Dampier Seawater Desalination Plant

Dilution Modelling Study – Parker Point 8GL/a

Rio Tinto

11 May 2022

311012-00015-CS-REP-0005

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PROJECT 311012-00015-CS-REP-0005: Dampier Seawater Desalination Plant - Dilution Modelling Study – Parker Point 8GL/a

Rev	Description	Author	Review	Advisian approval	Revision date	Client approval	Approval date
0	Final	J. Jiang	M. Klabbers	P. Nichols	11.05.2022		

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Executive summary

Introduction

Hamersley Iron Pty Limited (the Proponent) is proposing to develop a desalination plant with a capacity of up to 8 GL/a at Parker Point near the township of Dampier in the Pilbara region of Western Australia (the Proposal). The Proposal includes the design, construction, commissioning and operation of a seawater reverse osmosis desalination plant located approximately 1 km north-east of the Dampier township within the Proponent's existing Dampier port industrial area (Figure E-0-1).

During the desalination process, water is returned to the ocean as brine through the outfall. The outfall structure is proposed to be installed attached to the existing wharf. The selected outfall location on the wharf is shown in Figure E-0-2. This report presents the methodology and results for the dilution study.

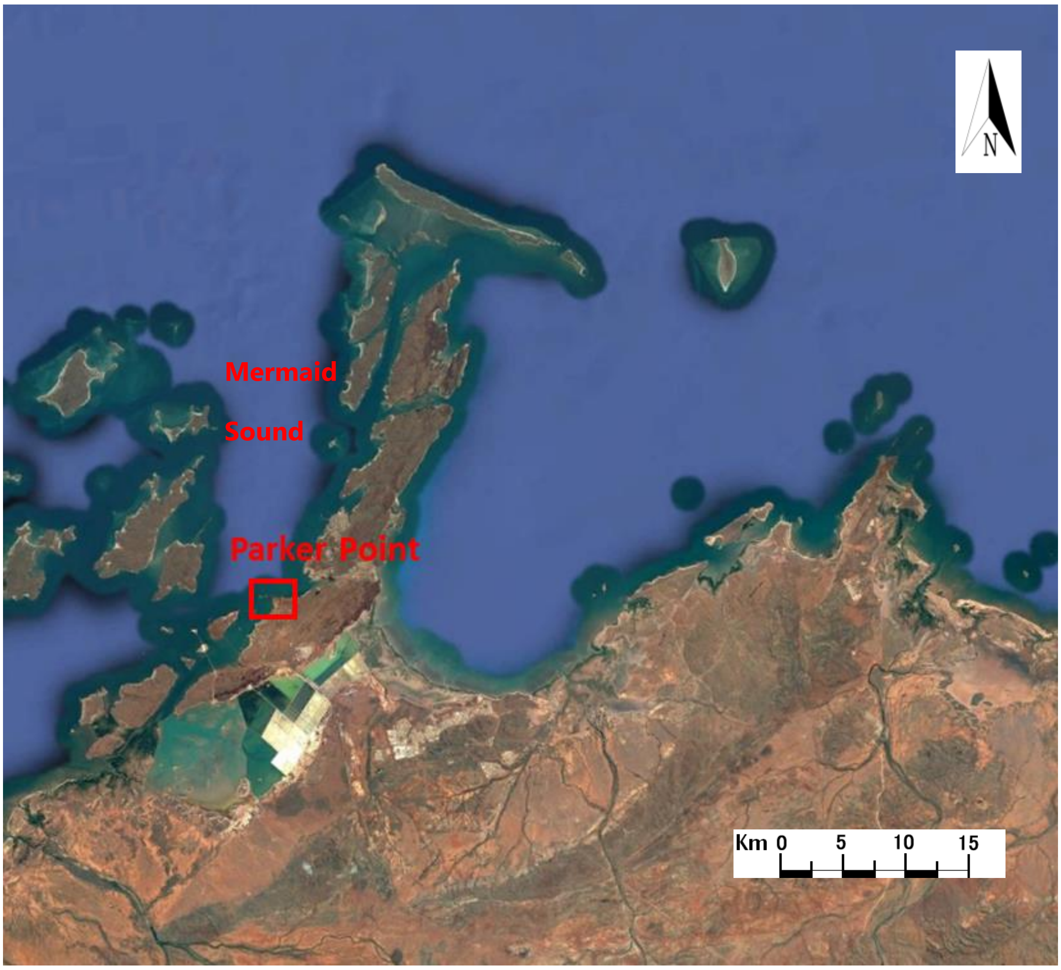


Figure E-0-1 General location of proposal outfall structure at Parker Point (courtesy: Google Earth)

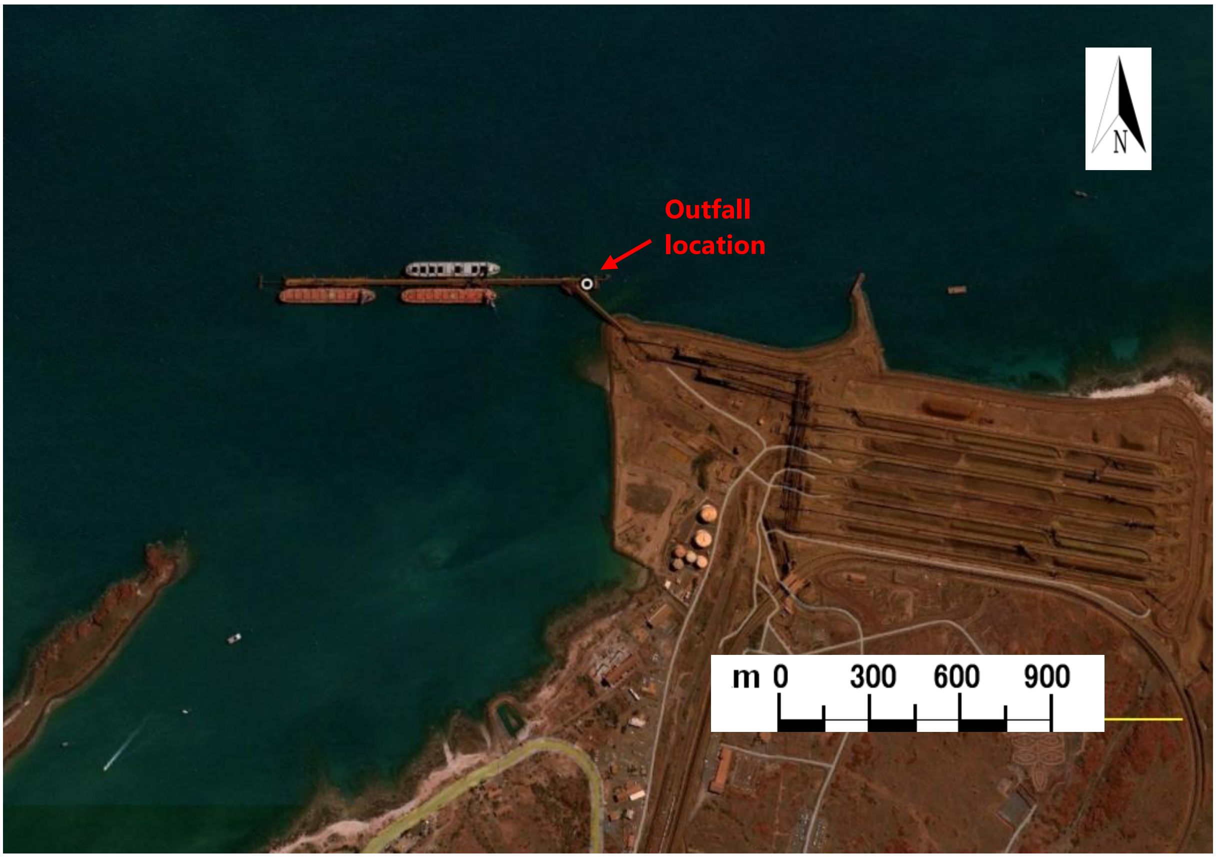


Figure E-0-2 Proposed outfall location of desalination plant (courtesy: Google Earth)

Purpose

Modelling the initial mixing rate of discharged hypersaline brine and seawater is important, both for engineering and to assess potential environmental impacts. Rio Tinto therefore commissioned Advisian Pty Ltd (Advisian) to evaluate the dispersion plume of the hypersaline brine from the proposed outfall location.

The purpose of this plume dilution modelling report is to determine the boundaries for the Levels of Ecological Protection (LEP). The LEPs are defined as the four levels of ecological protection (Maximum, High, Moderate and Low) as per Technical Guidance – Protecting the Quality of Western Australia's Marine Environment (EPA, 2016). Baseline water quality data collected by Advisian (2022) has been used to determine the baseline water quality values and the environmental quality criteria (EQC) for the LEP, for winter and summer seasons.

Method and results analysis

To inform the modelling, baseline in situ water quality data was collected to assess the baseline water quality conditions for temperature, salinity and turbidity at the proposed outfall location (Advisian, 2022). This data has been used to derive the seasonal baseline conditions to allow an absolute concentration to be assessed in the modelling. It was also used to develop environmental quality criteria (EQC) for the levels of ecological protection, for winter and summer seasons, in accordance with the *Technical Guidance – Protecting the Quality of Western Australia's Marine Environment* (EPA, 2016).

For the study, the empirical relationships developed by Roberts et al. (1997) were initially adopted to derive the characteristics of the near-field mixing zone. The near-field dilution process occurs because of the velocity, momentum and upwards trajectory of the discharge jet, which ensures diluted brine is rapidly dispersed before the plume reaches the ocean floor.

Table E-0-1 presents relevant data for the outfall discharge characteristics used for the modelling.

Table E-0-1 Outfall discharge characteristics

Parameter	Value
Received Ambient Sea Water Salinity (ppt)	Summer Season: 36.61 Winter Season: 35.78
Reject Water Salinity (ppt)	Summer Season: 65.898 Winter Season: 64.404
Outfall Discharge Rate (ML/day)	35.3
Number of Ports (Diffusers)	2
Diffuser Port Flow (from one port) (L/s)	204
Port Diameter	0.26 m
Diffuser Port Velocity	4.9 m/s (typical 3 – 6 m/s range)
Diffuser Port Angle	45 degrees upwards
Diffuser Port Location	470946.126 East, 7717934.561 North
Diffuser Port Water Depth	-7.4 mCD
Diffuser Discharge Water Depth	0.2 m above seabed

The near-field mixing zone dilution characteristics for the above outfall discharge are estimated using the Roberts et al. (1997) formula. To support the derived results for the near-field dilution, a 3D near-field model was set up using the Mike 3D 'Jet' plume function to predict the initial mixing zone. Near-field brine plume characteristics, predicted by both the Roberts et al. (1997) formula and the 3D near-field model, are summarised in Table E-0-2. The 3D near-field model results are comparable to the results derived from the Roberts et al. (1997) formula. The parameters are defined in Figure 4-1.

Table E-0-2 Comparison of near-field plume characteristics predicted by Roberts et al. (1997) and MIKE 3D model

Parameter	Roberts et al. (1997)	Near-field Model (summer)	Near-field Model (winter)
Terminal Rise Height y_t (m)	7.5 (reaches surface)	7.5	7.5
Distance to Impact x_i (m)	16.8	11.5	10.5
Distance to Ultimate Minimum Dilution x_m (m)	63	68	58

The 3D nearfield model was then coupled with a 3D far field model. This coupled 3D model was used to determine the boundaries of the levels of ecological protection. The 3D coupled model (coupled for both near-field and far-field model set up under one software) simulated the brine dilution process for both initial turbulence and mixing by seasonal tidal currents and wind forcing.

Both summer and winter scenarios show minor extensions of the existing Mermaid Sound Environmental Quality Plan (EQP) moderate level of ecological protection, Version 5 data (Department of Water and Environmental Regulation (DWER), 2019). The model predicts that the brine plume extends around 50 m to the east shown in Figure 6-1 and Figure 6-2, as a result of the proposed outfall location outside the existing moderate level of ecological protection zone.

Conclusions

Based on the assessment, the following conclusions can be drawn:

For the proposed hypersaline brine discharge from the outfall location:

- Predicted Low/Moderate Level of Ecological Protection criteria for salinity is not exceeded by the model results (Table E-0-3). The proposed outfall location at Parker Point allows for rapid brine dilution by means of initial mixing and further dispersion with the background tidal currents.
- Predicted Moderate/High Level of Ecological Protection for salinity extends around 250 m (Figure 6-1) and 170 m (Figure 6-2), respectively, to the northwest from the outfall location for summer and winter seasons. It extends around 50 m from the outfall location to the east (Figure 6-2).

Table E-0-3 Comparison of MIKE model results versus environmental quality threshold for salinity

Season	Background salinity value (ppt)	Predicted Low/moderate Level of ecological protection (ppt)	Predicted Moderate/High Level of ecological protection (ppt)	Maximum modelled salinity at Moderate/High Level of Ecological Protection boundary (ppt)	Mean modelled salinity at Moderate/High Level of Ecological Protection boundary (ppt)
Summer	36.61	37.08	36.86	38.60	37.01
Winter	35.78	36.20	36.07	36.28	35.90

For the discharge associated with increased of temperature from the outfall location:

- Modelled temperature does not exceed the criteria for temperature increase of 2°C and 5°C at the outfall location as can be seen in Table E-0-4. It is compliant with the existing Moderate/High Level of Ecological Protection.

Table E-0-4 Comparison of MIKE model results versus environmental quality threshold for temperature

Season	Background temperature (°C)	Predicted Low/moderate Level of ecological protection (°C)	Predicted Moderate/High Level of ecological protection (°C)	Maximum modelled temperature at Moderate/High Level of Ecological Protection boundary (°C)	Mean modelled temperature at Moderate/High Level of Ecological Protection boundary (°C)
Summer	29.64	31.95	30.46	30.40	29.92
Winter	23.18	27.28	25.58	25.04	23.87

For the discharge associated with total suspended solid (TSS) and whole of effluent toxicity (WET) from the outfall location:

- TSS and WET concentration show rapid dilution within the near-field area, resulting in the far-field TSS and component ratio to be above 50 (1:50 folders) (Figure 6-7 to Figure 6-10). The ratio or folders refer to the dilution levels, for instance, if the concentration at point is 1 in 10 of the initial effluent concentration from outfall, we say the ratio as 10 or the folder as 1 in 10.
- Predicted Low/Moderate Level of Ecological Protection criteria for WET (Table E-0-5) is within 50 m away from the outfall location (Figure 6-9 and Figure 6-10). The proposed outfall location at Parker Point allows for rapid WET dilution by means of initial mixing and further dispersion with the background tidal currents.

Table E-0-5 Comparison of MIKE model results versus environmental quality threshold for WET

Season	Background dilution	Predicted Low/moderate Level of ecological protection	Predicted Moderate/High Level of ecological protection	Maximum modelled WET at Moderate/High Level of Ecological Protection boundary	Mean modelled WET at Moderate/High Level of Ecological Protection boundary
Summer	Not Applicable	1:59	1:222	1:183	1:510
Winter	Not Applicable	1:59	1:222	1:180	1:493

Note: The units for the presented values are 'number of dilutions in folders'

- Precited Moderate/High Level of Ecological Protection for WET (Table E-0-5) extends around 310 m to the southeast from the outfall location for summer (Figure 6-9) and around 450 m to the south from the outfall location(Figure 6-10), respectively.

Acronyms, abbreviations and definitions

Acronym/abbreviation	Definition
AHS	Australian Hydrographic Service
AWAC	Acoustic Wave and Current Profilers
BoM	Bureau of Meteorology
CD	Chart Datum
CPU	Central Processing Unit
CTD	Current, Temperature and Depth profiler
EQC	Environmental Quality Criteria
Folder	dilution level. For instance, if the concentration at point is 1 in 10 of the initial effluent concentration from outfall, we say the ratio as 10 or the folder as 1 in 10.
Froude Number	a dimensionless number defined as the ratio of the flow inertia to the external field
HD	Hydrodynamic
LAT	Lowest Astronomical Tide
LEP	Levels of Ecological Protection
MHWS	Mean High Water Spring
MHWN	Mean High Water Neap
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
NWS	North West Shelf
ppt	parts per thousand
RMS	Root Mean Square
S_m	increment of salinity at end of nearfield
SSDP	South Seawater Desalination Project
TDS	Total Dissolved Solids
the Proponent	Hamersley Iron Pty Limited
the Proposal	Planned development of a desalination plant with a capacity of up to 8 GL/a at Parker Point in the Pilbara region of Western Australia
TSS	Total Suspended Solids
x_j	Distance to End of Nearfield
x_m	Dilution at End of Nearfield

Acronym/abbreviation	Definition
y_L	Spreading layer thickness
y_t	Terminal rise height

1 Introduction

1.1 Background

Hamersley Iron Pty Limited (the Proponent) is proposing to develop a seawater reverse osmosis desalination plant with a capacity of up to 8 GL/a at Parker Point near the township of Dampier in the Pilbara region of Western Australia (the Proposal). The Proposal includes the design, construction, commissioning and operation of a seawater reverse osmosis desalination plant located around 1 km north-east of the Dampier township within the Proponent's existing Dampier port industrial area (Figure 1-1).

The combined discharge rate to the ocean is 12.88 GL/a based on a 45% seawater reverse osmosis recovery. The outfall structure is proposed to be installed attached to the existing wharf. The selected outfall location on the wharf is shown in Figure 1-2.

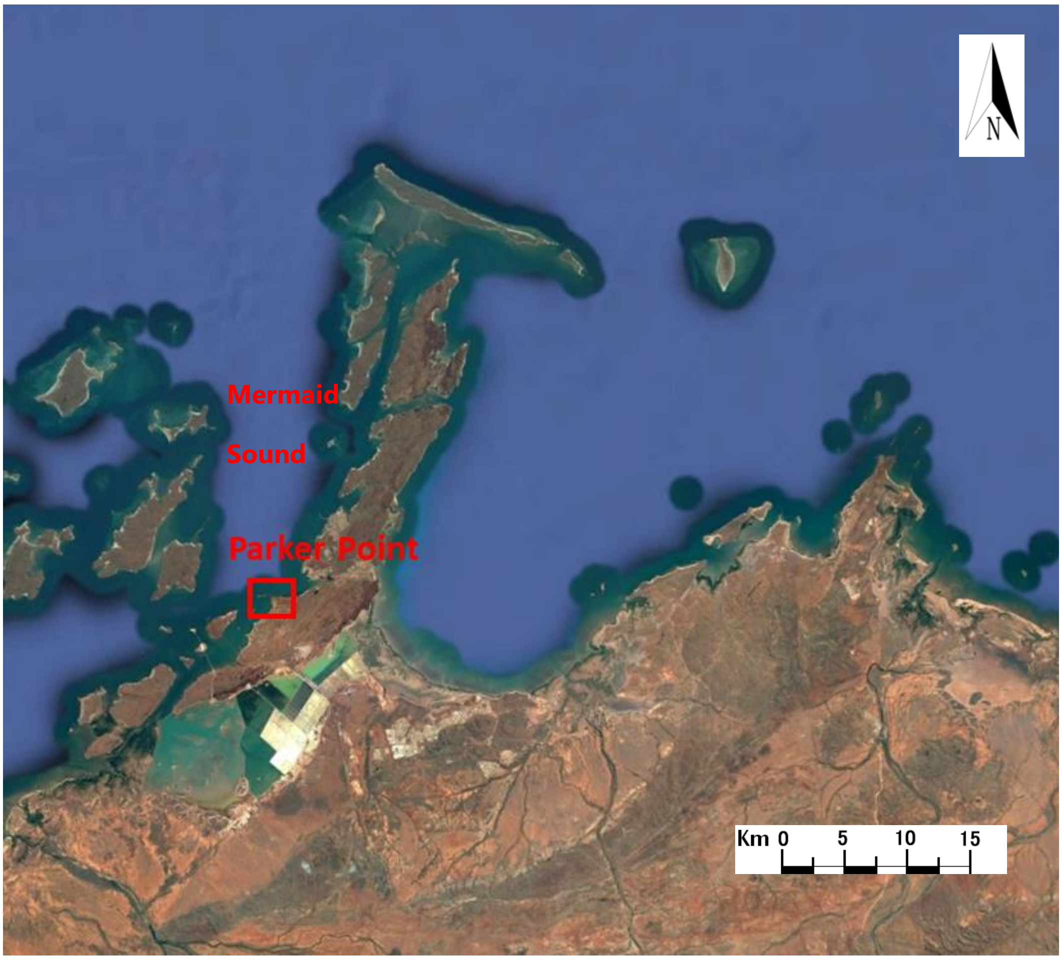


Figure 1-1 General location of proposal outfall structure at Parker Point (courtesy: Google Earth)

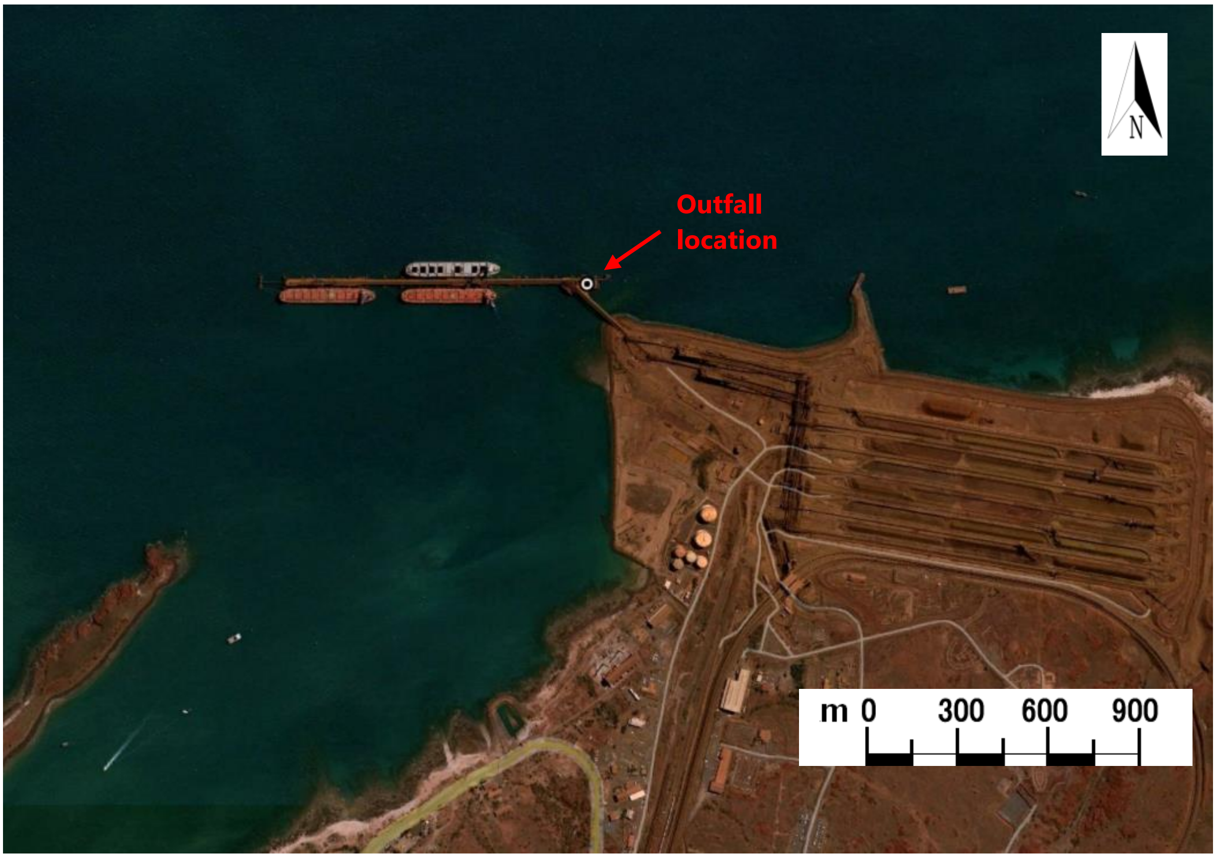


Figure 1-2 Proposed outfall location of desalination plant (courtesy: Google Earth)

1.2 Project area and outfall parameters

The project includes the desalination plant on land, outfall structure at jetty and pipeline to allow the brine water discharge.

