CHEVRON AUSTRALIA PTY LTD

REPORT

MINISTERIAL APPROVAL SUPPORTING DATA – OCEAN OUTFALL DILUTION MODELLING

For The

GORGON PROJECT
BARROW ISLAND LNG PLANT

Document No.: G1-TE-Z-4500-TCN1502

Revision:	**0**	**1**		
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Revision Date:	07Jul09	May13		
Issue Purpose:	IFI	IFI		

Kellogg Joint Venture Gorgon
KBR JGC HATCH CLOUGH

Chevron

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1. ABBREVIATIONS

Table 1-1 Abbreviations and Definitions

Term	Definition
ADCP	Acoustic Doppler Current Profiler
BOD	Basis of Design
BOM	Bureau of Meteorology
CVX	Chevron Australia
EMP	Environmental Management Plan
ETC	Chevron Energy Technology Company
KJVG	Kellogg Joint Venture Gorgon
mCD	metres, with respect to Chart Datum
MOF	Materials Offloading Facility
LNG	Liquefied Natural Gas
NTC	National Tide Centre
NWS	North-West Shelf
RFSU	Ready For Start-Up
RO	Reverse Osmosis

2. EXECUTIVE SUMMARY

The Gorgon Project on Barrow Island (BWI) will use Reverse Osmosis (RO) to desalinate seawater and provide fresh water to Project users. This report addressed the permanent RO set up on BWI. An ocean outfall is the proposed method for disposing of RO reject streams, subject to Ministerial Approval satisfying Condition 30 of the State Environmental Approval Conditions.

In order to gain approval for the permanent RO facility, Chevron (CVX) will submit an updated Reverse Osmosis Brine Disposal via Ocean Outfall Environmental Management and Monitoring Plan (EMMP) [18] to the Minister to provide environmental impact assessments and management measures for the proposed permanent ocean outfall facilities in addition to the existing temporary facilities.

This technical note has been prepared to demonstrate to CVX that the current design concept for an ocean outfall, located in proximity of tug harbour, is capable of achieving the dilution levels specified in the ocean outfall Basis of Design (BOD) [15] (100 fold dilutions within the mixing zone as a minimum).

The information presented is based on modelling of the ocean outfall design concept as of January 2011, noting that the concept presented in this updated note differs from the previous version of the report (Rev 0) and BOD documentation. The modelling in this revision of the report is a further update to previous versions, responding to the current (modified) layout plan of the MOF [17], and the change in the proposed location of the ocean outfall diffusers.

The relevant forcing for and verification of the oceanographic model is based on original design specifications, as outlined in previous revisions of this report. Further simulations required as a result of design modifications use the same model setup with changes only in initial and flow/transport conditions.

The resultant salinity and dilution values confirm that the current design concept for an ocean outfall to dispose of RO reject streams is capable of achieving the dilution criterion specified in the ocean outfall BOD. Furthermore, a 40-fold dilution can be achieved within the Zone of High Impact surrounding the MOF for a range of potential operating scenarios. In addition, the modelling demonstrates that the currently modelled case exhibits similar performance for dilution of the RO reject stream as per the previous reports, leading to the following observations:

- Mixing is dominated by the astronomic tide whilst heat input, that could lead to the development of stratification, exhibits negligible influence
- Mixing of the discharge is not adversely affected by the presence of the MOF or tug harbour, meaning the selected location ensures unimpeded flushing of the RO reject by the ocean currents
- A minimum level of 100 fold dilution can be achieved within the mixing zone as defined in the BOD [15].

3. INTRODUCTION

The Greater Gorgon area gas fields, situated approximately 130 km off the north-west coast of Western Australia, contain two of the largest individual gas fields, i.e. the Gorgon and Jansz fields, ever discovered in Australia. Chevron (Company) is nominated operator of the Gorgon gas field and proposes to develop the Greater Gorgon gas fields, commencing with the Gorgon and Jansz fields, with its Gorgon Joint Venture (GJV) partners, Shell and ExxonMobil.

Central to the commercial viability of the proposed development is the establishment of the gas processing facility and supporting infrastructure on Barrow Island (BWI), which lies directly between the gas fields and the Australian mainland. The marine waters surrounding the island are of significant conservation value, with some designated for a Marine Park and other areas categorised as Marine Management Area. These waters provide habitat for some significant benthic communities, including corals and other listed under the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act, such as some marine turtle species.

3.1 General

The Gorgon Project on Barrow Island (BWI) will use Reverse Osmosis (RO) to desalinate seawater and provide fresh water to Project users. This report addresses the permanent RO set up on BWI. Ocean outfall is the proposed as a method for disposing of RO reject streams, subject to Ministerial Approval satisfying Condition 30 of the State Environmental Approval Conditions.

In order to gain approval for the permanent RO facility, Chevron (CVX) will submit an updated Reverse Osmosis Brine Disposal via Ocean Outfall Environmental Management and Monitoring Plan (EMMP) [18] to the Minister to provide environmental impact assessments and management measures for the proposed permanent ocean outfall facilities in addition to the existing temporary facilities.

This technical note outlines the environmental engineering aspects of the ocean outfall design. The technical note addresses the near field analysis of the outfall (i.e. evaluation of the dilution in the vicinity of the outfall diffusers) and the far field flushing efficiency away from the outfall. For properly designed ocean outfalls, both the near field dilution and far field flushing are critical aspects. Dilution is achieved by the engineering design of the system (near field), while the overall flushing efficiency (far field) requires sufficient continuous supply of “fresh” water in the water column.

The regulatory authorities define the zone within which the they require the achievement of the particular concentration and/or dilution. This zone is called mixing zone. The near field on the other hand is the zone where high dilution can occur, as a result of effluent mixing with the ambient. Dilution significantly reduces as the effluent travels further away from the near-field. The authorities may prescribe a mixing zone bigger than the near field. For the project the boundary of the High Impact Zone was defined as the boundary of the mixing zone.

This technical note has been prepared to demonstrate to CVX that the current design concept for an ocean outfall is capable of achieving the dilution levels specified in the ocean outfall Basis of Design (BOD) [15]. Thus it also demonstrated that the commitment of a 40 fold dilution in the High Impact Zone can be achieved. In doing so, CVX can validate that the BOD dilution criterion is indeed realistic and, consequently, the EMMP submission is supported by the latest design concept.

The information presented is based on modelling of the ocean outfall design concept as of January 2011, noting that the concept presented in this updated note (outfall located in proximity of tug harbour) differs from the previous report and BOD documentation.

3.2 Background

CVX undertook a feasibility study for an ocean outfall to support the Gorgon Project water treatment facility. The aim of this study was to assess appropriate environmental performance criteria for dispersion of RO reject streams in the marine environment, and to establish an associated BOD to be used by Kellogg Joint Venture Gorgon (KJVG) for development of a detailed design.

The feasibility study was led by Chevron Energy Technology Company (ETC) in collaboration with consulting firms RPS and Flow Science Incorporated [3]. ETC solicited information from potential RO vendors to characterise liquid reject streams and frame the study; RPS and Flow Science undertook environmental assessments and hydrodynamic modelling, respectively. Outcomes of this work are presented in a report containing the BOD and a summary of the study [2], along with supporting documents for brine characterisation [1], environmental assessments [4], and hydrodynamic modelling [3].

Amongst other criteria, the CVX feasibility study determined the dilution criterion for the diffuser as follows:

- A minimum dilution of 40 to 1 must be achieved in the high impact zone surrounding the MOF and Jetty.

The modelling undertaken within CVX's technical note (Rev 2) is intended to determine if this dilution criterion can be reasonably achieved for the final design. 100 fold dilutions are targeted in the near-field (i.e. zone in the near proximity of the discharge) under minimum and maximum operating conditions. Near-field dilution modelling is carried out to this effect.

4. WATER SYSTEM SUMMARY

4.1 General

The water system provides potable and service water to support the Project's requirements through construction, commissioning and operations for the life of the LNG facility. The water system is made up of the following components:

- Seawater intake: an open intake integrated with the MOF
- Water treatment plant: RO units and associated pre-treatment to desalinate seawater and deliver product water at the desired quality
- RO reject disposal: ocean outfall to dispose of liquid reject streams from the water treatment plant
- Reticulation system: delivers product water from the water treatment plant to the end users.

Additional information on the water system is contained in the utilities BOD [14].

4.2 Water Balance and System Flow Rates

Based on the water balance [8,10], the water system is designed for a normal product water flow rate of 1400m^3/day (100% capacity) [15]. The design incorporates 3x700m^3/day RO units, being 3x50% units installed in a 2-operating/1-standby configuration at the normal product water flow rate. The system will be capable of producing a maximum of 2100m^3/day of product water with all three RO units in operation.

For this report, two cases were investigated, brine disposal at maximum and minimum discharge rates.

4.3 Ocean Outfall Current Design

The current design assumptions, as well as the design parameters used within the previous version of this report (Rev 0), are summarised in Table 4-1. This table also provides some of the considerations to be addressed in the detailed design.

The outfall location in the current design is based on recent consideration of environmental impacts and the modification of the MOF layout. The outfall pipe from the RO plant is to be within two caissons near a berth approximately 2km from the shore, with the diffusers coming out through the caisson near the surface of the ocean at LAT (shown schematically in Figures 4-1, 4-2 and 4-3).

Figure 4-1 Location of Diffuser (a) with respect to the whole MOF and (b) in close plan view

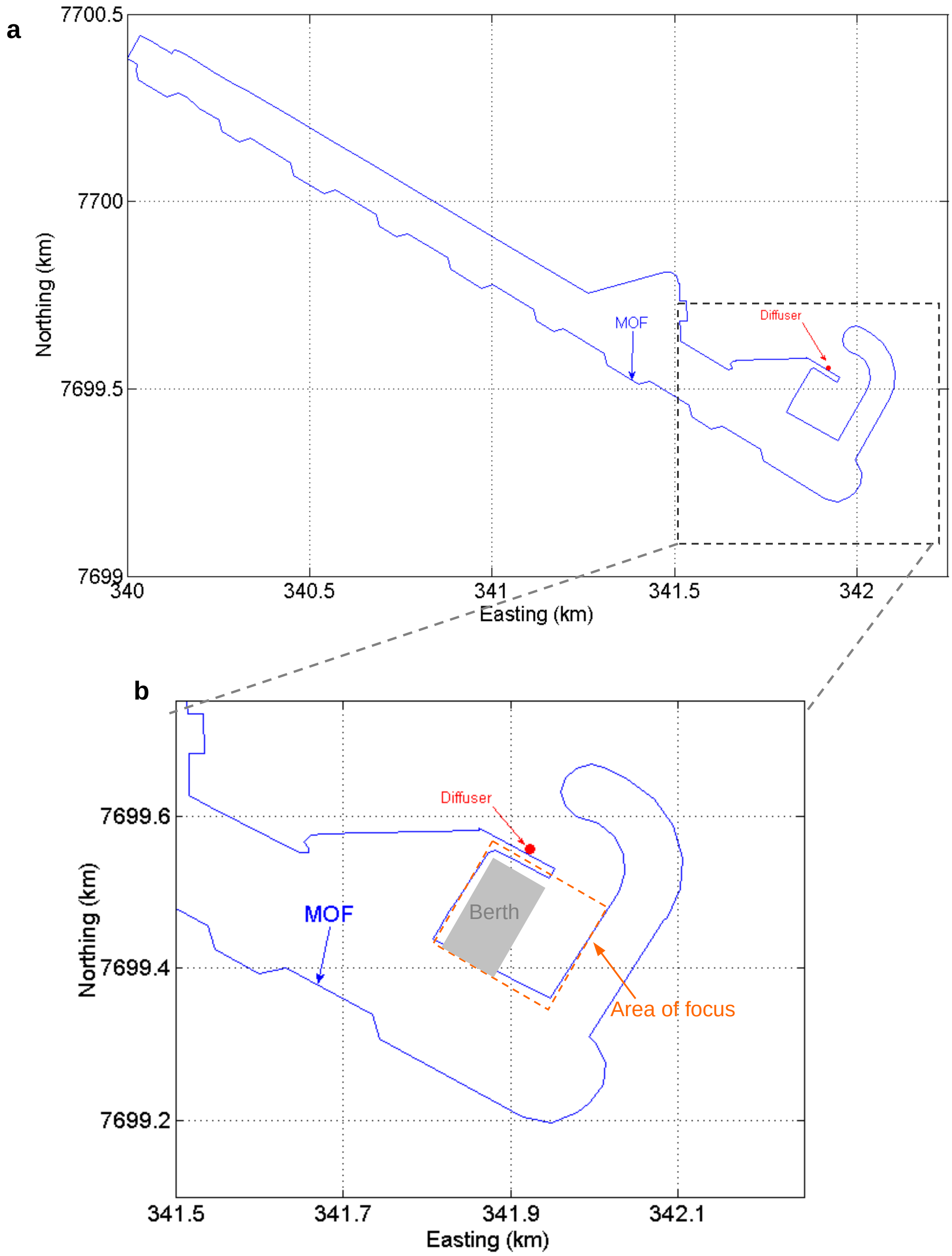

a
7700.5
7700
7699.5
7699
Northing (km)
340
340.5
341
341.5
342
Easting (km)
MOF
Diffuser
b
7699.6
7699.4
7699.2
Northing (km)
341.5
341.7
341.9
342.1
Easting (km)
MOF
Diffuser
Berth
Area of focus

Figure 4-2 Location of a Diffuser (a) cross-section view, with respect to the caisson and (b) in close plan view of the single outfall, with diameters relevant to modelling within this document. There exist two outfalls with three diffusers each. The spacing between diffuser ports is 1.5m.

