Adelaide Desalination Plant Outfall Dilution Modelling Validation

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1. INTRODUCTION

A validation exercise has been performed on the outfall dilution modelling undertaken for the detailed design of the Adelaide Desalination Plant outfall. The validation exercise has been performed by comparing a range of hydrodynamic and salinity measurements undertaken around the outfall operating at 100% capacity during a dodge tide to a modelled hindcast of the hydrodynamic and desalination plant operating conditions over the same period. The validation period included a dodge tide centred on the 25th October 2012 and the days leading up to the dodge tide from approximately the 21st October 2012.

1.1 Scope of Works

The validation modelling exercise included the following scope of works:

- Re-establish the two- and three-dimensional hydrodynamic models utilised in the outfall dilution modelling assessment from the project archive;
- Work with Adelaide Aqua to develop the salinity monitoring program to capture the extent of the diluted brine plume during dodge tide conditions;
- Undertake the monitoring and data analysis with Adelaide Aqua;
- Hindcast the two- and three-dimensional models over the validation period; and
- Compare and analyse the modelled versus observed hydrodynamic and salinity conditions.

2. TWO-DIMENSIONAL GULF ST VINCENT MODEL

The primary purpose of the Gulf St Vincent model is to provide more accurate boundary conditions for the three-dimensional mid-field model of the coastal waters in the main area of interest around Port Stanvac. Validation of this model focusses on the model's ability to accurately replicated astronomical tides and meteorological water levels in the vicinity of Port Stanvac. This ensures that hydrodynamic conditions extracted from this model provide a good representation of boundary conditions to the more detailed mid-field modelling of the outfall.

2.1 Model Setup

The hydrodynamic (HD) module of the Danish Hydraulic Institute's MIKE 21 modelling system was used previously to develop the Gulf St Vincent model. MIKE 21 is a state of the art modelling system for simulating water level variations and depth averaged flows in response to a variety of forcing functions in rivers, lakes, estuaries and coastal areas. MIKE 21 HD solves the vertically integrated equations for the conservation of continuity and momentum in two horizontal directions.

2.1.1 Domain Schematisation

The extent and bathymetry of the Gulf model is shown in Figure 2-1. The model is aligned north-south, and covers the whole of Gulf St Vincent and the main part of Investigator Strait. The main western boundary of the model extends from Stenhouse Bay on the southern tip of the Yorke Peninsula to Western River on the north coast of Kangaroo Island. There is a second boundary offshore from Backstairs Passage. This extends southwards to just south of Cape Willoughby on Kangaroo Island, and eastwards to Victor Harbour. The model uses a 500 m square grid, and a time step of 60 seconds.

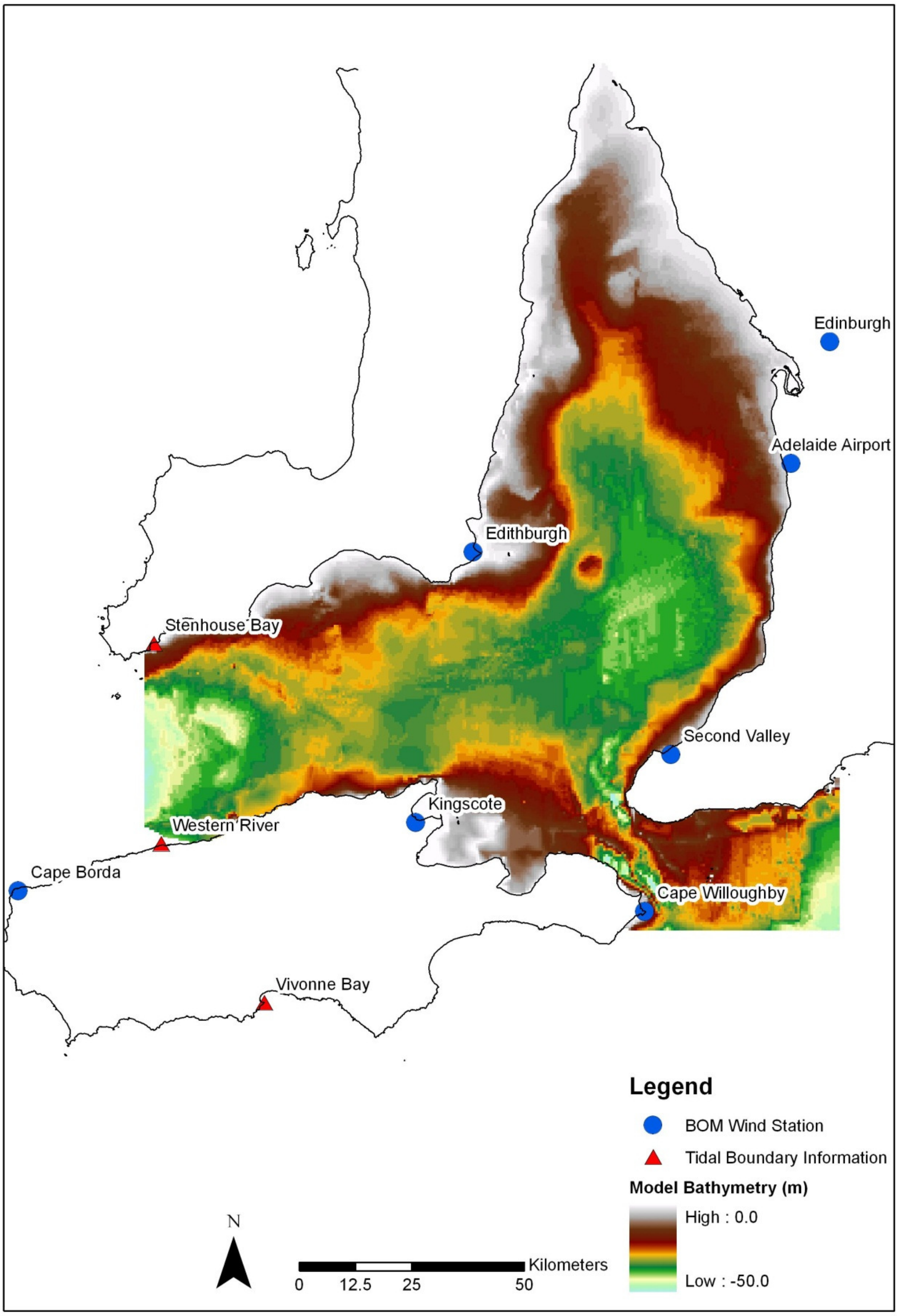

Figure 2-1 Two Dimensional Gulf St Vincent Model Domain and Bathymetry

2.1.2 Boundary Conditions

The open boundaries at the entrance to Investigator Strait and offshore from Backstairs Passage are driven by a combination of astronomical tides and meteorologically derived water level variations Resultant boundary conditions are shown in Figure 2-2. For the Investigator Strait boundary, the astronomical tides were developed from tidal constituents derived from tidal measurements at Stenhouse Bay and Western River. For the Backstairs Passage boundary, the astronomical tides were developed from a combination of tidal constituents for Victor Harbour and Vivonne Bay. For both boundaries, the meteorologically derived water level variations were developed from water level variations measured at Thevenard. A previous comparison in Water Technology (2009) showed that the non-tidal water level variations at Thevenard were reasonably representative of the tidal residuals along much of the coast in the general area, even though Thevenard is approximately 400 km from Investigator Strait. The raw residual water level record from Thevanard was passed through a low pass filter and a 9.5 hour phase lag was applied.

