Report to:
Jacobs Group (Australia) Pty Ltd

AGL Gas Import Jetty Project
Crib Point Jetty, Western Port

Modelling and Assessment of Biological Entrainment into Seawater Heat Exchange System

FINAL

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AGL Gas Import Jetty Project

Modelling and Assessment of Biological Entrainment into Seawater Heat Exchange System

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.

Regasification involves the heating of the LNG stored at -162^{o}C 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, and is used here as the upper limit for modelling.

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. The scope of this desktop assessment was to investigate the potential for biological entrainment into the seawater heat exchange for the FSRU and review potential implications to the marine ecosystem. This report was 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*,
- Identification of requirements under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act).

Initial modelling undertaken as part of this assessment shows that:

- The seawater intake on the FSRU is positioned and designed to minimise the entrainment of fish.
- Larvae that can maintain position in preferred nearshore habitats such as mangroves seagrasses and shallow nearshore waters should not be entrained.
- Larvae, eggs and other propagules (e.g. mangrove seeds) that drift or travel on the water surface or near the seabed should not be entrained.
- Short-lived larvae will only be entrained in proportions potentially >1 % in total if they commence their larval existence only within 3 km of Crib Point, and on the western side of North Arm.
- Long-lived larvae will be entrained in proportions potentially >1 % in total if they commence their larval existence within about 10 km of Crib Point, and on the western side of North Arm.
- The entrainment rate is expected to be about 2 to 3 % for sites on the western edge of the channel (including the adjacent mudflats) within about 8 km of Crib Point, and about 10 % for sites on the western edge of the channel (including the adjacent mudflats) within about 750 m of Crib Point (as shown in Figure 12).

- In the context of the wider Western Port area, for larvae commencing at 2 km or more north or south of the FSRU intake, less than 2 % of larvae would be entrained.
- Overall, the proportion of larvae entrained from populations of widespread biota in Western Port is less than 1% and the effect is likely to be undetectable.

The modelling completed for this report and other supporting studies was based on the original FSRU seawater flow rate through the heat exchanger of 450,000 m^3/day. AGL has advised that a seawater flow-through rate of 300,000 m^3/day corresponding to a lower regasification rate is more likely. In this case, the proportion of plankton entrained may be reduced by approximately one third.

The assessment suggests that the design of the FSRU water intake will minimise the direct risk of biological entrainment and operation on many ecosystem components.

Estimation of the proportion of planktonic populations that may be entrained are dependent on a range of factors including:

1. The nature, distribution and annual variation of planktonic populations in North Arm of Western Port, which are currently undocumented; and
2. Hydrodynamic model configurations specific to entrainment.

It is recommended that the following studies are undertaken to provide greater certainty to the entrainment estimates reported in this study:

- Particle entrainment modelling of North Arm be developed to provide entrainment proportion contours for FSRU heat exchange flow options.
- A plankton and larval sampling program be designed and implemented to provide baseline information on spatial and temporal variations in plankton populations in North Arm focussing on the proposed location and position of the FSRU intake.
- A review of available information and literature on the effects of entrainment on semi-enclosed marine ecosystems to provide guidance on long-term ecosystem implications of plankton entrainment.

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.

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 gas.

Regasification involves the heating of the LNG stored at -162°C 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 may be pumped at a rate of 5.2 m^3/s through heat exchangers in the FSRU, and is used here as the upper limit for modelling. This is a similar (but smaller) volume of seawater withdrawn by the Victorian Desalination Plant at Wonthaggi, which operates intermittently according to storage dam levels. The FSRU is also expected to operate with variations in flow depending on LNG supply and gas demand. AGL advises that the seawater flow the heat exchanger is likely to be 300,000 m3/d based on more recent estimates of regasification rate requirements.

1.2 Purpose of this report

The scope of this desktop assessment was to investigate the potential for biological entrainment in to the seawater heat exchange for the FSRU and review potential implications to the marine ecosystem. This report was 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;*
- Identification of requirements under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act).

2 INTAKE CONSIDERATIONS

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). Hence, heat exchange seawater will be withdrawn from the main channel of North Arm.

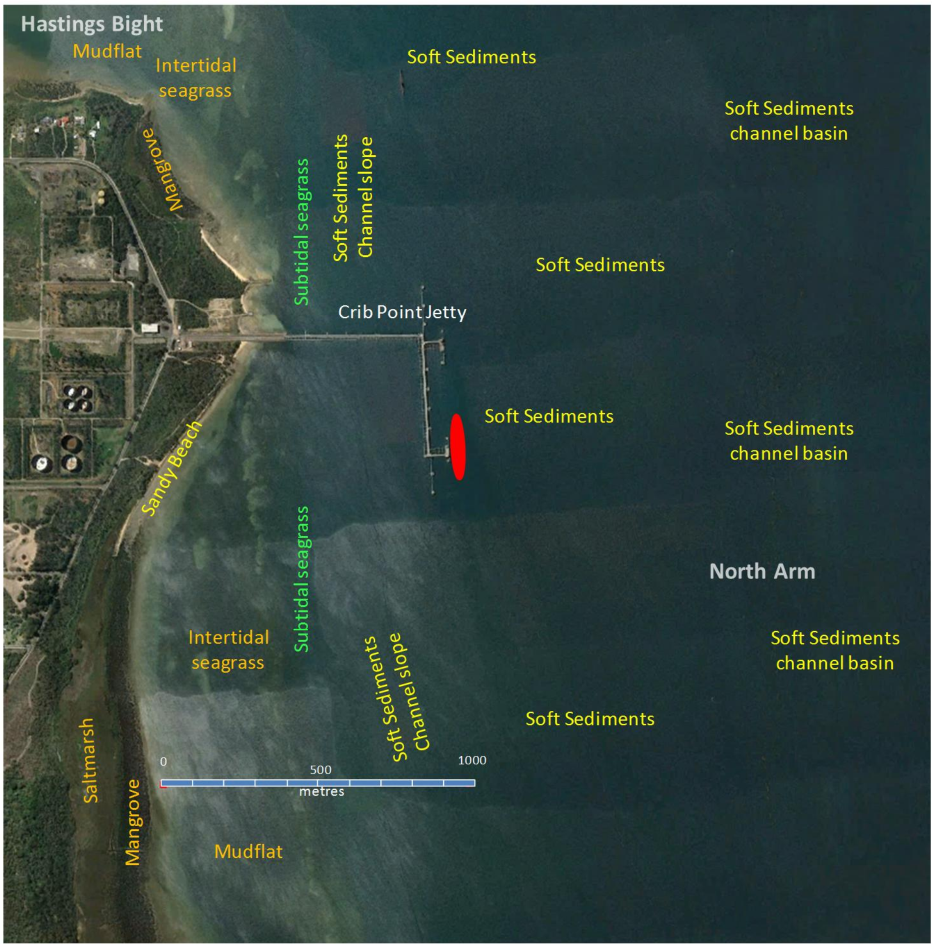


Figure 1. Natural marine ecosystem components at Crib Point
(Position of FSRU shown in red)

The distribution of habitats (Figure 1) and conceptual model of the marine ecosystem in the vicinity of Crib Point (Figure 2) are based on CEE’s understanding of the distribution and characteristics of North Arm from previous reviews (Bok 2017, CEE 2009 and 2014, EPA 1996, 2001, Kimmerer and McKinnon 1987a and 1987b, Melbourne Water 2011, Ministry for Conservation 1975). The figures show that the FSRU is relatively remote from intertidal and nearshore marine ecosystem components and is located in an area of the channel characterised by plankton (plankton, larvae, eggs, small fish) and larger marine species including fish, diving seabirds such as penguins, cormorants and gannets and mammals such as seals and native water rats. Hence, a range of small marine species and, if appropriate mitigations are not put in place, some large biota (Figure 2) in the immediate vicinity have the potential to be drawn into the heat exchange system by the intake current to the seawater pumps and heat exchange pipework of the regasification facility on the FSRU.

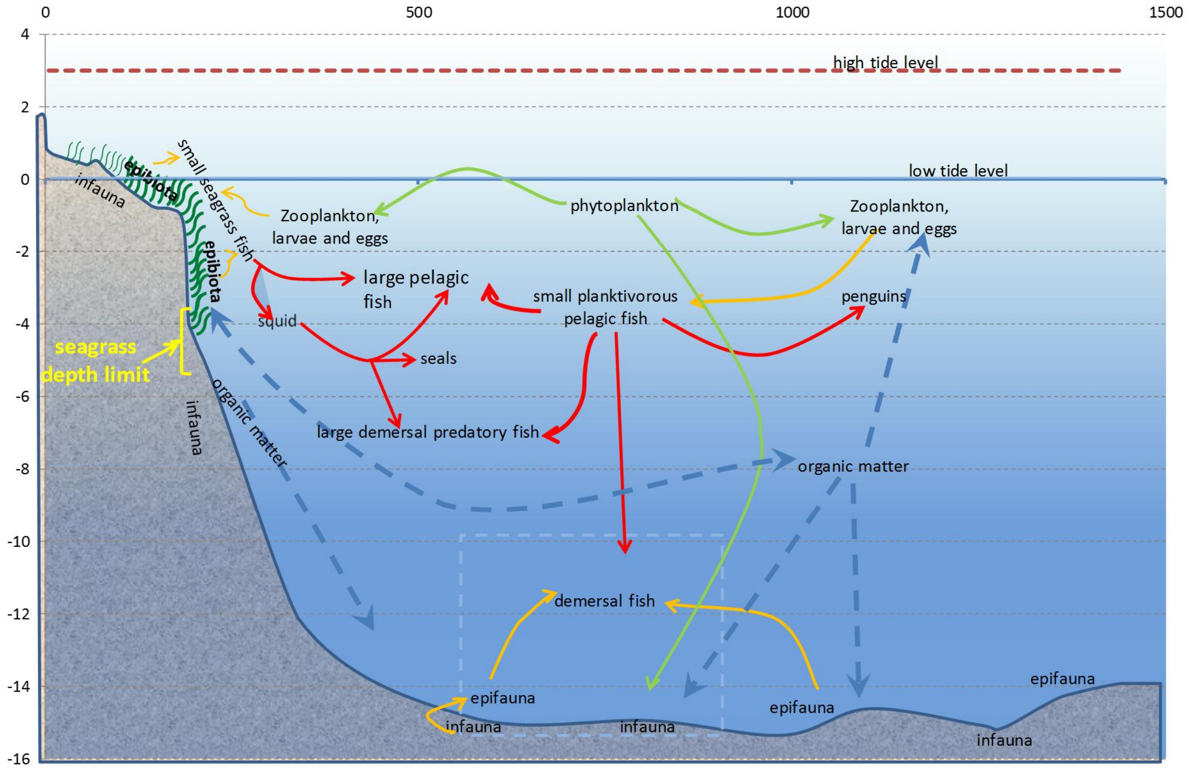


Figure 2. Conceptual model of Western Port marine ecosystem in Crib Point area
(Adapted from CEE 2009)

This preliminary assessment examines the potential effects of entrainment on:

- Large biota that may be caught and damaged or drowned on screens at the intake without appropriate mitigation; and
- Small biota that may pass through screens and suffer further damage in the pumps and pipework of the heat exchangers as well as being exposed to chemical processes to prevent marine growth on the internal components of the water circulation circuit.