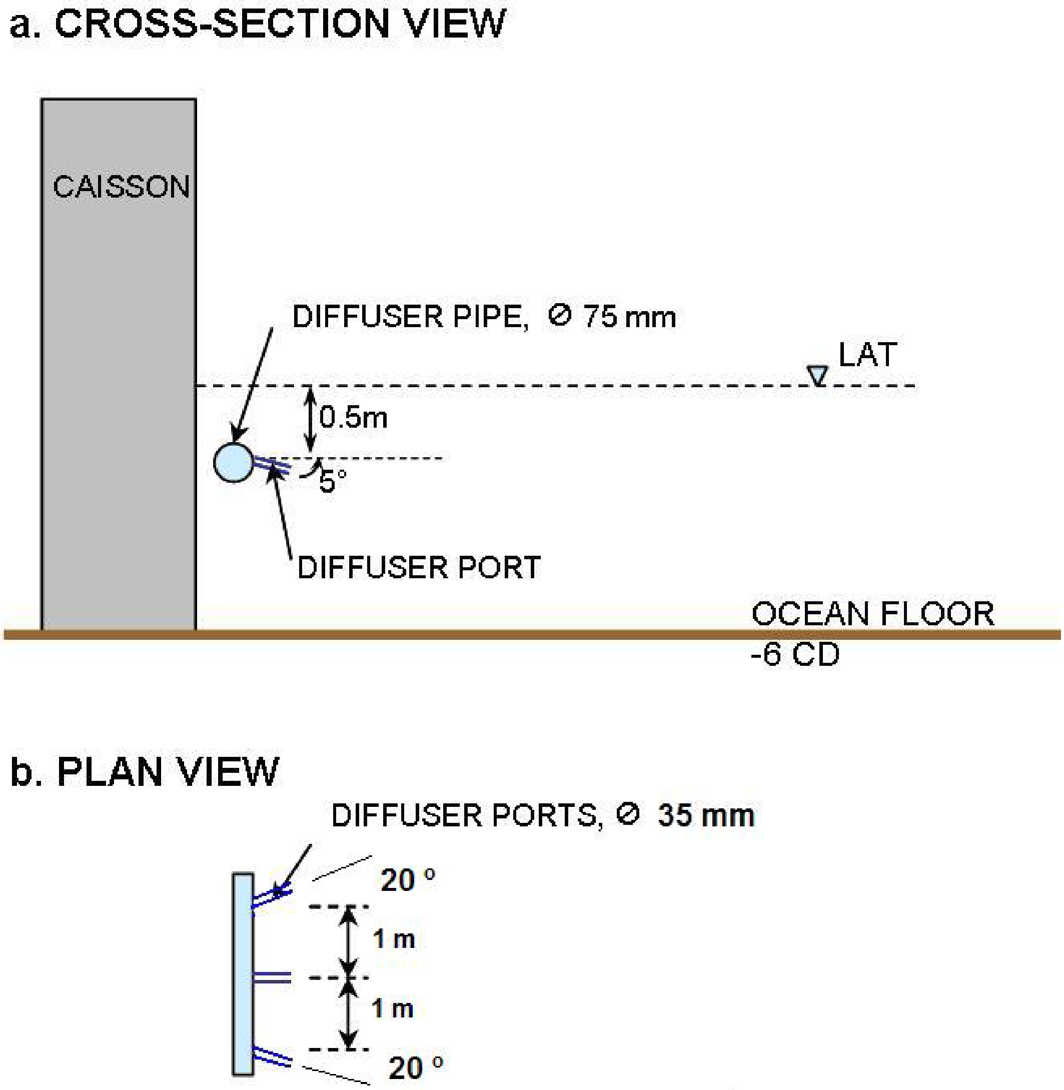
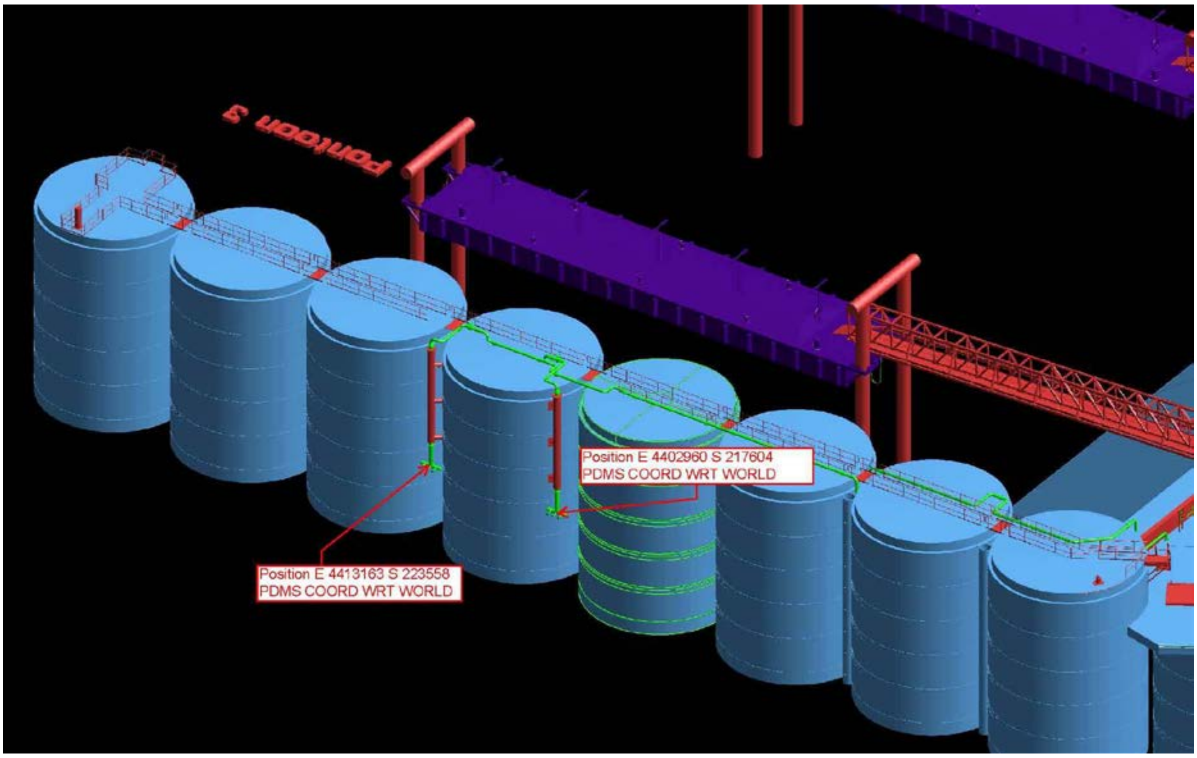


Figure 4-3 View of the two outfalls located along caissons.



The following reference material is also available to support the current design summarised in the table:

- Near-field dilution calculation[1] [9], which is investigated more closely in this report to ensure the 100-fold dilution;
- Sketches showing the current design layout [5], longitudinal profile [6] and diffuser detail [7];
- Previous and current design for other marine infrastructures (Materials Offloading Facility (MOF), and dredging) [16, 17].

Table 4-1 Ocean Outfall: Previous Design and Current Design parameters

Item	Design Component	Previous Design (Rev 0)	Current Design	Development Considerations
1.	Discharge flow rate (total)	0.073 (m^3/sec)	Min: 0.01 (m^3/sec) Max: 0.038 (m^3/sec)	

[1] Design of the diffuser is governed by the near-field dilution target. In the near-field, dilution is achieved via entrainment of seawater into the turbulent negatively buoyant jet being discharged from each diffuser port. The "near-field" region is defined by the distance taken for the turbulent negatively buoyant jet to hit the ocean floor (refer to the diffuser detail drawing for a diagrammatic representation [7]).

2.	Discharge salinity	60 psu	64.371 psu	Salinity derived from the current RO design and recovery.
3.	Diffuser	2 diffusers Number of ports: 6 Port diameter: 40mm	2 diffusers Total number of ports: 6 (3 ports at each diffuser) Port diameter: 35mm	
4.	Diffuser locations	E: 341872 N: 7699150 And E: 342000 N: 7699180	E: 341925 N: 7699535	Location may change if recirculation with the intake is of concern, or if dictated by conflicts with other marine infrastructure.

5. MODELLING METHODOLOGY

The key objective of oceanographic modelling is to illustrate and quantify the likely temporal and spatial evolution of the brine once it has been released into the marine environment. Two major steps were undertaken during modelling in order to establish the key processes affecting this behaviour:

- Review of relevant forcing
- Establishment of criteria to select an appropriate oceanographic model and associated steps in oceanographic modelling.

The above applies to the two steps considered in the dilution of the reject brine, addressed separately in the following sections:

- Near-field dilution, dilution immediately of the diffusers (within the grid cell of the diffuser location)
- Far-field dilution, further dilution and interaction with the ocean water

Both the near field and the far field are important for the reject brine's dilution. Initial dilution, at the exit from the diffuser ports, is governed by the outfall's hydraulic design, particularly by the jet exiting velocity. As the diluted brine travels further from away the outfall, along the ocean floor, it further entrains the sea water which may further dilute the brine. Ambient currents assist this process by providing "fresh" water for continuous dilution and further dispersing the brine. Accordingly, both the contribution of the near and the far field have to be quantified.

Summary of the relevant forcing is presented below, followed by the modelling considerations.

5.1 Relevant Forcing

A review of the available metocean reports and other relevant regional data was conducted to gain an understanding of the environmental conditions that are relevant to dilution and dispersion [12]. The study concluded that the following general assumptions are relevant:

- In general, waves are small and can be discounted in a worst case scenario affecting mixing;
- Stratification acts to inhibit mixing, however in this case it can be neglected when establishing the model due to lack of an observable thermocline or pycnocline in near-shore waters;
- In the context of mixing processes, the periods with low winds represent the most adverse conditions as they lead to the reduced mixing in the water column;
- The review of the available current data indicates that the currents within the region are tidally dominated.

As a result of these findings, the primary force used in the hydrodynamic model will be tide (which generates currents). Atmospheric heat will also be used as an input force to simulate mixing in two seasons, i.e. high heat input and lower heat input.

Wind forcing has been excluded from the model due to the observation that tidal forces dominate. Furthermore, the absence of wind represents an environment with reduced mixing (i.e. more conservative).

5.1.1 Tides

In the area around the proposed RO Intake and Outfall the water depth is shallow (<5mCD). Water level variations are predominantly driven by astronomic forces (i.e. tides) and represent significant changes to the height of the water column. These variations will act as one of the driving forces for the dispersion and mixing of the brine.

Figure 5-1shows measured currents and water levels taken in 2003/2004 [11] from a location approximately 2km away from the proposed outfall. This figure demonstrates the relationship between currents and tides that has been assumed: the driving force behind currents in the area is variations in water level.

When the tide's range is at its maximum this is called the spring tide, When the tide's range is at its minimum this is called the neap tide.

Current magnitudes are observed to range from 0-0.5 m/s, with maximum current velocities occurring during spring tides and minimum current velocities occurring during neap tides. The occurrence of a neap tide consequently represents a worst case scenario for the mixing of the brine.