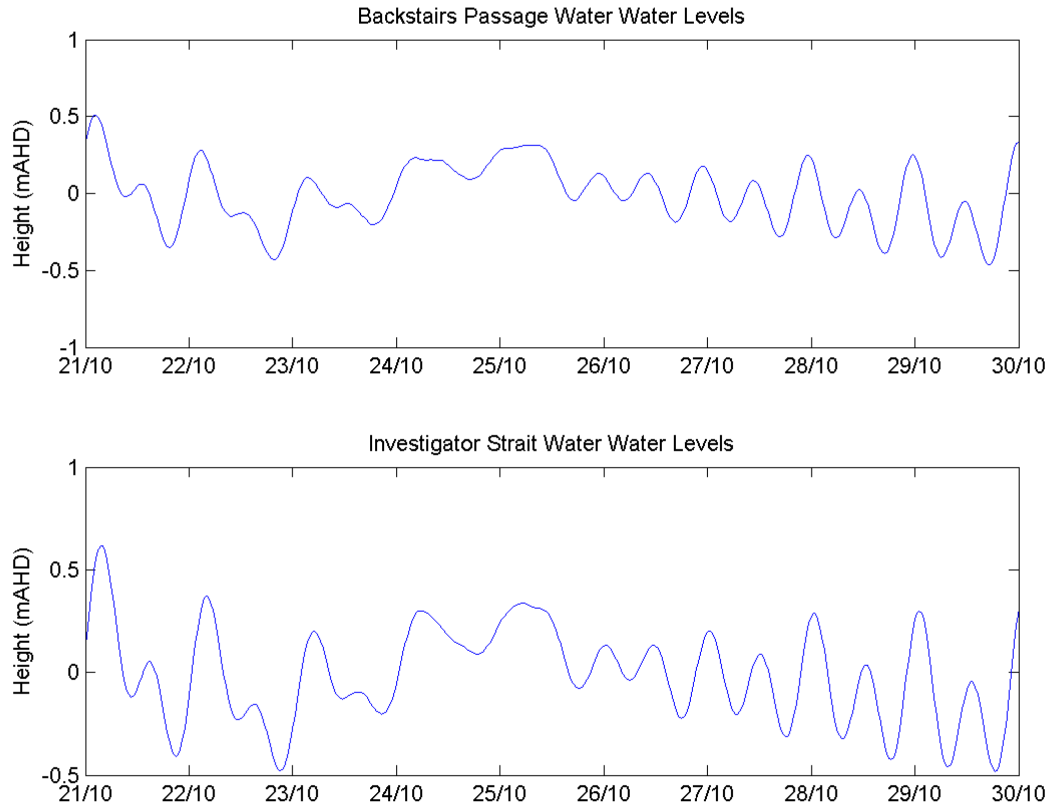

Figure 2-2 2D Model Water Level Boundary Conditions

2.1.3 Wind Forcing

Wind shear on the water surface drives secondary circulations within Gulf St Vincent. A temporally varying wind field was created using wind measurements recorded by the Bureau of Meteorology (BoM) at the Adelaide Airport weather station.

2.2 Model Validation

Validation of the two-dimensional hydrodynamic model consisted of comparing the model's ability to replicate astronomical tides and meteorologically-driven water level variations at the Port

Adelaide Outer Harbour. Water level variations within Gulf St Vincent can also be caused by low-frequency shelf waves propagating into the Gulf, and local wind forcing within the Gulf. Figure 2-3 shows a comparison of observed and modelled water levels at Port Adelaide outer Harbour, followed by a breakdown comparing the observed and modelled astronomical tidal components and the residuals (which represent the meteorologically-driven water level variations). The resulting model performance is good. The r^2 correlation coefficient for the astronomic tides was 0.998, while the residuals was 0.790, resulting in an overall water level correlation coefficient of 0.901.

It is noted that a significant tidal residual of approximately 0.3m was observed coincident with the dodge tide event around the 25th October. The propagation of the tidal residual past Port Stanvac during the dodge tide event increased current speeds beyond that which would be expected under a pure dodge tide condition. The increased difficulty in predicting current fields at the outfall associated with meteorlogical forcings is considered to have had some bearing on the level of agreement achieved between the modelled salinities compared to those observed and is discussed in more detail in later sections of the report.

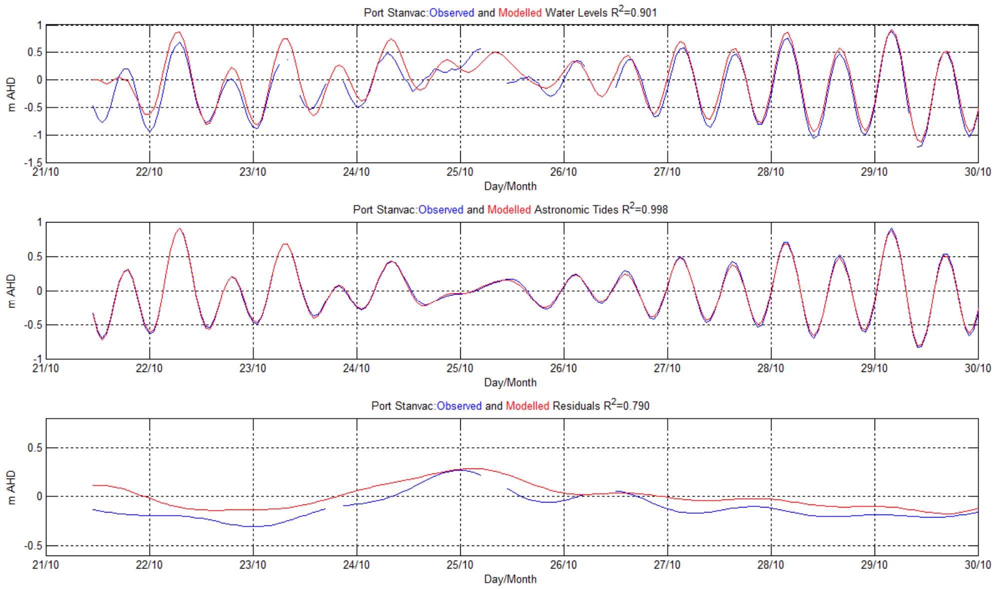

Figure 2-3 Comparison of Observed and Modelled Water Levels at Port Adelaide Outer Harbour

3. THREE-DIMENSIONAL HYDRODYNAMIC MODEL

Detailed three dimensional, mid-field numerical modelling of the hydrodynamics in the coastal waters in the vicinity of Port Stanvac was undertaken to model the dilution performance of the Adelaide desalination plant outfall. The following sections describe the three dimensional model validation. The modelling was carried out using the Flexible Mesh (FM) version of MIKE 3. This uses finite volume techniques to solve the variable density Reynolds-averaged Navier-Stokes equations for the conservation of mass and momentum. The model domain can be described as a combination of triangular and quadrilateral elements of varying size.