For this preliminary assessment, it is assumed that all biota passing through the heat exchanger will not survive the passage. However, in reality a proportion of biota will survive that are sufficiently robust to withstand the stresses during the short passage through the heat exchange system. Hence, the outcomes of this assessment are conservative (worst case) with respect to the effects of entrainment on marine biota.

2.1 Intake design to minimise effects on marine biota

The configuration and position of the FSRU seawater intake involves the following environmental considerations:

1. Minimise intake and capture of large actively swimming marine organisms such as diving birds (cormorants and penguins), mammals (seals and native water rats), fish and molluscs (squid).
    - From this consideration, the intake should not be near the surface or near the seabed, and should be protected by appropriate screens. In addition, the intake should be designed so that water enters horizontally at a velocity of 0.1 to 0.15 m/s.
    - Many mobile vertebrate marine organisms (fish, birds, mammals) cannot detect vertical velocity components (upward or downward currents), so the water must enter the intake horizontally to enable marine vertebrates the opportunity to detect

the lateral currents and swim away from the intake. This is standard practice from modern heat exchange and desalination intake design.

2. Minimise entrainment of marine plankton, eggs and larvae. These are the very small plants and animals and the propagules of larger plants and animals that are found throughout the water column. They may have some capability for movement but are relatively passive swimmers and are carried with the prevailing currents. The waters of North Arm are relatively well mixed by strong tidal currents, but there may be the tendency for some species to be found in the upper or lower parts of the water column at different times of day or at different stages of their life-cycle, particularly during periods of low tidal currents.
    - From this consideration, the intake should not be near the surface or near the seabed. This assessment will be informed by the proportion of marine plankton, eggs and larvae that will not survive the entrainment process. The assessment includes modelling that takes into account the specified seawater inflow rate, location at Crib Point, residence time of waters in Western Port and ecological parameters.

2.1.1 FSRU seaworthiness and engineering considerations

The design criteria described below are based on experience including the assessments and specified requirements for seawater intakes at Desalination Plants throughout Australia, and overseas power plants (e.g. US EPA cooling water intake regulations).

Practical, seaworthiness and engineering considerations for the design of the intake for an FSRU are not discussed in this document including:

- Avoiding re-circulation of the heat exchange water discharge back into the intake
- Seaworthiness of vessel with environmental intake
- Biofouling (including drift material) management of the intake.

2.2 Position of intake in water column

The sea surface and seabed are physical boundaries where movements of planktonic, pelagic biota (fish and molluscs) and air breathing animals (seals, water rats, penguins) are most likely to be concentrated. Hence, it is recommended to ***avoid*** placing the intake close to these two natural water column boundaries. These are also the boundaries where most drifting buoyant or dense material tend to accumulate.

AGL has advised that the seawater intake for the heat exchange system will be installed in the sea chest within the hull or as an attachment on the side of the vessel. The intake will therefore move up and down with the tide. In either case, the intake structure will be placed in a specific water depth range to reduce the potential for intake of biota or debris.

The water depth at the site is approximately 14 m from seabed to sea surface at lowest astronomical tide, with an additional 3 m depth at highest tides. To reduce the effect of the intake of seawater on ecosystem components, the seawater intake should be positioned

a) At least 5 m above the seabed; and
b) At least 4 m below the water surface.

Hence FSRU intakes are designed to be located in the water column layer between 5 m to 10 m above the seabed as shown in Figure 3.

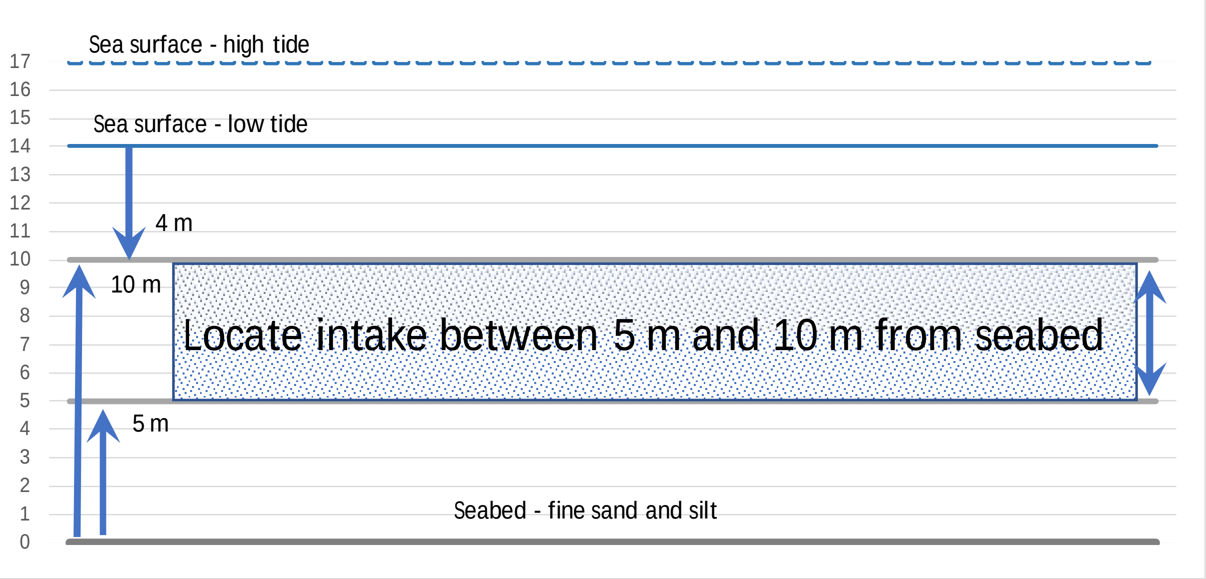


Figure 3. Critical water depths at Crib Point facility

2.3 Intake velocity – orientation and size of the intake

The intake opening should be designed so that water is drawn into the intake in a horizontal plane at a speed < 0.15 m/s (Figure 4 and Figure 5). The intake should be oriented parallel to the ambient tidal currents, either flush with the hull of the FRSU or mounted on the hull or jetty piles.

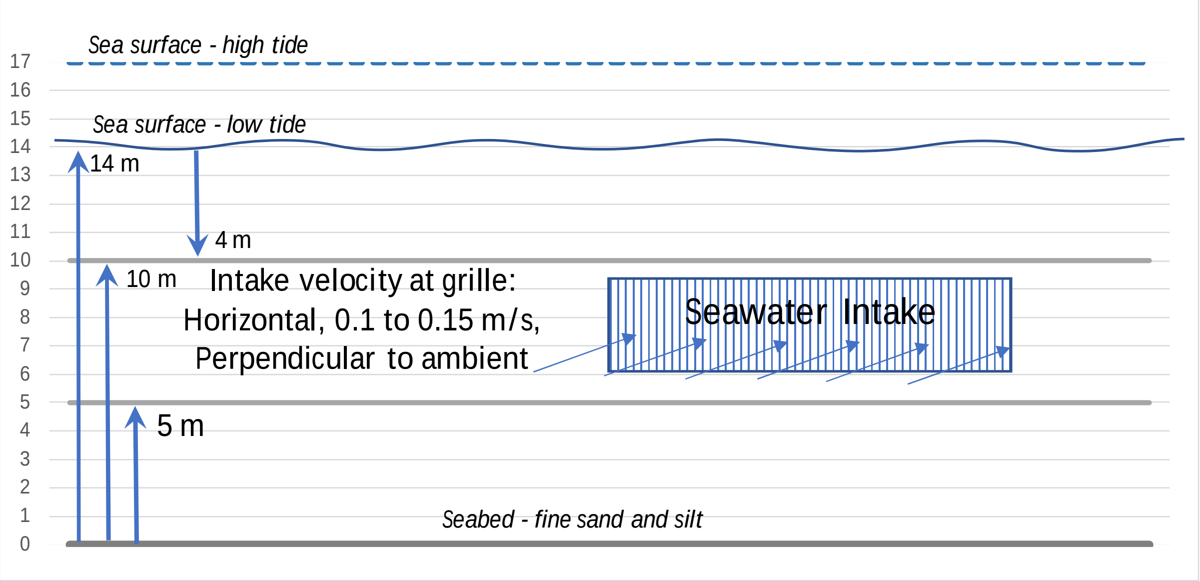


Figure 4. Seawater intake environmental parameters at Crib Point facility

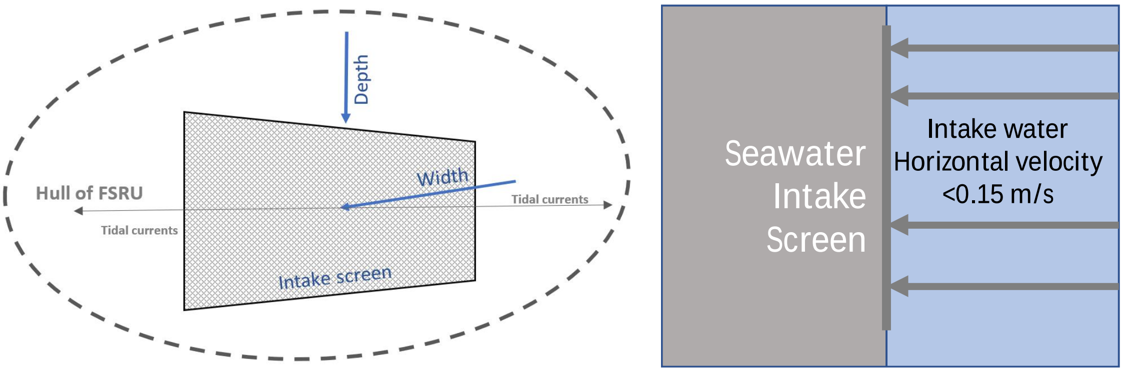


Figure 5. Environmental parameters at seawater intake: oblique and section

The volume of water drawn into the intake will be relatively constant, but the width (horizontal distance perpendicular to the screen) and depth (vertical distance above and below the screen) of the zone from which seawater will be entrained around the intake will vary as water currents change over the tide cycle.