5.1.2 Seasonal Heating Effects

In order to account for seasonal heating effects in the model, air temperature was used as an indicator of heat flux acting on the surface of the water. The heat flux acts to raise or lower the temperature of the water body to simulate different mixing patterns during the different seasons.

This enables the model to account for any localised stratification effects that may be induced from atmospheric heating; however, as noted in section 5.1, a thermocline is not observed in the shallow, well mixed near-shore region and is therefore not included as an initial condition when setting up the model.

Datasets containing the recorded air temperatures at BWI Airport from 2001 to 2007 were obtained from the Bureau of Meteorology (BOM). Analysis of this data shows that recorded temperatures over the period are very similar (Figure 5-2), with 2005 and 2006 being the hottest and coldest years, respectively (Figure 5-3).

Additional factors that where included in evaluation of heat flux over these periods were:

- Humidity
- Cloud cover (assumed as 100% for winter and 0% for summer)
- Latitude

Figure 5-1 Current readings from August 6, 2003 through to February 2, 2004

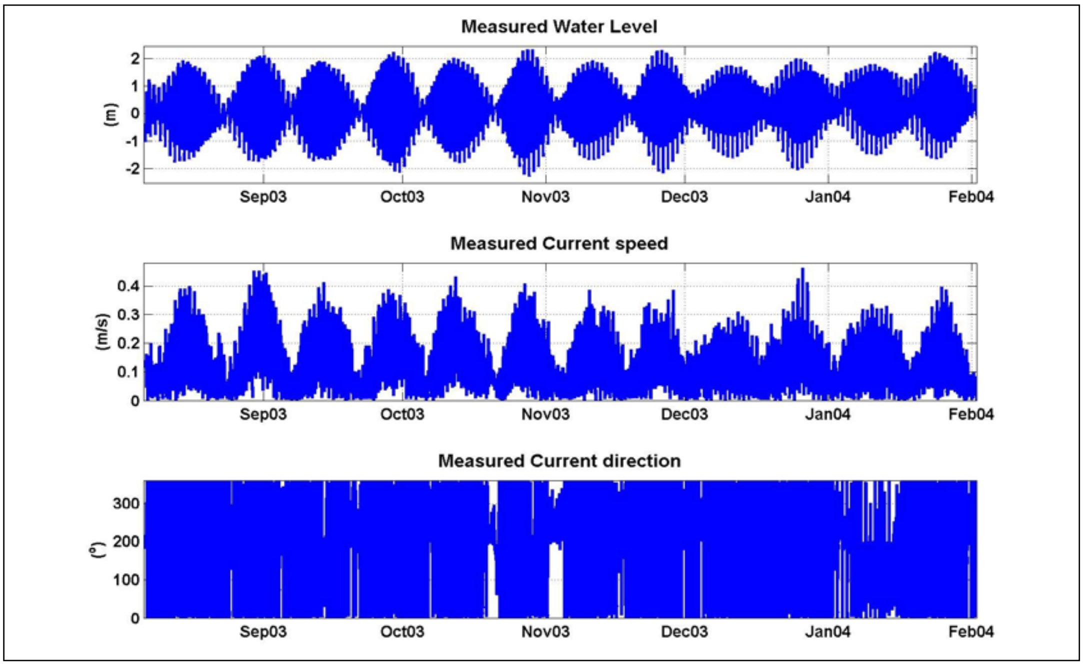


Figure 5-2 Cumulative distribution of air temperatures at BWI Airport, 2001 - 2007

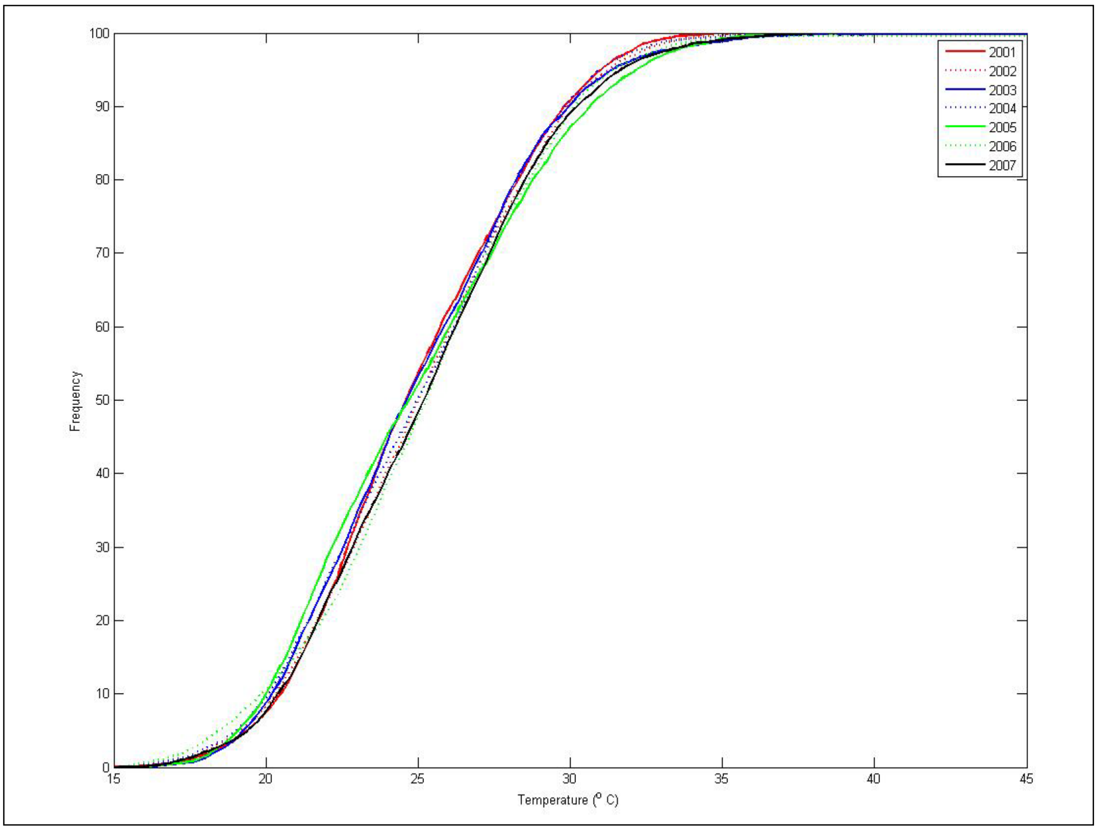
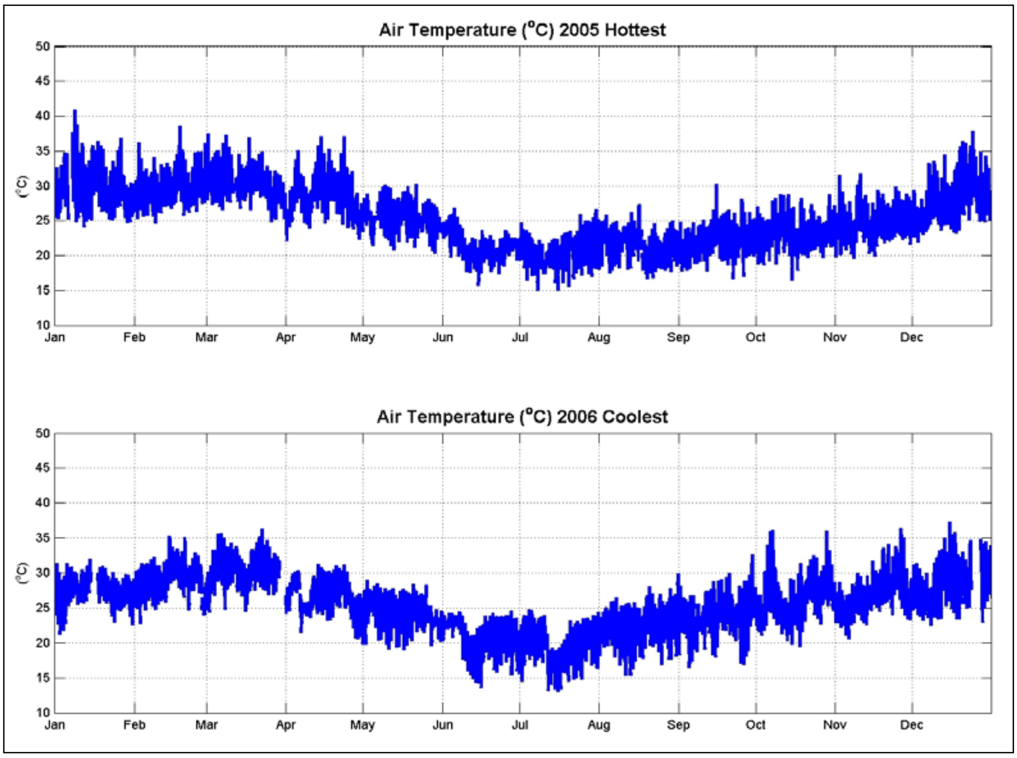


Figure 5-3 Local air temperatures at BWI during the warmest year (2005) and the coolest year (2006) between 2001 and 2007



6. NEAR-FIELD DILUTION MODELLING

6.1 Modelling Criteria

Key criteria considered in establishing the near-field dilution model can be summarised as follows:

- Set up a well established and verified near field model for the project area
- Establish appropriate ambient or background oceanographic conditions in the model to simulate likely and conservative scenarios for mixing and brine dispersion.
- Present key modelling results graphically to illustrate key features and to facilitate its review by other parties.

The Visual Plumes model has been selected because of its track record in similar studies[2].

6.2 Visual Plumes Model Description

Visual Plumes (VP) simulates single and merging submerged plumes in arbitrarily stratified ambient flow and buoyant surface discharges. VP is one of the most recent outcomes of the US Environmental Protection Agency's efforts since 1979 to develop and disseminate models that predict the physical properties and dilution of plumes. It is widely used by the US EPA in particular to simulate waste water outfalls.

From the suites of five models recommended in VP (DKHW, NRFIELD/FRFIELD, UM3, PDSW, DOS PLUMES), the most commonly used UM3 was selected to predict near-field dilution. UM3 is an acronym for the three dimensional Updated Merge (UM) model for simulating single and multi-port submerged discharges. UM3 is a Lagrangian model that features an established hypothesis (Winiarski and Frick 1976, Frick 1984, Rawn, Bowerman, and Brooks, 1960), which quantifies forced entrainment, the rate at which mass is incorporated into the plume in the presence of current.

6.3 Model Setup: Input Data

Key input data used to establish the model included: current speed and direction, seawater quality, outfall geometry, and the initial effluent discharge parameters. The table below summarise inputs used for plumes modelling. They are based on the current design.

[2] Some local references include a study for Sydney Water Corporation by Cardno LawsonTreloar, "Desalinated Water Delivery System Pipeline Crossing of Botany Bay", and a study for Queensland Department of Natural Resources by GHD "Report for SEQ Regional Desalination Plant Siting Study".

Table 6-1 Input data to model near-field dilution using Visual Plumes model

Parameters	**Unit**	Case 1 (minimum flow)	Case 2 (maximum flow)
Diffuser			
Port diameter	m	0.035	
Port elevation	m	6	
Vertical angle	º	-5	
Horizontal angle	º	90	
Number of ports		6	
Port spacing	m	1	1
Acute mix zone	m	10	
Chronic mix zone	m	100	
Port depth	m	0.5	
Effluent flow	m^3/s	0.01 (minimum flow)	0.038 (maximum flow)
Effluent salinity	psu	64.371	
Effluent temperature	º	24	
Effluent concentration	ppm	1	
Ambient			
Measurement depth/height	m	0	
Current speed	m/s	0	
Current direction	º	0	
Ambient salinity	psu	35.6	
Ambient temperature	º	24	
Background concentration	ppm	0	
Pollutant decay rate	s^{-1}	0	
Far-field diffusion coefficient	$m^{2/3}/s$	0.0001	

7. FAR-FIELD DILUTION MODELLING

7.1 Modelling Criteria

Key criteria considered in establishing the oceanographic model can be summarised as follows:

- Set up a well established and verified oceanographic model for the project area
- Undertake grid size analysis to determine the size of the grid spacing necessary to cover the critical areas of diffusers and ocean floor, but without compromising the speed of the simulations
- Undertake verification simulation runs using the observed ocean currents. The purpose of these verifications was to:
  - Ensure that the model had been properly set up prior to undertaking the simulation of the ocean currents/mixing during the seasonal simulations
  - Establish the grid size that would lead to a balance between the computational accuracy and reasonable computational times suitable for the execution of planned simulations over extended periods
  - Confirm that the model, with its current configuration, is able to resolve important features within the study area at the appropriate level of accuracy (in particular, the vertical mixing and spatial dispersion of the brine).
- Determine the appropriate initial conditions for the ‘near-field’ region (i.e. the zone in the immediate vicinity of the outfall diffuser). The initial conditions are dependent on the diffuser performance and the properties of the discharged liquid.
- Establish appropriate oceanographic and meteorological forcing conditions in the model to simulate likely and conservative scenarios for mixing and brine dispersion.
- Present key modelling results graphically as well as by means of computer animations, to illustrate key features and to facilitate its review by other parties.