MIKE 3 has the capability to model the effects that both salinity and temperature have on the density of water and includes eddy viscosity formulations to take into account the effects that sub-grid scale turbulence has on mixing. For horizontal mixing, a “Smagorinsky”-type formulation is used to calculate time and space varying eddy viscosity coefficients as a function of the local flow conditions. For vertical mixing, a more sophisticated "k-ε" formulation is used to include the effects that density stratification can have on reducing the effects of vertical mixing.

3.1 Domain Schematisation

The model domain covers an area 20 km by 11.5 km, and is shown relative to the two-dimensional Gulf model in Figure 3-1. The horizontal resolution of the model is higher in the vicinity of the outfall diffuser and intake riser where the density gradients are the greatest. The vertical layering is represented by 17 layers of equidistant thickness (sigma coordinates), resulting in a vertical resolution of approximately 1 m at the location of the outfall diffuser.

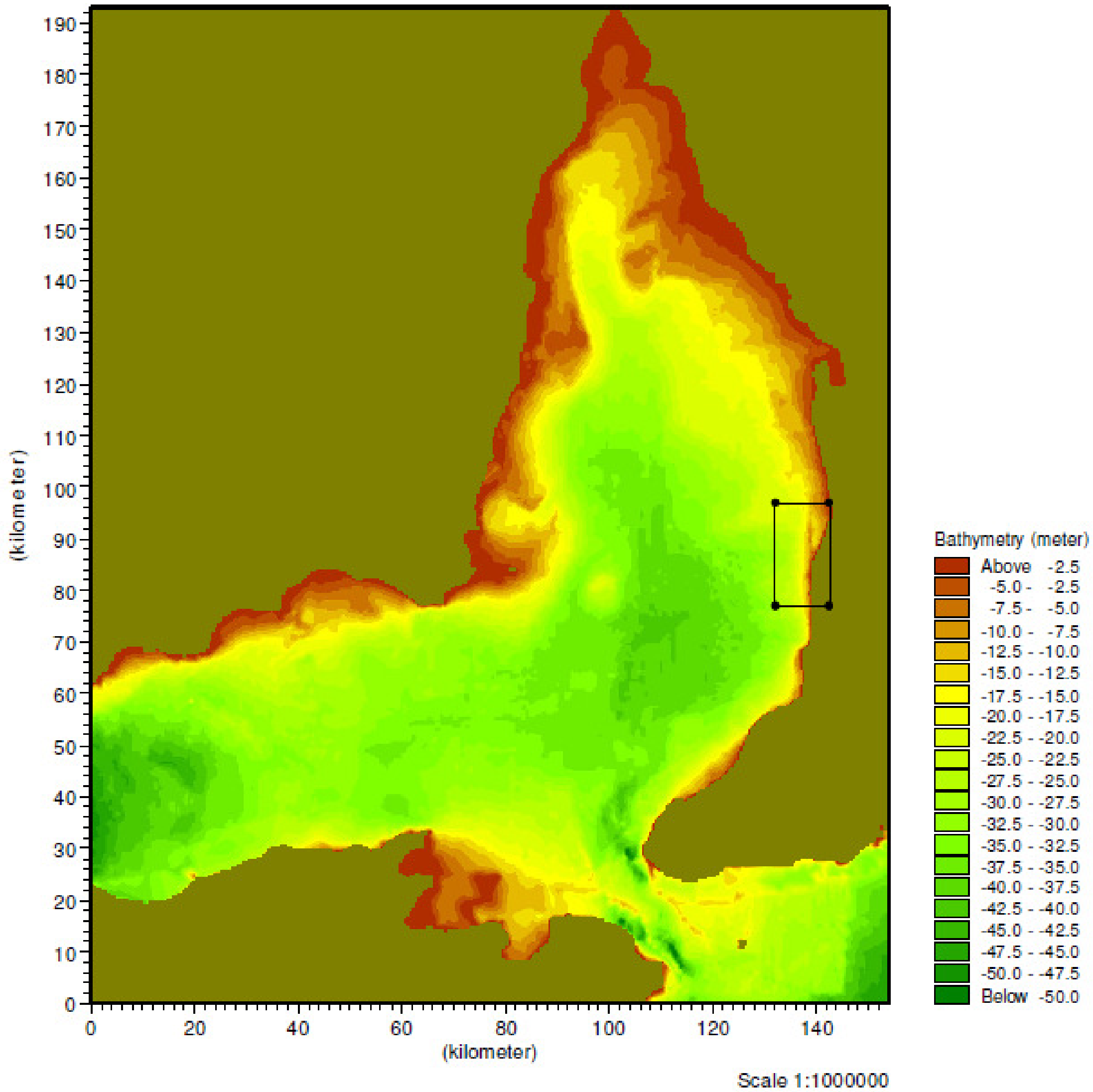

Figure 3-1 Mid-field Three Dimensional Model Extent Compared to Gulf St Vincent Model.

3.2 Initial conditions

The model was simulated from 11 am on the 21st of October 2012 until 11 pm on the 30th of October 2012, allowing sufficient spin up time prior to the dodge tide event centred on the 25th. The background temperature and salinity were set to 16°C and 36.31 PSU respectively, as recorded by the ambient CTD logger (AMB MPE) on the model start date/time. The salinity reading had a correction factor applied by Adelaide Aqua.

3.3 Boundary Conditions

The mid-field model hydrodynamic boundaries were derived directly from the results of the Gulf St Vincent model. The mid-field model is effectively nested within, but decoupled from the Gulf St Vincent model. The mid-field model boundaries were therefore fully specified, in a two-dimensional sense, to the multiple forcing processes that influence the hydrodynamics of the Gulf St Vincent and at Port Stanvac.

3.4 Intake and Outfall

3.4.1 Intake and Outfall Flow Rates

The intake and outflow discharge rates over the validation period are displayed in Figure 3-2 below. The intake flow rate represents only the flows that passed through the reverse osmosis. Some of the intake flows bypassed the plant and were returned via the outfall, the intake and outflow rates are therefore not equivalent. The intake flow rate was applied to the model at the location of the intake riser, while the outfall discharges were applied as per the technique described in Water Technology (2009).