Figure 6 shows the variation in the size of the zone from which seawater will be entrained over the tide cycle. The zone extends over a depth range of 2.6 m (at peak tidal currents) to 7 m (at slack water). Thus, for example, if the intake is at 8 m depth, seawater will be drawn into the heat exchanger at slack water from depths of 4.5 to 11.5 m below sea level. At peak currents, the depth range will be from 6.7 m to 9.3 m below sea level. The width of the zone will vary over the tide cycle from about 6 m to 15 m, depending on the current speed.

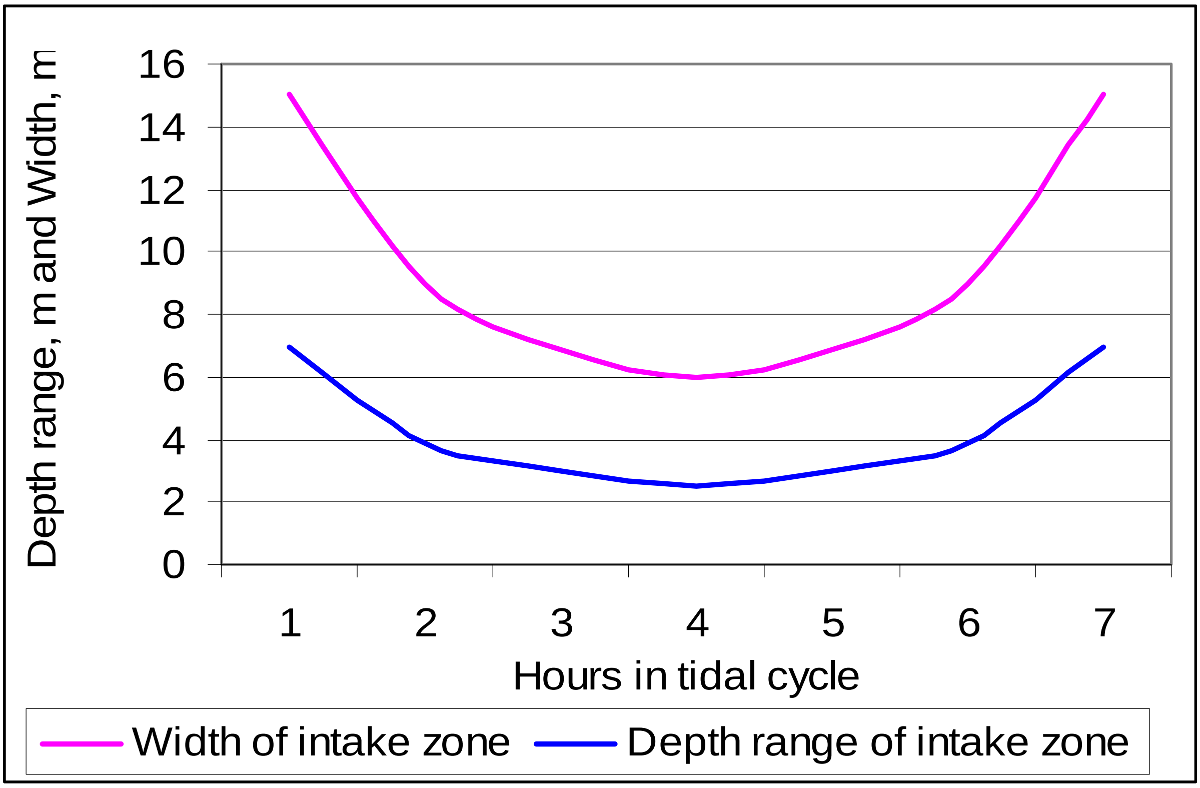


Figure 6. Variation in width and depth of seawater intake zone over tide cycle

2.4 Intake grille and screens

Intake grilles will reduce the likelihood of larger mobile marine animals and drifting debris from entering the seawater heat exchange system.

Environmental specifications for the Victorian Desalination Plant Intake were “Bar grille spacing 100 mm horizontal by 100 mm vertical or 50 mm horizontal spacing of vertical bars”. The installed screens are shown in Figure 7.

Figure 7. Seawater intake grille at Victorian Desalination Plant
(Photo by M Venturoni)

2.5 Residual effect of intake on entrained biota

As a result of the design features described above, the main unavoidable adverse effect of the heat exchanger system is to entrain the smaller marine organisms (very small fish, zooplankton and phytoplankton), drifting eggs and larvae in the central part of the water column in the intake zone. It is assumed for this preliminary assessment that all of entrained biota will not survive as a result of mechanical damage and exposure to chlorine biocide during passage through the heat exchange system. However, in reality it is likely that some biota will survive the entrainment process and relatively short period of exposure to chlorine as they pass through the heat exchange system.

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 North Arm of Western Port has not been comprehensively studied since the early 1970s (Zooplankton - Macreadie 1972; phytoplankton and zooplankton - Ministry for Conservation 1975) and 1980s (zooplankton -Kimmerer and McKinnon 1985, 1987a, 1987b), but, like most marine bays, it comprises holoplankton populations (those that live their entire lives suspended in the water column such as phytoplankton and zooplankton) and meroplankton populations. Meroplankton include the eggs, larvae and other undeveloped life stage (propagules) of a wide range of adult marine plants, invertebrates and fishes. The adults may live in the water column (such as fish or squid) or on the seabed (including seaweeds, shellfish, crabs, sea urchins, sea squirts, fish).

Phytoplankton and zooplankton (holoplankton) generally reproduce in the water column, with different rates of reproduction or turnover between species, seasons and years. The characteristics and duration of the meroplanktonic life stages 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 environmental conditions (currents, water temperature, primary productivity) can affect larval recruitment and is a key factor affecting the abundance and composition of many important ecological community components as well as commercial fisheries species.

Planktonic larvae originate from a range of adult biota. The adults may disperse eggs or larvae widely, resulting in widely dispersed planktonic larvae. Alternatively, they may lay eggs or release larvae in particular habitats that subsequently disperse along relatively defined hydrodynamic pathways.

At this stage of the Project, the effects of entrainment will be assessed in terms of the proportion of seawater that passes through the FSRU over representative time periods. This will enable subsequent assessment of the scale of effects on the marine ecosystem in relation to the area of North Arm affected and the biota most affected (see “Marine Ecosystem Protected Matters” CEE 2018b).

The assessment of entrainment effects of the seawater heat exchange system relies substantially on understanding of local hydrodynamics and flushing in Western Port, as discussed following sections.

3 HYDRODYNAMICS OF WESTERN PORT

Western Port is a large tidal inlet that extends for approximately 30 km from north to south and for approximately 40 km east to west. Western Port has an area of approximately 680 km^2 and estimated volume of 0.8 km^3. The features that strongly influence the hydrodynamics of Western Port are:

1. The two large islands in the Bay – French Island and Phillip Island
2. The extensive areas of shallow mudflats, particularly in the northern sector of the Bay
3. The relatively large tidal range (approximately 3 m) in Bass Strait at the entrances to Western Port. Figure 8 shows the two main islands and the bathymetry of Western Port.