The reject brine from the desalination plant reverse osmosis system, as well as neutralised discharge water from pre-treatment backwash and ultra-filtration cleaning processes, will be conveyed via a pipeline to the ocean outfall location along the existing Parker Point access jetty. Both of these streams will be blended and discharged continuously while the plant is in operation. The ocean outfall will comprise a multi-outlet diffuser arrangement supported from an existing jetty pile, which have been sized to achieve an exit velocity for adequate mixing in the receiving environment.

For the reverse osmosis desalination plant at Parker Point, the processed brine outfall flow rates and ambient and reject water salinity are presented in Table 1-1.

Table 1-1 Salinity and outfall brine discharge rate

Parameter		Value
Received Ambient Sea Water Salinity (Parts per Thousand (ppt)):		Summer Season: 36.61 Winter Season: 35.78
Outfall Brine Discharge Rate:	GL/a	12.88
	L/s	408
Reject Water Salinity (ppt):		Summer Season: 65.898 Winter Season: 64.404

Except of the hypersaline brine discharge from the outfall, the reject brine possible includes a certain level of total suspended solid (TSS) material sourced from intake water, thermal water and potential effluent toxicity material due to the process.

1.3 Purpose

Modelling the initial mixing rate of discharged brine and seawater is important, both for engineering and to assess potential environmental impacts. Rio Tinto therefore commissioned Advisian to evaluate the dispersion plume for the proposed outfall discharge.

This study predicts the extent of the mixing zone for the hypersaline discharge and predicts the boundaries for the Levels of Ecological Protection (LEP).

The LEPs are defined as the four levels of ecological protection (Maximum, High, Moderate and Low) as per Technical Guidance – Protecting the Quality of Western Australia's Marine Environment (EPA, 2016). Baseline water quality data collected by Advisian (2022) has been used to determine the baseline water quality values and the environmental quality criteria (EQC) for the LEP, for winter and summer seasons.

Except for the modelling hypersaline brine discharge from the outfall, the model also predicts the extent and dilution factors of the reject brine associated with the total suspended solid (TSS) material sourced from intake water, thermal water and potential effluent toxicity material due to the process.

1.4 Scope of work

Advisian's scope of work includes:

- modelling and analysing the near-field mixing zone of the discharged brine and seawater
- validating and calibrating its 3D West Pilbara Hydrodynamic Model and predicting the spatial extent of the discharge plume at which the EQC for the LEP are met
- utilising the 3D model to determine the boundaries of the LEP
- simulating dilution of salinity, thermal changes, dispersion of total suspended solids (TSS) and water quality (effluent toxicity associated with the process water) of the discharge plume for summer and winter conditions
- presenting the outcomes in a report.

1.5 Datum and direction conventions

Water depths and levels presented in this report are referenced to Cape Lambert Chart Datum (CD).

Geographical positions are provided in the Map Grid of Australia coordinate system, zone 50, based on Geocentric Datum of Australia Geodetic Datum, unless stated otherwise.

All directions are presented in degrees with respect to true north. The normal direction conventions that have been adopted are:

- winds – coming from
- currents – flowing towards.

1.6 Modelling methodology

Discharge from the outfall mixes with the ambient seawater in two zones, namely the ‘near-field’ and ‘far-field’. The near-field dilution process occurs because of the velocity, momentum and upwards trajectory of the discharge jet, which ensures diluted brine is rapidly dispersed before the diluted plume reaches the ocean floor. The far-field dilution process occurs when initial turbulence decays and mixing happens because of turbulence generated by tidal currents and the plume dispersion itself.

For this study, the empirical relationships developed by Roberts et al. (1997) were initially adopted to estimate the characteristics of the near-field mixing zone. Corresponding results were compared to near-field numerical simulation results. For numerical modelling, Advisian modified its existing 3D West Pilbara Hydrodynamic Model by refining the model mesh in the discharge area, especially for the initial mixing zone (near-field). The model bathymetry was also improved by including the measured data provided by Rio Tinto for the Parker Point area and the channel depths based on navigation charts.

The model was then used to predict absolute salinity and temperature values by using baseline values from data collected within the vicinity of the discharge from monitoring in 2020 to 2021 (Advisian, 2022). Multiple dilutions were modelled to assess the toxicity of the discharge. The dilution of TSS was also investigated to determine the TSS loads for varying discharge concentrations.

In the study, the thresholds and baseline data for the modelling were derived by deploying a current, temperature and depth profiler (CTD) close to the proposed outfall location (Advisian, 2022). Thresholds (EQC) for the LEP were developed in accordance with the Technical Guidance – Protecting the Quality of Western Australia’s Marine Environment (EPA, 2016a).

To determine the boundary and distance of the Moderate LEP and High LEP, two models were adopted:

1. **Near-field Model** – To estimate the effluent dilution for the near-field, the outfall performance was preliminarily analysed using the Roberts et al. (1997) formula, which was based on extensive laboratory experiments. To support the derived results about the near-field dilution, a 3D near-field model was set up using MIKE 3D hydrodynamic (HD) model. The near-field model resolution was refined to 5 m, covering the proposed outfall area, to provide accurate initial mixing zone results. For this study, the near-field model with the refined model resolution was run for a ‘jet’ plume to determine the initial near-field mixing zone. For later far-field modelling, this nearfield model was then coupled with a far-field model domain.

2. **Far-field Model** – To determine the spatial extent of the LEP, a far-field model was used that takes into account both the near-field initial mixing and far-field mixing associated with complex tidal and wind forcing. A local MIKE 3D HD model of the project area was used to simulate the brine plume dilution in the far-field domain. This 3D coupled model simulated the dilution process for both initial turbulence and the mixing by tidal and wind forcing. The far-field model results determined the boundary and distance of the LEP under the predicted hydrodynamic conditions for the region.

2 Review of available information and data

2.1 Summary

This section presents the review of available data relevant to the project area, and presents the details of the datasets/information obtained, including spatial and temporal coverage, and describes how each dataset/information is used in this study.

A range of datasets was sourced from Advisian's in-house dataset and the public domain. The datasets include local wind, water level, currents and bathymetry. Local salinity, temperature and turbidity datasets were also collected from the baseline water quality monitoring in 2020 to 2021 (Advisian, 2022). These datasets are described in Sections 2.2 to 2.7. Their application for the dilution model set-up is discussed in Section 5.

2.2 Regional context

The proposed desalination plant intake/outfall location is in Mermaid Sound (shown in Figure 1-1), within the continental shelf waters of the North West Shelf (NWS). The waters of NWS are dominated by semi-diurnal tidal cycle with a pronounced spring-neap cycle. Tidal currents within Mermaid Sound are influenced by the islands of the Dampier Archipelago and range up to 5.1m (Mills, 1985). Tidal currents within Mermaid Sound are channelled through the islands and along Mermaid Sound and Mermaid Strait, converging near the Intercourse Islands at the south of the archipelago (Pearce et al., 2003).

Wave heights in Mermaid Sound typically reduce by at least 50% as they move down Mermaid Sound from the open ocean (Pearce et al., 2003). The waters of Mermaid Sound are oligotrophic, however, on occasions, blooms of nitrogen-fixing microbes such as *Trichodesmium* or mangrove mud-flat cyanobacterium may contribute significant amounts of nutrients into the marine environment (Pearce et al 2003). Water quality of the NWS, and within Mermaid Sound, is typically of very high quality (Wenziker, et al., 2006).

2.3 Bathymetric data

The model bathymetry was based on the data extracted from the MIKE C-MAP digital nautical chart database (DHI, 2019), available data within the project area from Advisian's in-house database and measured data supplied by Rio Tinto for the Parker Point area. Digitised data from the navigation charts were also applied for the depths of the navigation channels.

2.4 Wind data

The model was forced with local wind data from the Bureau of Meteorology (BoM) weather station at Legendre Island (20.36ºS, 116.84ºE). This station was chosen as it is expected to be the most representative of wind conditions in the Dampier region, and is located approximately 33 km from the proposed outfall location for the desalination plant. Wind speed and direction data (ten-minute mean) are available as a timeseries for the period February 1992 to July 2011.

The wind rose plot shows there is a clear seasonal cycle in the wind fields (Figure 2-1). During the summer season, the dominant wind comes from west to south-westerly directions, while during the winter season, the wind usually comes from an easterly direction with higher speeds.

Tropical cyclones, result in the highest wind speeds and occur from November to April. Based on a 48 year period from the 1969/70 to 2017/18 tropical cyclone season, they affect the project area on average about once every two years (Tropical cyclone climatology maps sourced from the BoM (BoM, 2022)). High winds are also associated with occasional winter storms. The present study does not include the plume dilution during cyclone events; however, these events are expected to facilitate higher rates of dilution compared with the modelled scenarios due to the higher wind.

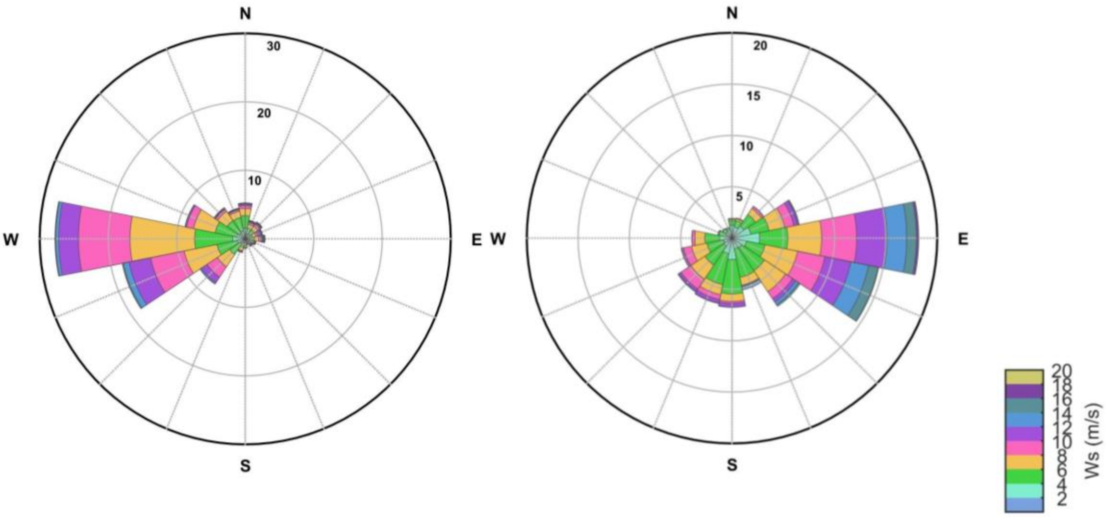


Figure 2-1 Seasonal wind roses, summer (left) and winter (right) derived from Bureau of Meteorology data at Legendre Island

2.5 Tidal station data

Tidal data for stations on the coast of Australia are available in the Australian National Tide tables, published annually (AHS, 2011). The publication includes both standard tidal levels and harmonic constituents (phase and amplitude).

Tidal predictions for the following stations have been applied as tidal forcing at the model boundary:

- Trimouille Island: 20°23’S,115°33’E
- Depuch Island 20°37’S,117°45’E.

These stations are located approximately 130 km from the project area to ensure sufficient modelling domain for circulation simulation.

Data is available at Port Walcott Tidal Station (Cape Lambert 20°35’S,117°11’E) for model calibration as a timeseries of observed water level, predicted tide and residual for the period May 1983 to October 2010. The time interval between observations was 15 minutes from 1983 to 2000 and five minutes from 2000 to 2010. For the present numerical modelling, the year 2001 has been selected, which represents an average year, (Section 5.7).

2.6 Salinity

Within the Dampier Archipelago (Murujuga), surface salinity decreases from inshore (around 36.7 ppt) to further offshore (about 35.5 ppt). Mermaid Sound displays a ‘winter hydrodynamic regime’ whereby denser (cooler and more saline) waters from within the Dampier Archipelago (Murujuga) wedge seaward beneath open-ocean North West Shelf (NWS) waters. During summer, a 'summer hydrodynamic regime' is characterised by vertical stratification on the open-ocean continental shelf waters and elevated salinity in shallower coastal waters (Pearce et al., 2003).

Mean values of salinity, averaged over sites and depths, showed there was minimal spatial variation across the predicted plume extent. Salinity varied spatially by 0.1 ppt between inner sites (shallow sites within the area south of the Parker Point wharf outside of channels, berths and swing basins) and outer sites (deeper sites around the wharf and to the north and west of the wharf). Salinity in near-seabed waters varied temporally. Median summer salinity values were 0.83 ppt higher than the median salinity values recorded in winter (Advisian, 2022).

Heavy rainfall from cyclones may significantly reduce surface salinity at times (Stoddart & Anstee, 2005). Advisian (2022) noted that the salinity typically fell during periods of heavier rainfall when collecting baseline data close to the proposed outfall location. More pronounced dips in salinity were associated with rainfall events in excess of 25 mm. These typically occurred concurrently with the rainfall event, apart from the most significant dip, which was observed four days after a rainfall event. This event lasted for around 24 hours and may be attributed to the delayed surface runoff or another influx of fresher water during this period (Figure 2-2).

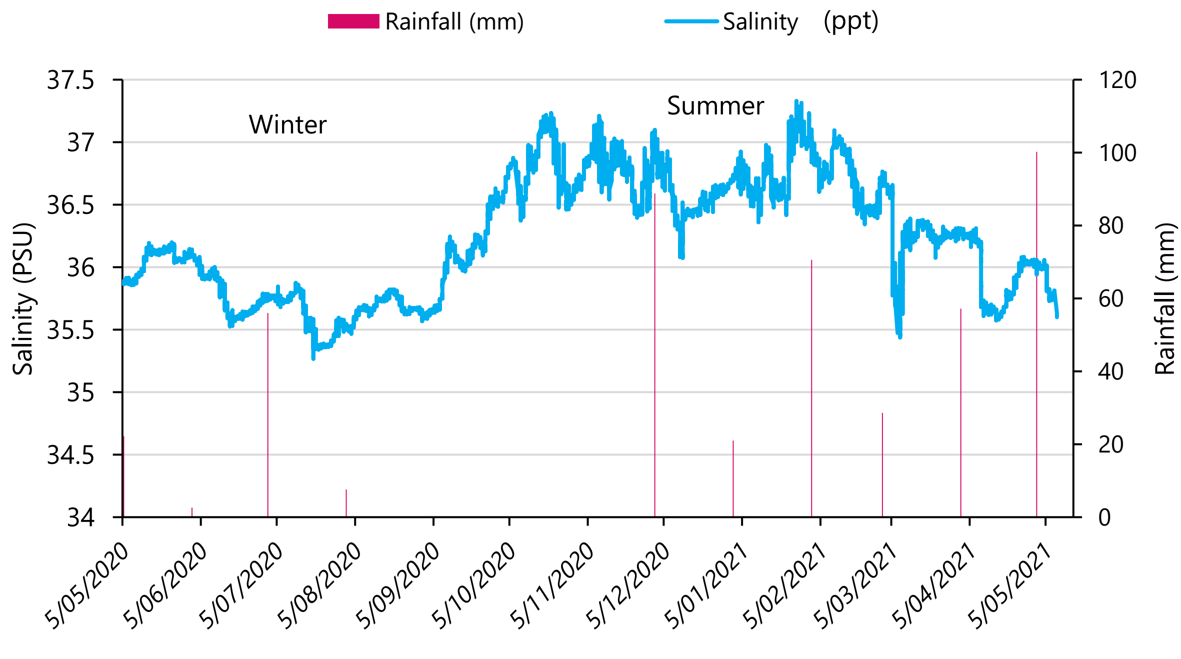


*Figure 2-2 Salinity (practical salinity unit) of water at Parker Point monitoring location. *Monthly rainfall (mm) for Karratha airport (BoM, 2022).*

CTD casts were also completed in summer and winter to assess the spatial variation in water quality and stratification of the water column (MScience, 2021). Spatial variation of salinity and stratification of the water column was low during winter, with some slight stratification during summer: bottom samples had salinities on average 0.12 g/l greater than the surface (MScience, 2021). Median seasonal salinity values collected (Advisian, 2022) from a CTD moored close to the proposed outfall location were used to provide background salinity value in the model (Table 2-1) (MScience, 2021).

Table 2-1 Seasonal background salinity values applied to the model

Season	Background salinity value (ppt)
Summer	36.61
Winter	35.78

2.7 Temperature

Waters of the North West Shelf are usually temperature-stratified, with a mean sea surface temperature of 29.3°C in March, dropping to 24°C in August (Pearce et al., 2003). Nearshore, in the semi-enclosed waters of the Port of Dampier, temperature means vary from 21°C in July/August to 31°C in February (Stoddart & Anstee, 2005). Sampling to read the water temperature (MScience, 2021) across the potential outfall plume footprint demonstrated the waters were typically well mixed in winter and during higher energy metocean conditions. There was some slight stratification during summer in periods where tidal mixing was lower and surface irradiance was higher. Median summer temperature values were around 4°C higher than the median temperature values recorded in winter. Water temperature at the proposed outfall location varied seasonally, closely following trends in air temperature (Figure 2-3) (Advisian, 2022).

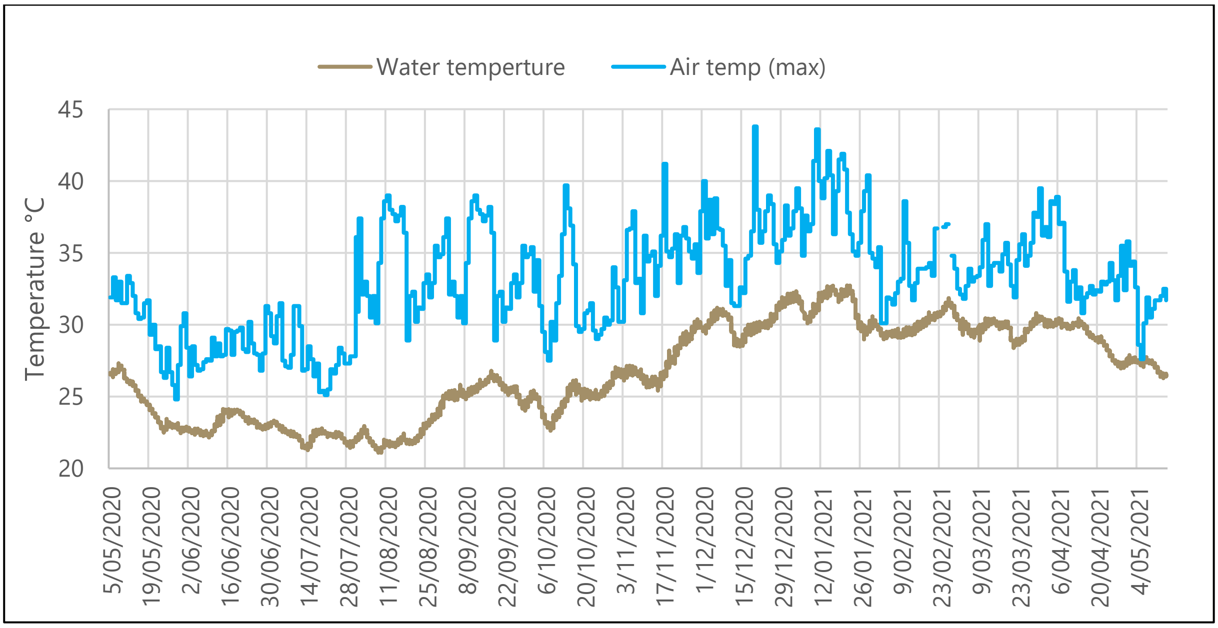


Figure 2-3 Temperature data from moored current, temperature and depth profiler near the proposed outfall location

CTD casts were also completed in summer and winter to assess the spatial variation in water quality and stratification of the water column (MScience, 2021). There was little indication of spatial variation in surface water temperatures across the predicted plume footprint. However, in both summer and winter sampling, water temperatures rose throughout the day in response to solar heating. In summer, surface temperatures rose faster than bottom temperatures, with a greater differential between surface and bottom waters in summer providing some evidence of incomplete mixing (MScience, 2021).

Median seasonal temperature values collected (Advisian, 2022) from a CTD moored close to the proposed outfall location were used to provide background temperature value in the model (Table 2-2). The applied modelling for the study has simulated the absolute temperature variations, which also include the heat exchange between the air and the marine water to reflect the seasonal variations (MScience, 2021).

Table 2-2 Seasonal background temperature values applied to the model

Season	Background temperature value (°C)
Summer	29.64
Winter	23.18

2.8 Measurement data for model calibration

The existing local hydrodynamic model used for the present dilution study was calibrated and validated using current and water level measurements (three months of data covering the period 17 April to 20 July 2011). The instruments used for the measurements were:

- a 1 MHz Acoustic Wave and Current (AWAC) profiler (inshore location 20°34.486’S, 117°06.157’ E) in a water depth of 11.2 m (CD)
- a 600 kHz AWAC (offshore location 20°25.983’S, 117°09.283’E) in a water depth of 21.8 m (CD).

The location of the deployed instruments is shown in Figure 2-4. It is noted that, due to the equipment being redeployed after one-month of measurement, the measurement locations from 27 May 2011 slightly shifted to the southwest after the redeployment. Both AWAC instruments were primarily deployed to measure current velocity and water level, but also recorded wave conditions.

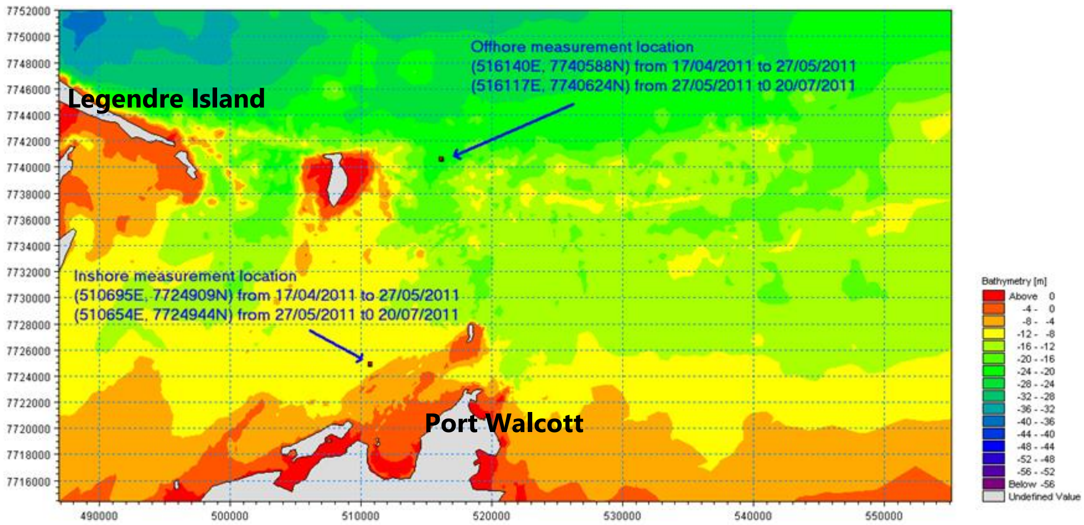


Figure 2-4 Location of measurement sites (offshore and inshore) for current and water levels

Further details of the model calibration are provided in Section 5.5.