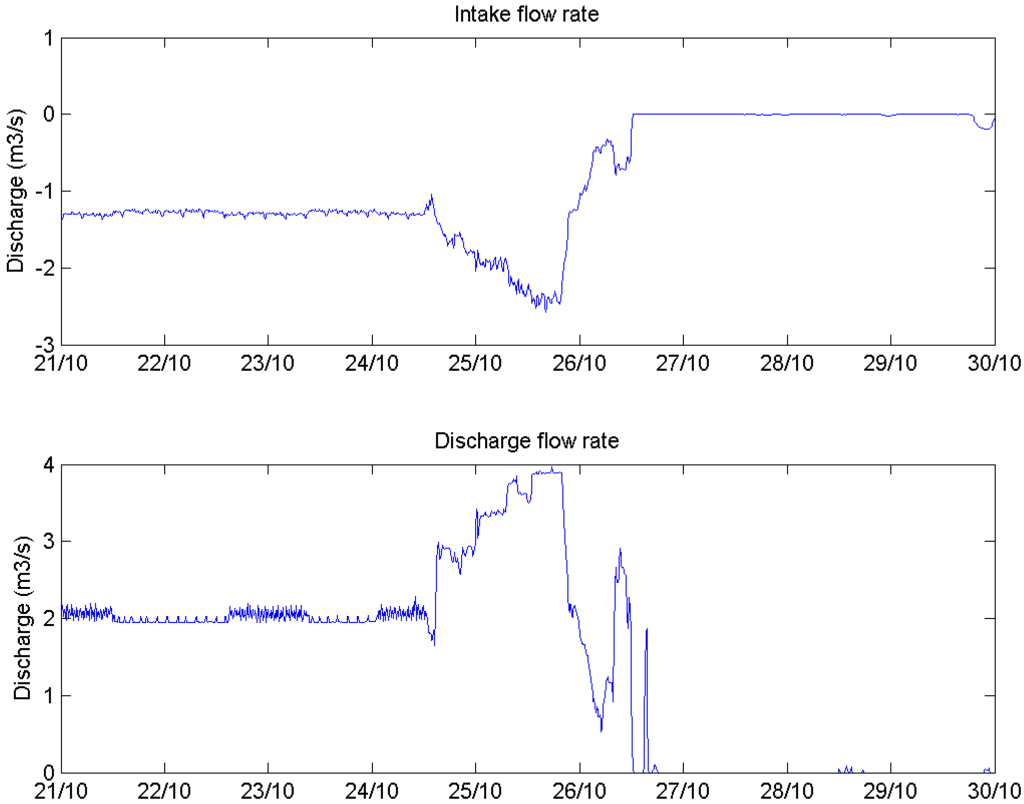

Figure 3-2 Intake and Outfall Flow Rates

3.4.2 Outfall Temperature and Salinity

The outfall temperature and salinity were kept constant at 16°C and 72.5 PSU respectively. For the purposes of the validation assessment, Practical Salinity Units (PSU) have been considered equivalent to Parts Per Thousand (PPT) unit which is used by Adelaide Aqua in associated publications to this assessment.

3.5 Hydrodynamic Validation

Validation of the three dimensional hydrodynamic modelled currents has been undertaken by comparison with ADCP current data at a location close to the outfall. The ADCP was installed at monitoring location MP2 (refer to Figure 3-6 for location). The observed and modelled u- and v-velocity components were compared at ADCP bins and model layers equivalent to approximately 2m (bottom), 10m (middle) and 16m (top) of the water column. Figure 3-3 to Figure 3-5 below display the modelled u and v velocity components compared to the ADCP data.

The modelled current velocities are in general considered to be in reasonable agreement to the ADCP data. The most significant deviations between the observed and modelled current velocities occur during the dodge tide on the 25th October and are associated with meteorologically forced water level variations propagating through the Gulf St Vincent from the Southern Ocean. Attempts to improve the description of boundary and wind field forcing on the two dimensional model was undertaken to determine whether the modelled current fields in the three dimensional model could be improved. However, only relatively minor improvements were able to be achieved. The discrepancies between the observed and modelled current fields in the vicinity of the outfall diffuser during the dodge tide event are considered to have impacted the level of agreement achieved by the modelled salinities compared to those observed and is discussed in more detail in later sections of the report.

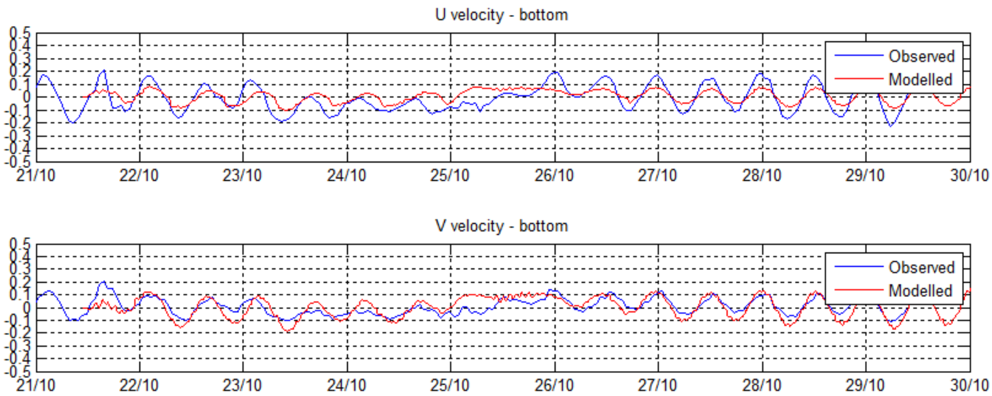

Figure 3-3 Observed Versus Modelled Velocities Near the Surface (z = 16m)

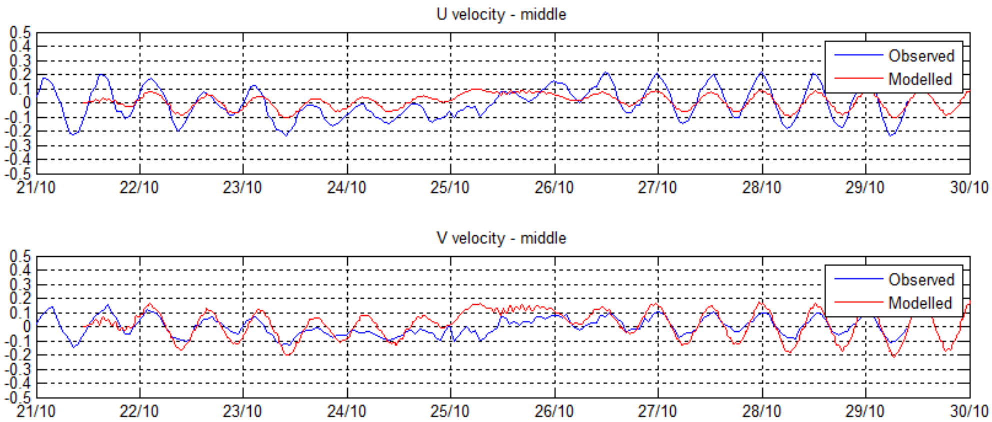

Figure 3-4 Observed Versus Modelled Velocities at Mid-depth (z = 10m)