The oceanographic Delft3D model has been selected because of its track record in similar studies[3].

7.2 DELFT3D Model Description

Delft3D is a 2D/3D modelling system that is used to investigate hydrodynamics, sediment transport and morphology as well as water quality for fluvial, estuarine and coastal environments.

The software was used and has proven its capabilities on many places around the world, such as; the Netherlands, USA, Hong Kong, Singapore, Venice and Australia. The software is continuously improved and developed over time as a consequence

[3] Some Australian references include a study for Sydney Water Corporation by Cardno LawsonTreloar, “Desalinated Water Delivery System Pipeline Crossing of Botany Bay”, and a study for Queensland Department of Natural Resources by GHD “Report for SEQ Regional Desalination Plant Sitting Study”.

of the research work undertaken by the Delft Institute. The most current version of Delft3D-FLOW (3.27.01) has been selected for use on the Gorgon Project.

The FLOW module is the heart of Delft3D and is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary fitted grid. In 3D simulations, such as the evolution of a brine plume, the vertical grid is defined following the so-called sigma coordinate approach, leading to a constant number of vertical layers being evaluated over the whole field.

Delft3D-FLOW evaluates the following parameters for use in simulation:

- Coriolis force
- An advection-diffusion solver to compute density gradients (due to non-uniform temperature and salinity concentration distributions)
- The inclusion of pressure gradients terms in the momentum equation (density driven flows)
- Turbulence models to account for the vertical turbulent viscosity and diffusivity based on the eddy viscosity concept. Four options: k-epsilon, k-L, algebraic and constant model are available, k-epsilon has been selected for use in this simulation
- Shear stresses exerted by the turbulent flow on the bottom based on a quadratic Chézy formula
- Simulation of the thermal discharge, effluent discharge and the intake of cooling water at any location and any depth in the computational field (advective-diffusion module)
- Simulation of drying and flooding of inter-tidal flats (moving boundaries) for both 2D and 3D cases

7.3 Model Setup: Input Data

Key input data used to establish the model included: bathymetry, computational grid, meteorological conditions, tidal elevations, seawater quality, outfall geometry, and the initial effluent discharge parameters. The sections below summarise inputs used for hydrodynamic modelling.

7.3.1 Bathymetry Data and Computational Grid

Bathymetry in the area of interest has been established via an aerial survey conducted by Tenix LADS Corporation in 2005 [13]. The survey covered a large proportion of the east coast of BWI, with a high resolution of soundings around the Town Point area covering the area of the proposed discharge location. A detailed bathymetric map was then developed using this data (see Figure 7-1).

Particular attention was paid to ensure the conformity of the local coastline, which could have an impact on local circulation and consecutively the transport of the brine away from the diffuser.

A basic computational grid was initially deployed and tested to ensure that the depth profiles were suitable for use in oceanographic modelling. Polygon outlines of the MOF and dredge pockets were used to alter specific depths over the computational domain. It is worth noting that the Gorgon jetty structure was excluded from the model due to the fact that the piled design (concrete caissons with pre-fabricated steel topsides) is not expected to influence either ocean currents or propagation of the RO reject.

The grid utilises a Cartesian coordinate system with the x-axis increasing eastwards and the y-axis northwards, with variable resolution in the longitudinal and transverse directions. Of the total grid cells in a horizontal plane, most represent the actual water surface and correspond to non-zero depths. The final grid used for simulations was developed as per the method outlined in the initial oceanographic dispersion study undertaken by Flow Science to establish the CVX BOD [3]. Key features of the deployed grid can be summarised as follows, and are illustrated in Figure 7-2:

- The grid was rotated 28 degrees from north, in order to align with the semi-major axis of the tidal ellipse and to be positioned perpendicular to the shoreline. The grid extends 6.9 km in the long-shore direction and 8.9 km in the off-shore direction.
- For accuracy and efficiency, a stretched horizontal grid was used that consists of three parts: an interior grid with constant 15 m cells, covering 150 m by 150 m; an intermediate grid where the cell sizes are increased with a stretch ratio of 1.05, covering approximately 1.5 km by 1.5 km; and an exterior grid where cell sizes are increased with a stretch ratio of 1.2.
- The constant 15 m part of the grid is centred about the outfall location. The intermediate grid uses a moderate stretch ratio of 1.05, such that the plume and the complex flow around the MOF can be accurately resolved in this region.
- The exterior grid uses a larger stretch ratio of 1.2. This is in regions farther away from the plume and MOF, and thus the possible reduction in numerical accuracy resulting from larger stretch ratio and elongated cells is not as critical. This region of the grid essentially serves to move the domain boundaries away from the much smaller domain of interest. It should be noted that the cell width in the on-shore direction was not stretched beyond 45 m. This ensures that there was adequate resolution in the near-shore region where cells wet-and-dry with changing tides.

Parameters of interest used in the simulations are provided in Table 7-1.

Figure 7-1 Outline of bathymetric grid showing the aerial survey output (in m)

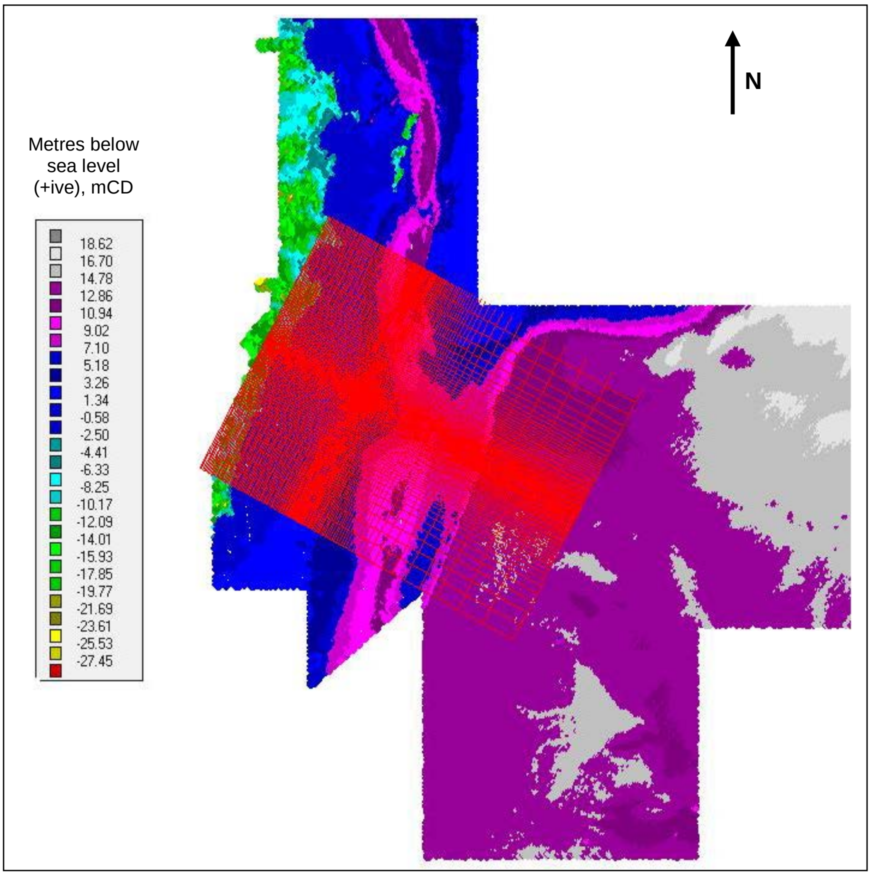


Figure 7-2 Model Grid applied in Delft3D

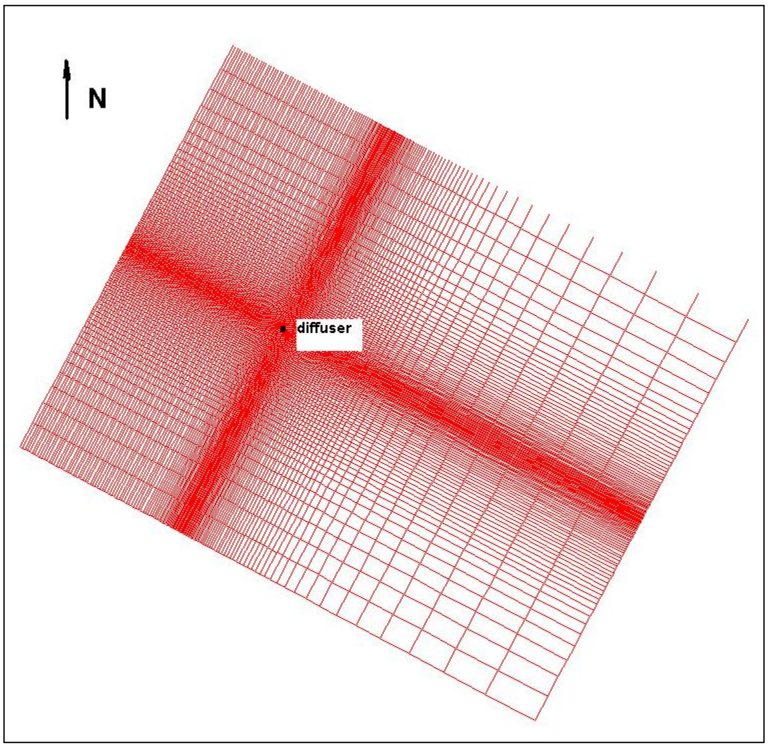


Table 7-1 Parameters used in the numerical simulations

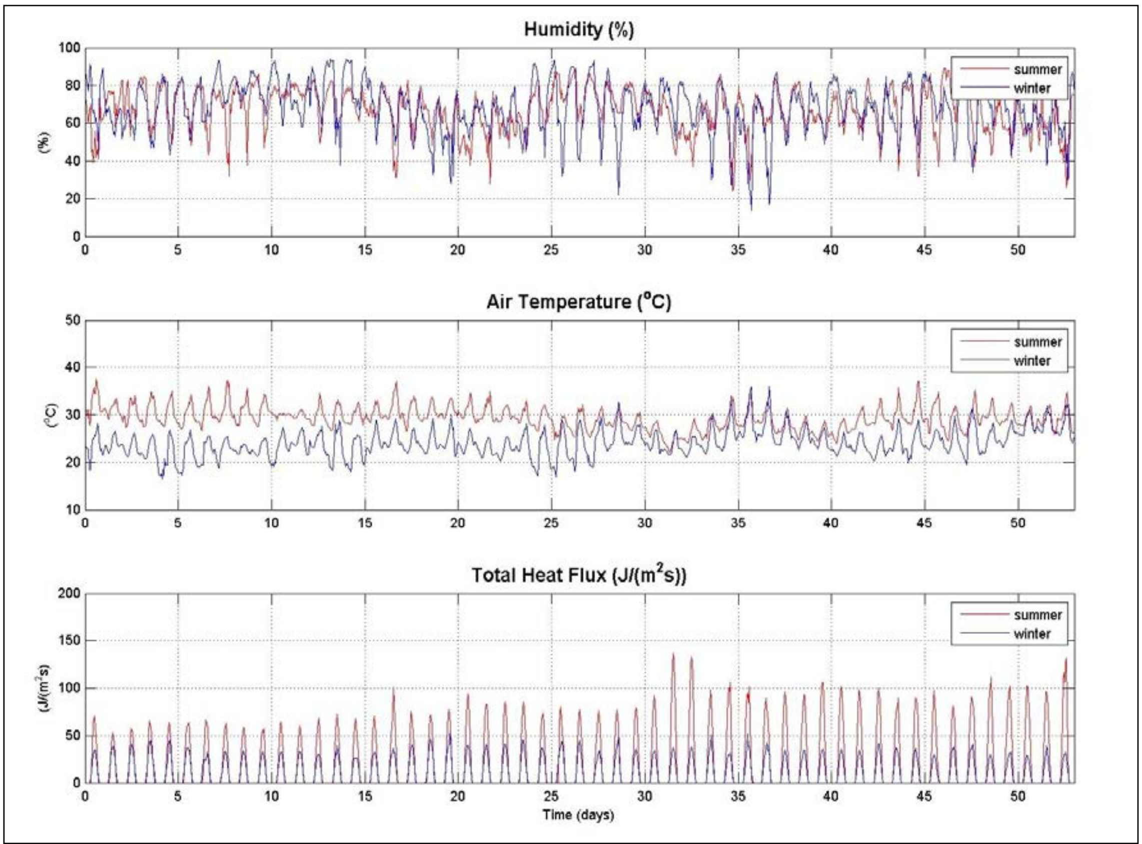
Parameter	Value
Number of cells in longitudinal direction (horizontal plane)	101
Number of cells in transverse direction (horizontal plane)	131
Vertical layers(of variable thickness)	14
Minimum grid size in horizontal plane (m)	15
Δt time step (min)	1
Eddy viscosity scheme	k-ε

7.3.2 Meteorological Conditions

Meteorological data used in the analysis was obtained from the BOM. Most of the meteorological data were from the BOM's weather stations at BWI Airport and Learmonth (located near Exmouth in Western Australia). This data was used to develop synthetic meteorological data sets reflecting two seasons: summer (having high heat flux) and winter (having lower heat flux). The available data sets were reviewed and the periods were selected having continuous data over the same summer/winter periods.