2.9 Measurement data for model validation

Current transect measurements were collected with a vessel-mounted Workhorse acoustic doppler current profiler during flood and ebb tides to validate the model. Data was recorded during a king spring tide on 3 November 2020 (ebb) and 4 November 2020 (flood). The locations of the transects are presented in Figure 2-5. These transect locations were selected since the flux within the waterway of the channels can confirm the hydrodynamic model performance in terms of appropriate flow distributions in the region. The validation using these measured fluxes will improve the prediction of the hydrodynamics at the Parker Point outfall location.

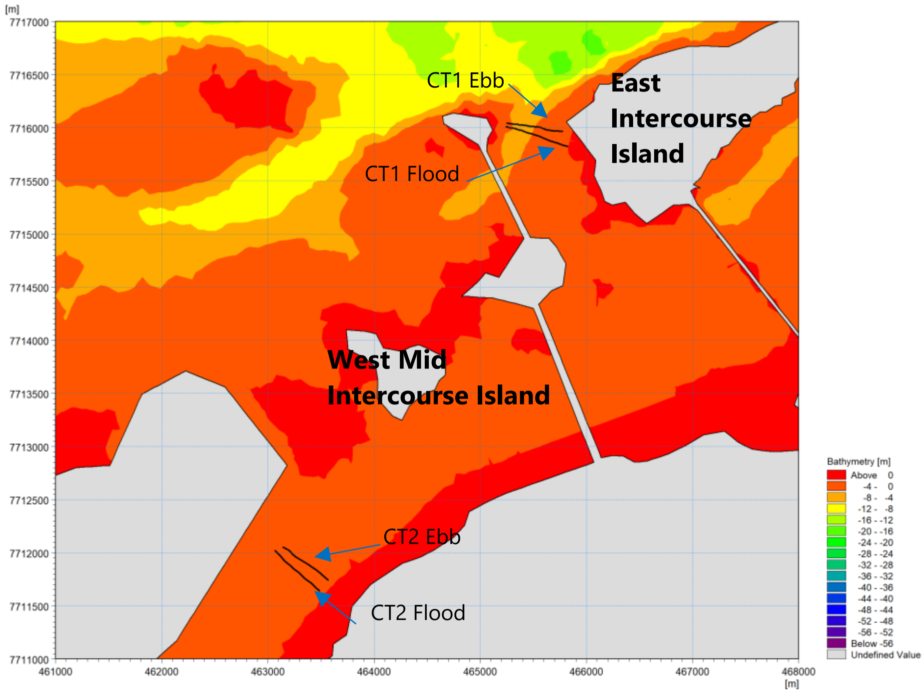


Figure 2-5 Location of transect measurements during flood and ebb tides

Further details of the model validation are provided in Section 5.6.

3 Environmental quality criteria review

3.1 Whole of effluent toxicity

While discharge water for the proposed desalination plant is not yet available, whole of effluent (WET) testing of desalination discharge water has been performed on occasion for previous Australian desalination projects. BMT (2021) reviewed desalination discharge environmental management triggers for desalination plants across Australia to determine suitable dilution thresholds for the current project. Publicly available WET test data was collated from reports from nine desalination plants across Australia: four in Western Australia, three in South Australia, one in Victoria and one in New South Wales (Table 3-1) (BMT, 2021).

Tests were completed using a variety of bioassay, including macroalgae, microalgae, diatoms, bivalves, crustaceans, polychaetes, echinoderms, cephalopods and fish (BMT, 2021). As the reported target dilutions included slight differences in the calculations, they were recalculated using the EC10 recommended by ANZG (2018) (BMT, 2021). The updated protocols apply a log-logistic fit, instead of the previous Burr type III, where there are less than five data points. Results will therefore be slightly different to published values calculated using the previous (ANZECC/ARMCANZ, 2000) approach. Data from acute toxicity tests was adjusted using an acute to chronic ratio of 2.5 (typically applied to desalination WET tests).

The number of dilutions required to achieve 99% (for a high LEP) and 90% (for a moderate LEP) species protection values were then calculated. The target dilutions calculated from a test on the Perth Seawater Desalination Plant discharge in 2006 were very different from the tests completed subsequently and do not appear to be representative of the contemporary discharge. This extreme outlier was omitted from the analysis.

Table 3-1 Desalination plant discharge concentration triggers and target dilutions for high and moderate levels of ecological protection (BMT, 2021)

Desalination plant	Year	Dilutions required for a high level of ecological protection	Dilutions required for a moderate level of ecological protection
Perth Seawater Desalination Plant	2007	45	16
	2015	10	5.3
Southern Seawater Desalination Plant	2012	147	27
	2013	48	12
	2014	7.7 (8.3)[1]	3.7 (2.8)[1]
Cape Riche Desalination Plant [4]	2011	222	59
Olympic Dam Desalination Plant	2008	48	29
	2011	38	22
Barrow Island Desalination Plant [4]	2008	14	8
Adelaide Desalination Plant	2009	48 (115)[3]	11.8 (17.24)[3]
Victorian Desalination Plant	2008	28	13
Point Lowly Desalination Plant	2009	121	36
Median [2]		**47**	**15**
Average [2]		**65**	**20**
Worst case [2]		**222**	**59**

Notes

1 The copepod test included results for pulsed (and non-pulsed) exposure to the effluent.

2 Excludes Perth Seawater Desalination Plant 2006 outlier.

3 The water samples were tested with (and without) anti-scalant.

4 Tests were performed using simulated desalination brine.

The variability in the results in Table 3-1 may be explained due to the differences in the test species used, natural variability in the tolerance of test species, differences in number of tests, uncertainty in the statistical fit of the species' sensitivity distribution and variability in the discharges (BMT, 2021).

Falkenberg and Styan (2015) reviewed the WET testing results on simulated effluents of brine-only and combined (brine and chemicals) discharge water for Australian desalination plants at Cape Riche, Victoria and Barrow Island. In all three cases, there was no evidence of any combined discharge streams being more toxic than just the brine component; it is a widely held view that the toxicity of brine is largely due to osmotic stress (BMT, 2021). However, WET testing at Perth Seawater Desalination Plant and Southern Seawater Desalination Plant based on a range of salinities (52 to

65 ppt) found the target dilutions required to achieve a high or moderate LEP were independent of the salinity (Table 3-2).

Table 3-2 Relationship between desalination discharge water salinity and dilution required for a high level of ecological protection at Perth Seawater and Southern Seawater Desalination Plants (BMT, 2021)

Plant	Year	Salinity	Dilutions required
Perth Seawater Desalination Plant	2007	62	45
	2015	65	10
Southern Seawater Desalination Plant	2012	58	147
	2013	51.8	48
	2014	61.5	8

Given the demonstrated uncertainty in WET testing results, the worst-case dilution scenarios were selected to assess the potential toxicity of the Proposal's discharge, with 59 dilutions used as the threshold to define the predicted spatial extent of the low LEP and 222 dilutions used for the moderate LEP. Additionally, the 95th percentile of modelled data (rather than the median used for physico-chemical parameters) was used, as per the recommendations in *Technical guidance – Protecting the quality of Western Australia's marine environment* (EPA, 2016c).

Table 3-3 Environmental quality criteria for WET

Level of ecological protection	Percentile of natural background data	Season	Threshold/EQC (no. of dilutions in folders)
Low/moderate boundary	Seasonal 95th percentile of background data	Summer	1:59
		Winter	1:59
Moderate/high boundary	Seasonal 80th percentile of background data	Summer	1:222
		Winter	1:222

3.2 Salinity

A baseline salinity dataset was collected over both summer and winter near the Proposal's outfall location from May 2020 to May 2021 (Advisian, 2022). Physico-chemical stressors are often locality-specific and the biological communities are generally adapted to these background conditions (EPA, 2016b). It is expected that species near the Proposal are adapted to the local conditions. Therefore, the approach to assess impacts from physico-chemical parameters (EPA, 2016b) was applied to assess the spatial extent of potential impacts from the salinity component of the discharge.

The baseline data was used to derive EQC for physico-chemical parameters as per *Technical guidance – Protecting the quality of Western Australia's marine environment* (EPA, 2016c). The EQC are summarised in Table 3-4. The 50th percentile of modelled data was compared with these thresholds.

Table 3-4 Environmental quality criteria for salinity

Level of ecological protection	Percentile of natural background data	Season	Threshold/EQC (ppt)
Low/moderate boundary	Seasonal 95th percentile of background data	Summer	37.08
		Winter	36.20
Moderate/high boundary	Seasonal 80th percentile of background data	Summer	36.86
		Winter	36.07

3.3 Temperature

A baseline temperature dataset was collected over both summer and winter near the outfall location (Advisian, 2022). Physico-chemical stressors are often locality-specific and the biological communities are generally adapted to these background conditions (EPA, 2016b). It is expected that species close to the Proposal are adapted to the local conditions. Therefore, the approach to assess impacts from physico-chemical parameters (EPA, 2016b) has been applied to assess the spatial extent of potential impacts from an elevated seawater temperature associated with the discharge.

The baseline data was used to derive EQC for physico-chemical parameters as per *Technical guidance – Protecting the quality of Western Australia's marine environment* (EPA, 2016c). The EQC are summarised in Table 3-5.

Table 3-5 Environmental quality criteria for temperature

Level of ecological protection	Percentile of natural background data	Season	Threshold/EQC (°C)
Low/moderate boundary	Seasonal 95th percentile of background data	Summer	31.95
		Winter	27.28
Moderate/high boundary	Seasonal 80th percentile of background data	Summer	30.46
		Winter	25.58

The temperature of the discharge water at the point of outfall was modelled under two scenarios. The median values of modelled data were compared with the EQC in:

- Scenario 1: the temperature of the discharge was modelled at 2^0C above the ambient seawater temperature:
  - summer – discharge water 31.64^0C at the point of outfall discharge
  - winter – discharge water 25.18^0C at the point of outfall discharge.
- Scenario 2: the temperature of the discharge was modelled at 5^0C above the ambient seawater temperature:
  - summer – discharge water 34.64^0C at the point of outfall discharge
  - winter – discharge water 28.18^0C at the point of outfall discharge.

4 Near-field analysis

The most rapid discharge dilution occurs in the near-field zone. For the study, the near-field was analysed, both analytically using the Roberts et al. (1997) formula and numerically using the MIKE 3D Hydrodynamic Model.

4.1 Discharge characteristics

The characteristics of discharge used as input for the near-field analysis modelling are presented in Table 4-1.

Table 4-1 Outfall discharge characteristics

Location/Parameter	Parker Point
Received Ambient Sea Water Salinity (ppt)	Summer Season: 36.61 Winter Season: 35.78
Reject Water Salinity (ppt)	Summer Season: 65.898 Winter Season: 64.404
Outfall Discharge Rate (ML/day)	35.3
Diffuser Port Flow from one port (L/s)	204
Port Diameter (m)	0.23
Number of Ports (Diffusers)	2
Diffuser Port Velocity (m/s)	4.9 (typical 3 to 6 m/s range)
Diffuser Port Angle	45 degrees upwards
Diffuser Port Location	470946.126 East, 7717934.561 North
Diffuser Port Water Depth (mCD)	-7.4
Diffuser Discharge Water Depth (m)	0.2 m above seabed

4.2 Dilution estimate (Roberts et al., 1997)

For this study, the empirical relationships developed by Roberts et al. (1997) were adopted to derive the characteristics of the near-field mixing zone. The definition sketch of the jet is presented in Figure 4-1 and the corresponding plume characteristics are estimated as presented in Table 4-2.

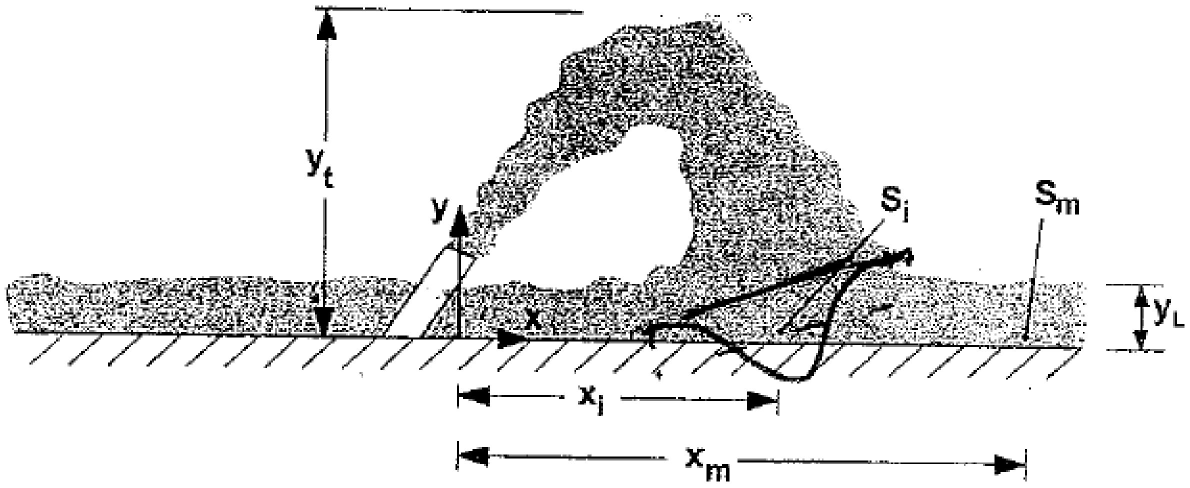


Figure 4-1 Definition sketch for inclined dense jet (Roberts et al., 1997)

Table 4-2 Proposal plume characteristics estimated by Roberts et al. (1997)

Parameter	Value
Terminal Rise Height y_t (m)	7.5 (reaches surface)
Distance to Impact x_i (m)	16.8
Distance to Ultimate Minimum Dilution x_m (m)	63
Thickness of Spreading Layer y_L (m)	4.9

4.3 Near-field modelling (MIKE3 HD)

4.3.1 Modelling software

To refine and confirm the results of the dilution estimate (Roberts et al. 1997), the MIKE3 HD Model was applied to simulate the near-field dilution. This model allows the simulation of additional and absolute effects by applying baseline water quality values.

The near-field dilution is modelled as a jet source in the MIKE3 Hydrodynamic Model. The jet source is based on integral jet model equations described by Jirka (2004). It determines the steady state solution of the jet/plume by solving conservation equations for flux and momentum, salinity and temperature (if included) under the given ambient conditions.

To isolate the purely jet characteristic for comparison with the initial mixing zone derived by the Roberts et al. (1997) formula, jet flow was simulated under stagnant conditions without any tidal or wind forcing. The results were compared to the derived results based on Robert et al. (1997)'s formula. This was done to check the initial mixing zone to ensure the brine plume is rapidly diluted from the outfall to seabed (the model results are presented in Section 4.3.3). The model was then coupled with the far-field model to run with seasonal tidal and wind forcing, to determine the final LEP boundaries described in Section 5. Table 4-1 presents the model input discharge characteristics.

Figure 4-2 presents the definition sketch of the near-field jet in which *s* represents the axial distance along the trajectory and *b* is the characteristic width of the jet.

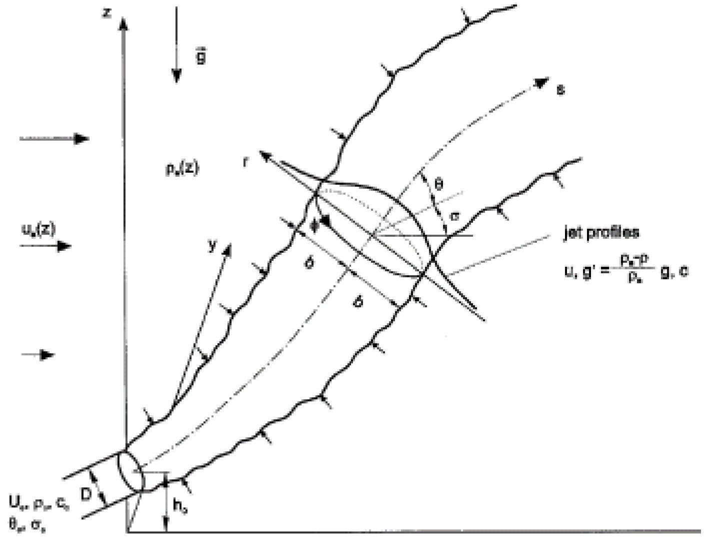


Figure 4-2 Near-field jet integral model definition sketch (DHI, 2019a)

4.3.2 Model domain and bathymetry

The jet plume associated with the brine water discharge for the near-field model was simulated and coupled with the far-field model domain and bathymetry. The model domain was developed for the Parker Point area as presented in Figure 4-3. The domain was developed such that it has sufficient area to accommodate the jet plume from the near-field dilution. Table 4-1 presents the model input discharge characteristics. The model resolution was refined to 5 m, covering the near-field model domain.

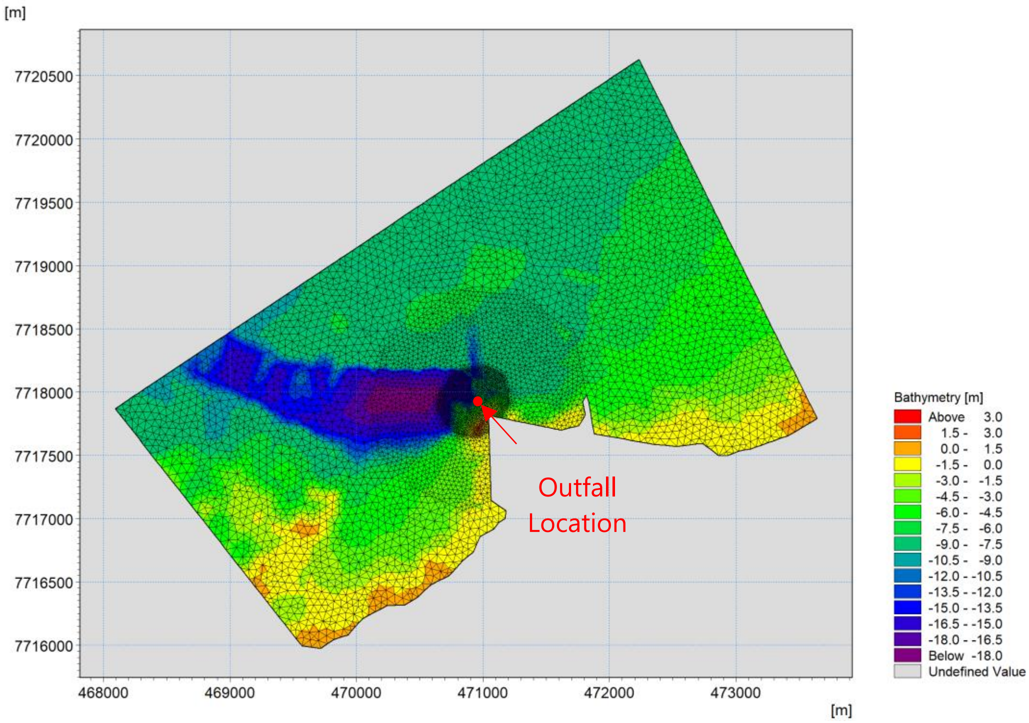


Figure 4-3 Model bathymetry and mesh for near-field simulation for the Proposal discharge location

4.3.3 Near-field model results

Figure 4-4 presents the far-field plume dilution pattern due to the near-field jet plume generated for the Proposal's discharge, based on the near-field model for summer season. Discharge from only one diffuser port is shown as an example for clarity, since discharge from two diffusers creates mixing of flows that makes it difficult to distinguish individual jet flows. Figure 4-5 presents the vertical profile of brine plume patterns at the outfall discharge location and the end of the near-field jet plume boundary. The terminal rise (y_t defined in Figure 4-1) plume height, distance to impact and the distance to end of nearfield are around 7.5, 11.5 and 68 m, respectively.

Figure 4-6 and Figure 4-7 present the plume dilution pattern due to the near-field jet and the vertical profile of diluted brine plume pattern, respectively for winter season. The terminal rise plume height, distance to impact and the distance to end of nearfield are around 7.5, 10.5 and 58 m, respectively.

The values predicted from the numerical model are comparable with Roberts et al. (1997), as presented in Table 4-3.

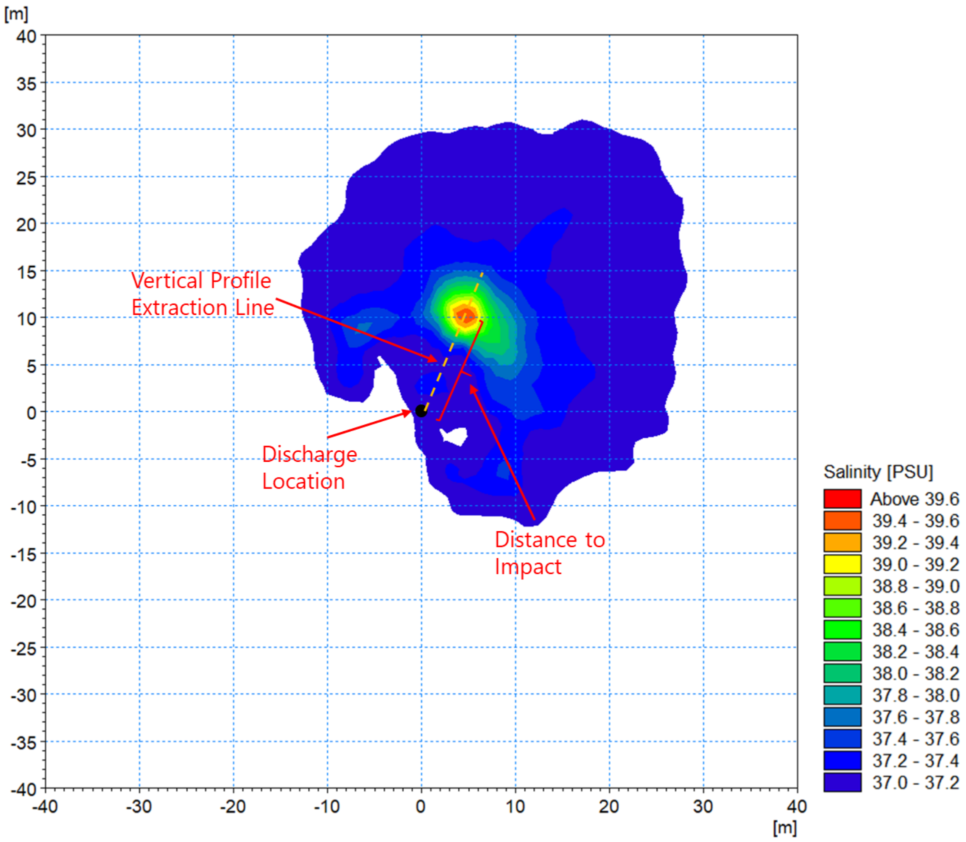


Figure 4-4 Spatial plume dilution showing the extent of the near-field jet plume generated for the Proposal discharge (summer)