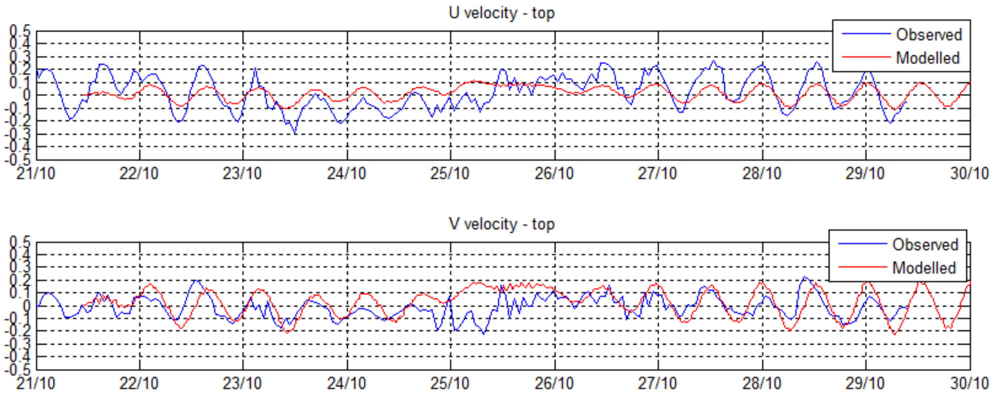

Figure 3-5 Observed Versus Modelled Velocities Near the Bed (z = 2m)

3.6 Salinity Validation

3.6.1 Observations

Modelled salinity was compared to measurements made via a combination of permanently and temporarily moored conductivity-temperature-depth (CTD) loggers, and via spot CTD measurements collected on the afternoon of the 25th of October during the dodge tide. Figure 3-6 displays the location of the moored CTD loggers and spot CTD measurement locations in relation to the outfall diffuser.

There are five permanently installed CTD's which are continuously measuring and recording conditions immediately around the diffuser. These are labelled MP1 to 4 and AMBMP2. For the purpose of this validation modelling exercise, five more CTD's were installed further away from the diffuser to better capture the plume extent and better record ambient conditions. These are labelled MPA to D and AMBMPE in Figure 3-6.

Adelaide Aqua has had ongoing difficulty in calibrating the CTD loggers. Therefore a comprehensive analysis process was undertaken where-by recorded salinities were post-processed and a correction factor applied in most cases. Details of this correction process may be found in Adelaide Aqua (2012).

On the 25th of October during the dodge tide event, 23 spot CTD measurements were made by lowering a CTD probe off the side of a boat to locate the extent of the plume and its salinity at the seabed. These 23 monitoring locations are shown in Figure 3-6.

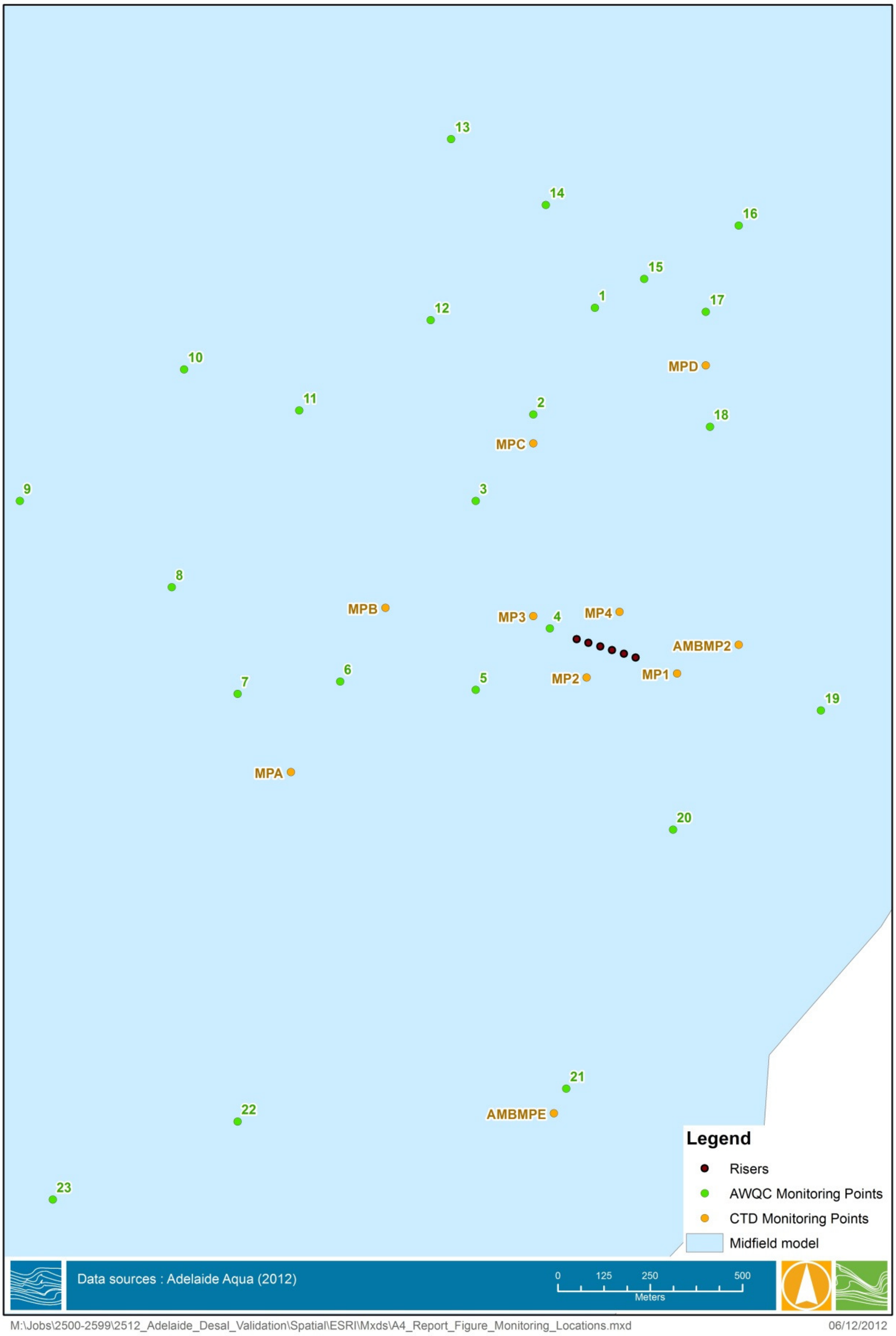

Figure 3-6 Salinity Monitoring Locations

3.6.2 Salinity Validation

Modelled and observed salinities at each of the stationary CTD locations are compared for the modelled period in Figure 3-7 to Figure 3-11. Table 3-1 compares the minimum and maximum salinities during the 24 hour dodge tide period starting from 12:00 am on the 25th of October.