Figure 7-3 displays the summary of the deployed meteorological data used to drive heat flux in the model.

Figure 7-3 Heat flux and atmospheric conditions used in the model to simulate summer and winter heat conditions



7.3.3 Tidal Elevations

Data from the National Tidal Centre (NTC) was used to derive the tide input parameters that were used to force the model. This approach ensured the tides used were representative of reasonably expected worst case conditions determined from regional knowledge.

The alternate approach would involve forcing the model using tidal readings measured during field survey programmes. This consequently would limit selection of the forcing conditions to a restricted set of tidal information that has been recorded in the locality of the outfall, which may or may not include the reasonably expected severe conditions which are of interest when evaluating evolution of the RO reject.

Tides were included on all the open boundaries, based on the tidal constituents provided by the NTC. Eight tidal constituents were used in the simulations: M2, S2, K2, N2, K1, P1, Q1 and O1. These constituents were derived from the NTC's ORSOM model which has been verified to demonstrate high quality data in the North-West Shelf (NWS) region (Appendix A). The values of the constituents vary over the latitude and longitude of the model boundary. Refer to Table 7-2 for values of the constituents used in model simulations.

7.3.4 Seawater Quality

Data collected from field surveys was used to evaluate background seawater temperature and salinity profiles for the various simulations [11]. Averaged temperature and salinity values were then selected from seasonal water column averages at the Acoustic Doppler Current Profiler (ADCP) site and applied to the entire domain:

- A temperature of 24°C was selected as a background condition
- A salinity of 35.6 ppt (psu) was selected as a background condition

7.3.5 Outfall Geometry and Effluent Discharge Parameters

The Current Design parameters summarised in Table 4-1 were used to set the initial effluent discharge parameters used in the model.

Table 7-2 NTC Tidal constituents used in simulations

Location		Q1		O1		P1		K1		N2		M2		S2		K2	
Latitude	Longitude	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)	Phase (°)	Amplitude (m)
-20.8291	115.4651	164.23	0.0302	173.98	0.1397	186.41	0.0738	183.61	0.2253	55.74	0.1632	87.51	0.9178	146.05	0.5467	151.75	0.1453
-20.842	115.4901	164.27	0.0302	174	0.1396	186.47	0.0737	183.62	0.2251	55.87	0.1626	87.63	0.9153	146.24	0.5453	151.94	0.145
-20.8547	115.5152	164.12	0.0301	174.02	0.1396	186.46	0.0736	183.61	0.2251	55.87	0.1628	87.64	0.9169	146.28	0.5464	151.87	0.1455
-20.8274	115.531	163.78	0.0301	173.88	0.1396	186.18	0.0737	183.47	0.2251	55.29	0.1632	87.1	0.9192	145.61	0.5472	151.08	0.1458
-20.8	115.5468	163.3	0.03	173.76	0.1394	185.97	0.0736	183.36	0.2243	54.85	0.1623	86.71	0.9135	145.12	0.543	150.41	0.1448
-20.7872	115.5218	163.4	0.03	173.82	0.1394	186.11	0.0737	183.49	0.2243	55.19	0.1618	87.05	0.91	145.47	0.541	150.79	0.144
-20.7744	115.4967	163.4	0.0299	173.87	0.1394	186.22	0.0738	183.62	0.2243	55.52	0.1614	87.39	0.9072	145.83	0.5394	151.1	0.1434

7.4 Model Verification

The aim of the model verification was to ensure and demonstrate that the selected model can accurately reproduce all the critical features identified as factors affecting the temporal and spatial evolution of the brine in the considered area.

As stated earlier, behaviour of the brine plume will be primarily driven by the ocean currents which, in turn, are dominated by tidal changes. Accordingly, the objective of model verification was to ensure that the model replicates the observed ocean currents when driven by changes in tide, with accuracy appropriate to the considered modelling objectives.

Measured ADCP tide and current data was used to verify the model. The relevant data set consisted of 6-months continuous readings from 6 August 2003 to 2 February 2004 at 342,824 E and 7,697,029 N (20.82°S 115.49°E) [11]. This data was collected by means of an ADCP located 6m above the seafloor to provide current magnitudes and directions every 2 minutes. The ADCP location is approximately 2km South-East of the area of interest for the proposed outfall and sits within the model domain.

The verification exercise used tides to drive the model at the boundary of the domain, with the aim to get simulated water levels and currents to correlate with the measured data in “tide.xls” and “current.xls” [11], respectively. Figure 7-4 shows a selection of measured water levels/velocities (in blue) against water levels/velocities extracted from the simulation (in red). It is worth noting that the simulated currents were recorded at the location of the ADCP meter, with only the background bathymetry included in the model (i.e. without the MOF or dredge pockets). Figure 7-5 shows a longer period of measured velocities against velocities extracted from the simulation. The comparison shows good correlation, indicating the simulation adequately captures long-shore and cross-shore currents. Of importance to note is the observation that the modelled current velocities generally tend to slightly under-predict measured values, applying a conservative force to mixing within the water column. This under-prediction is important when analysing the worst case scenario effecting the dispersion of the brine.

Figure 7-4 Selection of modelled current velocities (red) compared to measured current velocities (blue) (approx. 1-month duration)

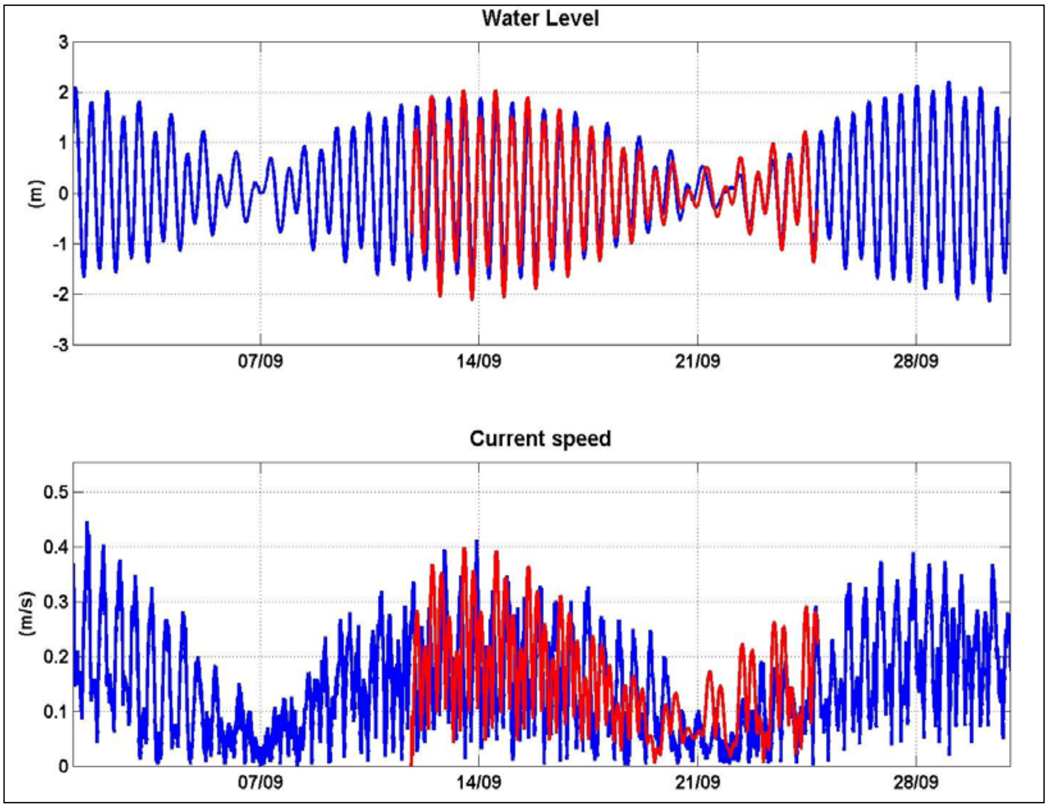
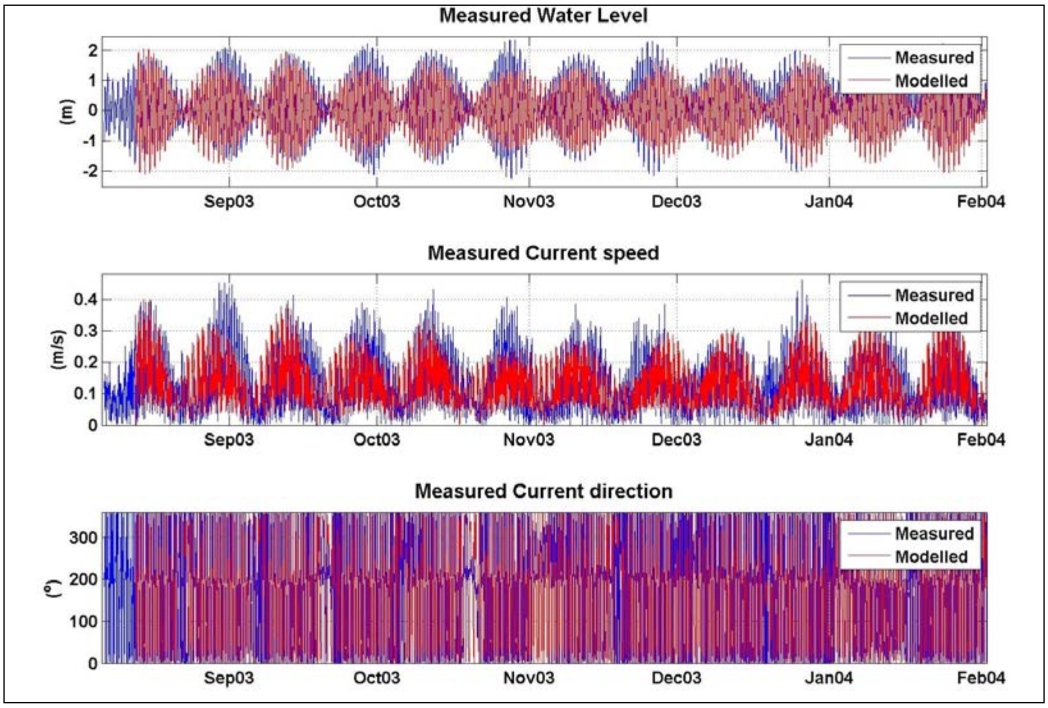


Figure 7-5 Selection of modelled current velocities (red) compared to measured current velocities (blue) (approx. 6-month duration)



7.5 Model Setup: Input Data

The model setup and input data for the simulations using current design specifications are largely the same as those for model verification, which used previous design specifications. The differences in initial, flow, and transport conditions to current final design specifications are summarised in Table 4.1.

The same grid is used, while the bathymetry reflected the new MOF layout. The diffuser location was altered considerably to a location very close to the berth, between two of the caissons of the MOF (Figure 4.1).

8. MODELLING RESULTS AND ANALYSIS: NEAR-FIELD REGION

8.1 Simulation Cases

Simulations were performed for the brine flow as outlined in Table 6.1. Two cases were considered corresponding to best and worst case dilution scenarios: brine stream at maximum and minimum flow rates, respectively.

