantly exposed to cool seawater from either a single-port or six-port discharge will be the water column and seabed within the fall line of the descending cool plume. The water temperature differential in the discharge plume will reduce from 7°C below ambient at the point of discharge to 0.8°C below ambient close to the seabed for the single port discharge and 0.3°C below ambient close to the seabed for the six-port discharge. As discussed in Section 2, the cold-water will then disperse to the north during flood tides and the south during ebb tides, resulting in a variable exposure to cold-water on the seabed along the dispersion pathways.

For the single-port discharge, cold-water at 0.8°C below ambient will spread along the seabed as an elongate pool for a possible distance up to 600 m north during the flood tide and south during the ebb tide, 60 minutes either side of the turn of the tide. Tidal currents during the middle 5 hours (approximately) of the tidal cycle will be sufficient to disperse the pool. The cycle will repeat approximately every twelve hours for both single and dual discharge options.

For a six-port discharge, the water column and seabed within the fall line of the descending cool plume will be the only location that will be constantly exposed to cool seawater. The cold-water plume will be 0.3°C below ambient and will disperse rapidly under most conditions without forming a layer on the seabed. A temporary pool up to 200 m long may form for less than an hour at some low tides if cross-currents are particularly weak. The pool is likely to be patchy due to the small temperature of the dilute cold-water discharge and natural variation in ambient seawater temperature.

The temperature exposure profile for positions along the cold-water dispersion pathways will be highly variable over time due to changes in initial dilution due to tide height and water depth below the discharge, reversals in tidal current direction, changes in tidal current speed over the tidal cycle, intermittent formation of the cold-water pool and the effect of seabed slope on the trajectory of the dispersion pathway at different current speeds.

3.3.1 Review and monitoring of temperature variation

Biological activity and movement of many migratory fish species in Western Port tends to follow the increase in day length and water temperature in spring and through summer to early autumn. Hence, this is the period that small differences in temperature variation may affect migration of demersal fish species and biological processes such as spawning, growth and larval settlement of invertebrate species in the channel seabed community.

The effect of temperature variations on individual species is likely to vary substantially from species to species and also vary between biological processes within individual species. This is difficult to determine for the range of species in North Arm. However, the significance of the magnitude of temperature variations and the spatial extent predicted in the modelling so far do not appear sufficient to substantially affect populations of invertebrates in North Arm. The maximum temperature difference between the cold-water plume and ambient seawater after initial dilution is predicted to be 0.8°C for the single discharge option and 0.3°C for the six-port discharge option. Seawater temperature at Long Island Point can vary naturally by 0.3°C over a 4-hour period (as recorded in March 2016 by CEE). The effect of the cold-water is unlikely to be detectable at 600 m from the point of discharge.

The natural short term (daily to weekly) range of temperature variation should be investigated to provide context for assessing the potential proportional seawater temperature reduction due to the cold-water discharge from the FSRU.

4 CONCLUSION

The behaviour of the cold-water discharge plume was modelled using known and quantified physical fluid dynamics processes, the characteristics of seawater in North Arm of Western Port and tidal current characteristics at Crib Point. Data relating to the temperature of the discharge from the FSRU, the distance of the discharge below the water line and the daily flow of the FSRU were provided by AGL for the initial dilution and nearfield modelling tasks.

The cold-water discharged from the FSRU heat exchanger will initially be 7°C cooler than ambient (at the point of exit). In the conservative model using one or two port discharge from the FSRU, the cool seawater will leave the FSRU as a horizontal dense jet of water and mix with the surrounding, warmer seawater as it turns downward from horizontal and descends due to gravity in the warmer water column. Within seconds, the descending plume will be close to the seabed and will have mixed with sufficient surrounding seawater to reduce the temperature difference to 0.8°C cooler than the ambient seawater temperature. The cooler water will then disperse close to the seabed with tidal currents and gravity. The adoption of the six-port discharge will ensure that any temperature difference will be within ambient range within 200 m downstream of the FSRU discharge point.

Cold-water resulting from the discharge will only be present in the deeper channel of North Arm at water depth greater than 12.5 m. Hence all marine ecosystem components that are distributed at depths less than 12.5 m will be unaffected by direct contact with the cold-water.

Saltmarsh, mangrove, mudflat, intertidal seagrass, subtidal seagrass and channel slope communities and sensitive species that occupy habitats in water depth less than 12.5 m water depth will be unaffected by contact with the cooler water resulting from the heat exchange water discharge.