Figure 3-12 displays the spatial distribution of observed and modelled maximum bed salinities around the outfall during the 24 hour dodge tide period starting from 12:00am on the 25th of October.

Table 3-1 Comparison of Modelled and Observed Min and Max Salinities over the 25th and 26th of October 2012

		MP1	MP2	MP3	MP4	MPA	MPB	MPD	AMBMPE
Modelled	Min	36.3	36.4	36.4	36.3	36.5	36.4	36.3	36.3
	Max	37.1	37.4	37.3	37.4	36.9	37.1	36.5	36.3
Observed	Min	36.7	36.8	36.8	37.0	36.5	36.7	36.2	36.3
	Max	37.2	37.3	37.2	37.3	37.0	37.1	36.7	36.4
Obs – mod	Min	0.4	0.4	0.4	0.7	0.0	0.3	-0.1	0.0
	Max	0.1	-0.1	-0.1	-0.1	0.1	0.0	0.2	0.1

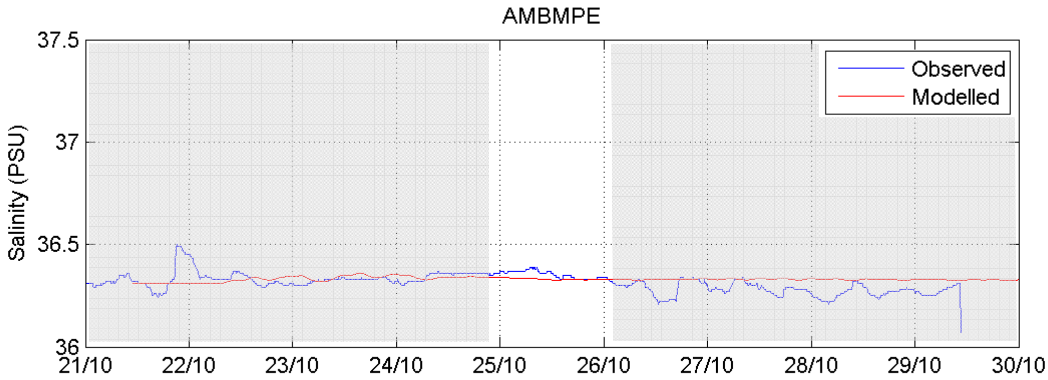