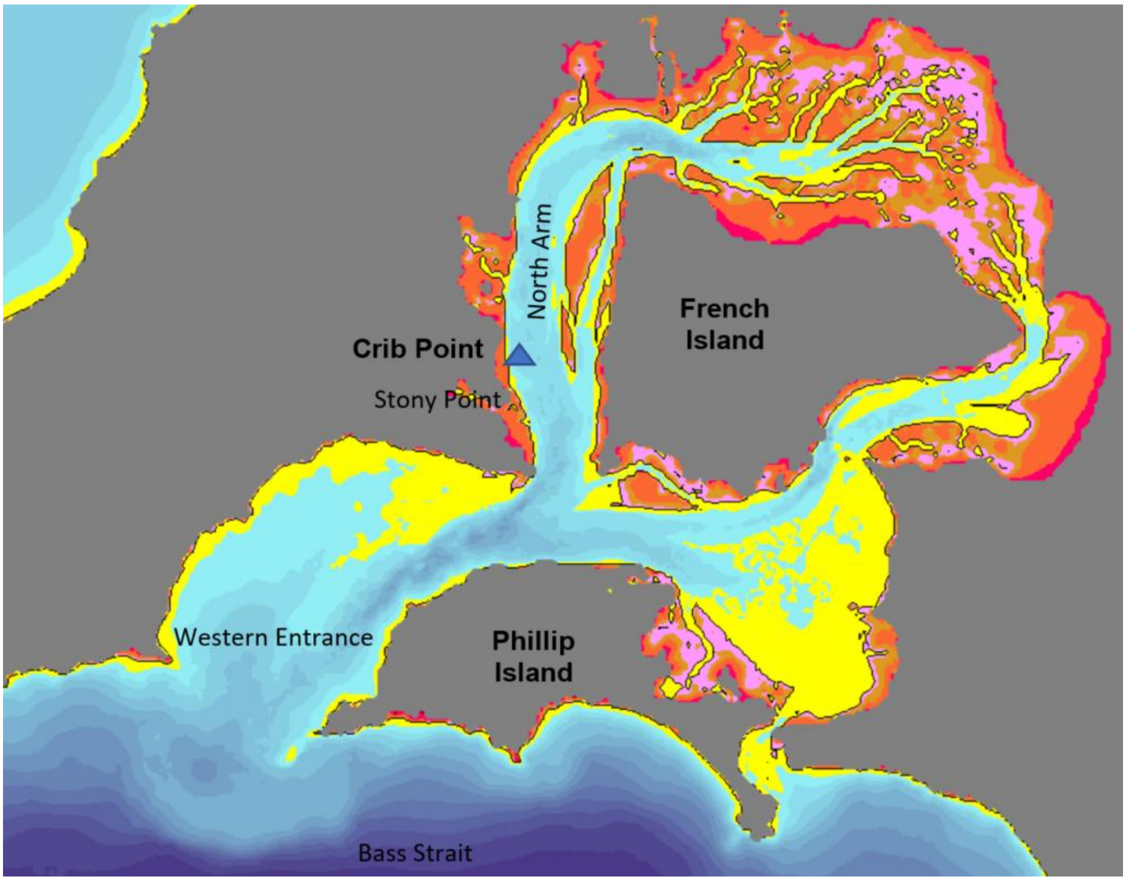
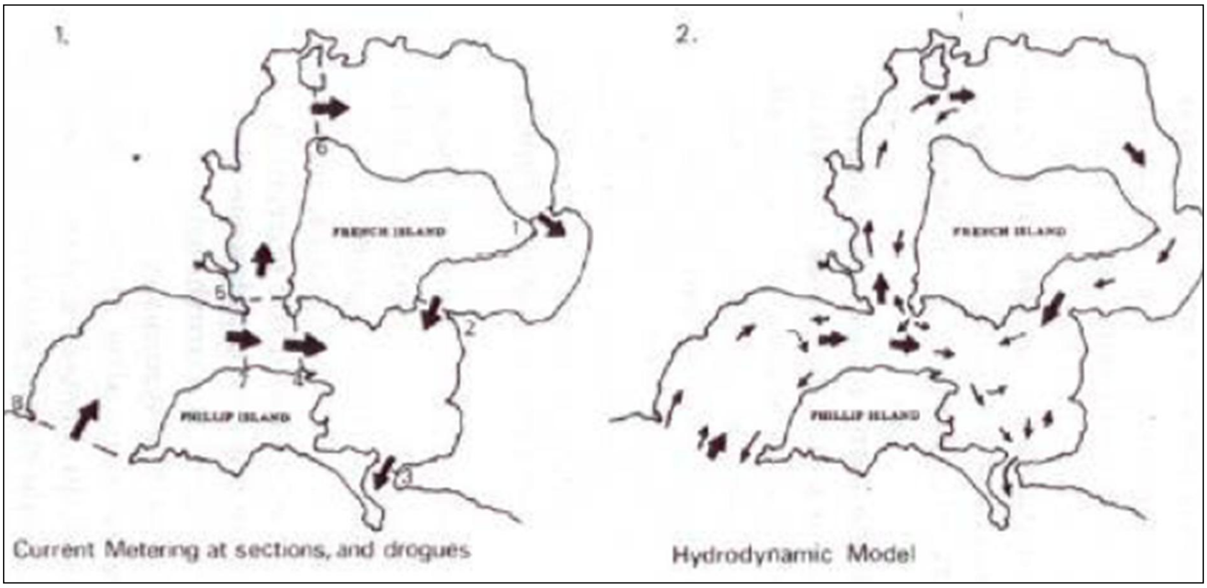


Figure 8. Islands and Bathymetry of Western Port
(Yellow areas less than 6 m deep; Red areas less than 3 m deep)

Average tides (MHHW to MLLW) range from 2.1 m in Bass Strait at Flinders in the entrance to Westernport to 2.2 m at Stony Point, Crib Point and Bouchier Channel in the north of the Bay (VRCA 2018). Largest tides may range up to 3.3 m at Stony Point. As a consequence of these large tidal ranges and the large surface area of the Bay, large volumes of water enter and leave Western Port each tidal cycle.

Estimates have been made of the tidal prism - the volume of seawater that enters and leaves Western Port each (average) tide cycle - from current measurements and hydrodynamic model predictions. Figure 9 shows the location of cross-sections at which the tidal prism has been calculated. About 960 million m^3 (Mm^3) of seawater enters Westernport on an average tide. Most of the water (about 900 Mm^3) enters via the Western Entrance and only about 60 Mm^3 through the eastern channel at San Remo.



1 = Hinwood and Jones (1979); 2 = Hinwood (1979)

Figure 9. Water Movement in Western Port

Approximately 350 Mm^3 of the flows travels up the western side of North Arm and of this volume, about 200 Mm^3 spreads over the mudflats in the north of the Bay. A further 130 Mm^3 of seawater enters North Arm along the Arm's eastern side (Hinwood Hydrodynamic Model, Figure 10).

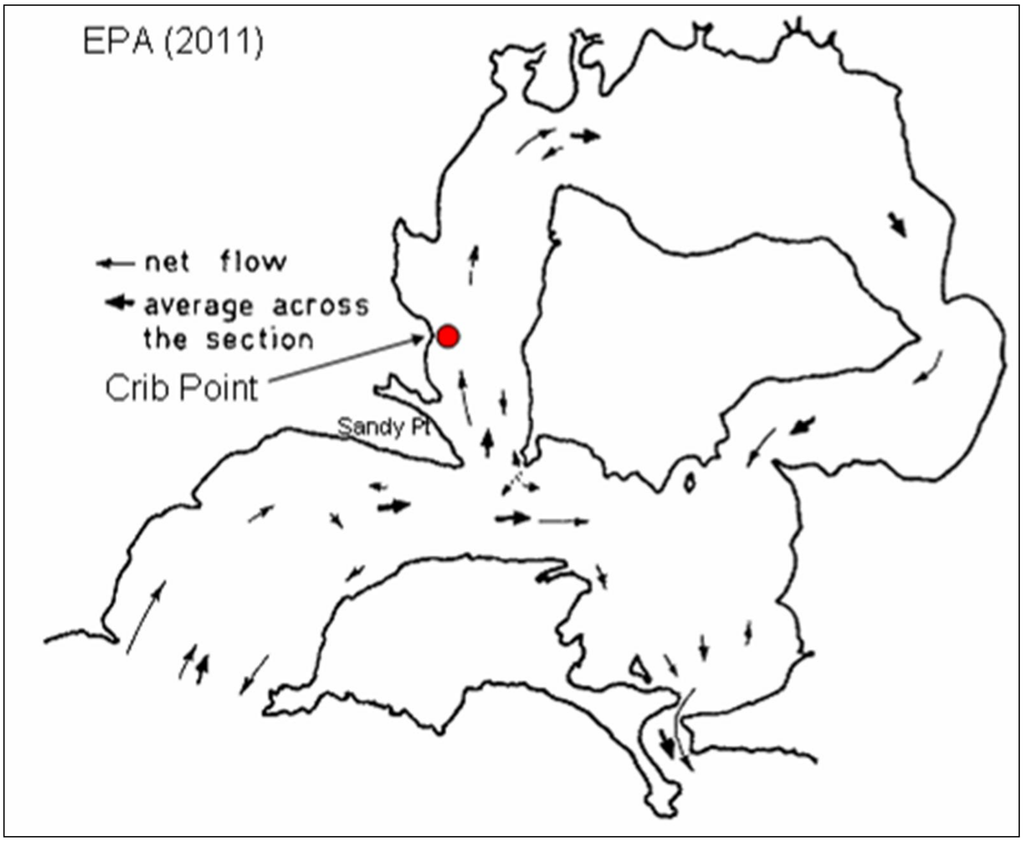


Figure 10. Water Movement in Western Port relative to Crib Point

3.1 Net Water Movement

The net water movement in Western Port is usually (but not always) clockwise around French Island and Phillip Island as illustrated by the wider arrows in the bottom chart of Figure 10. Persistent strong winds can reverse the direction of the net flow from clockwise to anticlockwise (Hinwood, 1979).

At Crib Point, most measurements and analyses (Hinwood 1979, EPA 2011) indicate an excursion of a theoretical water particle on the flood tide inflow of about 6 km up the channel (to the north), followed by an excursion of about 5.5 km down the channel (to the south). This results in a net tidal movement of about 0.5 km per tide cycle to the north. Thus, a theoretical water particle would move in a sinusoidal fashion up and down the western channel with a net movement of 0.5 km north per tide cycle (corresponding to 1.0 km/d, as there are two tide cycles per day). It is apparent that this theoretical particle would have travelled back and forth past Crib Point about 12 times (over six days) before finally escaping to the northern mudflats.

In practice, the picture is much more complex, as there are faster currents in the main channel and slower currents on the mudflats, so the tides on the mudflats turn about 30 minutes before the flow in the main channel, causing a net lateral movement. Draining of the mudflats at low tide and the effects of wind add further complexity. Nonetheless, for this preliminary assessment of entrainment by the FSRU at Crib Point, a simple oscillating current pattern is adopted, with a residence time at Crib Point of six days.

This is consistent with recent estimates of flood tide:ebb tide current ratios of 53:47 at Crib Point, which confirmed the clockwise circulation in Western Port (Royal Haskoning 2015), although ebb tides at the Crib Point extraction point of the model were stronger than flood tides, and southerly net water movement was noted at Stony Point and Long Island Point extraction points. These ‘anomalies’ were explained as resulting from eddies at the turn of the tide and from non-tidal effects in model inputs, as noted by Hinwood 1979. The use of tidal stream data alone shows net northerly water movement at all model extraction points, which results in net northerly flow along the western side of North Arm.