8.2 Output Data and Interpretation of Results

The outcome of the model runs demonstrates, as shown in Figures 8-1 and 8-2 for port spacing of 1m, that effective dilution for both cases were similar, at approximately 100-fold dilution. This value of near-field dilution was, in turn, used to inform (far-field) oceanographic modelling.

Figure 8-1 Profile view of the plume trajectory and dilution of brine, from source (diffuser) to the ocean floor, for a maximum flow rate

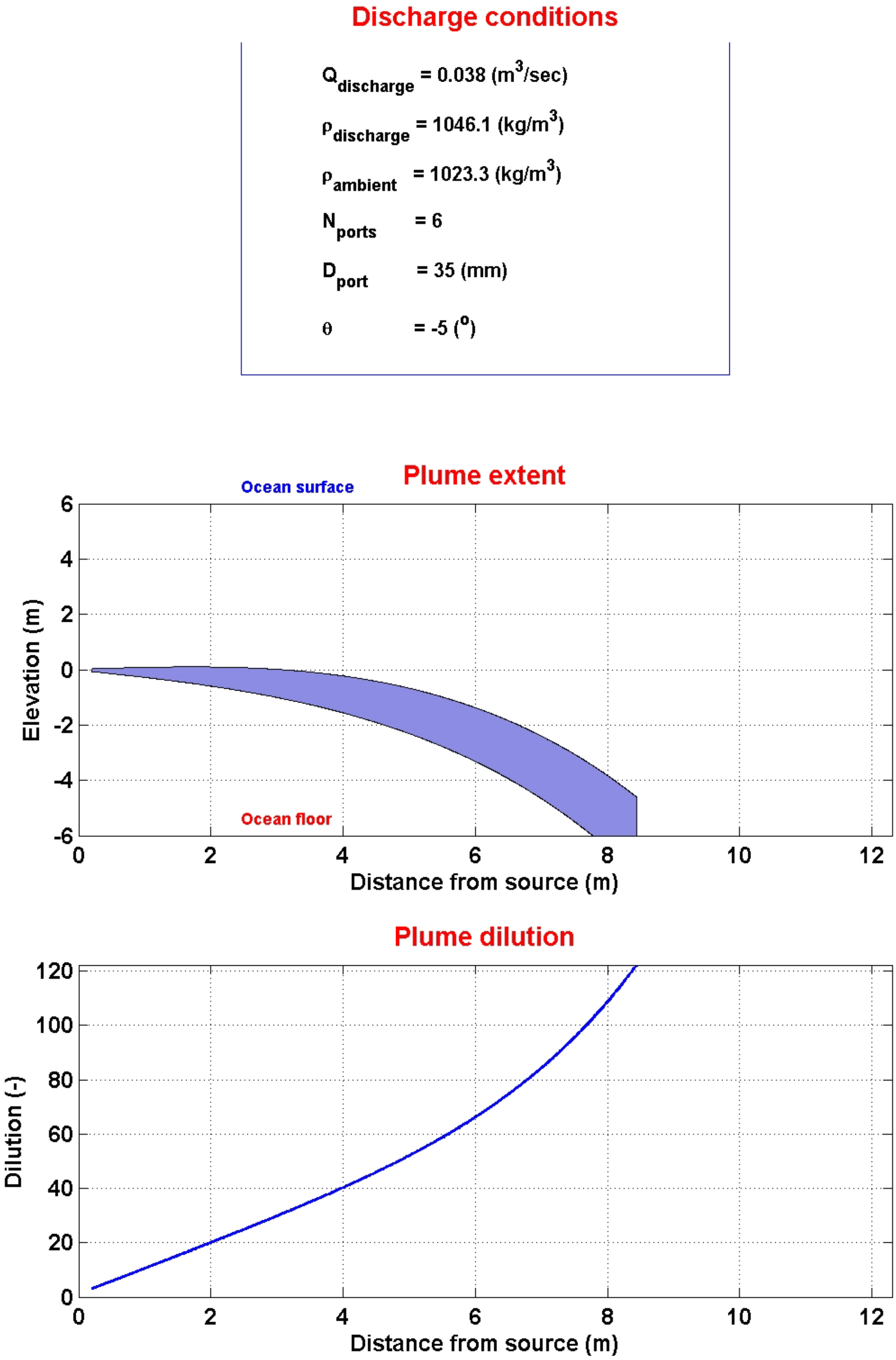
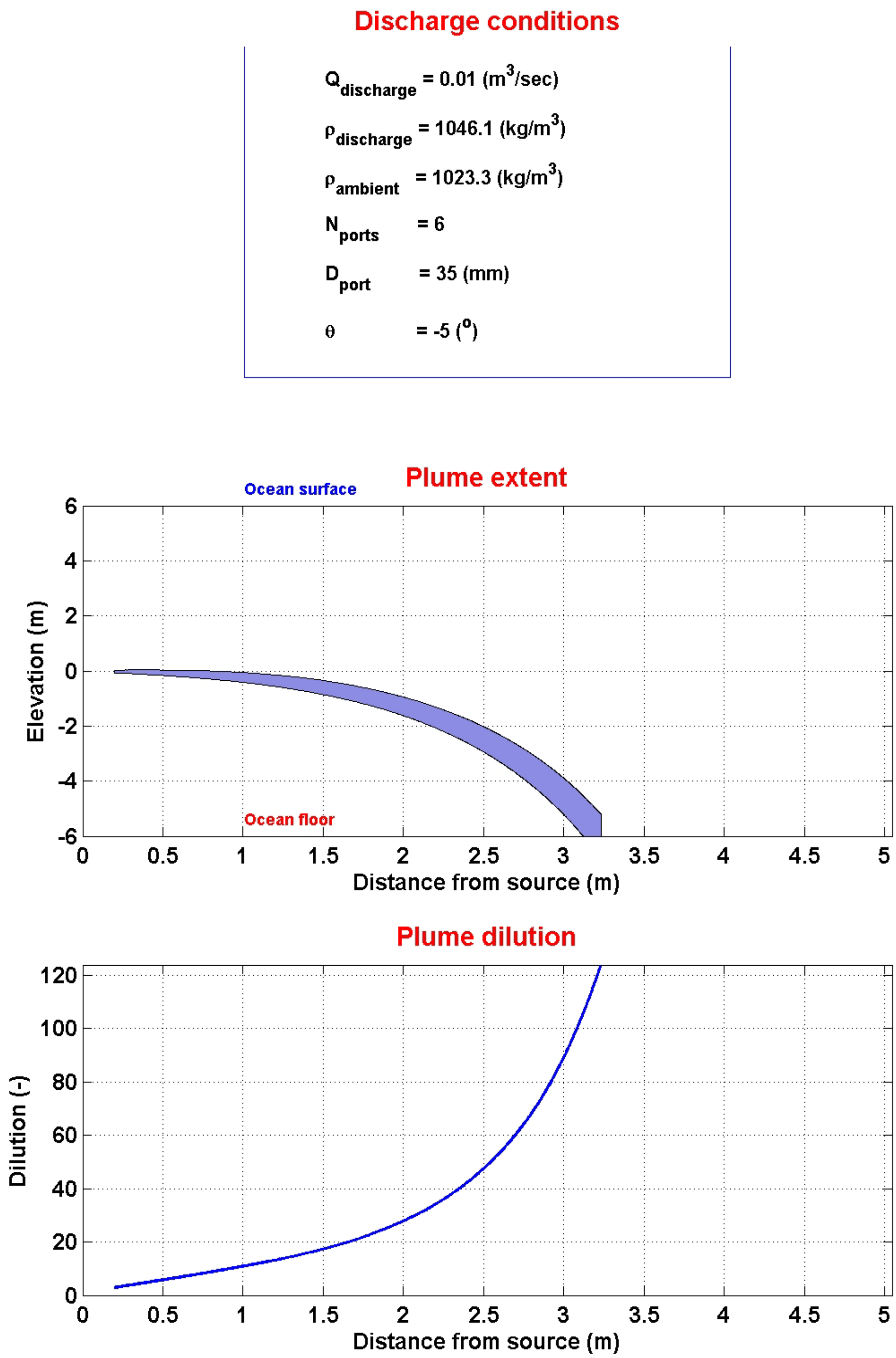


Figure 8-2 Profile view of the plume trajectory and dilution of brine, from source (diffuser) to the ocean floor, for a minimum flow rate



9. MODELLING RESULTS AND ANALYSIS: FAR-FIELD REGION

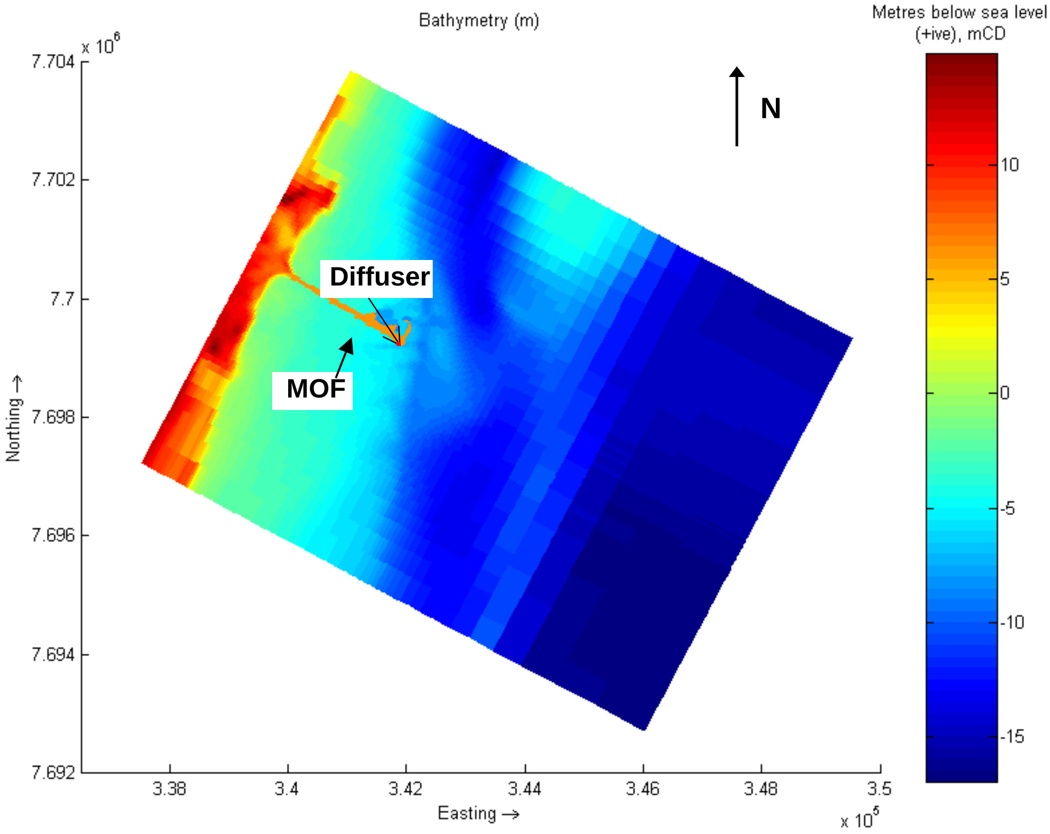
9.1 Simulation Cases

An oceanographic simulation was run for the current design brine flow as outlined in Table 4-1. Given that in the previous simulations (for model verifications) the temperature has been seen to produce minimal effect towards the dilution of the brine temperature has been removed from the modelled simulations. Furthermore, based on the investigation of near-field dilution through VP model, effective dilution in the near-field region is 100-fold. This is the region within the cell where the diffuser is located. Therefore calculated brine salinity of 35.9 psu in the diffuser cell was used to further simulate for dilution in the far-field using DELFT3D.

The modelled cases below represent one operating environment with the current MOF structure, with the expected range of flow modelled. This corresponds to two simulations, with minimum and maximum flow of the reject brine stream.

An image showing the model's interpretation of this infrastructure is included in Figure 9-1. (Figure 4-1 in Section 4 shows the MOF structure in more details as well as the location of the diffuser in relation to the structure.)