Figure 3-7 Modelled and Observed Salinity at AMBMPE

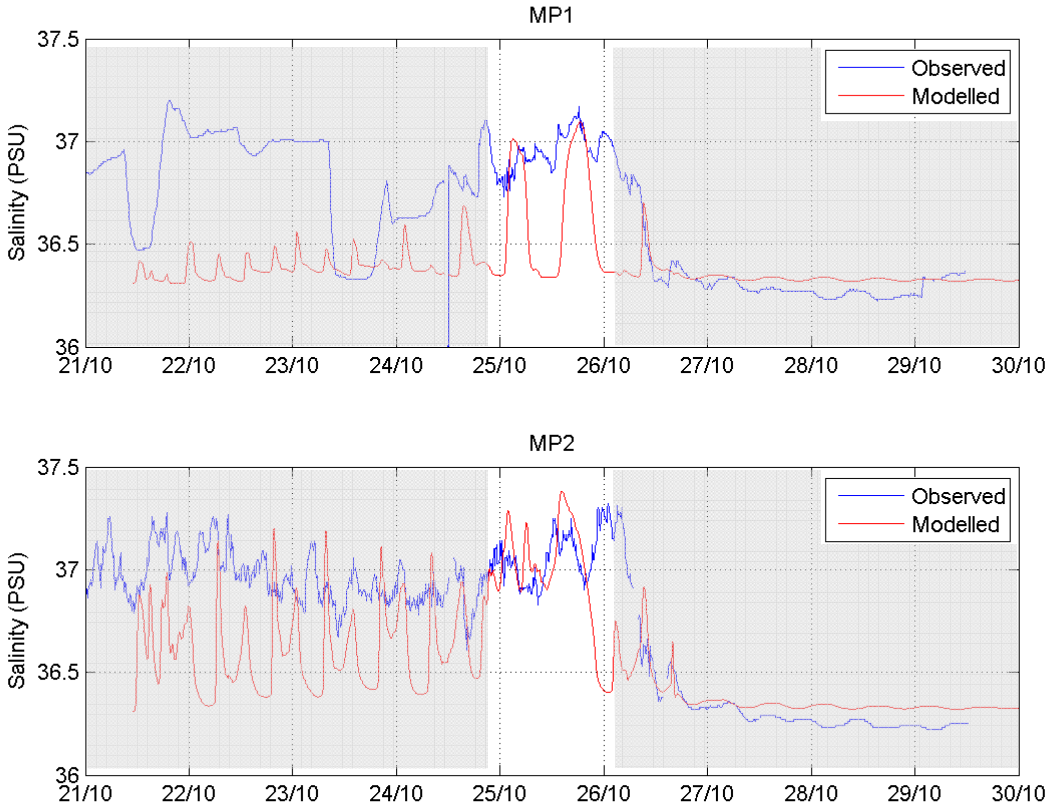

Figure 3-8 Modelled and Observed Salinity at MP1 and MP2

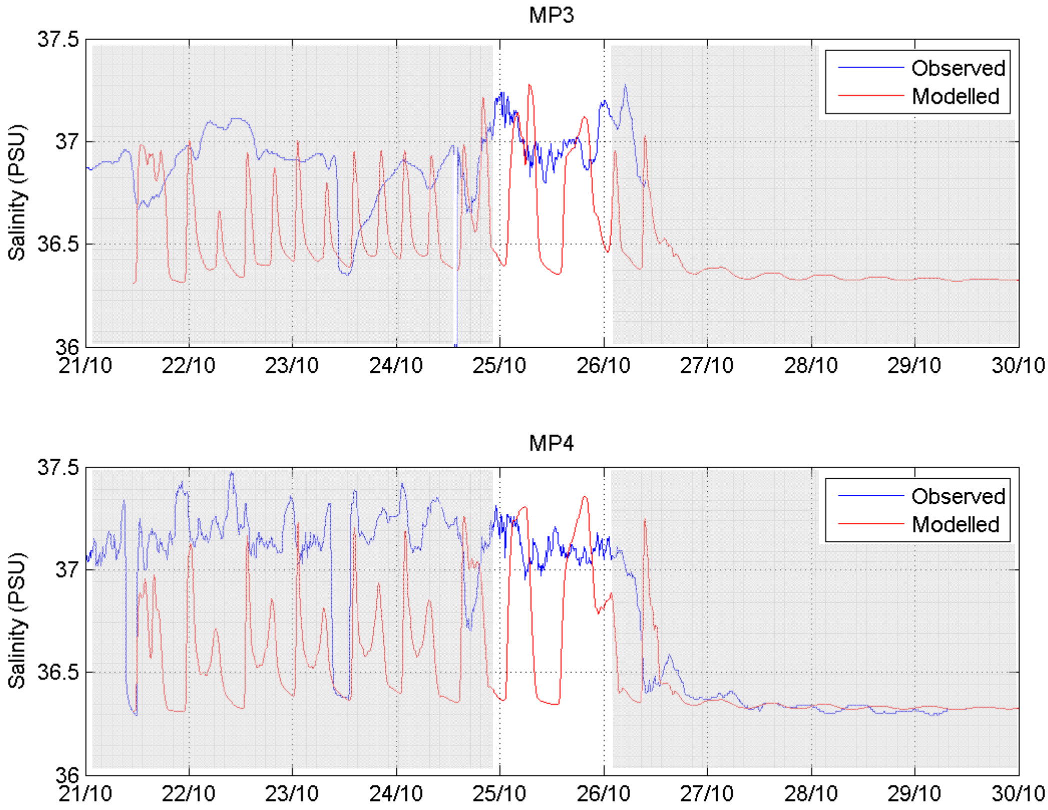

Figure 3-9 Modelled and Observed Salinity at MP3 and MP4

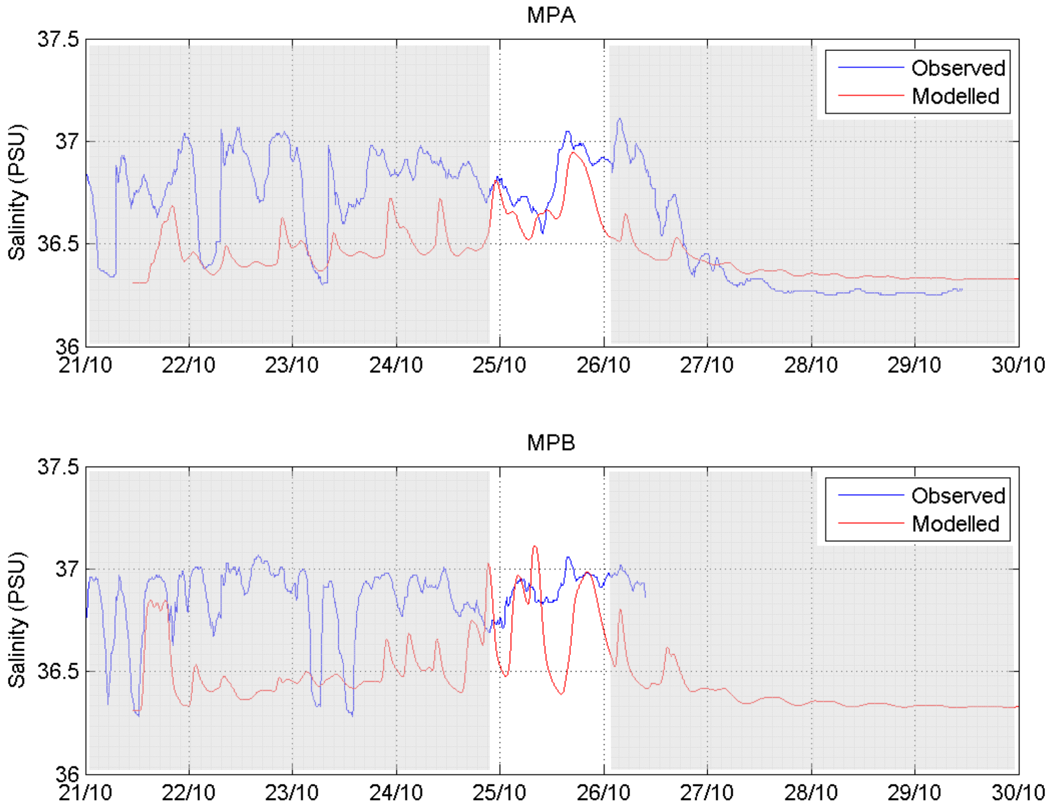

Figure 3-10 Modelled and Observed Salinity at MPA and MPB

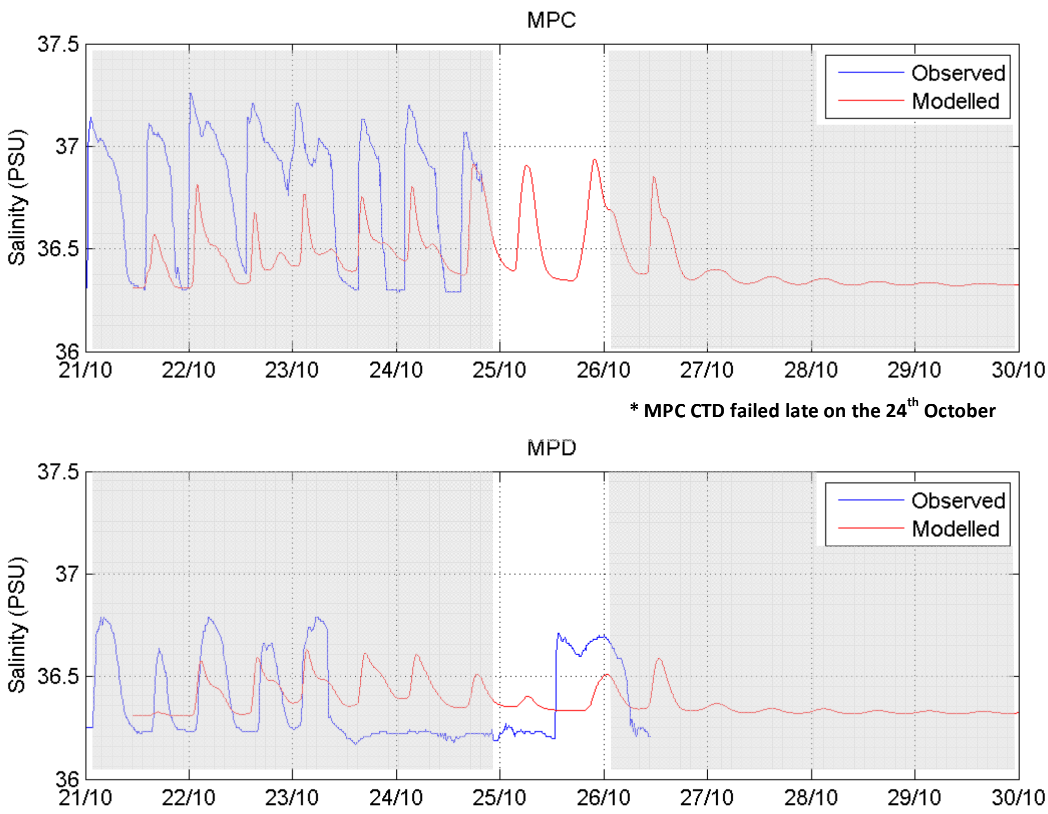

Figure 3-11 Modelled and Observed Salinity at MPC and MPD

The ability of the model to reproduce the observed plume extent at the bed was determined by spatially comparing the observed and modelled maximum salinities between the 25th and 26th of October.