Table 1. Current speed statistics (Royal Haskoning 2015)

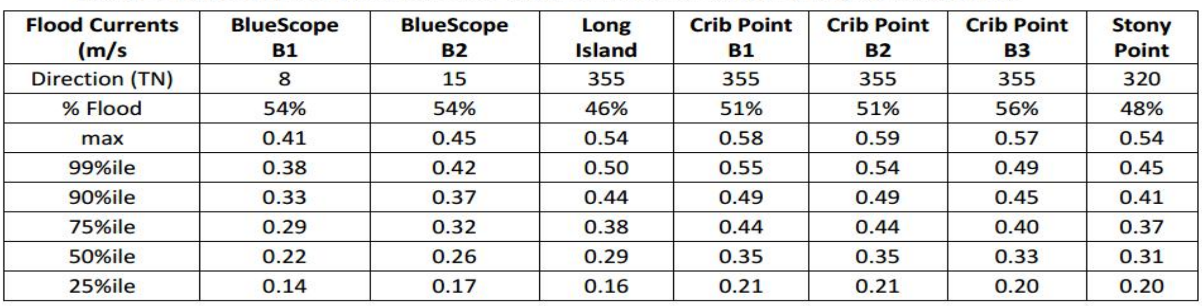


Table 2: *Current Speed Statistics Flood Tide Conditions (1 month fine grid simulation)*

Flood Currents (m/s	BlueScope B1	BlueScope B2	Long Island	Crib Point B1	Crib Point B2	Crib Point B3	Stony Point
Direction (TN)	8	15	355	355	355	355	320
% Flood	54%	54%	46%	51%	51%	56%	48%
max	0.41	0.45	0.54	0.58	0.59	0.57	0.54
99%ile	0.38	0.42	0.50	0.55	0.54	0.49	0.45
90%ile	0.33	0.37	0.44	0.49	0.49	0.45	0.41
75%ile	0.29	0.32	0.38	0.44	0.44	0.40	0.37
50%ile	0.22	0.26	0.29	0.35	0.35	0.33	0.31
25%ile	0.14	0.17	0.16	0.21	0.21	0.20	0.20

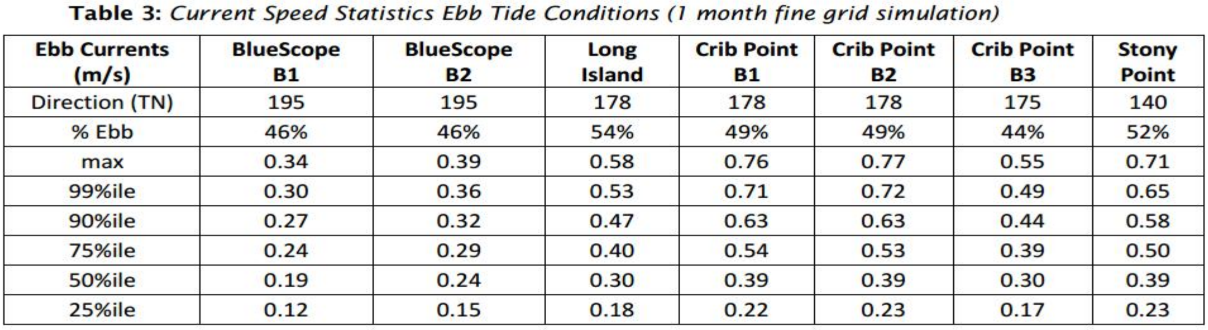


Table 3: *Current Speed Statistics Ebb Tide Conditions (1 month fine grid simulation)*

Ebb Currents (m/s)	BlueScope B1	BlueScope B2	Long Island	Crib Point B1	Crib Point B2	Crib Point B3	Stony Point
Direction (TN)	195	195	178	178	178	175	140
% Ebb	46%	46%	54%	49%	49%	44%	52%
max	0.34	0.39	0.58	0.76	0.77	0.55	0.71
99%ile	0.30	0.36	0.53	0.71	0.72	0.49	0.65
90%ile	0.27	0.32	0.47	0.63	0.63	0.44	0.58
75%ile	0.24	0.29	0.40	0.54	0.53	0.39	0.50
50%ile	0.19	0.24	0.30	0.39	0.39	0.30	0.39
25%ile	0.12	0.15	0.18	0.22	0.23	0.17	0.23

3.2 Water Technology Hydrodynamic Model

The results from Water Technology hydrodynamic modelling for the Project (Water Technology 2017) show a completely different pattern of net water movement from earlier models, as illustrated in Figure 11.

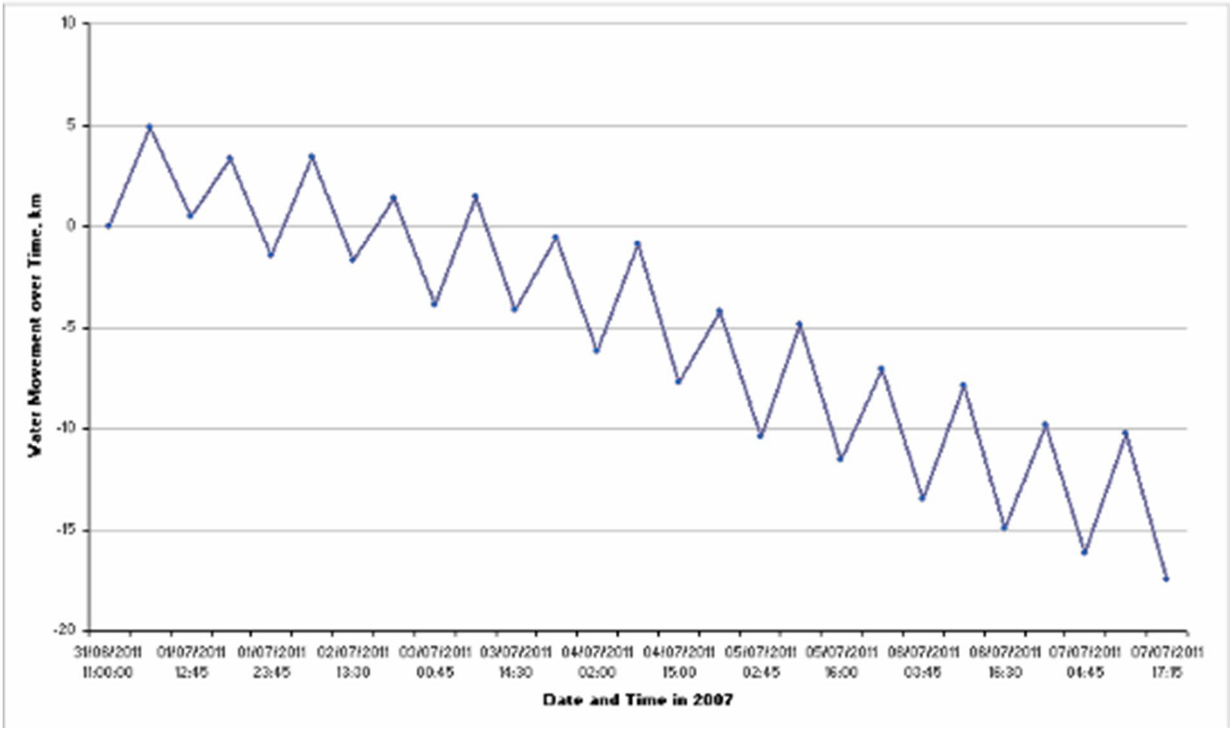


Figure 11. Water Movement at Crib Point from Water Technology Model

The flood tide excursion averages 4.6 km to the north while the ebb tide excursion averages 6.0 km to the south. Thus, there is a net particle movement south of 1.4 km per tide cycle and a residence time of only two days.

4 ENTRAINMENT OF DRIFTING MARINE BIOTA

None of the small organisms taken into the heat exchanger are assumed to survive passage from the intake to the point of discharge. A first assessment of the potential effects of larvae abundance can be made by considering the intake volume as a proportion of the volume of water that flows past Crib Point each tidal cycle. This volume is known as the "tidal prism" as it is effectively the volume of water between high and low tide levels.

Hinwood and Jones (1979) calculated the tidal prism in the western channel of North Arm at Sandy Point from modelled tide and current patterns to be 350 Mm^3 (see above) and this corresponds at Crib Point to approximately 300 Mm^3.

In a tide cycle of 12.25 hours, the volume of seawater extracted by the FSRU is approximately 230,000 m^3. Using these data, the bulk entrainment proportion of planktonic biota including larvae in the North Arm may be calculated as follows:

Proportion entrained = Extraction x Residence time / Tidal prism
= 230,000 x 12 / 300,000,000
= 0.009 (0.9 percent)

Thus, as a first approximation, the cooled seawater produced by the FSRU heat exchange system could potentially impact about 0.9 percent in total of planktonic biota in the western channel of North Arm in Western Port. This applies over a flushing period of six days, as estimated from net current flux in North Arm (Hinwood and Jones 1979) and assuming an even distribution of planktonic biota through the water column.

4.1 Position in western channel of North Arm

The next step in the analysis of larvae entrainment was to examine the influence of position in the western channel, relative to Crib Point, on the probability of entrainment. Obviously larvae in the western side of the channel moving into Western Port, where the FSRU would be located, would have a high risk of entrainment than larvae on the eastern side.

Also, with a northward net current, larvae commencing their cycle at more than 6 km north of Crib Point would be largely unaffected, while larvae commencing close to Crib Point, particularly just to the south of Crib Point, would be at greater risk.

For this preliminary analysis, Water Technology were engaged to model the probability of particles being entrained, while being released at various points in Westernport. Three sites for release of larvae were selected for this preliminary analysis:

1. Western Channel near entrance to North Arm
2. Mangroves to north of Hastings Bay
3. Seagrass bank to north-east of Crib Point.

These three sites are shown in Figure 12.

In interpreting the Water Technology model results, it must be kept in mind that their model predicts a strong southerly drift past Crib Point, as illustrated in Figure 12, whereas other models predict a persistent northerly drift.

The Water Technology model operated by releasing particles each time step and then counting how many particles were 'entrained' in an intake flow of 450,000 m^3/d at Crib Point. The results are summarised in Figure 12. It can be seen that about 3 percent of larvae from the mangrove site were captured, 1 percent of larvae from the seagrass site were captured (similar to the bulk flow analysis given earlier) and 0.2 percent of the particles released from the western channel site were captured.