Figure 9-1 Background Infrastructure for Simulations



9.2 Output Data and Interpretation of Results

Output data from the modelling software package was stored as follows (for each simulated case):

- A complete (three dimensional) record of the simulated parameters over the entire computational domain, stored at a frequency of 2-hours;
- A record of the simulated parameters at a series of selected monitoring locations, stored at a frequency of 10minutes
- The stored data was then processed and statistically analysed using DELFT3D's QUICKPLOT, which in turn incorporates a numerical software package, MATLAB®, to facilitate interpretation and presentation of the results.

The purpose of the modelling was to ensure adequate dilution in the area surrounding the ocean outfall. The most recent change in the location of the outfall diffusers close to tug harbour (area of focus, Figure 4-1b) also means the focus of the output becomes this area, with the risk of less dilution due to likely smaller effects of tides and currents. The focus area was analysed for maximum salinity to present the worst case scenario, and this is presented below as Figures 9-2 and 9-3, for minimum and maximum flow, respectively. Water level at time of maximum salinity is also included, showing maximum salinity occur at water level around 0m LAT.

To assist interpretation of the results, it is worth noting that salinity is inversely proportional to dilution according to the following relationship:

$$D_{(x,y,z)} = \frac{S_{Disch\arg e} - S_{Background}}{S_{(x,y,z)} - S_{Background}}$$

Where D is the dilution;

S is the salinity;

(x, y, z) is the point of interest;

$Disch\arg e$ is the value at the point of discharge from the diffuser; and

$Background$ is the value of the background reading.

Table 9-1 shows indicative dilution/salinity values determined from the above relationship and the background conditions used in the model.

Table 9-1 Indicative Dilution/Salinity values

Dilution	Salinity (ppt)
1	64.371
50	36.2
100	35.9
200	35.7

Table 9-2 shows the corresponding dilution for maximum salinity values within the area of focus, at minimum and maximum flow scenarios (Figures 9-2 and 9-3). After the initial 100-fold dilution achieved in the near-field region (dilution achieved via outfall design), further dilution of at least around 300-fold can be achieved at the worst case scenario of maximum flow or load. Model results thus show the current design concept complies with dilution requirement for approval.

Table 9-2 Dilution/Salinity values for worst case in model scenarios

Scenario	Maximum Salinity (ppt)	Dilution
Minimum flow	35.637	782
Maximum flow	35.705	275

Figure 9-2 Maximum salinity in the area of focus for the simulation scenario of minimum flow, time series of salinity at the maximum location both in detail and in the context of ambient and discharge salinity.

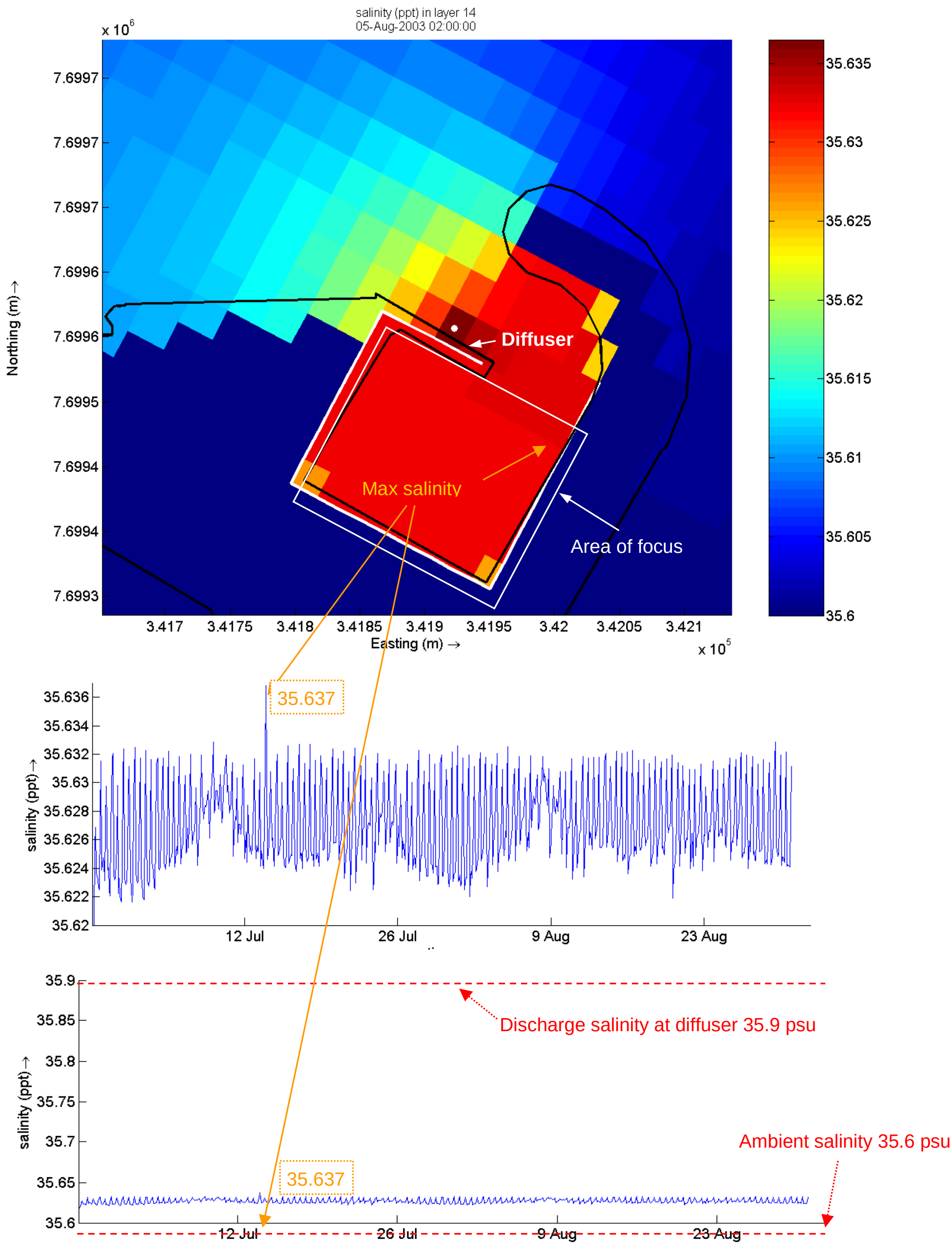
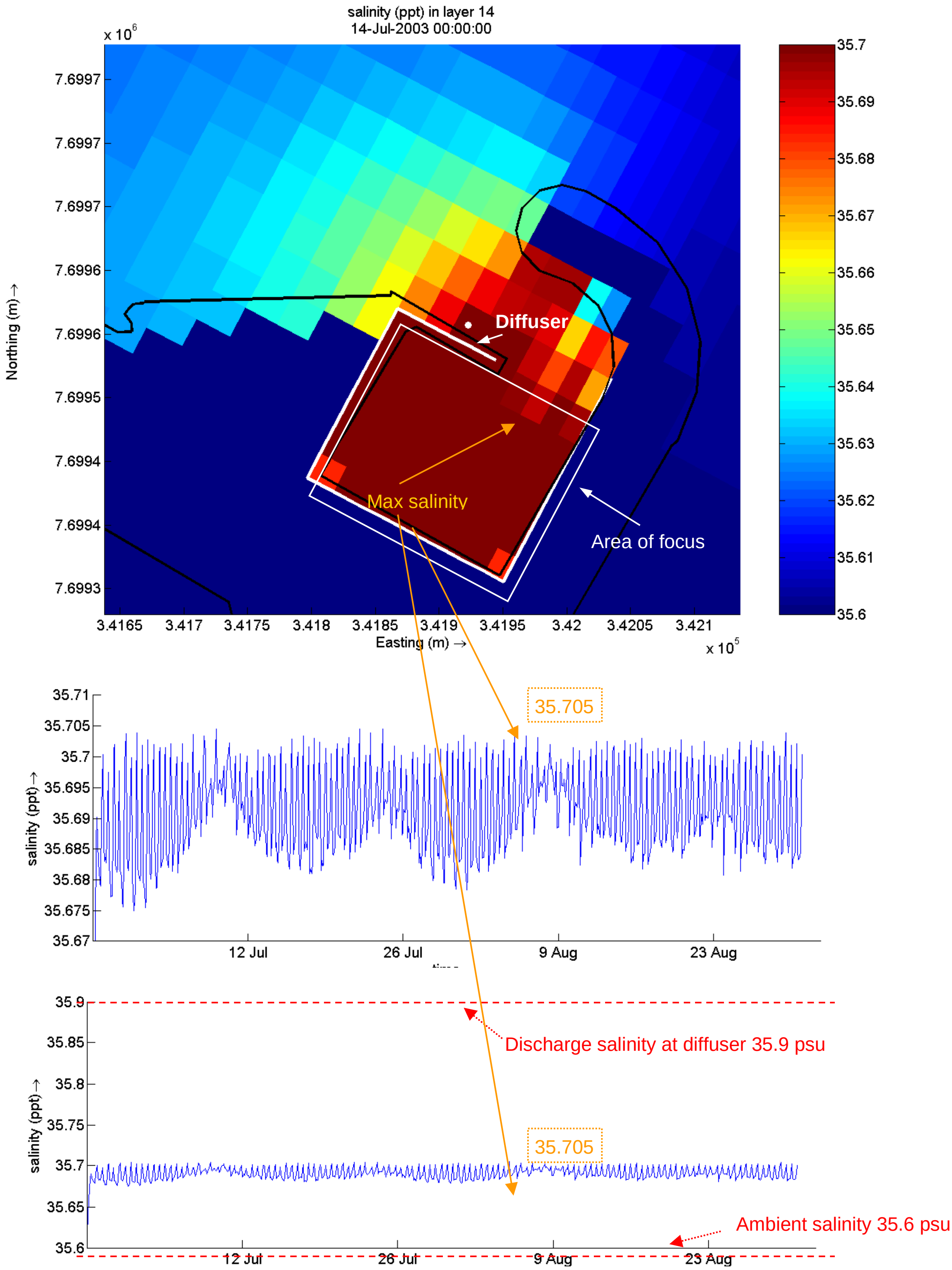


Figure 9-3 Maximum salinity in the area of focus for the simulation scenario of maximum flow, time series of salinity at the maximum location both in detail and the water level at the diffuser location in the context of ambient and discharge salinity.



10. CONCLUSIONS

The analysis and modelling conducted to support the Ministerial Approval application confirms that, based on analysis of a select operating case and system configuration as at January 2011, the current design concept for an ocean outfall to dispose of RO reject streams is capable of achieving the dilution criterion specified in the ocean outfall BOD [2], and thus the commitment of a 40 fold dilution in the high impact zone surrounding the MOF. In particular, it is evident from the selected case that 100 fold dilution can be achieved in the near-field by performance of the diffuser alone, through variables such as flow rate and port spacing.

By appropriate analysis of the relevant forces and set-up of the model, the simulations err towards a conservative mixing environment in order to avoid the potential to overstate dilutions in the far-field whilst being representative of what can be reasonably expected. This is important when analysing the worst case scenario effecting dispersion of the RO reject.