The biota that will have variable contact with the cold-water will be the invertebrates living on or in the soft sediments of the channel, the fish that may swim along the seabed and the animals that are found under the Crib Point Jetty. Mobile species in the area may be exposed over a shorter period and may avoid the cooler water by moving higher in the water column or around the water body if affected.

The invertebrate communities in the area that may be exposed to temperatures up to 0.8°C below ambient are thought to be widespread in North Arm. A maximum of 1 percent of the invertebrate community of the North Arm channel is expected to be exposed to temperatures up to 0.8°C below ambient for a single-port discharge and less than 0.3°C below ambient for a six-port discharge.

The only species of significance that is documented from the area that may be exposed to cooler water are ghost shrimp. The entire species of *Michelea microphylla* is known from one individual collected near Crib Point at 19 m water depth in 1965. No other individuals have been found anywhere since the first and only collection, including extensive studies in 1974/75 for the Western Port Bay Study. *Calliax tooradin* is known only from a total of five individuals. Four were collected subtidally in grab samples offshore from Crib Point in 1965 and since then have not been recorded in Western Port.

Initial dilution and nearfield modelling suggest that the water temperature differential of the discharged seawater of 7°C below ambient at the point of discharge will reduce to 0.8°C below ambient near the seabed for a single-port discharge and 0.3°C below ambient near the seabed for a six-port discharge. The effect of the discharge from a single-port discharge is unlikely to be detectable at 600 m from the FSRU and less than 200 m from the preferred six-port discharge.

The only location that will be constantly exposed to cool seawater will be the water column and seabed within the fall line of the descending cool plume next to the FSRU. Almost all other areas will be unaffected. Overall, the impact to the surrounding marine ecosystem from the discharge of cooled water at 200 m from the FSRU is expected to be undetectable when operating using the preferred six-port discharge.

The characteristics of the invertebrate communities within in North Arm have not been documented for more than 40 years. Hence channel infauna and jetty epibiota baseline monitoring have been recommended to provide present-day context to refine the detail of ecosystem effects assessment. Victorian Regional Channels Authority (VRCA) intends to level 95 m^2 of isolated high points at Berth 2 of Crib Point Jetty and engaged CEE to investigate the presence of threatened ghost shrimps in the vicinity of the high points in July 2018. No threatened species of ghost shrimp were found during the survey (CEE 2018b). A specific sampling program extending over a larger area of the seabed for ghost shrimp has been recommended for this Project.

Water temperature monitoring has been recommended to provide ambient context for assessment of the magnitude of natural short-term variation against the temperature differentials predicted by the initial dilution and near field models.

5 REFERENCES

CEE 1995. *A review of Western Port Marine Environment*. Report to Environment Protection Authority Victoria by CEE Pty Ltd Consulting Environmental Engineers Richmond.

CEE 2009. *Port of Hastings Stage 1 Development. Marine Ecosystem. Preliminary Considerations*. Report to AECOM and the Port of Hastings Corporation. CEE Consultants Pty Ltd, Richmond, Victoria.

CEE 2018a *Plume Modelling of Discharge from Floating Storage and Regasification Unit, AGL Gas Import Jetty Project*. Report to Jacobs for AGL. CEE Pty Ltd, Cheltenham Victoria.

CEE 2018b Threatened ghost shrimp survey Berth 2 Crib Point Jetty Risk from bed levelling of isolated high points. Report to VRCA, August 2018.

Coleman N, W Cuff, M Drummond and JD Kudenov (1978). *A quantitative survey of the macrobenthos of Western Port, Victoria*. Australian Journal of Marine and Freshwater Research 29(4):445 - 466

EPA 1996. *The Western Port Marine Environment.* EPA Publication no 493. Environment Protection Authority

Melbourne Water Corporation. (2011). *Understanding the Western Port environment: a summary of current knowledge and priorities for future research*. Melbourne Water, Melbourne.

Ministry for Conservation (1975) *Westernport Bay Environmental Study 1973-1974*. Ministry for Conservation, Victoria.

O'Hara T, Barmby V (2000) *Victorian Marine Species of Conservation Concern: Molluscs, Echinoderms and Decapod Crustaceans*. Parks, Flora and Fauna Division, Department of Natural Resources and Environment, East Melbourne, Australia.