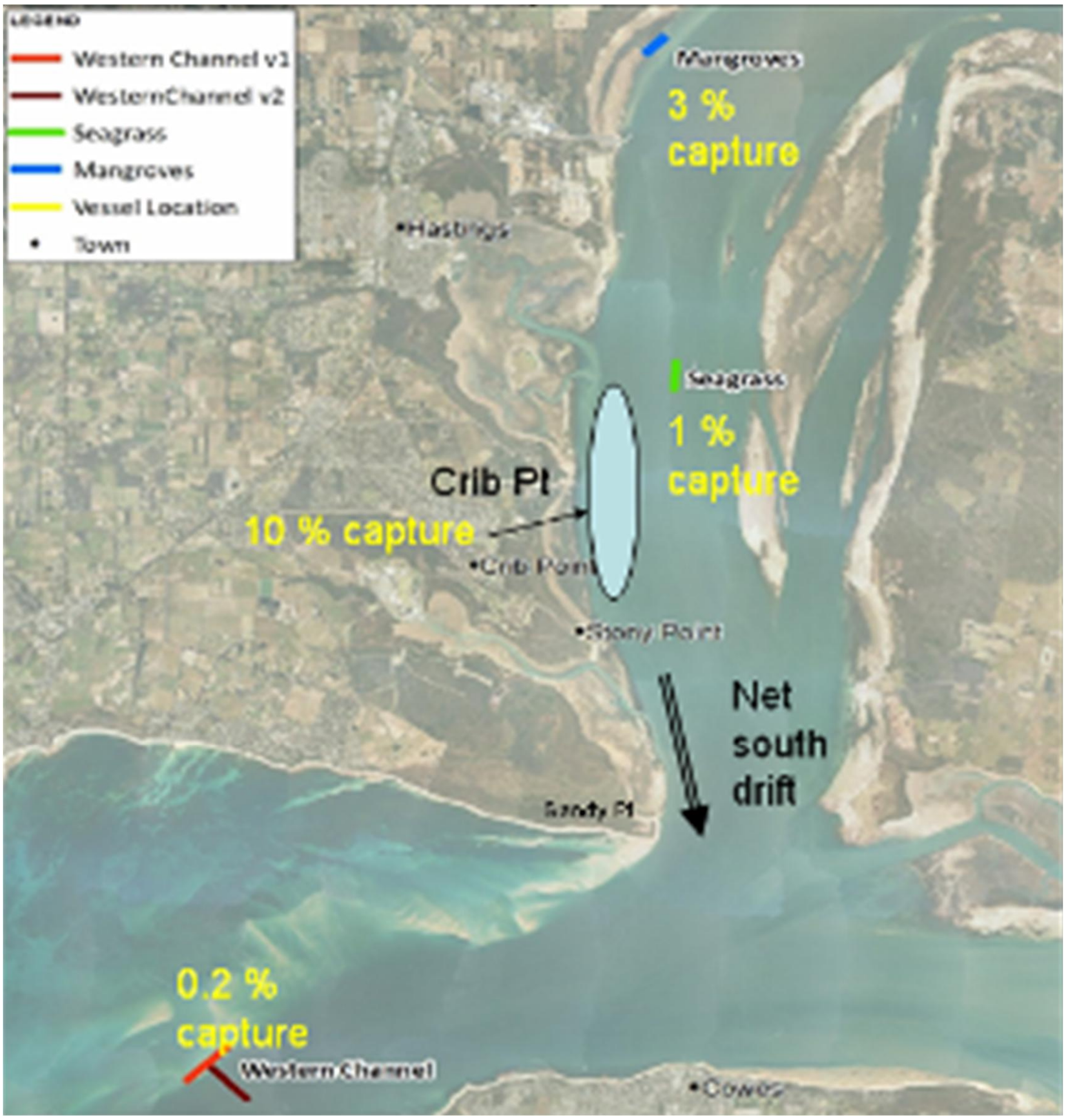


Figure 12. Probability of Entrainment from Water Technology Model

It can readily be appreciated that these results would be reversed if there were a net northward drift. It can also be appreciated that higher capture would occur with a six-day residence time compared to the two-day residence time of the Water Technology model.

Figure 13 shows a time series of larvae capture over two days (based on Water Technology's two-day flushing period) illustrating the importance of the combination of the tide and the net drift (southerly in this scenario). On the ebb tide, up to 4 % of larvae from the mangrove area were entrained, and up to 1.5 % of larvae from the seagrass site.

In contrast, larvae from the western channel inlet were entrained in small proportions on the flood tide – although this result very much reflects the strong net southerly flow in the model. With a different model having a net northerly flow, it is expected that 3 to 4 % of the larvae entering North Arm could be entrained (effectively the inverse of the pattern in Figure 13.

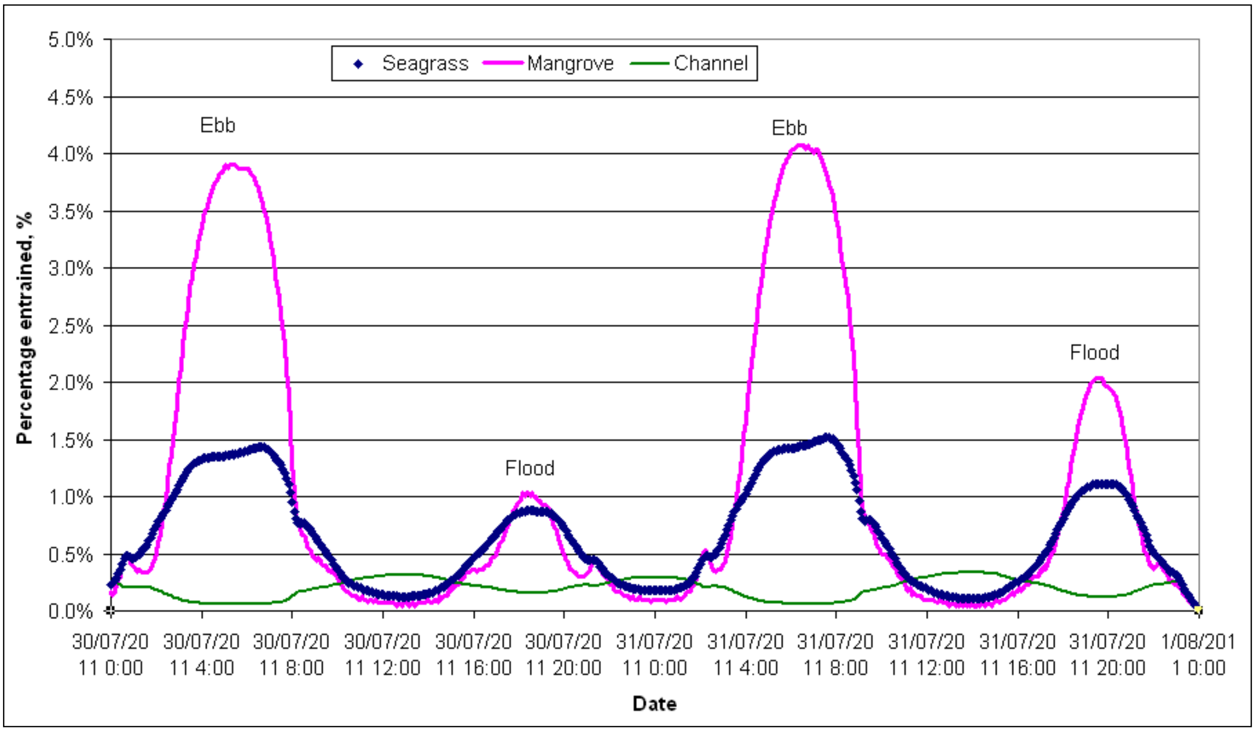


Figure 13. Time Series of Entrainment - from Water Technology Model

4.2 The process of entrainment

As described in Section 2.3, to be entrained into the seawater intake, a larva has to enter the intake zone (shown in Figure 6) which extends over a depth range of 2.6 m (at peak tidal currents) to 7 m (at slack water). The width of the zone will vary from 6 to 15 m wide, or outwards from the intake screen (depending on the tidal current speed). With these dimensions of the intake zone and allowing for horizontal and vertical dispersion it has been calculated that in a single pass, the likelihood of larvae entering the intake (out to a distance of 15 m from the screen) is a maximum of 25 %, while the likelihood of passing the intake is a minimum of 75 %.

However, with a residence time of two days, and allowing for lateral mixing, the probability of entrainment increases to 68 %, as larvae flow back and forth four times past the intake screens (four passes with a 25 % risk of entrainment each time). However, over two days, the risk of entrainment decreases substantially with distance up and down North Arm from the intake, as illustrated in Figure 14. This figure was derived by applying typical rates of horizontal and vertical dispersion to a patch of water travelling to Crib Point from the north (on the ebb tide), and another patch from the south (on the flood tide).

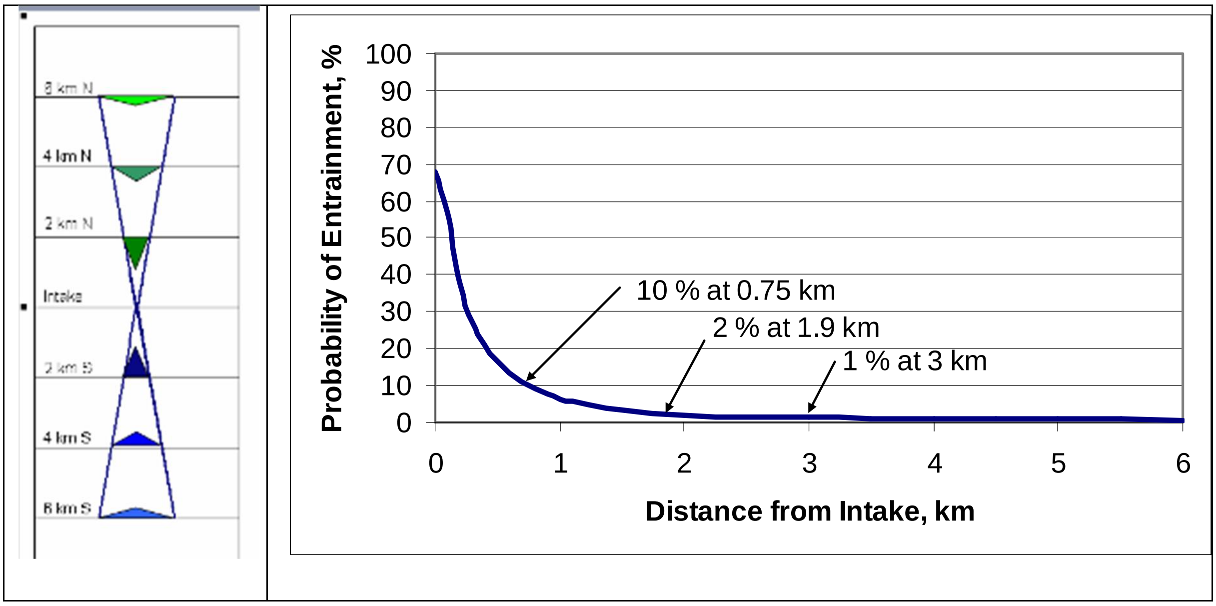


Figure 14. Entrainment with Distance - from Dispersion Analysis

The diagram on the left side of Figure 14 illustrates the effects of lateral dispersion. The greater the distance from Crib Point, the wider the zone from which particles of water can be entrained but, also, the smaller the probability of being entrained from any given flow path.