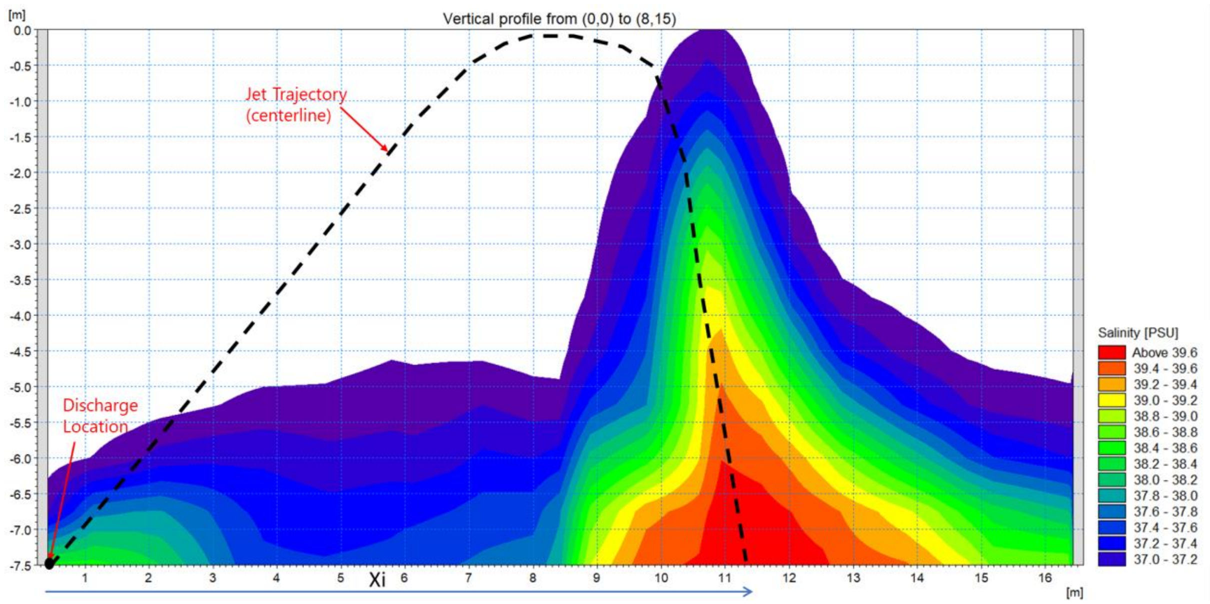


Figure 4-5 Vertical distribution of salinity along the line presented in Figure 4-6. The brine plume showing a dilution pattern for far-filed immediately after initial near-field dilution for the Proposal (summer)

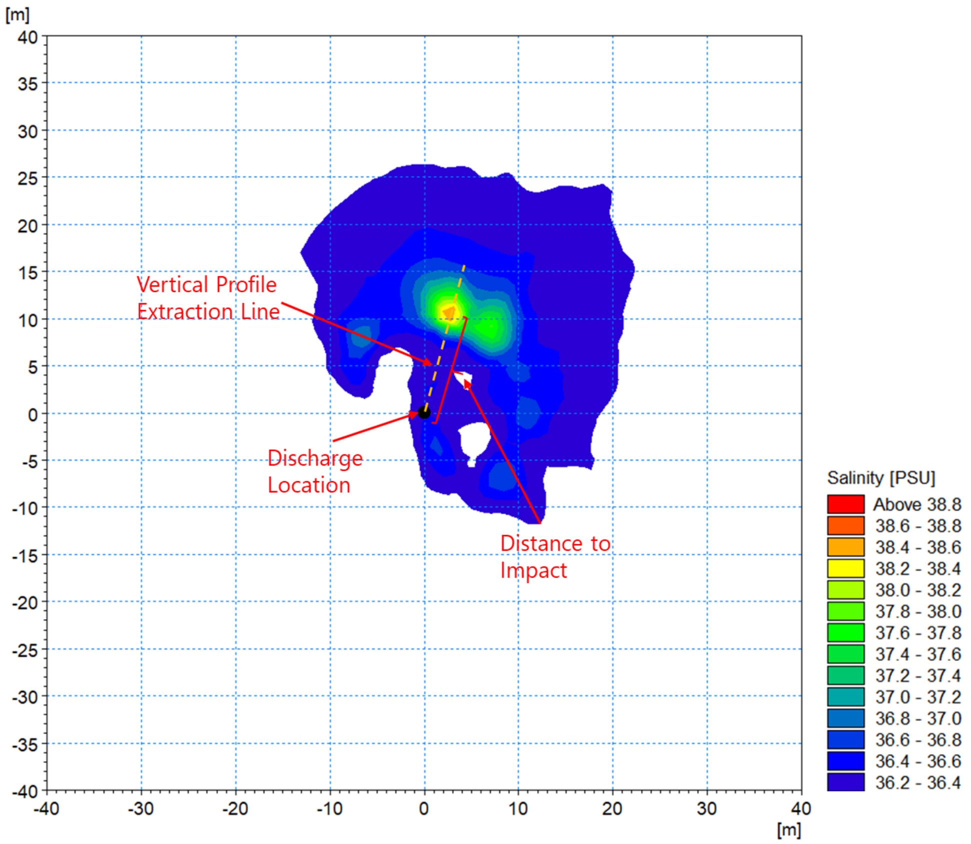


Figure 4-6 Far-field plume dilution showing the extent of the near-field jet plume generated for the Proposal discharge (winter)

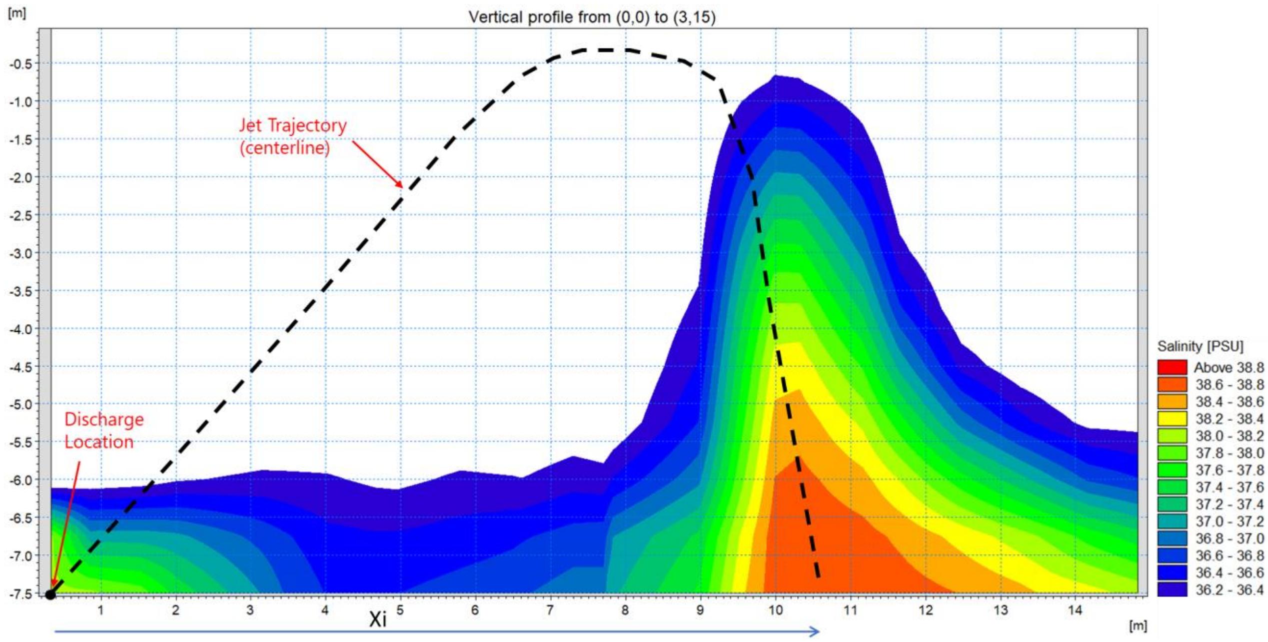


Figure 4-7 Vertical distribution of salinity along the line presented in Figure 4-6. The brine plume showing a dilution pattern for far-filed immediately after initial near-field dilution for the Proposal discharge (winter)

Near-field plume characteristics predicted by the MIKE3 model are summarised in Table 4-3. The model results are comparable to the analysis results derived from Roberts et al. (1997) formula, which indicated the initial arrangement for the jet flow is valid for the rapid dilution. To determine the final LEP boundaries, the model needs to couple with the far-field model under seasonal tidal current and wind forcing, as such hydrodynamic forcing may retain the brine plume continuously discharged from the outfall. This may raise the salinity levels, which potentially affects the final LEP zone and boundary. Therefore, the near-field model was coupled to the far-field model to simulate the outfall discharge under seasonal tidal currents and wind forcing to determine the LEP boundaries, which is described in Section 5.

Table 4-3 Comparison of near-field plume characteristics predicted by Roberts et al. (1997) and MIKE3 model

Parameter	Roberts et al. (1997)	Near-field Model (summer)	Near-field Model (winter)
Terminal Rise Height y_t (m)	7.5	7.5	7.5
Distance to Impact x_i (m)	16.8	11.5	10.5
Distance to Ultimate Minimum Dilution x_m (m)	63	68	58

5 Far-field dilution model

5.1 Modelling software

Advisian's West Pilbara Hydrodynamic Model employs the dynamic MIKE3 HD modelling software suite.

It is considered that within the model domain, barotropic effects (wind and water level variations) would be the dominant forcing mechanisms. Therefore, tide and wind forcing were applied as the model drivers. The dense flow due to the brine discharge was also included in the model, with the density function formula accounting for temperature and salinity effects also included.

5.2 Model domain and bathymetry

The model domain covers the coastline from Depuch Island to Cape Preston and extends offshore to a water depth of around 100 m. Figure 5-1 and Figure 5-2 show the model computational mesh and bathymetry over the full domain and for an enlarged section in the vicinity of the outfall location, respectively. The mesh incorporated in the model is flexible, which allows for higher resolution around areas of specific interest or areas with complex bathymetry. Computational length scales of the mesh triangles ranged from 3 km at the coarsest scale down to 20 m at the finest scale. These scales were selected to minimise run time, while still giving a suitable level of accuracy in the results.

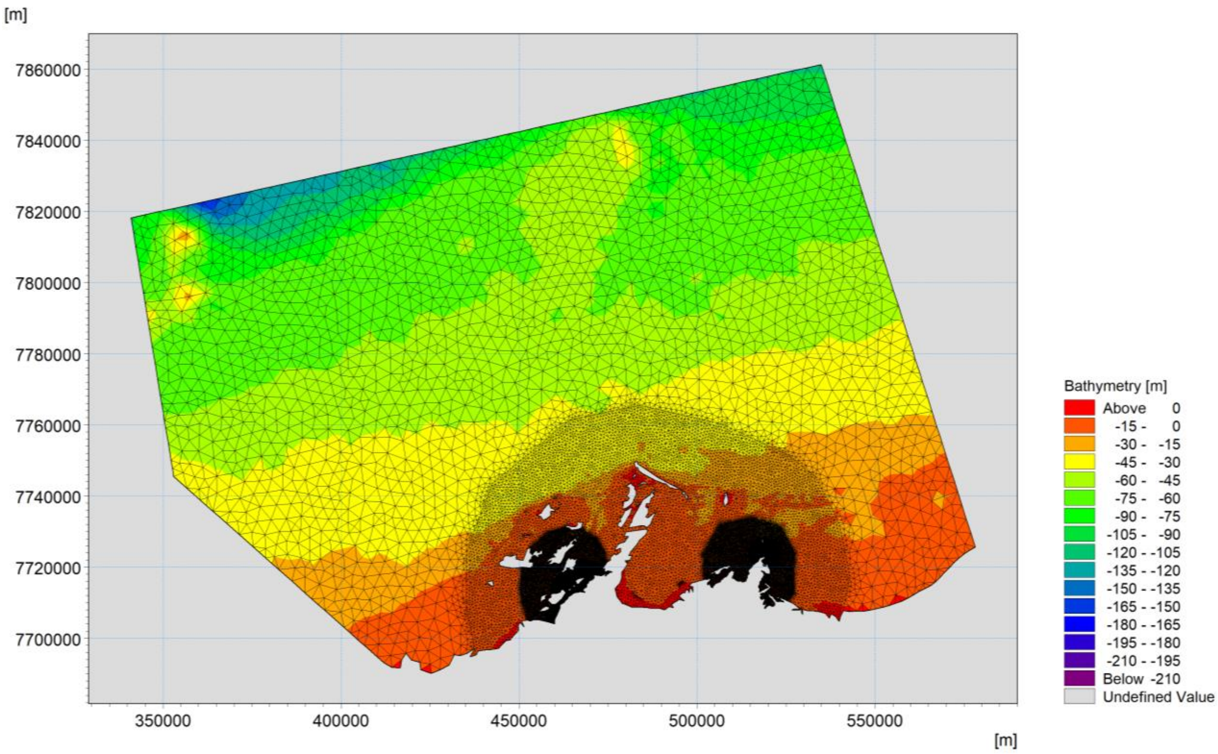


Figure 5-1 West Pilbara region model bathymetry and mesh

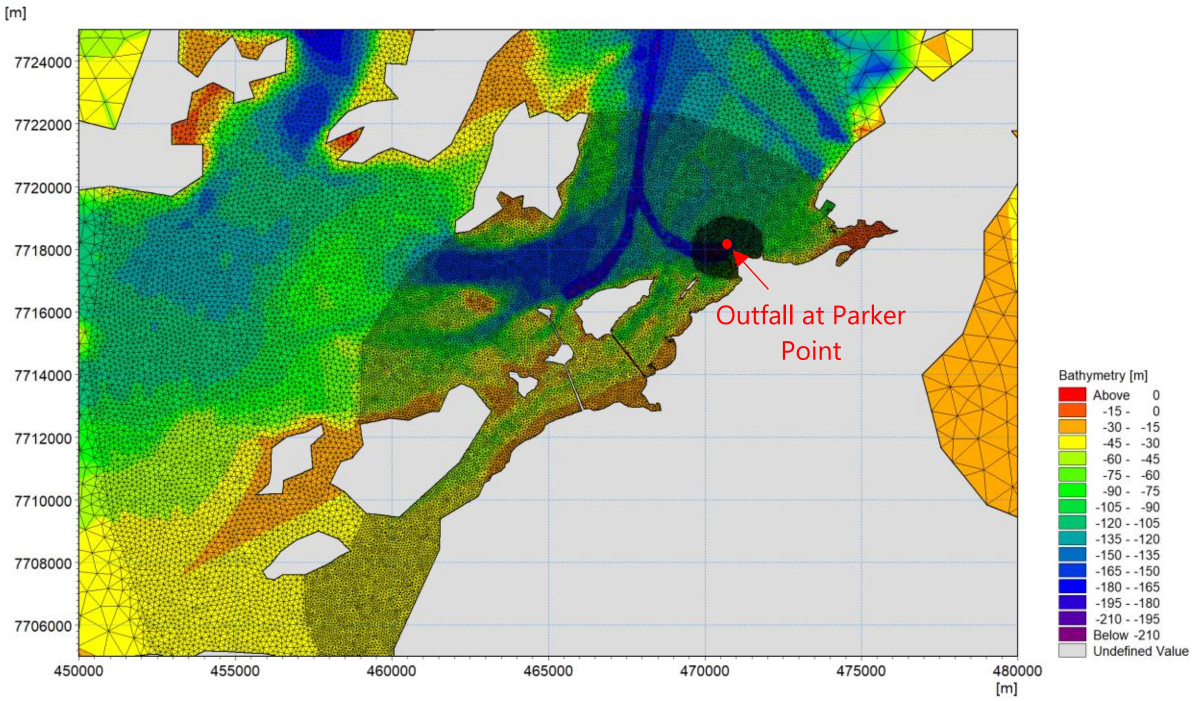


Figure 5-2 Model bathymetry and mesh zoomed to Parker Point

5.3 Model parameters

The main model input parameters are:

- time step interval of 600 seconds
- vertical division of the model domain into ten layers, proportionate to the water depth, comprising 10% of the local water depth for each layer
- horizontal momentum diffusivity, with Smagorinsky formulation, c=0.28
- vertical eddy viscosity diffusion, k-epsilon formulation
- bed resistance, roughness height 0.03 m
- flexible mesh and thus grid dimensions varying from 20 m to 3 km (offshore boundary)
- horizontal dispersion coefficient, scaled eddy viscosity formulation with a constant value of 1
- vertical dispersion coefficient, scaled eddy viscosity formulation with a constant value of 0.1.

5.4 Model forcing

5.4.1 Hydrodynamic driving forces

The main hydrodynamic driving forces can be divided into tidal and non-tidal processes. Non-tidal processes include forcing by the local meteorological conditions (such as winds), ocean flow and the hydrology (not included in the present model) of the adjacent watershed (such as river discharge), as well as the denser flow from the plume discharge.

Tidal forcing is dominant in the Parker Point region, owing to the high tidal range (which is around 5 m at springs). Wind forcing also contributes to the current regime, especially with respect to surface currents. Density flows (due to salinity and temperature differences of the discharge water) will also contribute to the current regime. All three mechanisms were simulated in the model. The good correlation of the model results against measured data, as discussed in Section 5.5, suggests other non-tidal forcing on flows is insignificant at this site for hydrodynamic model applications.

5.4.2 Tidal forcing

Tidal forcing was included in the model by imposing predicted tidal levels on all the open boundaries. The predicted tidal levels are site-specific and vary in time and along each boundary line. At the points along the boundary where water is flowing into the model domain, the flow was forced perpendicular to the boundary orientation; at points where the water is flowing out of the model domain, the flow direction was extrapolated from the nearest points inside the model domain.

Tidal levels at the model boundaries were predicted from tidal harmonic constituents using the Institute of Oceanographic Sciences method (Foreman, 1996). The harmonic constituents were taken from tidal stations on the model boundary. Offshore, harmonic constituents were estimated from global tide model data incorporated in the MIKE 21 Toolbox. The global tide model data includes the major diurnal (K1, O1, P1 and Q1) and semidiurnal tidal constituents (M2, S2, N2 and K2) with a spatial resolution of 0.25° by 0.25° based on TOPEX/Poseidon altimetry.

At the northern boundary, along around the 100 m depth contour, tidal constituents were based on the TOPEX/Poseidon data. The annual (Sa) and semi-annual (Ssa) constituents, based on tidal predictions at Port Walcott (AHS, 2011), were also included to account for seasonal changes in mean sea level. The Depuch Island tidal station is located on the eastern boundary and the Trimouile Island tidal station is located on the south-west boundary. Along the east and west boundaries, tidal conditions were generated by interpolation between tidal constituents from the relevant tidal station and the TOPEX/Poseidon data.

5.4.3 Wind forcing

Wind forcing was applied as a timeseries over the whole domain. Wind forcing was derived from wind measurements at the Legendre Island BoM weather station. The Legendre Island dataset was interpolated to an hourly time interval and applied over the whole domain.

The timeseries of wind speed and direction from the Legendre Island weather station during the calibration period is shown in Figure 5-3.

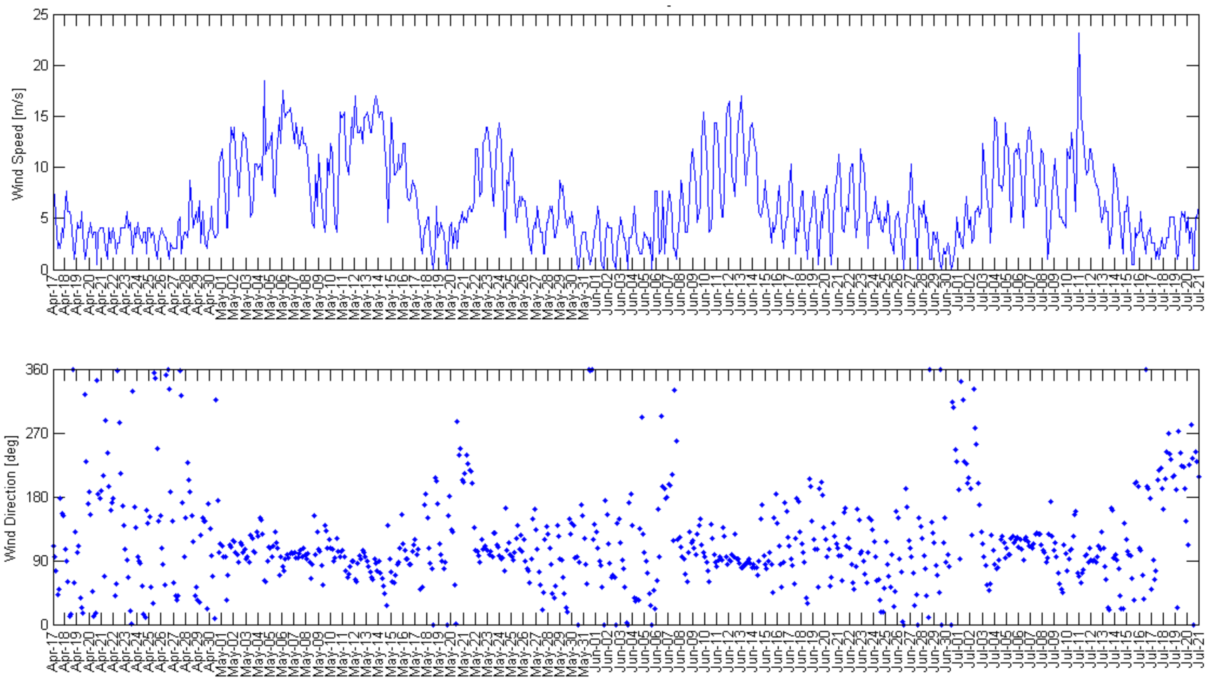


Figure 5-3 Wind speed and direction recorded at Legendre Island, 17 April to 21 July 2011

5.4.4 Heat exchange

Heat exchange was included in the model to incorporate heat in water to interact with the atmosphere. Timeseries of air temperature and the relative humidity was included in the model based on data measured by BoM at Legendre Island. Therefore, the model has simulated the absolute ambient temperature associated with the discharge water temperature above ambient temperature.

5.5 Model calibration

5.5.1 Calibration process

Model calibration is the process by which the main governing conditions of the model are adjusted to produce the best reflection of measured data from the calibration control period. The performance of the model is then verified against an independent set of data (often a different survey period) while holding the previously determined calibration parameters constant. If the validation is unsuccessful, the process returns to the calibration stage and the cycle is repeated.

The main governing conditions which affect the performance of the hydrodynamic model are:

- boundary conditions
- bathymetry
- bottom resistance
- eddy viscosity.

5.5.2 Model calibration: water level performance

The performance of the model water level predictions was assessed by comparison against measured water level data at three locations within the model domain, specifically:

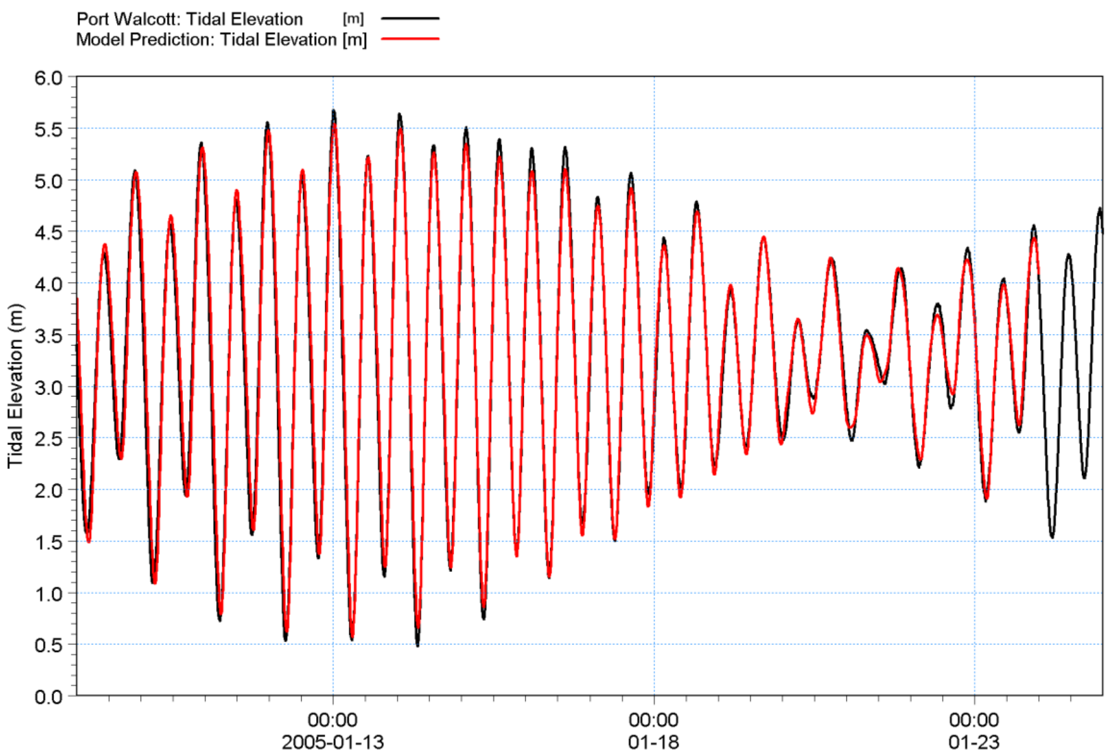
- Port Walcott tidal station
- inshore AWAC location
- offshore AWAC location.