The observed salinity plume was mapped by interpolating the salinities measured at the 23 AWQC monitoring locations and the maximum salinities measured by the temporary and permanent CTD's over the period of interest. Refer to Figure 3-6 for monitoring locations.

Figure 3-12 shows the modelled and 'observed' plume extents.

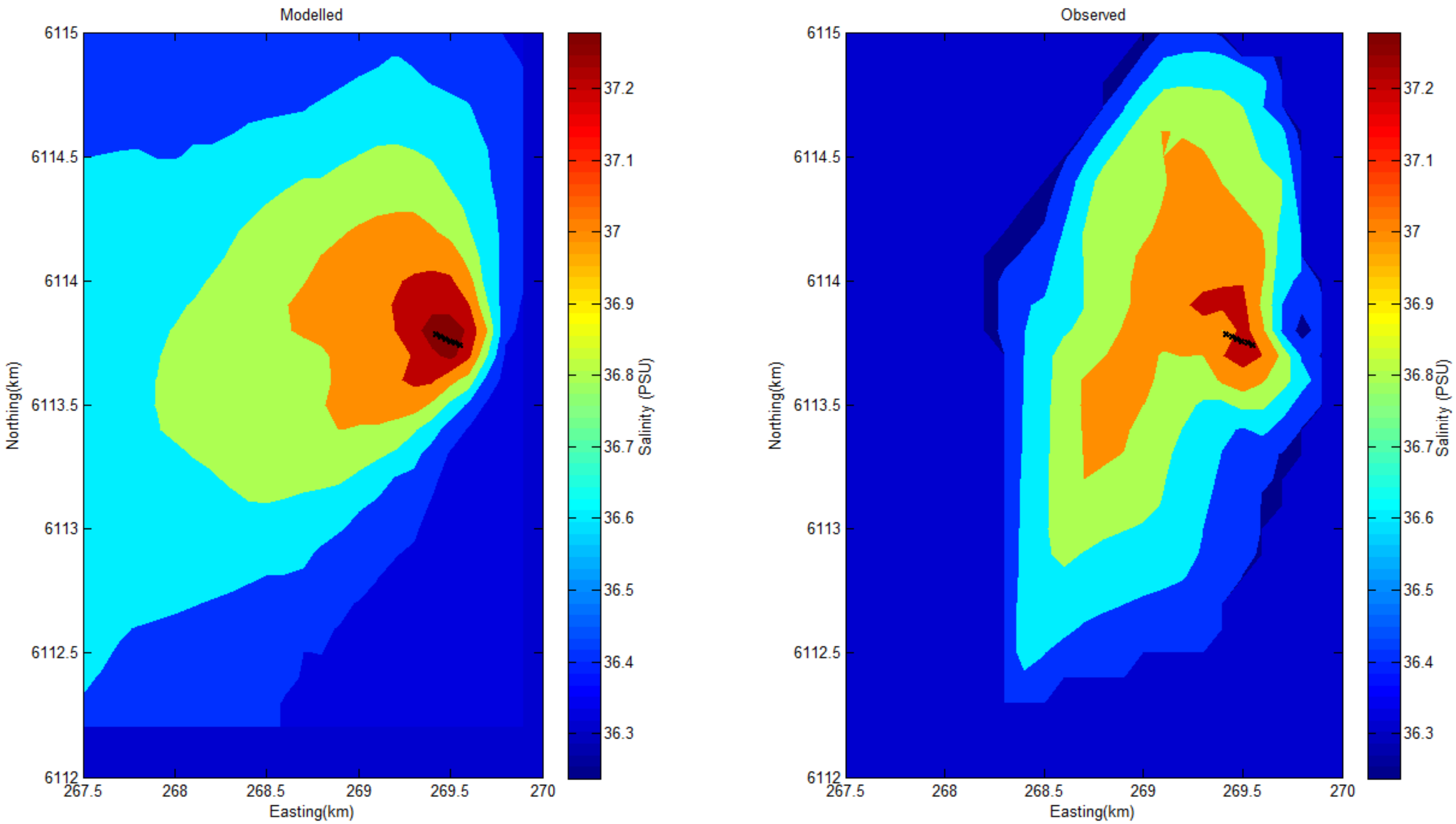

Figure 3-12 Comparison of Maximum Bed Salinity between the 25th and 26th of October 2012

4. DISCUSSION

A validation exercise has been undertaken by comparing modelled hydrodynamic and salinity conditions around the outfall to those observed with the plant operating at 100% capacity during a dodge tide. The following summarises the results of the comparisons of the magnitude, spatial scales and temporal variability of the modelled salinity compared to the observed salinity around the outfall during the dodge tide event:

- During the 24 hour dodge tide period, the modelled salinities at the CTD loggers directly around the outfall (MP1-MP4) are considered to show reasonable levels of agreement in terms of maximum salinity, however there are some significant temporal differences. It is expected that some of the temporal differences between the observed and modelled salinity at these locations close to the outfall are a function of the known limitations of the modelling method that was applied, which could not fully integrate the initial mixing and subsequent dilution achieved by the diffusers. The high level of agreement however between maximum modelled and observed salinity at these locations during the dodge tide are considered to validate the estimates of the initial plume dilutions that could be expected from the duckbill valves that was developed as part of the diffuser design.
- Further away from the outfall, the comparisons of the modelled salinity compared to the CTD loggers (MPA-MPD) show improved reproduction of the temporal variation in salinity. At these distances from the outfall, the behaviour of the diluted brine plume is influenced by the larger scale tidal and current variations in the region which are resolved by the hydrodynamic model. It is considered however that the level of agreement achieved at these CTD logger locations was somewhat impacted by the extent of the meteorologically forced current variations that were observed during the dodge tide. Nevertheless, the maximum salinities during the dodge tide period are generally in good agreement between those observed and the modelled results at these locations.
- The comparison between the modelled and observed spatial extents of the maximum bed salinities around the outfall during the dodge tide period are considered to demonstrate good levels of agreement in terms of the general plume location and extent. The relative magnitudes and the spatial extents of areas of higher salinities around the outfall are also considered to be within expected tolerances. This is considered to provide confidence that the predicted extents and magnitudes of the diluted brine plumes around the outfall under worst case dodge tide scenarios developed as part of the outfall design are valid to within reasonable levels of accuracy.

5. REFERENCES

Adelaide Aqua (2012). Inter-calibration of Salinity Date During Plume Dispersion Test (25-10-2012). White paper.

Water Technology (2009). Adelaide Desalination Project Outfall Dilution Modelling Assessment. Report R01.