The diagram on the right side of Figure 14 illustrates the outcome in terms of the probability of entrainment of short-lived larvae. The entrainment of larvae from within 750m of the intake could possibly be 10 percent capture, but less than 2 percent of larvae commencing at 2 km or more north or south of the intake could be entrained. The effects on short-lived larvae are likely to be negligible from sites that are 3 km or more from Crib Point. The zone of high entrainment is illustrated by the ellipse around Crib Point in Figure 12.

5 MARINE ECOSYSTEM EFFECTS OF ENTRAINMENT

The effects of entrainment on marine ecosystem components in Western Port can be assessed at a high level using an understanding of known ecological processes and the hydrodynamic modelling discussed above.

The discussion above indicates that the risk of entrainment is greatest to planktonic biota that are evenly distributed over the water column within approximately 1 km of the FSRU.

5.1 Holoplankton

The holoplankton are the very small plants (phytoplankton) and animals (zooplankton) that spend their entire life cycle in the water column and drift with the tidal currents. These biota are important components in the Western Port marine food chain.

The composition and productivity of holoplankton communities typically varies substantially over the seasons and between years due to a range of interacting physical (temperature, daylight), chemical (salinity, nutrients) and ecological (competition, predation) factors. Reproductive cycles may be very rapid at some times of year – typically in spring when water temperatures are increasing.

The characteristics of the holoplankton community in Westernport are likely to vary spatially due to regional differences in water quality, circulation and flushing. The characteristics of the holoplankton community in North Arm is likely to vary spatially from north to south and laterally due to the natural gradient in flushing time between the north and south of the Arm (Kimmerer and McKinnon 1987a), effects in of mixing and periodic inundation and drainage of the mudflats along the sides of the channels.

Conceptually, if a steady state of holoplankton characteristics were to be established (for example a typical, constant composition over a particular season), this would mean that plankton community turnover (or population replacement) would equal flushing time in that part of North Arm. The analysis of existing hydrodynamic models in Section 4.0 above indicated that flushing time (or residence time) in North Arm at Crib Point is between two and six days. Hence the natural replacement rate of constant state holoplankton population is between two days and six days. For a six-day residence time, simple continuity of mass modelling shows that the FSRU operating at 450,00 m^3/day through flow would entrain 0.9 percent of the volume of North Arm, and the water passing through it, in that six-day period. The maximum proportion of holoplankton communities entrained over a flushing period could therefore be estimated at approximately 0.9 percent of the community of North Arm if it was distributed evenly over the water column and width and length of the North Arm. For a flushing period of two days, population replacement would have to be more rapid and only 0.3 percent of the North Arm holoplankton community would be entrained.

The proportion of the population entrained would be less if parts of the planktonic community were, for some reason, more concentrated along the sides of the channels or in the top or bottom of the water column, which are positions the intake is less likely affect. However, Water Technology's entrainment model based on the finer scale hydrodynamic model of North Arm, shows that 10 percent of populations within 750 m of the FSRU may be entrained over a two-day flushing period, which would be equivalent to 30 percent for a six-day flushing period. Hence, estimates at this stage are strongly dependent on hydrodynamic model configuration.

The modelling completed for this report and other supporting studies was based on the original FSRU seawater flow rate through the heat exchanger of 450,000 m^3/day. AGL has advised that a seawater flow-through rate of 300,000 m^3/day corresponding to a lower regasification rate is more likely. In this case, the proportion of plankton entrained may be reduced by approximately one third. It is apparent that estimates of entrainment are strongly dependent on FSRU operating volumes, hydrodynamic model configuration and planktonic distribution.

5.1.1 Implications

The analysis so far indicates the proportion of holoplankton entrained over the entire North Arm area is likely to be small (<1 percent) in terms of the total standing population of North Arm. However, the modelling shows that 10 percent (and up to 30 percent depending on model configuration) of the population within 750 m of the FSRU may be entrained at full operating capacity. This would seem likely to result in changes to the population structure of the plankton community in the immediate locality of the FSRU. The long term consequences of this change on other components of the marine ecosystem in the vicinity of the FSRU that are strongly dependent on plankton are uncertain.

The proportion of populations entrained are likely to decrease at least in proportion to reduction in water flow through the FSRU. Hence if flows through the FSRU are initially one third of full capacity and the FSRU operates intermittently over the first years, then entrainment during operation would be proportionately less.

Robust entrainment modelling and further understanding of plankton distribution and temporal variability in Western Port plankton populations is required to provide evidence-based context for further assessment of potential long-term and cumulative effects of entrainment on plankton communities and flow-on to interconnected ecosystem components. The modelling should be based on heat exchange flows corresponding to realistic operational scenarios. For example, a reduction in heat exchange flows from the modelled 450,000 m^3/day to 300,000 m^3/day is likely to reduce the proportion of entrainment by approximately one third.

Comprehensive review of literature on the effects of entrainment on semi-enclosed marine ecosystems is recommended to inform further assessment of potential effects of full production of the FSRU.

It is recommended that:

- Entrainment and hydrodynamic modelling for North Arm be developed to provide entrainment proportion contours based on heat exchange flows corresponding to realistic operational scenarios.
- An intensive plankton sampling program be developed to provide information on spatial and temporal variations in plankton populations in North Arm focussing on the proposed location and position of the FSRU intake.
- Available information of literature on the effects of entrainment on semi-enclosed marine ecosystems be reviewed.

5.2 Mangrove propagules

Mangroves in Western Port reproduce by releasing floating propagules that disperse with surface water currents influenced by wind. Mangroves are located discontinuously around the perimeter of Western Port. The closest mangroves are located more than 1 km from the proposed intake position. Floating propagules from these mangroves should not be entrained by the seawater heat exchange system.

5.3 Seagrass propagules

Seagrasses in North Arm of Western Port reproduce by releasing propagules and seeds and by vegetative fragments. Propagules and vegetative fragments tend to float and disperse widely. These floating propagules are unlikely to be entrained by the seawater heat exchange system. Seeds tend to accumulate within existing seagrass beds and should not be entrained by the seawater heat exchange system.

5.4 Fish and squid eggs and larvae

Most adult and mobile juvenile fish should not be directly affected by entrainment due to the design features of the intake and their ability to avoid the intake current.

Fish that breed outside North Arm but migrate into Western Port should not be directly affected by entrainment. The proportion of planktonic eggs and larvae of such species entrained that are produced outside North Arm is likely to be negligible as indicated by 0.2 % entrainment at near the entrance to North Arm from the Western Entrance (Figure 12).

Many larvae from fish that are resident in sheltered waters such as Western Port avoid predators associated with open waters or bare seabed by maintaining their position within favoured habitats, such as seagrasses and shallow waters. Juvenile fish, small species and larvae that are associated with shoreline or nearshore habitats such as seagrasses, mangroves, mudflats or channel slopes may have a low likelihood of entrainment due to the position of the intake in the water column at Berth 2, which is 500 m offshore from the seagrass beds and 300 m from the upper slope of the channel.

Some species attach eggs to the seabed (such as elephant fish and some squid and octopus). Juveniles with sufficient mobility to migrate from Western Port or avoid entrainment hatch directly from the eggs. The risk of entrainment to populations of such species is negligible.

Fish with planktonic eggs and larvae (anchovies) tend to breed over large areas of water bodies, with widespread dispersal and exchange of eggs, larvae and juveniles. A proportion of planktonic eggs and larvae of such species that are produced within North Arm may be affected by entrainment depending on the location of their release and the duration of the stages that are predominantly planktonic.

Figure 12 indicates that 10 % removal is possible for some larvae produced within 750 m of the FSRU. It is possible that larvae and juvenile fish that may be migrating along a relatively narrow route along the western side of North Arm channel to or from northern Western Port may also be at greater risk than more dispersed migratory paths or drift patterns. Although we are not aware of any particular species that may migrate along a narrow path centred on Crib Point jetty.

The modelling and plankton sampling program recommended in Section 5.1.1 should include consideration of the fish egg and larval content of the plankton communities sampled.

5.5 Benthic invertebrates

Much of Western Port’s seabed comprises soft seabed that is inhabited by a range of benthic invertebrates including sandworms, crustaceans, molluscs and echinoderms, with a wide range of reproductive strategies, including planktonic stages. There are few natural hard seabeds (reefs) in North Arm, with the notable exception of Crawfish Rock located more than 10 km north of Crib Point.

It is expected that planktonic propagules from soft seabed benthic invertebrates would be dispersed from widespread habitats over a large area. A proportion of these planktonic propagules will settle close to their release point, while others settle at distances from their release point dependent on the duration of the larval period and the strength of net transport currents. There is considerable mixing of planktonic propagules of different larval-age from different areas within North Arm and elsewhere in Western Port. Larvae from a wide range of source locations may settle at any one location (including the FSRU) over a period of time.