Plots of the measured water level compared with the model predictions are shown in Figure 5-4 to Figure 5-6. The comparison with the AWAC data (Figure 5-5 and Figure 5-6) is presented for the three months of data that was available at the time of this assessment (17 April 2011 to 20 July 2011). At Port Walcott (Figure 5-4), a comparison is provided for a typical winter (July) and summer (January) tidal cycle, to give an indication of seasonal model accuracy. All plots show a very close match and excellent agreement between the model simulation results and the measured water levels.

The quantitative performance of the model was assessed using the approach for specification of hydrodynamic models as recommended by the United Kingdom Foundation for Water Research (UKFWR, 1993). To assess performance, the root mean square (RMS) error of the model was compared against a given criterion. For hydrodynamic models the criterion was set to 10% of the spring tidal range (or highest recorded tidal range). The quantitative performance of the model tidal predictions is given in Table 5-1, with all RMS errors less than the criterion, indicating a satisfactory performance.

Table 5-1 Hydrodynamic model Performance – tidal levels

Location	Spring Tidal Range (m)	Criterion (m)	Model RMS Error (m)
AWAC Offshore	5.4	0.54	0.15
AWAC Inshore	5.6	0.56	0.16
Port Walcott Tidal Station	5.2	0.52	0.20



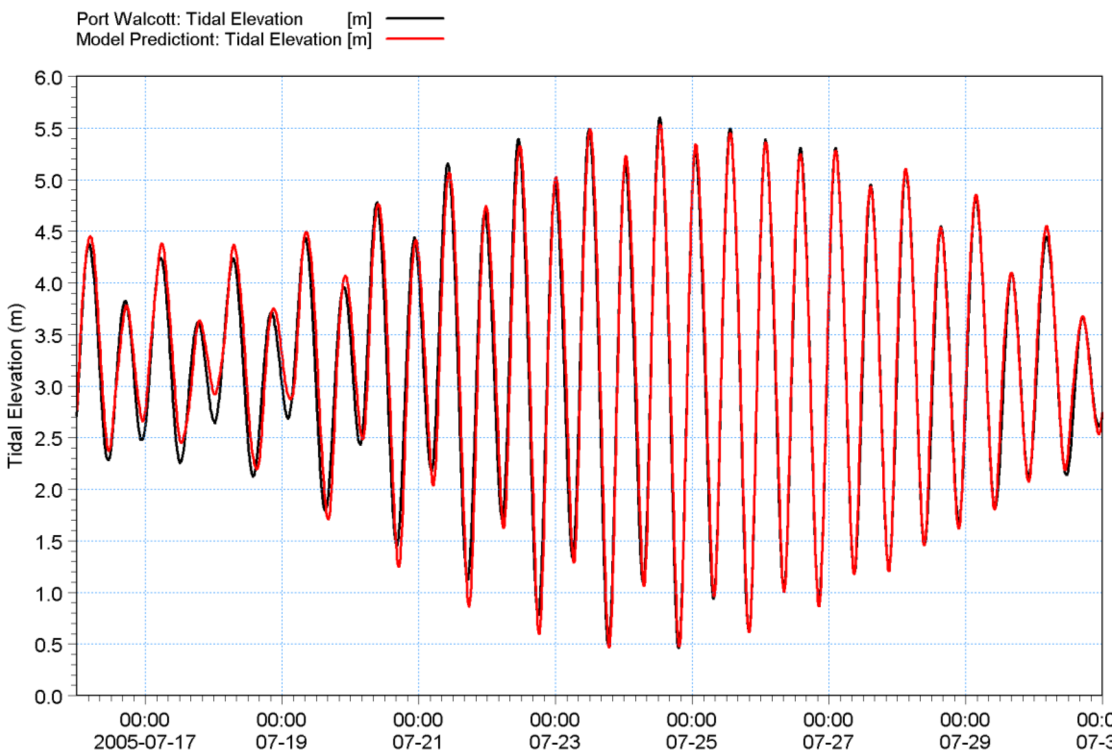


Figure 5-4 Comparison of model predicted and measured water level – Port Walcott tidal station

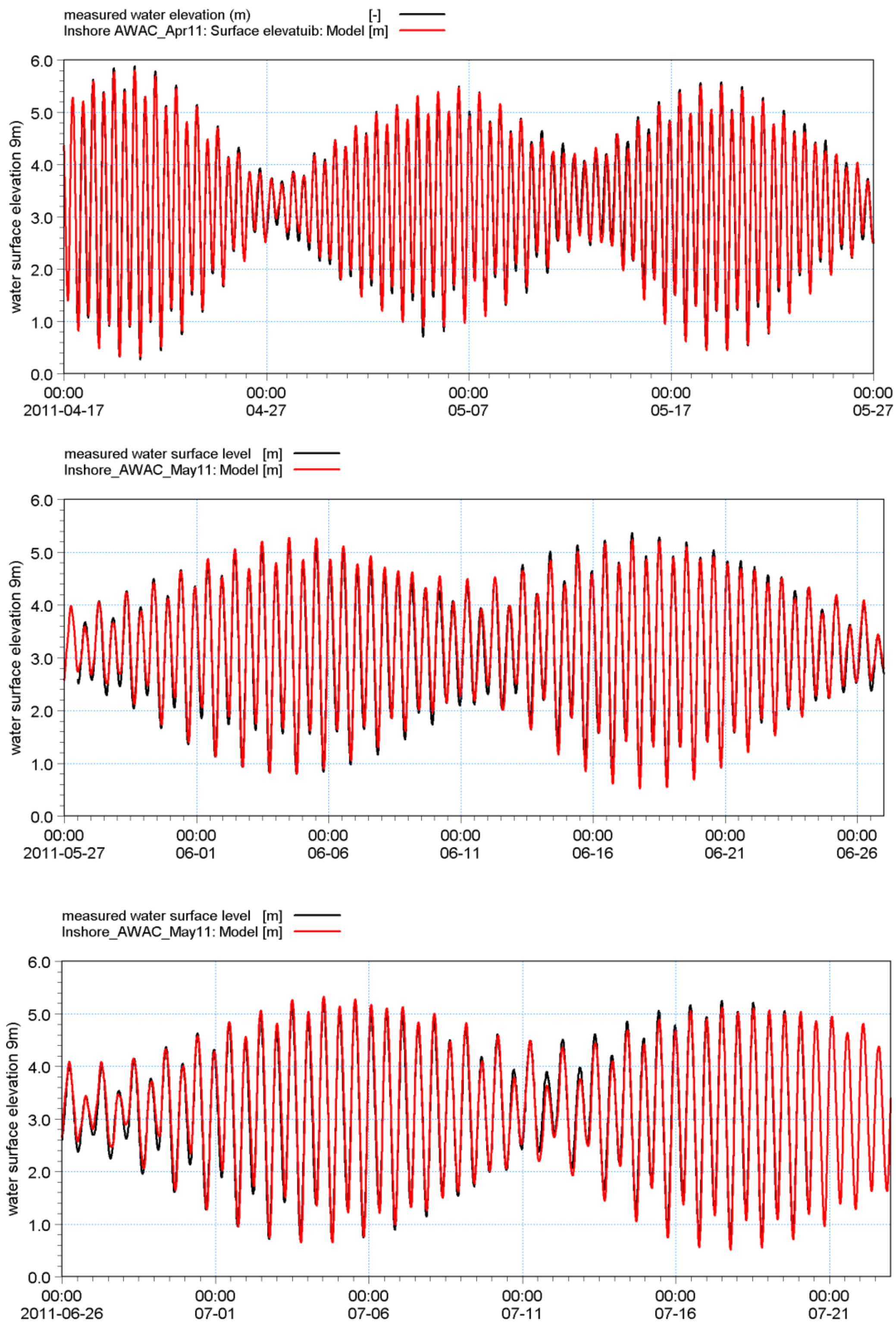


Figure 5-5 Comparison of model predicted and measured water level – inshore AWAC profiler location

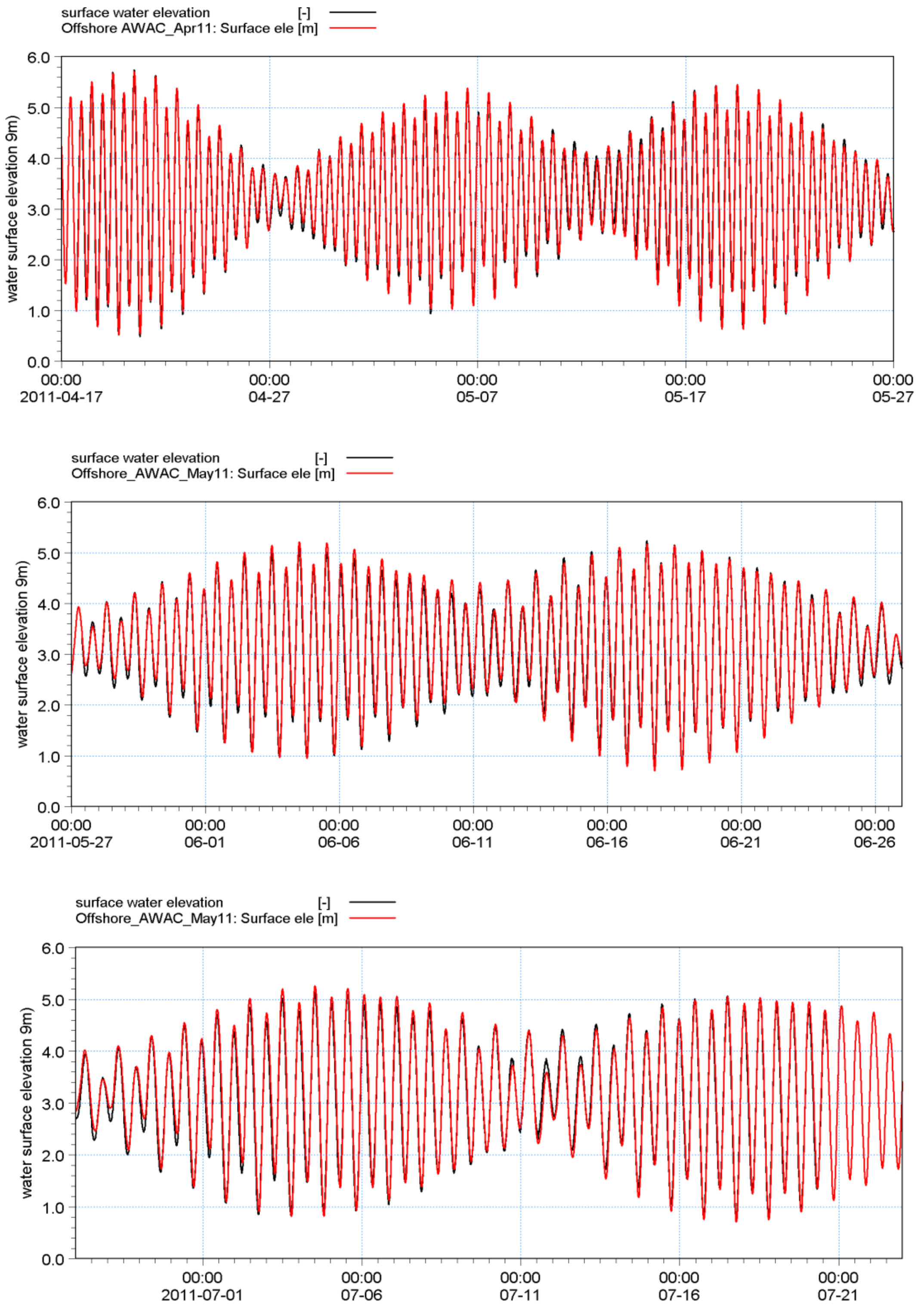


Figure 5-6 Comparison of model predicted and measured water level – offshore AWAC profiler location

5.5.3 Model calibration: current performance

5.5.3.1 Depth averaged current

The performance of the model current speed and direction predictions was assessed by comparison against measured current data at the inshore and offshore AWAC locations.

Critical to the model performance is an accurate replication of depth averaged current speed and direction. Plots of the measured depth averaged current speed and direction compared with the model predictions are shown in Figure 5-7 to Figure 5-13. These are presented for the full three months of measured data for both the inshore and offshore AWAC locations. The plots show a close match and good agreement between the model simulation results and the measured tidal levels.

Similar to the tidal levels, the quantitative performance of the model predictions of current speed and direction can be assessed by comparison against a given performance criterion. The criterion recommended for currents is an error up to 20% of the depth-averaged spring tidal current and direction within 15° (UKFWR, 1993). The quantitative performance of the model predictions is given in Table 5-2, with all RMS errors less than the criterion indicating a satisfactory performance. The RMS analysis investigated the whole period of calibration (three months) for both ebb and flood current conditions.

Table 5-2 Hydrodynamic model performance – current speed and direction

Location	Current Speed (m/s) and Direction (°)	Criterion (m/s) and (°)	Model RMS Error (m/s) and (°)
AWAC offshore	Current Speed	0.20	0.10
	Current Direction	15°	13.1°
AWAC inshore	Current Speed	0.13	0.08
	Current Direction	15°	11.8°

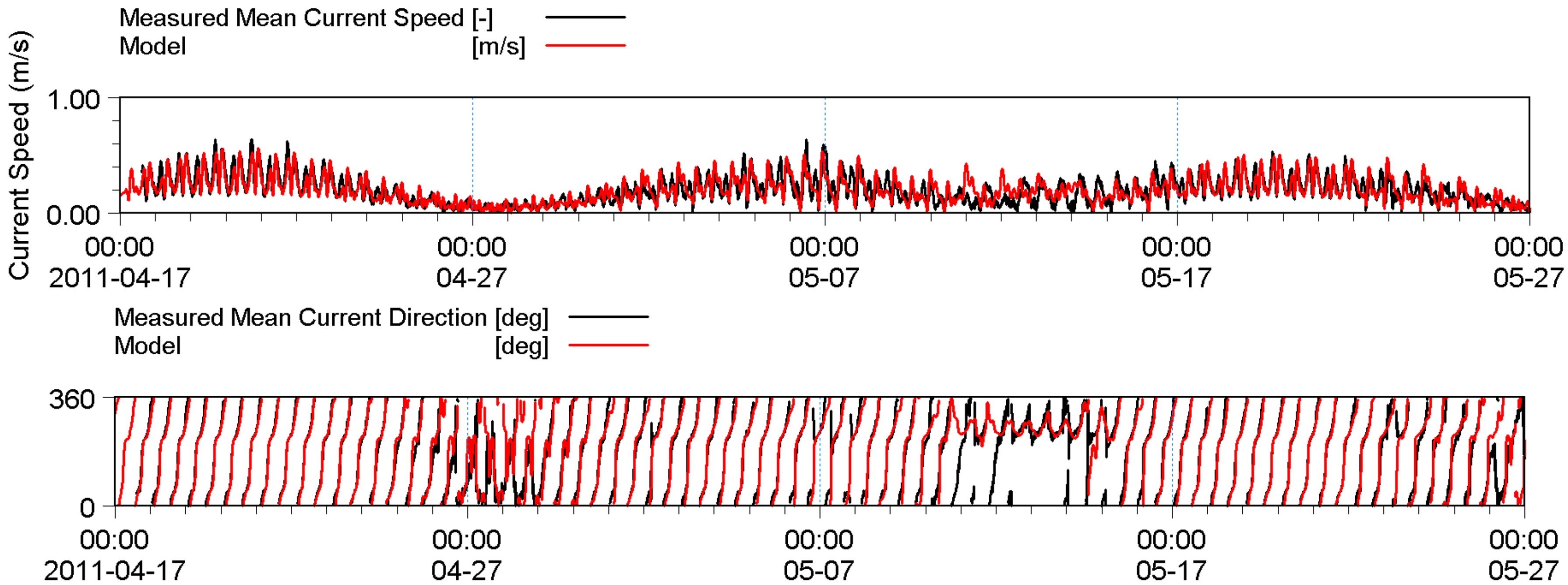


Figure 5-7 Comparison of model predicted and measured depth averaged current speed and direction (April/May) – inshore AWAC profiler location

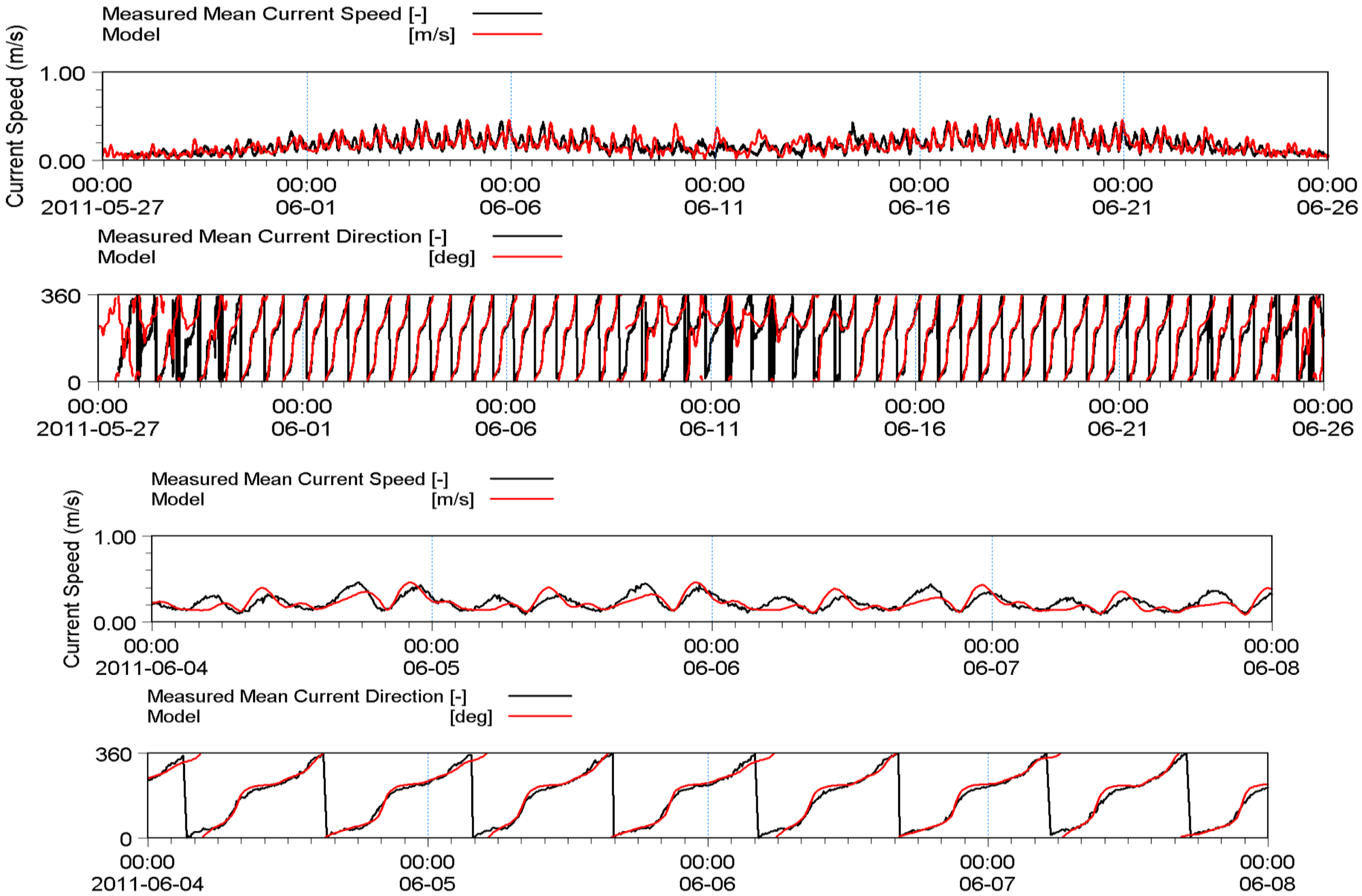


Figure 5-8 Comparison of model predicted and measured depth averaged current speed and direction (June) – inshore AWAC profiler location

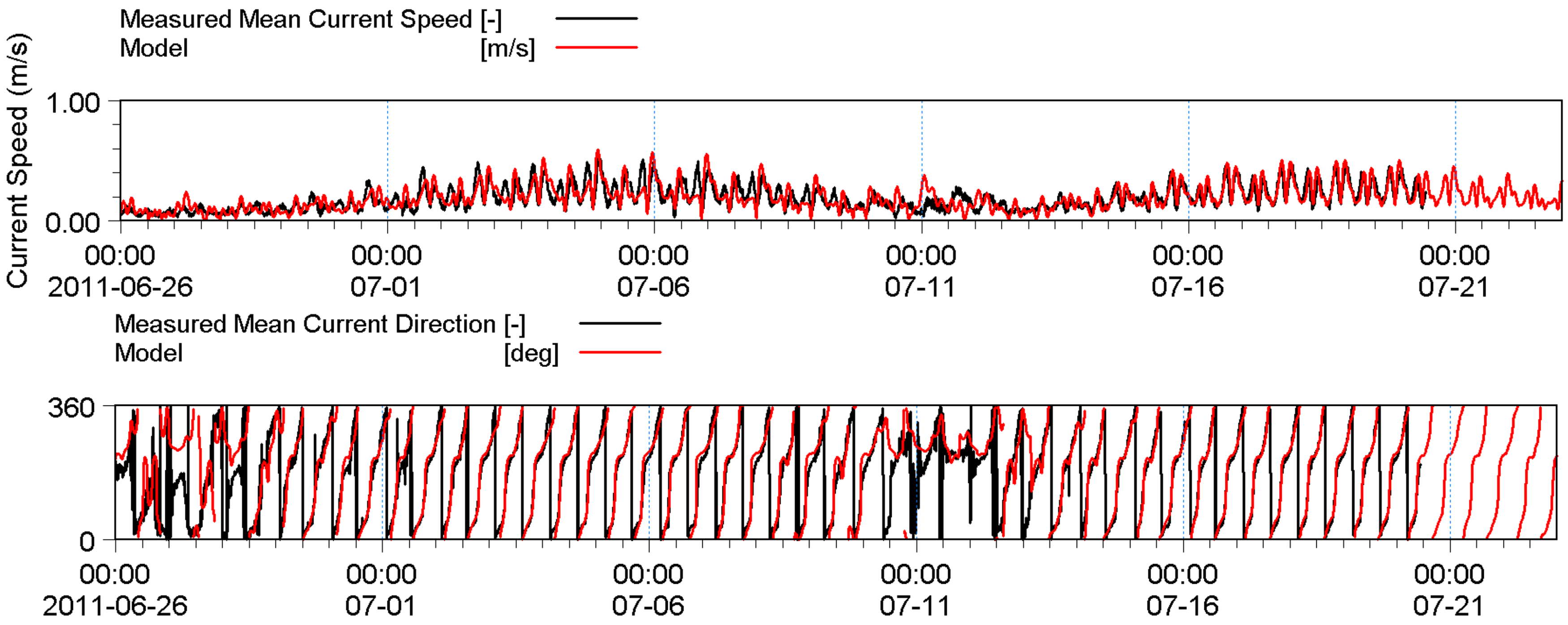


Figure 5-9 Comparison of model predicted and measured depth averaged current speed and direction (July) – inshore AWAC profiler location