In addition, the modelling (this report and the previous revisions of this work) demonstrates:

- Mixing is dominated by the astronomic tide whilst heat input, that could lead to the development of stratification, exhibits negligible influence
- Mixing of the discharge is not adversely affected by the presence of the MOF, meaning the selected location ensures unimpeded flushing of the RO reject by the ocean currents
- A minimum level of 100 dilutions can be achieved within the mixing zone as defined in the BOD [15].
- A dilution level higher than 100 fold can be achieved in the almost enclosed berthing area near the diffuser (risk area, Figure 4-1)

11. REFERENCES

Table 11-1 Project Documents and Drawings

Ref.	Document Number	Rev. (Date)	Title
1.	G1-NT-REPX0001077	3	CHARACTERISATION & PRELIMINARY TOXICITY ASSESSMENT FOR REVERSE OSMOSIS BRINE STREAM
2.	G1-NT-REPX0001097	2	REVERSE OSMOSIS PLANT REJECT BRINE DISPOSAL STUDY AND OCEAN OUTFALL BASIS OF DESIGN
3.	G1-NT-REPX0001104	-	DISPERSION MODELLING STUDY SEAWATER INTAKE & REJECT BRINE OUTFALL (20 Dec 07)
4.	G1-NT-REPX0001105	0	SEAWATER UPTAKE AND REVERSE OSMOSIS BRINE EFFLUENT DISCHARGE STUDY
5.	G1-TD-T-4500-SKH0600	C	WATER SYSTEMS (RO) - MINISTERIAL APPROVAL DATA OCEAN OUTFALL DILUTION SIMULATIONS LAYOUT
6.	G1-TD-T-4500-SKH0601	C	WATER SYSTEMS (RO) - MINISTERIAL APPROVAL DATA OCEAN OUTFALL DILUTION SIMULATIONS LONGITUDINAL PROFILE
7.	G1-TD-T-4500-SKH0602	C	WATER SYSTEMS (RO) - MINISTERIAL APPROVAL DATA OCEAN OUTFALL DILUTION SIMULATIONS DIFFUSER DETAILS
8.	G1-TE-P-4500-CAL1501	4	WATER BALANCE (PRE-FID THROUGH TO OPERATIONS)
9.	G1-TE-P-4500-CAL1504	1	DILUTION CALCULATIONS FOR OCEAN OUTFALL
10.	G1-TE-P-4500-TCN1504	6	TECHNICAL NOTE FOR GORGON PROJECT WATER BALANCE
11.	G1-TE-T-4500-RFI0500	(12 May 08)	METOCEAN DATA FOR SEAWATER INTAKE AND OCEAN OUTFALL MODELLING (CVX response to RFI, transmittal ICR-1549)
12.	G1-TE-T-4500-TCN0500	C	REVIEW OF REGIONAL AND LOCAL OCEANOGRAPHIC, METEOROLOGICAL AND HYDROLOGICAL FEATURES FOR OCEANOGRAPHIC MODELLING
13.	G1-TE-T-D0000-REPX001	(21 Dec 05)	REPORT OF SURVEY - BARROW ISLAND 2005
14.	G1-TE-Z-0000-PDB1501	3	BASIS OF DESIGN FOR OFFSITE UTILITIES
15.	G1-TE-Z-4500-PDB1500	0A	SEAWATER INTAKE AND OCEAN OUTFALL BASIS OF DESIGN
16.	G1-TD-T-7400-GEN0701	6	MATERIALS OFFLOADING FACILITY FULL MOF - GENERAL ARRANGEMENT SITE PLAN
17.	G1-TD-T-7400-GEN0702	7	MATERIALS OFFLOADING FACILITY FULL MOF - GENERAL ARRANGEMENT LAYOUT PLAN

Ref.	Document Number	Rev. (Date)	Title
18.	G1-NT-REPX0001483	2	REVERSE OSMOSIS BRINE DISPOSAL VIA OCEAN OUTFALL ENVIRONMENTAL MANAGEMENT AND MONITORING PLAN

Table 11-2 Published References

Ref.	Details
19.	Bhattacharyya G.K. and R.K. Johnson, 1977, Statistical Concepts and Methods, Wiley

Appendix A

NATIONAL TIDAL CENTRE'S ORSOM MODEL

Tidal Model of the Australian Region
National Tidal Centre
Bureau of Meteorology

Tidal Model Description

ORSOM is a two-dimensional, barotropic model developed by scientists at the National Tidal Centre. It solves the depth-integrated equations of mass and momentum on a finite-difference grid in either Cartesian or spherical coordinates. It accounts for Coriolis, non-linear advection, horizontal eddy viscosity, and quadratic bottom friction. An Orlanski-Sommefeld radiation condition is used on the open boundary. Other features available include spatially variable bottom friction, tidal potential, earth tides, self-attraction and loading, and a nudging data assimilation scheme.

ORSOM is used for simulation of tides and/or meteorological-driven motions over large domains, and has been used to derive a database of tidal constants and tidal planes over the entire Australian continental shelf at a resolution of 5 minutes in latitude and longitude.

Details

Australian Region Tidal Model
Latitude: 111º E to 156º E
Longitiude: 9º S to 45º S
Resolution: 5'
Tidal Constituents: Q1 O1 P1 K1 N2 M2 S2 K2

Quality Assessment

Quality assessment of model outputs is necessary firstly to calibrate user-specified model coefficients and secondly to validate the accuracy of information delivered to end-users. Models are compared against observations that are of good quality and acquired from marine environs suitably resolved by the model. For instance, assessment against data from a tide-gauge located some distance within an estuary may not be appropriate.

Tidal model errors are calculated on the basis of either harmonic tidal constants or tidal timeseries. Observed harmonic tidal constants should be derived from good-quality sea level observations of sufficient length. Observed tidal timeseries should be based on the same number of tidal constituents used in the model.

Tidal Constituent	Average Amplitude Error (metres)	Average Phase Error (degrees)
Q1	0.004	8
O1	0.016	6
P1	0.011	6
K1	0.025	6
N2	0.017	12
M2	0.094	8
S2	0.036	6
K2	0.013	11

Table 1. Average Absolute Errors of NTC Australian Tidal Model vs 81 standard ports

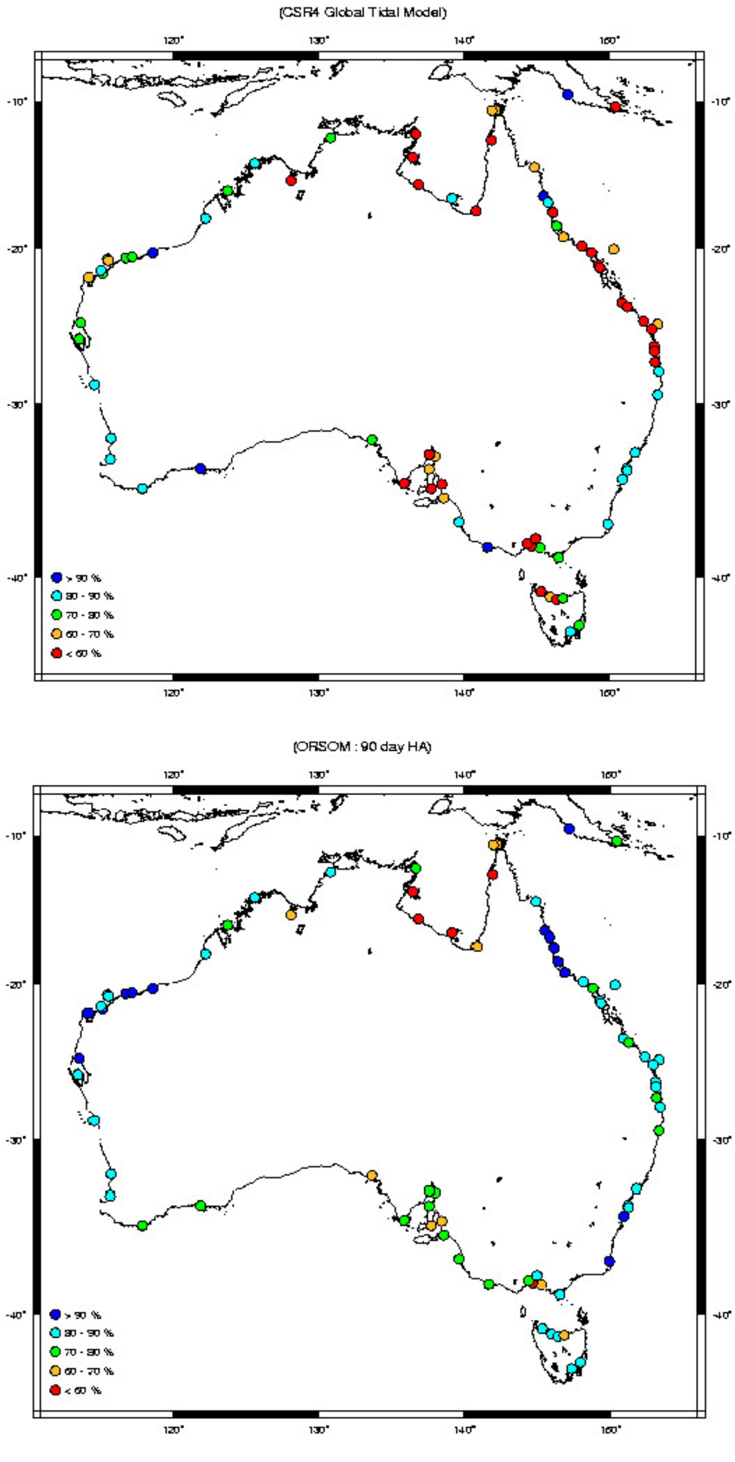


Figure 1. Reliability of tidal models on the basis of agreement with observed tidal constants at primary ports. Top: CSR4 0.5° Global Tidal Model. Bottom: NTC 5' Australian Tidal Model. A reliability of 90% means the maximum difference between an observed and modelled tidal prediction is less than 10 % taking into account errors in both height and timing.

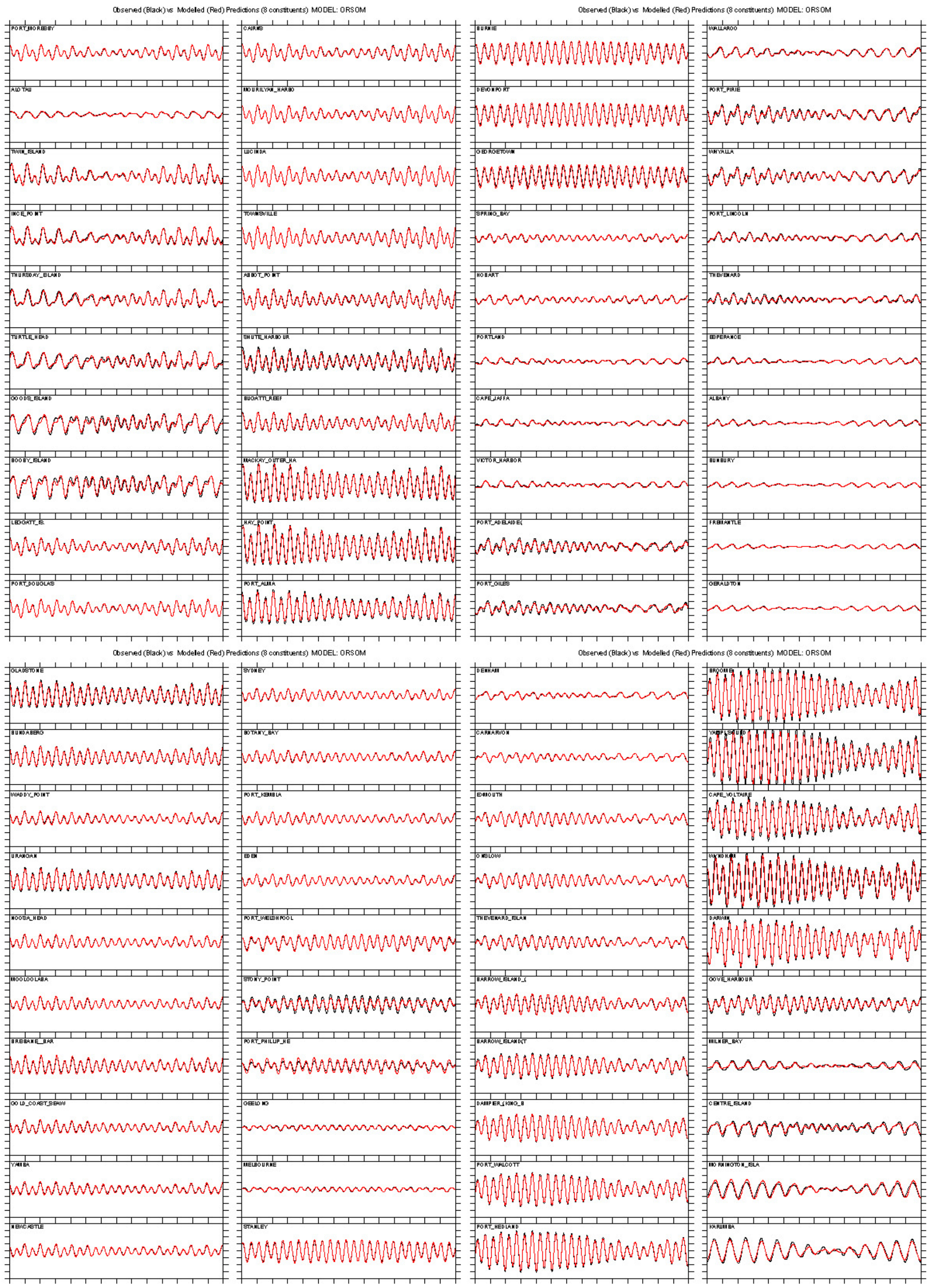


Figure 2. Comparison between tidal predictions derived from the NTC Australian 5' Tidal Model (red) and primary ports listed in the Australian National Tide Tables (black).