Larval durations of invertebrates vary widely, if they are known at all. For example, some species of thalassinidian shrimps related to those in Western Port have larval periods (with four or five stages) totalling more than 15 days, others have larval periods (with only two or three planktonic stages) totalling less than 14 days, while others have been estimated at 6 weeks (Butler, Reid and Bird 2009). Figure 12 indicates that 10 % entrapment of larvae that are produced in close vicinity of the FSRU (within 750 m) is possible. However, this may indicate that a particular population of invertebrate that is only found close to the location of the FSRU, with a planktonic period less than 8 days may be at risk from entrainment.

5.6 Comparison with Victorian Desalination Project

The proposed Crib Point Gas Import Jetty Project heat exchange system will withdraw seawater from Western Port at Crib Point at rate of 5.2 m^3/s. The Victorian Desalination Plant (VDP) was planned to withdraw seawater from Bass Strait offshore from Wonthaggi at a rate of 18.5 m^3/s (ASR 2008), although its present intake capacity is approximately 11.6 m^3/s. A summary comparison of the two systems is shown in Table 2.

Table 2. Comparison of Gas Import Jetty and Victorian Desalination seawater demand

Character	Heat exchange intake	Desalination intake
Flow rate	5.2 m^3/s	11.6 m^3/s
Operational requirement	Initially likely to be intermittent	Intermittent demand
Operational period	Initially likely to be intermittent	<4 months per year
Annual volume (estimate)	160 GL capacity (Likely less in initial period)	114 GL 2016, 34 GL 2017 (365 GL capacity)
Location	North Arm Western Port	Bass Strait, Wonthaggi
Water depth at intake	14 m plus 3.2 m tide	20 m plus 3 m tide
Water depth of intake	Between 5 m and 10 m above seabed	Between 4 m and 7.5 m above seabed
Intake water body	Embayment 5 km wide	Open coast
Currents at intake	Strong currents	Week tidal currents
Net current at intake	Strongly tidal with variable net current	Seasonally dependent

The table shows that there are substantial differences in the conditions at the intakes and the volumes and durations of seawater actually used in the two systems. Net current is the key factor determining the proportion of larvae entrained at a location. Entrainment models also differed between the two projects due to differences in: spatial scales and boundary conditions at locations (bay versus open ocean); tidal currents (strong versus weak); net water movement drivers (tidal currents and complex topography versus seasonal winds).

Entrainment proportions were estimated to be less than 1.5 % within 1 km of the intake for all durations modelled (1 to 14 days) for annual net current conditions at VDP (ASR 2008). Net current at VDP is dependent on regional winds. Hence, while entrainment proportions were less than 1% at 1 km of the intake for most combinations of larval duration and season and year, there were noticeable differences between seasons in the two years modelled due to differences in winds and net current.

It could be expected that the more confined nature of the water body of North Arm would result in higher proportions of larvae entrained at Crib Point despite the 50 percent lower intake flow rate relative to larger intake flow rate at open coastline at Wonthaggi. The Water

Technology and CEE modelling shown above shows that entrainment proportions up to 10% were possible for some larvae within 750 m of the intake based on currents predicted at Crib Point, but that entrainment was less than 1 percent over the whole of North Arm. The independent models of entrainment proportion are therefore generally consistent given the differences in intake flow and study boundary volumes.

Prediction of the proportion of larvae entrained is dependent on accurate estimation of tidal currents and net flux. As noted above, further studies are required to

a. resolve differences between tidal currents and net flux estimates from existing hydrodynamic models in Western Port and
b. characterise temporal and spatial scales of plankton community populations in Western Port.

6 CONCLUSION TO BIOLOGICAL ENTRAINMENT

Based on this analysis, the following conclusions are drawn:

- The seawater intake on the FSRU is positioned and designed to minimise the entrainment of fish and large mobile biota.
- The seawater intake on the FSRU is positioned and designed to minimise the entrainment of eggs, larvae, other planktonic biota and propagules that drift or travel in the water surface layer or near the seabed.
- The location of the FSRU at the end of the Crib Point Jetty more than 500 m offshore from the low tide mark substantially reduces the likelihood of entrainment of larvae that can maintain position in preferred nearshore habitats such as mangroves, seagrasses and shallow nearshore waters.
- Short-lived, dispersed larvae and eggs will only be entrained in proportions potentially >1 % in total if they commence their larval existence only within 3 km of Crib Point, and on the western side of North Arm.
- Long-lived, highly dispersed larvae will be entrained in proportions potentially >1 % in total if they commence their larval existence within about 10 km of Crib Point, and on the western side of North Arm.
- The entrainment rate at full operational capacity of the FSRU for immobile plankton that are dispersed over the column is expected to be about 2 to 3 % for sites on the western edge of the channel (including the adjacent mudflats) within about 8 km of Crib Point, and about 10 % for sites on the western edge of the channel (including the adjacent mudflats) within about 750 m of Crib Point but that entrainment was less than 1 percent over the whole of North Arm.
- In the context of the wider Western Port area, for larvae commencing at 2 km or more north or south of the FSRU intake, less than 2 % of larvae would be entrained.
- Overall, the proportion of larvae entrained from populations of widespread biota in Western Port is less than 1% and the effect is likely to be undetectable.

The modelling completed for this report and other supporting studies was based on the original FSRU seawater flow rate through the heat exchanger of 450,000 m^3/day. AGL has advised that a seawater flow-through rate of 300,000 m^3/day corresponding to a lower regasification rate is more likely. In this case, the proportion of plankton entrained may be reduced by approximately one third. It is apparent that estimates of entrainment are strongly dependent on FSRU operating volumes, hydrodynamic model configuration and planktonic distribution

Estimation of the proportion of planktonic populations that may be entrained are dependent on a range of factors including:

1. The nature, distribution and annual variation of planktonic populations in North Arm of Western Port, which are currently undocumented and
2. Hydrodynamic model configurations specific to entrainment.
3. Realistic regasification operational scenarios be defined so that the range of potential entrainment effects can be modelled.

It is recommended that the following studies are undertaken to provide greater certainty to the entrainment estimates reported in this study:

- Particle (or equivalent) entrainment modelling for North Arm be developed to provide entrainment proportion contours
- A plankton and larval sampling program be designed and implemented to provide information on spatial and temporal variations in plankton populations in North Arm focussing on the proposed location and position of the FSRU intake.

- Available information of literature on the effects of entrainment on semi-enclosed marine ecosystems be reviewed to provide guidance on long-term ecosystem implications of plankton entrainment.
- Realistic regasification operational scenarios be defined so that the range of potential entrainment effects can be modelled.

7 REFERENCES

ASR 2008. *Particle Dispersal Modelling: Seasonal and spatial variations. Victorian Desalination Project.* ASR Ltd, Raglan New Zealand.

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

EPA 2001. Protecting the Waters of Western Port and Catchment. EPA Publication no 797. Environment Protection Authority. Butler S N, Reid M and F L Bird 2009. *Population biology of the ghost shrimp* Tryapaea australiensis *and* Biffarius arenosis *(Decapoda Thalassinidae), in Western Port, Victoria.* Memoirs of Museum Victoria 66:43 - 59

CEE 2009. *Port of Hastings Stage 1 Development. Marine Ecosystem Preliminary Considerations*. Report to AECOM and Port of Hastings Corporation. CEE, Melbourne, August 2009.

CEE 2014. *Port of Hastings Seagrass Monitoring Pilot Study*. Report to Port of Hastings Development Authority. CEE Melbourne June 2014.

CEE (2018a) Plume Modelling of Discharge from LNG Facility at Crib Point, Western Port – AGL Gas Import Jetty Project. Report for AGL. Report for AGL.

CEE (2018b) Marine Ecosystem Protected Matters – AGL Gas Import Jetty Project. Report for AGL.

CEE (2018c) Assessment of effects of cold-water discharge on marine ecosystem at Crib Point – AGL Gas Import Jetty Project. Report for AGL.

Bok M, Chidgey S and P Crockett 2017. *5 years on: Monitoring of Long Island Point's Western Port wastewater discharge*. Conference Paper, APPEA Annual Conference 2017.

EPA 2011. *Environment Report - Port Phillip and Western Port Receiving Water Quality Modelling: Hydrodynamics*. (2011) EPA Publication 1377.

Harris JE, Hinwood JB, Marsden MAH & Sternberg RW 1979. *Water movement, sediment transport and deposition*. Western Port, Victoria', Marine Geology, Vol. 30, 131–61.

Harris JE, Robinson JB 1979. *Circulation in Western Port, Victoria, as deduced from salinity and reactive silica distributions*. Marine Geology, Vol. 30 101–16.

Hinwood J. B. and Jones J.C.E. 1979. *Hydrodynamic Data for Western Port, Victoria*. Marine Geology 30, 47-63.

Hinwood JB 1979, *Hydrodynamic and transport models of Western Port, Victoria*. Marine Geology, Vol. 30, 117–30.

Kimmerer W and A D McKinnon 1985. A comparative study of the *Zooplankton in two adjacent embayments: Port Phillip and Westernport Bay, Australia. Estuar coast Shlf Sci 21: 145-159*.

Kimmerer W and A D McKinnon 1987a. *Zooplankton in a marine bay.I. Horizontal distributions to estimate net population growth rates.* Mar Ecol Prog Ser 41: 43- 52.

Kimmerer W and A D McKinnon 1987b. *Zooplankton in a marine bay.II. Vertical migration to maintain horizontal distributions.* Mar Ecol Prog Ser 41: 53-60.

Melbourne Water (2011). *Understanding the Western Port Environment. A summary of knowledge and priorities for future research*. Editors M J Keough and R Bathgate for Melbourne Water, Port Phillip and Westernport CMA, Victoria.

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

Royal Haskoning 2015. *MetOcean Conditions at Existing Berths (HY-WP-27)*. Technical Note to Port of Hastings Development Authority, Draft 21 May 2015.

VRCA 2018. *Vic Tides 2018 Edition 2*. Victorian Regional Channels Authority.

Water Technology 2017. *Hydrodynamic & Water Quality Modelling, Western Port Bay*. Report to AGL Wholesale Gas Ltd.