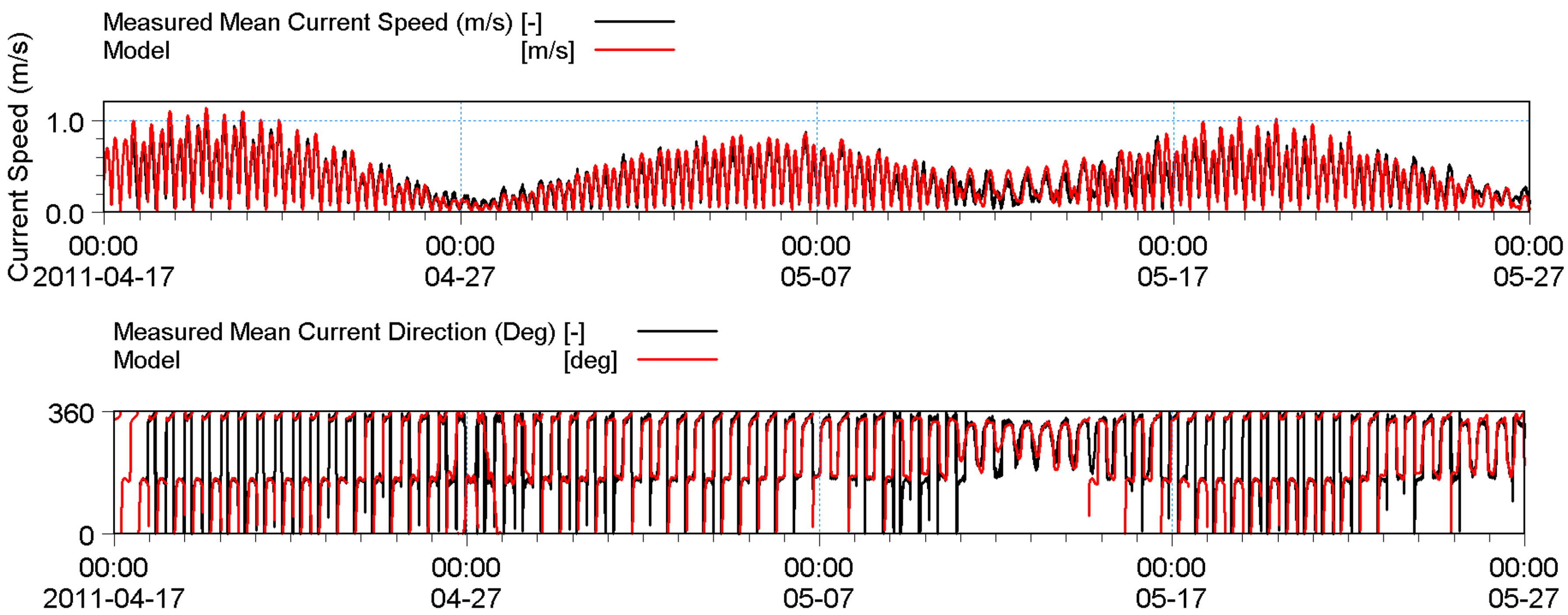


Figure 5-10 Comparison of model predicted and measured depth averaged current speed and direction (April/May) – offshore AWAC profiler location

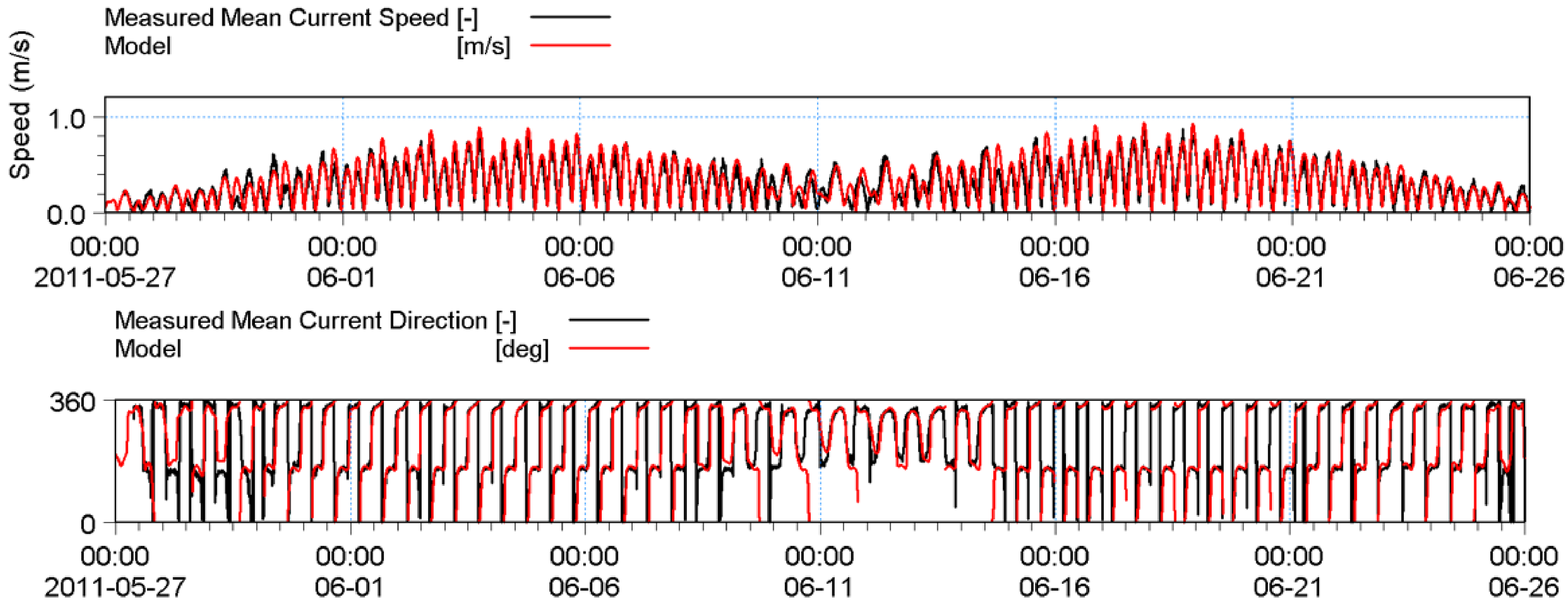


Figure 5-11 Comparison of model predicted and measured depth averaged current speed and direction (June) – offshore AWAC profiler location

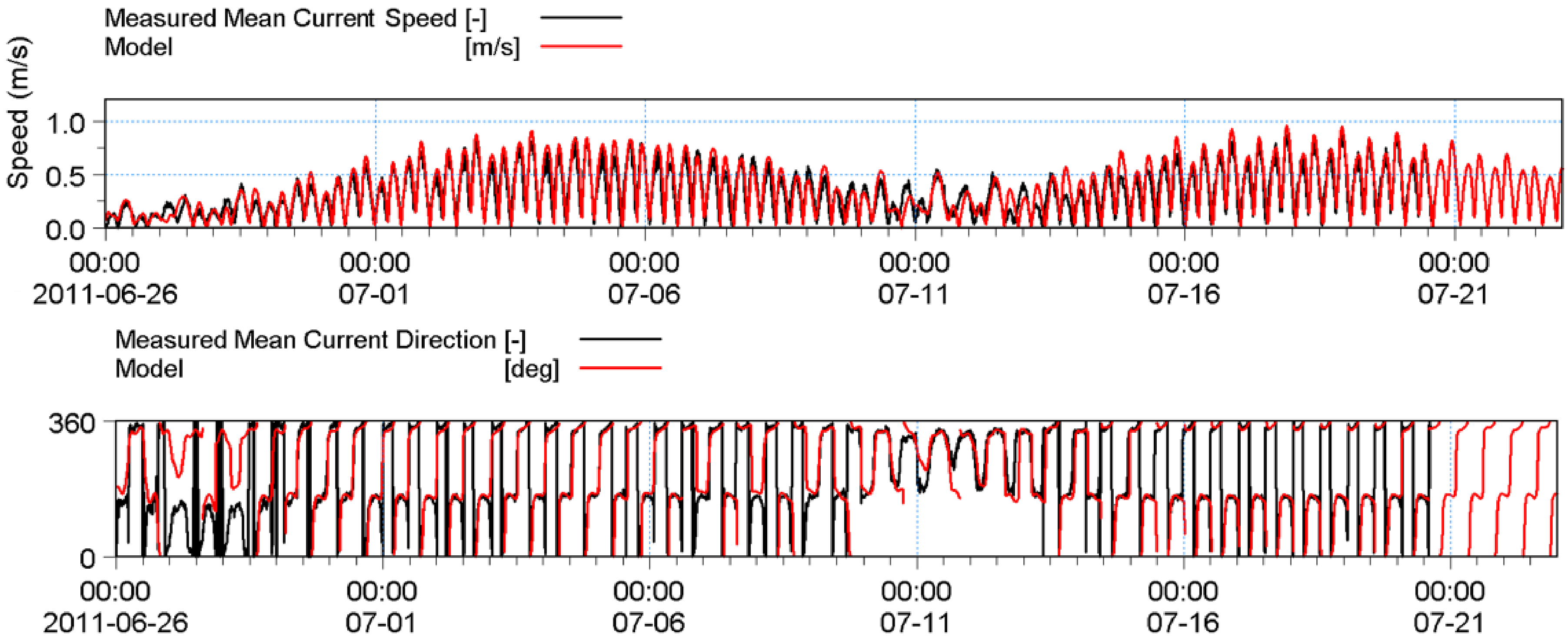


Figure 5-12 Comparison of model predicted and measured depth averaged current speed and direction (July) – offshore AWAC profiler location

5.5.3.2 *Surface current*

Wind forcing will affect current speed and direction, especially on the surface water layer. Figure 5-13 presents a comparison of the model-predicted and -measured surface current speed and direction. The selected comparison period in July includes the highest wind speed recorded during the measurement period (see Figure 5-3). It is noted that the highest wind speed occurred during a neap tide phase on 11 July 2011. It can be seen from Figure 5-13 that the model can reproduce the surface current speed and direction very well, even during the neap tide period with the strongest wind.

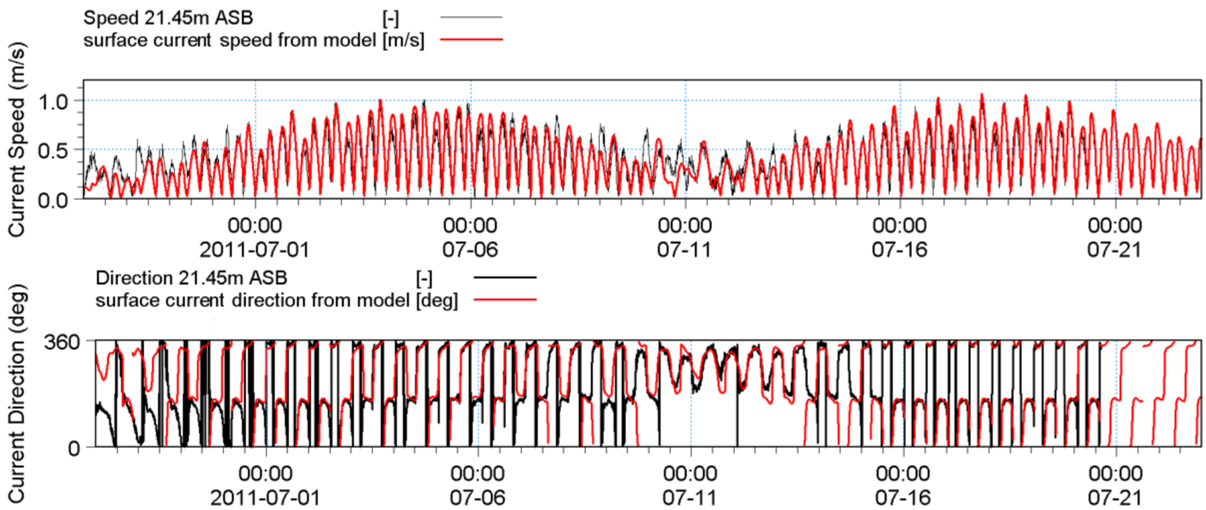


Figure 5-13 Comparison of model predicted and measured surface current speed and direction (July) – offshore AWAC profiler location

5.5.3.3 *Seasonal variation*

The typical components affecting the seasonal variation in local current speed and direction are:

- the annual (Sa) and semi-annual (Ssa) tidal harmonic constituents (which have been included in the model simulation)
- wind forcing
- baroclinic forcing due to salinity, temperature, solar heat exchange and air pressure. The denser flow due to the salinity and temperature has been included in the model. The air temperature and humidity inputs to the model are included based on measured data at Karratha airport as a time series and thus the heat exchange is incorporated in the model.

Interannual variability of oceanographic currents is also important in the hydrodynamic model calibration, requiring measured data from a number of years. Such variability over annual timescales can use the Southern Oscillation Index as an indicator of the regional interannual variability; as in, El Nino and La Nina.

To assess the seasonal variation, at least one year of measured data must be analysed. However, analysis of the available three months of measured data allows some identification of seasonal (monthly scale) variations. For instance, the mean and maximum current speeds are found to be larger in April to May in comparison with the measured data in June to July. The hydrodynamic model reproduces these trends successfully, as shown in Figure 5-14, which compares current roses (measured versus modelled) for the months April/May with those for June/July at the offshore AWAC location.

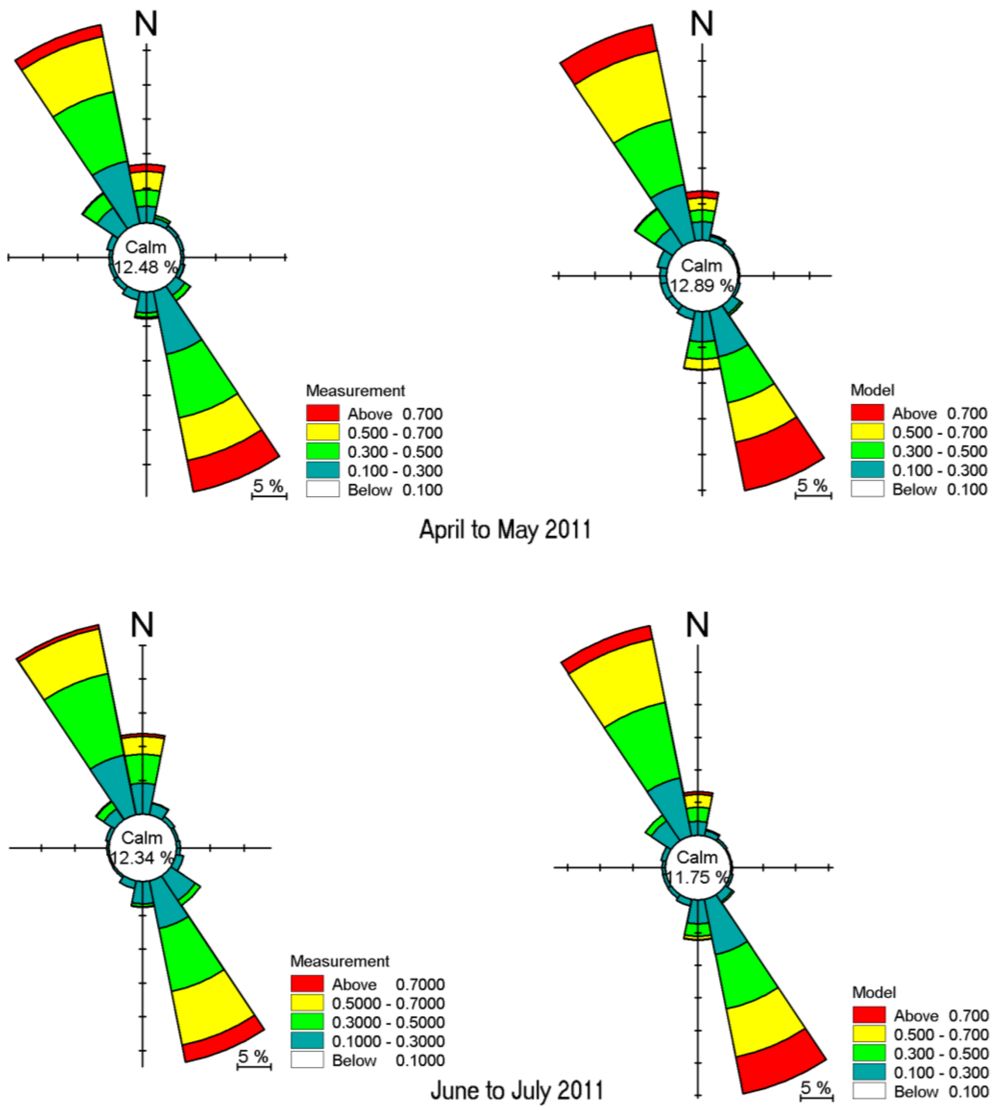


Figure 5-14 Monthly current roses, measured (left) vs. modelled (right) – offshore AWAC

5.6 Model validation

The comparisons of depth-averaged currents between modelled and measured data (on 3 and 4 November 2020) during the ebb and flood tides along transects CT1 and CT2 are presented in Figure 5-15 to Figure 5-18. Spurious measurements were filtered during the quality assurance and control process applied to the acoustic doppler current profiler data; the measurements presented in these plots represent the data after filtering. According to Figure 5-15 to Figure 5-18, satisfactory agreement was observed between modelled results and the measurements, confirming the model can accurately predict current conditions in the area surrounding the outfall location.

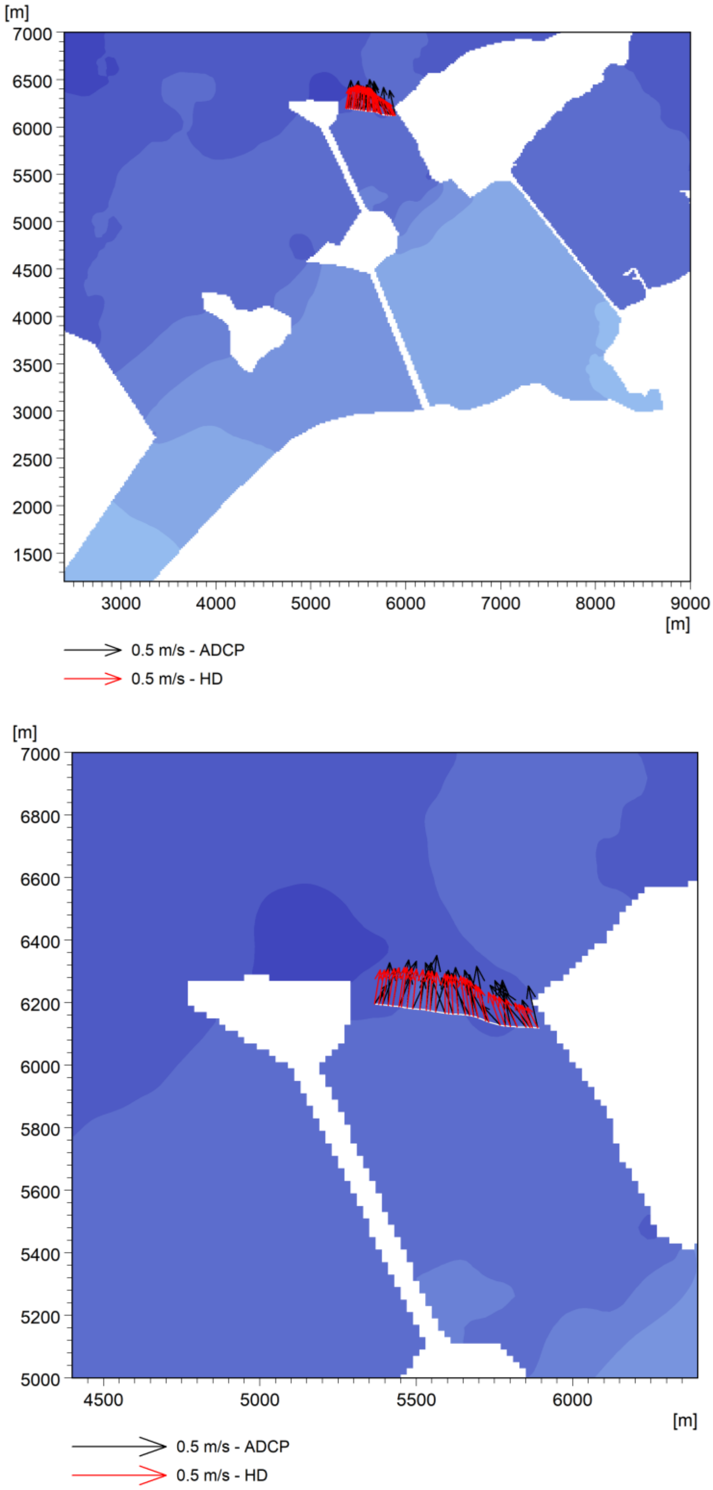


Figure 5-15 Comparison of model-predicted and -measured current speed at CT1 for ebb tide, top: within measurement area and bottom: zoomed to CT1 transect

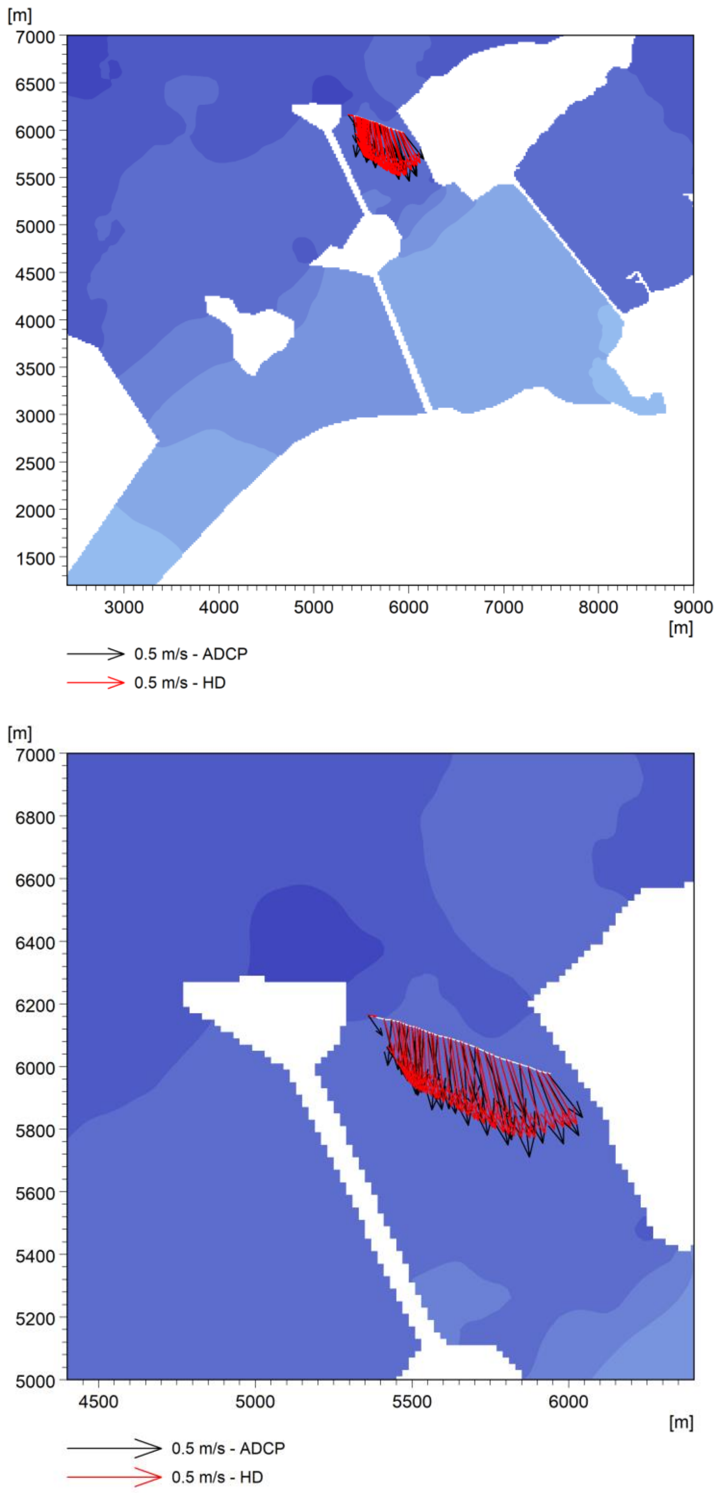


Figure 5-16 Comparison of model-predicted and -measured current speed at CT1 for flood tide, top: within measurement area and bottom: zoomed to CT1 transect

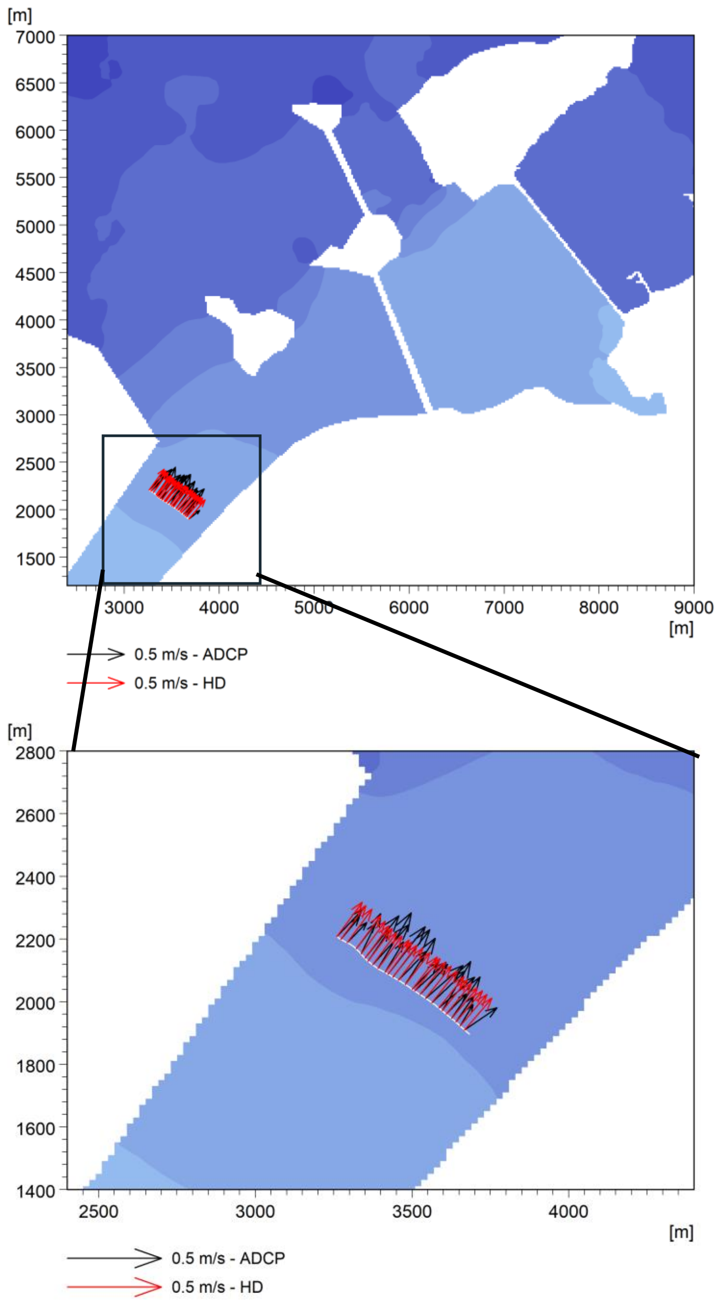


Figure 5-17 Comparison of model-predicted and -measured current speed at CT2 for ebb tide, top: within measurement area and bottom: zoomed to CT2 transect

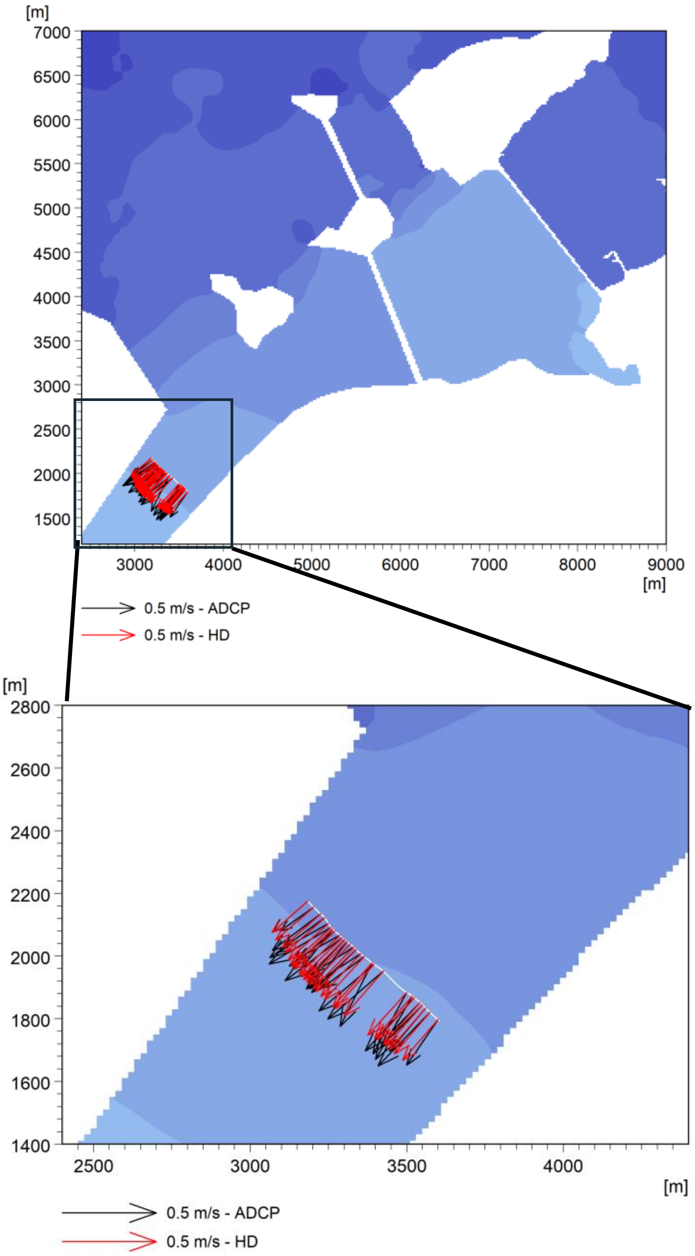


Figure 5-18 Comparison of model-predicted and -measured current speed at CT2 for flood tide, top: within measurement area and bottom: zoomed to CT2 transect

5.7 Selection of year for the simulation

Available wind measurements at Legendre Island (February 1992 to July 2011) were assessed to determine if this period is considered to be calm, average or stormy.

Table 5-3 presents the yearly average and 95th percentile of wind for this dataset. Year 2001 has been selected, which represents an average year based on the analysis.

Table 5-3 Yearly average and 95th Percentile wind speeds at Legendre Island

Year	Average Wind Speed (m/s)	95th Percentile Wind Speed (m/s)
1992	6.23	11.81
1993	6.57	12.39
1994	5.75	10.81
1995	6.99	13.89
1996	6.12	10.81
1997	5.98	11.81
1998	5.44	10.81
1999	5.54	12.28
2000	5.65	11.31
2001	**6.31**	**11.81**
2002	5.97	10.81
2003	6.31	11.31
2004	6.30	11.31
2005	6.42	11.31
2006	6.63	13.89
2007	6.38	11.81
2008	6.65	13.39
2009	6.50	11.81
2010	7.21	12.36
2011	6.72	13.72
Average	**6.28**	**11.97**
Min Value	**5.44**	**10.81**
Max Value	**7.21**	**13.89**

5.8 Model runs

5.8.1 Model scenarios

Advisian's West Pilbara Hydrodynamic Model was applied to simulate salinity, temperature, TSS and water quality dispersion for summer and winter seasons, each for 28 days covering two Spring-Neap tidal cycles. The ambient salinity and sea water temperature for the selected seasons were:

- summer (January): Salinity 36.61 ppt, Temperature 29.64 degrees Celsius
- winter (July): Salinity 35.78 ppt, Temperature 23.18 degrees Celsius.

The scenarios can be listed as in Table 5-4.

Table 5-4 Model simulation scenarios

Season	Salinity at Discharge (ppt)	Temperature at Discharge (° C)	Comments
Summer	65.898	Ambient	As a baseline for outfall discharge
Winter	64.404	Ambient	As a baseline for outfall discharge
Summer	65.898	31.64	Associated with discharge water temperature 2°C above ambient temperature
Winter	64.404	25.18	Associated with discharge water temperature 2°C above ambient temperature
Summer	65.898	34.64	Associated with discharge water temperature 5°C above ambient temperature
Winter	64.404	28.18	Associated with discharge water temperature 5°C above ambient temperature
Summer	65.898	Ambient	Associated with discharge water with water quality concern material
Winter	64.404	Ambient	Associated with discharge water with water quality concern material
Summer	65.898	Ambient	Associated with discharge water with sedimentation plume material
Winter	64.404	Ambient	Associated with discharge water with sedimentation plume material

5.8.2 Water quality dilution simulation

Water quality dilution was simulated using the hydrodynamic model coupled with the MIKE3 Transport module. The model results predict spatial dilution levels (based on dilution folders) assuming the results are valid for a range of effluent toxicity described in Section 3.1.

5.8.3 Total suspended solids simulation

The simulation of TSS was based on the MIKE3 Mud Transport multi fraction cohesive sediment transport model. As the sediment plume dispersion model is dynamically coupled with the hydrodynamic model, the sediment plume model adopted the same model domain as that used in the hydrodynamic model. The MIKE3 Mud Transport module describes erosion, transport and deposition of mud or sand/mud mixtures under the action of currents, wind and waves. The bed is described as layered and characterised by the density and critical shear strength for erosion.

Density and concentration were considered as 1100 kg/m^3 and an indicative concentration, assuming 150 mg/l. Three fractions, with particle micron range and average percentage as presented in Table 5-5, were used. Corresponding settling velocities were calculated using Stokes' law based on site sample results as presented in Table 5-5.

Table 5-5 Percentage of total suspended solids fractions

Particle Micron Range (µm)	Average Percentage (%)	Settling Velocity (mm/s)
2-14	34	0.0008
14-20	46	0.0048
Above 20	20	0.0561

6 Model results

6.1 Salinity modelling

The final boundary and distance of the Levels of Ecological Protection (LEP) were determined against the EQC in Table 3-4. The 50th percentile of the modelled data was compared with the EQC.

The modelling showed the plume rapidly dispersed, and when the 50th percentile of modelled data was compared with the EQC for a low LEP, the threshold was not exceeded due to the rapid dilution at the diffuser (Figure 6-1 and Figure 6-2). The thresholds for a moderate LEP were exceeded in the immediate vicinity of the outfall discharge location and in a small area within the existing moderate/high LEP boundary (Figure 6-1 and Figure 6-2).

The figures indicate:

- Predicted Low/Moderate LEP criteria (Table 3-4) for salinity is not reached by the model results as be outlined in the purple dashed lines (Figure 6-1 and Figure 6-2). The proposed outfall location at Parker Point allows for rapid brine dilution by means of initial mixing and further dispersion with the background tidal currents.
- Precited Moderate/High LEP (Table 3-4) for salinity extends around 250 m and 170 m, respectively, to the northwest from the proposed outfall location for summer and winter seasons. To the eastward, it extends up to 50 m. The predicted Moderate/High LEP boundary was outlined in the light blue dashed lines (Figure 6-1 and Figure 6-2).
- As a reference for all model result plots, the existing Mermaid Sound Environmental Quality Plan (EQP) moderate level of ecological protection (LEP), Version 5 data (2019) was outlined in the red dashed line in the plots. The precited Moderate/High LEP boundary exceeds up to 50 m outside the existing moderate LEP is due to the proposed outfall location.

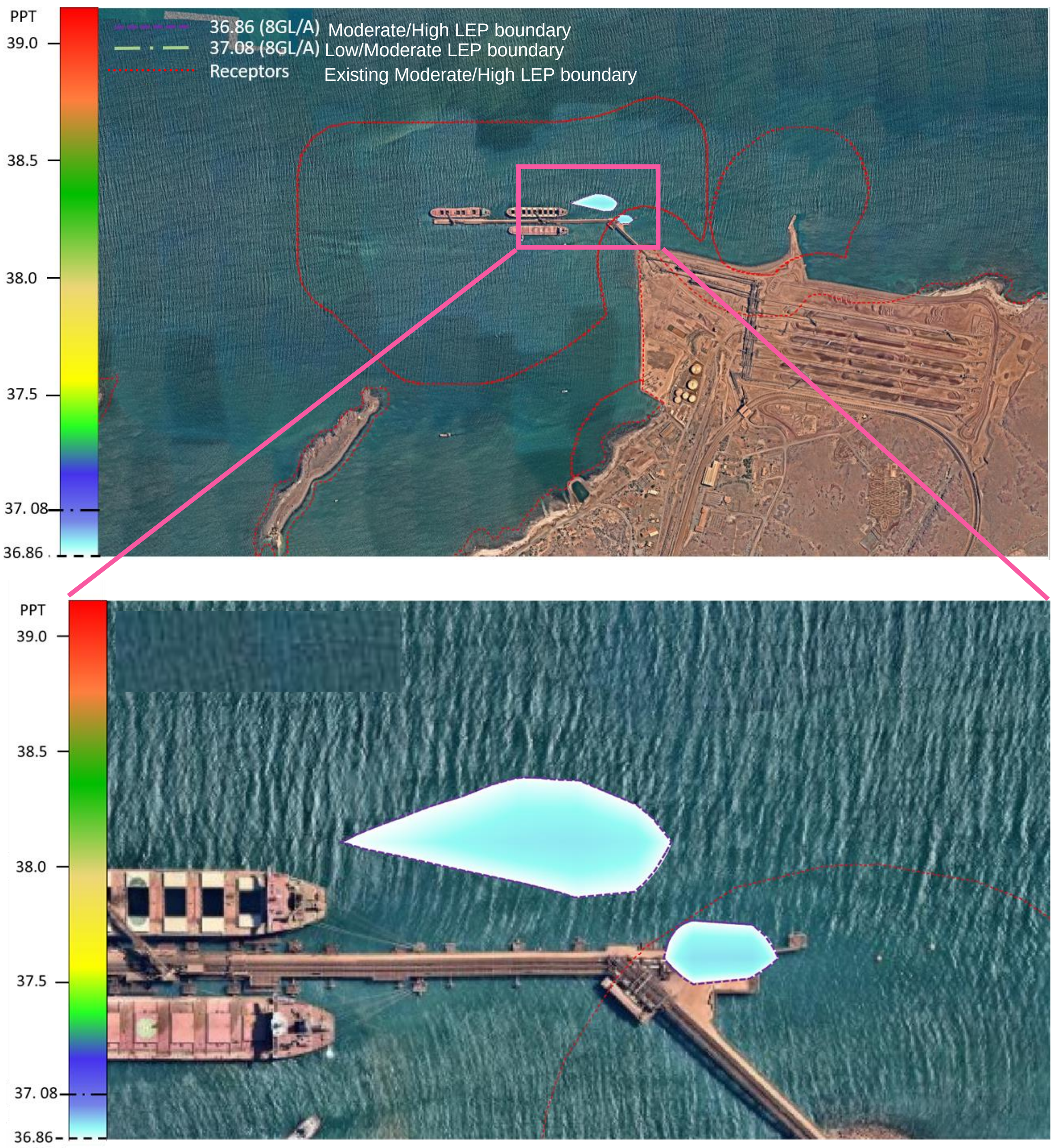


Figure 6-1 Salinity modelling results (bottom water layer, summer)

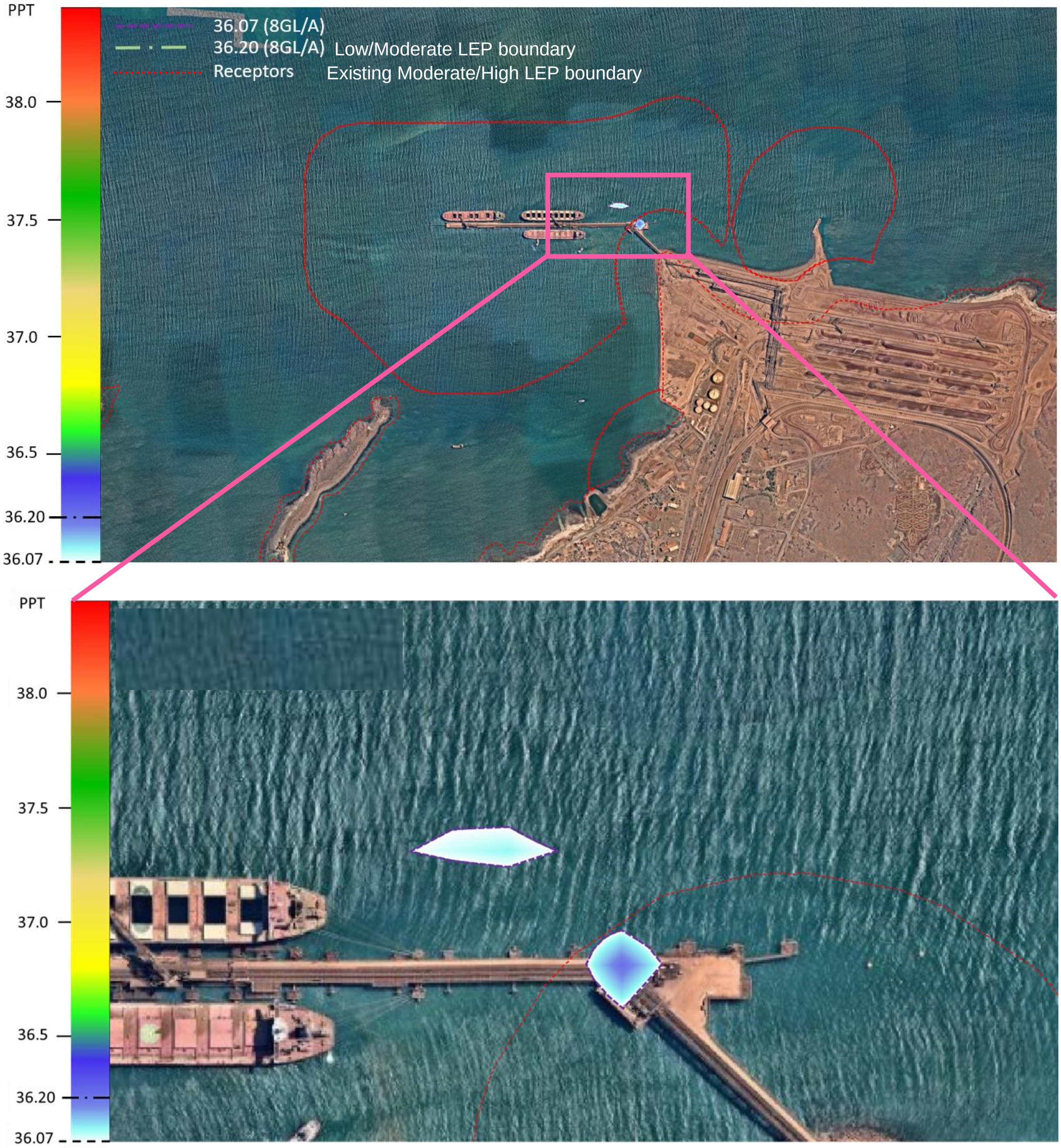


Figure 6-2 Salinity modelling results (bottom water layer, winter)

6.2 Temperature modelling

The final boundary and distance of the LEP were determined against the temperature EQC in Table 3-5. The 50th percentile of the modelled data was compared with the EQC.

The temperature modelling showed the plume rapidly dispersed, and when the 50th percentile of modelled absolute temperature was compared with the EQC listed in Table 3-5, the temperature thresholds for both Low/moderate boundary and Moderate/high boundary of LEP were not exceeded.

For the existing Moderate/High LEP boundary, the model predicated the temperature compliance for both two scenarios (Scenario 1: 2⁰C above the ambient seawater temperature and Scenario 2: 5⁰C above the ambient seawater temperature) for both summer and winter seasons.

In order to show the temperature difference under the two scenarios with the ambient temperature, the temperature difference between the case with outfall discharge (two scenarios) and the case without outfall discharge area presented in Figure 6-3, Figure 6-4, Figure 6-5 and Figure 6-6, in which the model results predict negligible temperature difference under the case with outfall discharge.

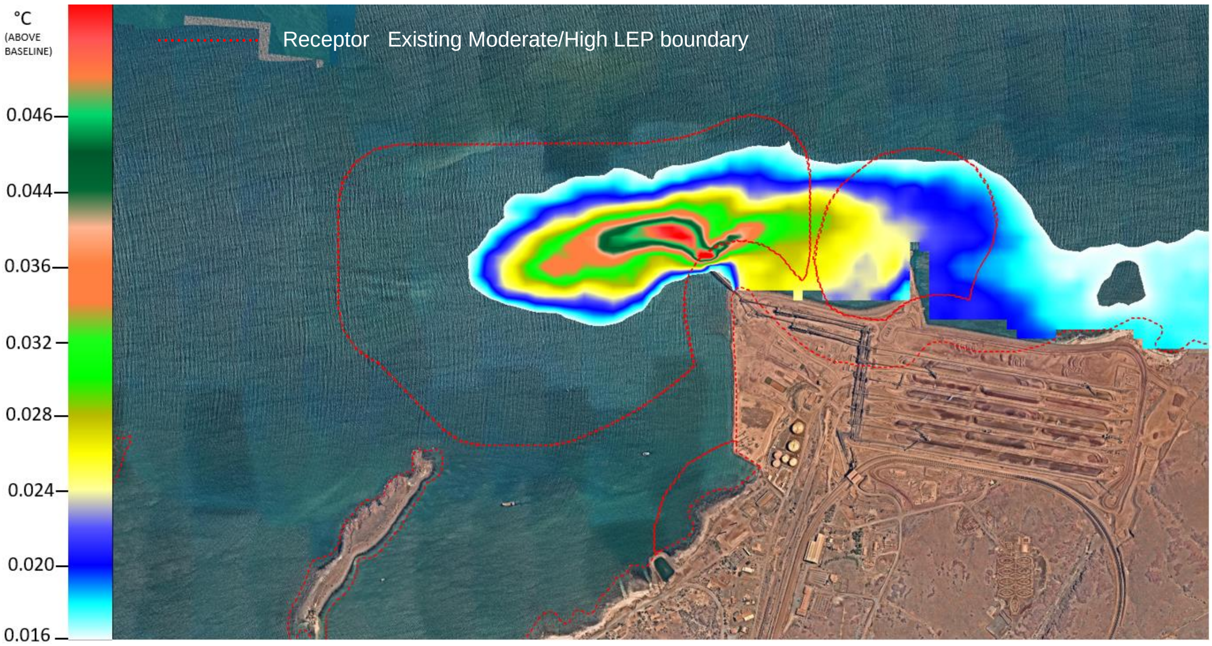


Figure 6-3 Modelled temperature difference results between case with outfall discharge and without outfall discharge (bottom water layer, summer): Scenario 1: 2⁰C above the ambient seawater temperature

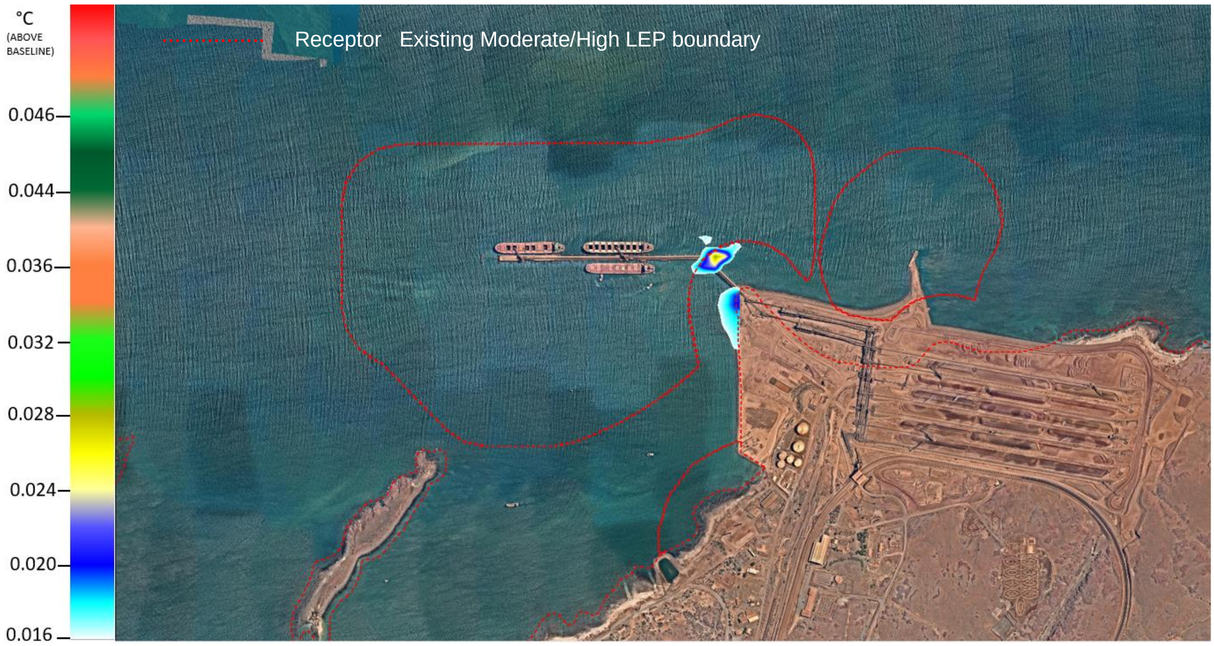


Figure 6-4 Modelled temperature difference results between case with outfall discharge and without outfall discharge (bottom water layer, winter): Scenario 1: 2^{0}C above the ambient seawater temperature

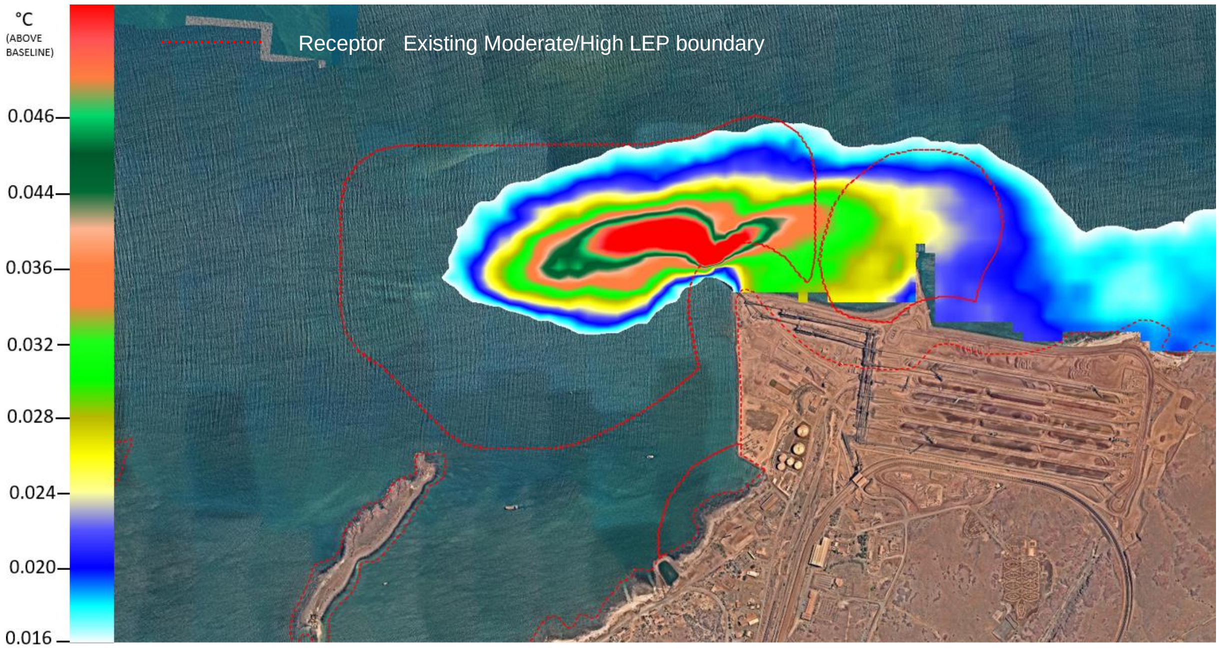


Figure 6-5 Modelled temperature difference results between case with outfall discharge and without outfall discharge (bottom water layer, summer): Scenario 2: 5^{0}C above the ambient seawater temperature

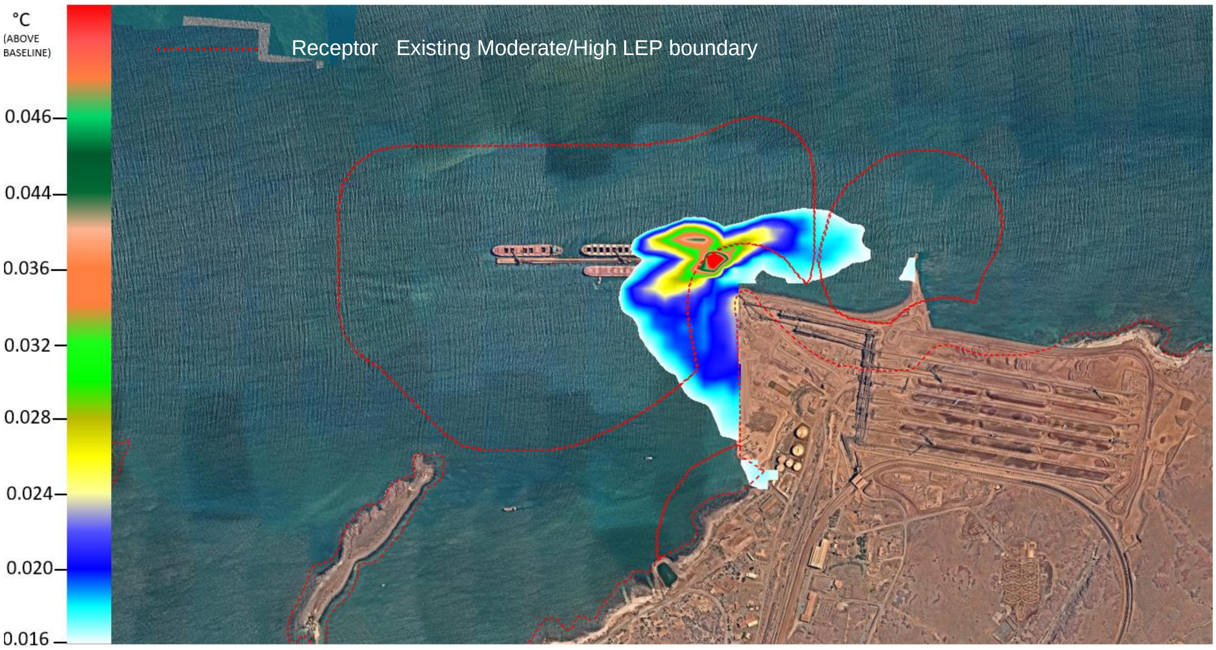


Figure 6-6 Modelled temperature difference results between case with outfall discharge and without outfall discharge (bottom water layer, winter): Scenario 2: 5⁰C above the ambient seawater temperature

6.3 Total suspended solids modelling results

Dilution contours are presented for modelling TSS to allow an assessment of varying concentrations of TSS at the outfall location. The model results indicate TSS concentrations will reduce to a range of 1:50 folders and 1:100 folders (between 1 in 50 and 1 in 100 of the initial TSS concentrations from the outfall location) within 50 m of the outfall, for both summer and winter conditions.

Figure 6-7 and Figure 6-8 present the spatial TSS dilution ratio (discharge TSS/modelled for diluted TSS) for summer and winter, respectively. Results were based on the exceedance of depth-averaged TSS for 95% of the time during the modelled period. TSS concentration shows rapid dilution within the near-field area, resulting in the far-field TSS being above 1:50 folders.

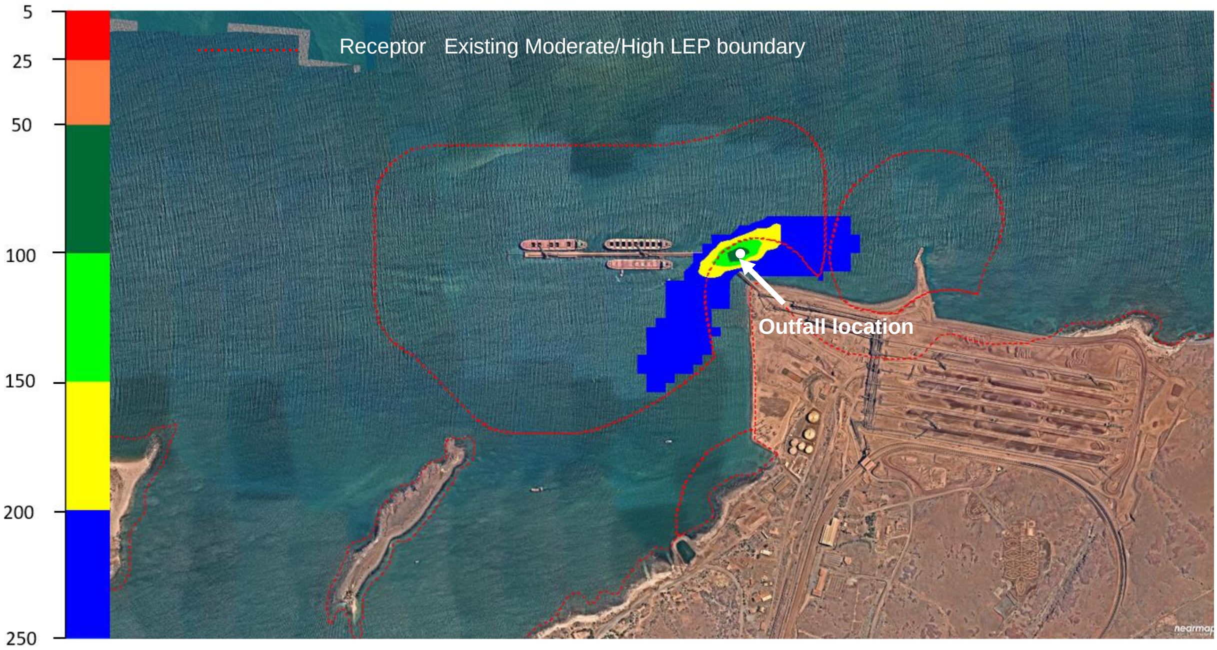


Figure 6-7 Modelled total suspended solids ratio in folders (summer)

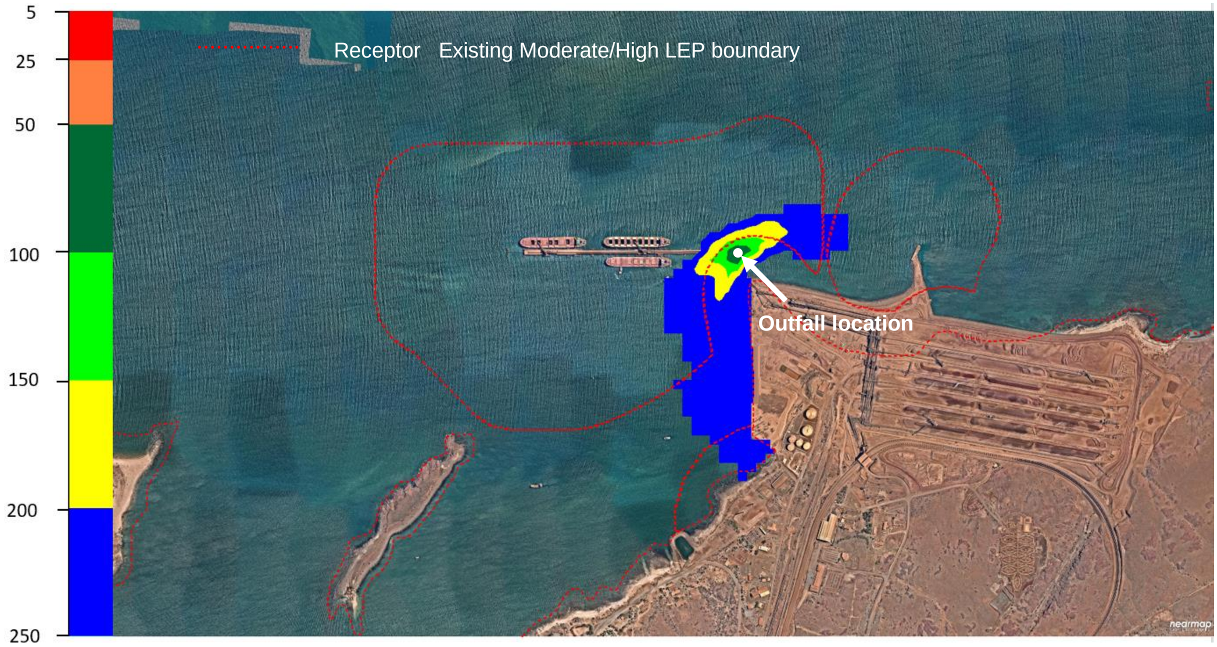


Figure 6-8 Modelled total suspended solids ratio in folders (winter)

6.4 Whole of effluent toxicity modelling

The final boundary and distance of the LEP (Figure 6-9 and Figure 6-10) were determined against the EQC in Table 3-3. The 95th percentile of the modelled data was compared with the EQC (Low/moderate boundary in 1:59 folders and Moderate/high boundary in 1:222 folders). Water quality concentration shows rapid dilution within the near-field area, resulting in the far-field water quality component ratio being above 1:50 folders. The Low/Moderate LEP boundary is within up to the 50 m from the outfall location to reflect the rapid dilution and mixing of the discharge flow with the ambient sea water. The Moderate/High LEP boundary is predicted to up to 310 m from outfall location in summer and up to 450 m from outfall location in winter to reflect the seasonal recirculation conditions.

Figure 6-9 and Figure 6-10 also present the modelled LEP and compare them with the existing zones of ecological protection. The predicted Moderate/High LEP boundary exceeds the existing zones of ecological protection due to the proposed outfall location.

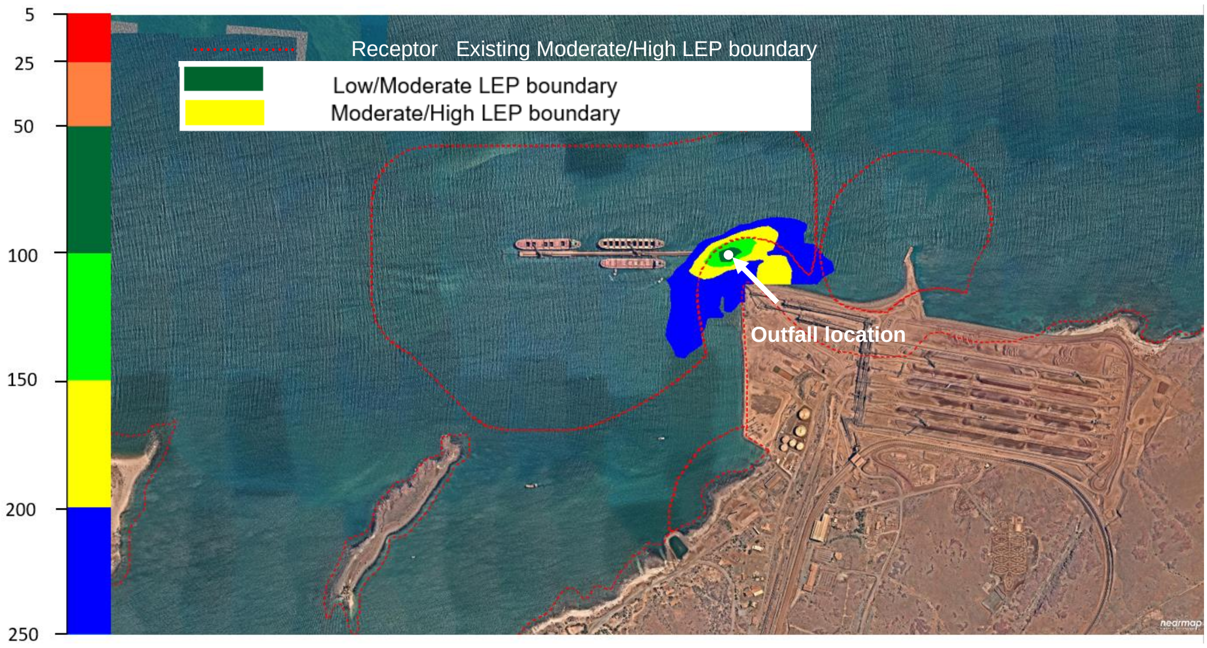


Figure 6-9 Whole of effluent toxicity modelled at the levels of ecological protection boundary (summer)

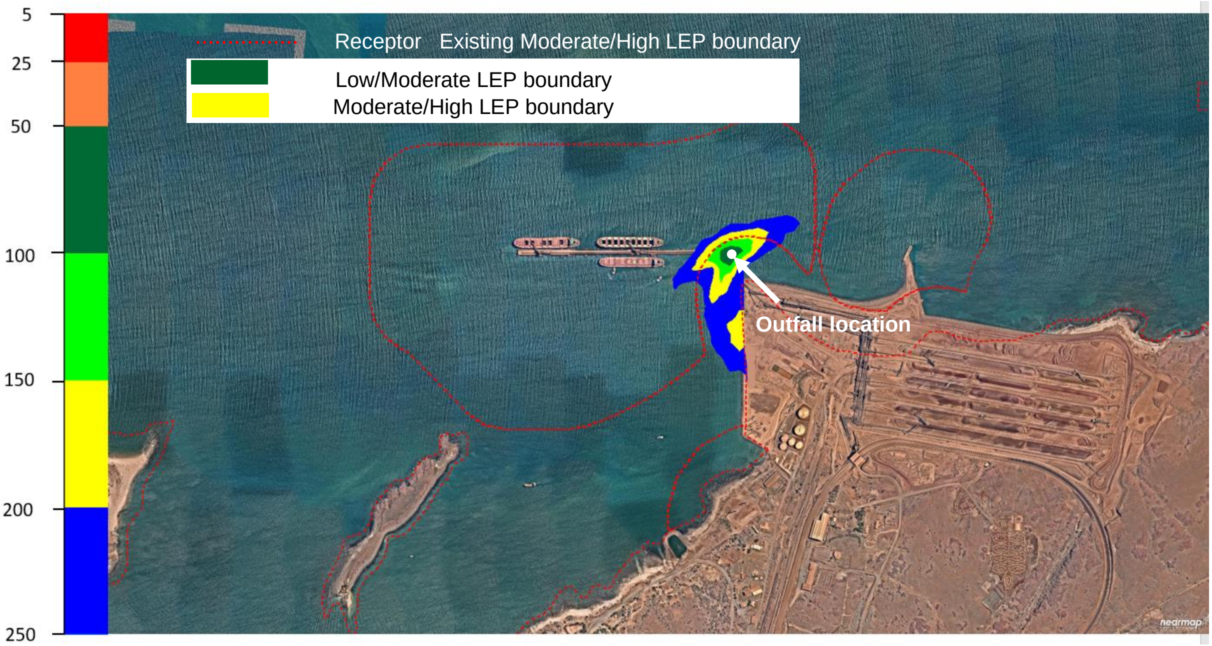


Figure 6-10 Whole of effluent toxicity modelled at the levels of ecological protection boundary (winter)

7 Conclusions

For the present brine plume discharge study for the Proposal, both empirical relationships and numerical modelling were applied to determine the predicted zone of low and moderate ecological protection using EQC derived from a baseline water quality dataset. Based on the assessment, the following conclusions can be drawn:

For the proposed hypersaline brine discharge from the outfall location:

- Predicted Low/Moderate Level of Ecological Protection criteria for salinity is not exceeded by the model results (Table 7-1). The proposed outfall location at Parker Point allows for rapid brine dilution by means of initial mixing and further dispersion with the background tidal currents.
- Precited Moderate/High Level of Ecological Protection for salinity extends around 250 m (Figure 6-1) and 170 m (Figure 6-2), respectively, to the northwest from the outfall location for summer and winter seasons. It extends around 50 m to the east (Figure 6-2).

Table 7-1 Comparison of MIKE model results versus environmental quality threshold for salinity

Season	Background salinity value (ppt)	Predicted Low/moderate Level of ecological protection (ppt)	Predicted Moderate/High Level of ecological protection (ppt)	Maximum modelled salinity at Moderate/High Level of Ecological Protection boundary (ppt)	Mean modelled salinity at Moderate/High Level of Ecological Protection boundary (ppt)
Summer	36.61	37.08	36.86	38.60	37.01
Winter	35.78	36.20	36.07	36.28	35.90

For the discharge associated with increased of temperature from the outfall location:

- Modelled temperature does not reach the criteria for temperature increase of 2°C and 5°C at the outfall location as can be seen in Table 7-2 Comparison of MIKE model results versus environmental quality threshold for temperatureIt is compliant with the existing Moderate/High Level of Ecological Protection.

Table 7-2 Comparison of MIKE model results versus environmental quality threshold for temperature

Season	Background temperature (°C)	Predicted Low/moderate Level of ecological protection (°C)	Predicted Moderate/High Level of ecological protection (oC)	Maximum modelled temperature at Moderate/High Level of Ecological Protection boundary (°C)	Mean modelled temperature at Moderate/High Level of Ecological Protection boundary (°C)
Summer	29.64	31.95	30.46	30.40	29.92
Winter	23.18	27.28	25.58	25.04	23.87

For the discharge associated with total suspended solid (TSS) and whole of effluent toxicity (WET) from the outfall location:

- TSS and WET concentration show rapid dilution within the near-field area, resulting in the far-field TSS and component ratio to be above 50 (1:50 folders) (Figure 6-7 to Figure 6-10). The ratio or folders refer to the dilution levels, for instance, if the concentration at point is 1 in 10 of the initial effluent concentration from outfall, we say the ratio as 10 or the folder as 1 in 10.
- Predicted Low/Moderate Level of Ecological Protection criteria for WET (Table 7-3) is within 50 m away from the outfall location (Figure 6-9 and Figure 6-10). The proposed outfall location at Parker Point allows for rapid WET dilution by means of initial mixing and further dispersion with the background tidal currents.

Table 7-3 Comparison of MIKE model results versus environmental quality threshold for WET

Season	Background dilution	Predicted Low/moderate Level of ecological protection	Predicted Moderate/High Level of ecological protection	Maximum modelled WET at Moderate/High Level of Ecological Protection boundary	Mean modelled WET at Moderate/High Level of Ecological Protection boundary
Summer	Not Applicable	1:59	1:222	1:183	1:510
Winter	Not Applicable	1:59	1:222	1:180	1:493

Note: The units for the presented values are ‘number of dilutions in folders’

- Precited Moderate/High Level of Ecological Protection for WET (Table 7-3) extends around 310 m to the southeast from the outfall location for summer (Figure 6-9) and around 450 m to the south from the outfall location(Figure 6-10), respectively.

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