Appendix I

Marine Modelling

Gladstone Pacific Nickel Advection Dispersion Modelling

FINAL REPORT

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Title:	Gladstone Pacific Nickel Advection Dispersion Modelling FINAL REPORT
Author:	Dr Michael Barry, Emma Gale, Dr Darren Lyons, Fanny Houdré
Synopsis:	This report describes the numerical modelling of discharges into Port Curtis, QLD, from the proposed Gladstone Pacific Nickel plant. The focus is on the near and far field distribution, extent and concentrations of the pollutants.

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1 INTRODUCTION

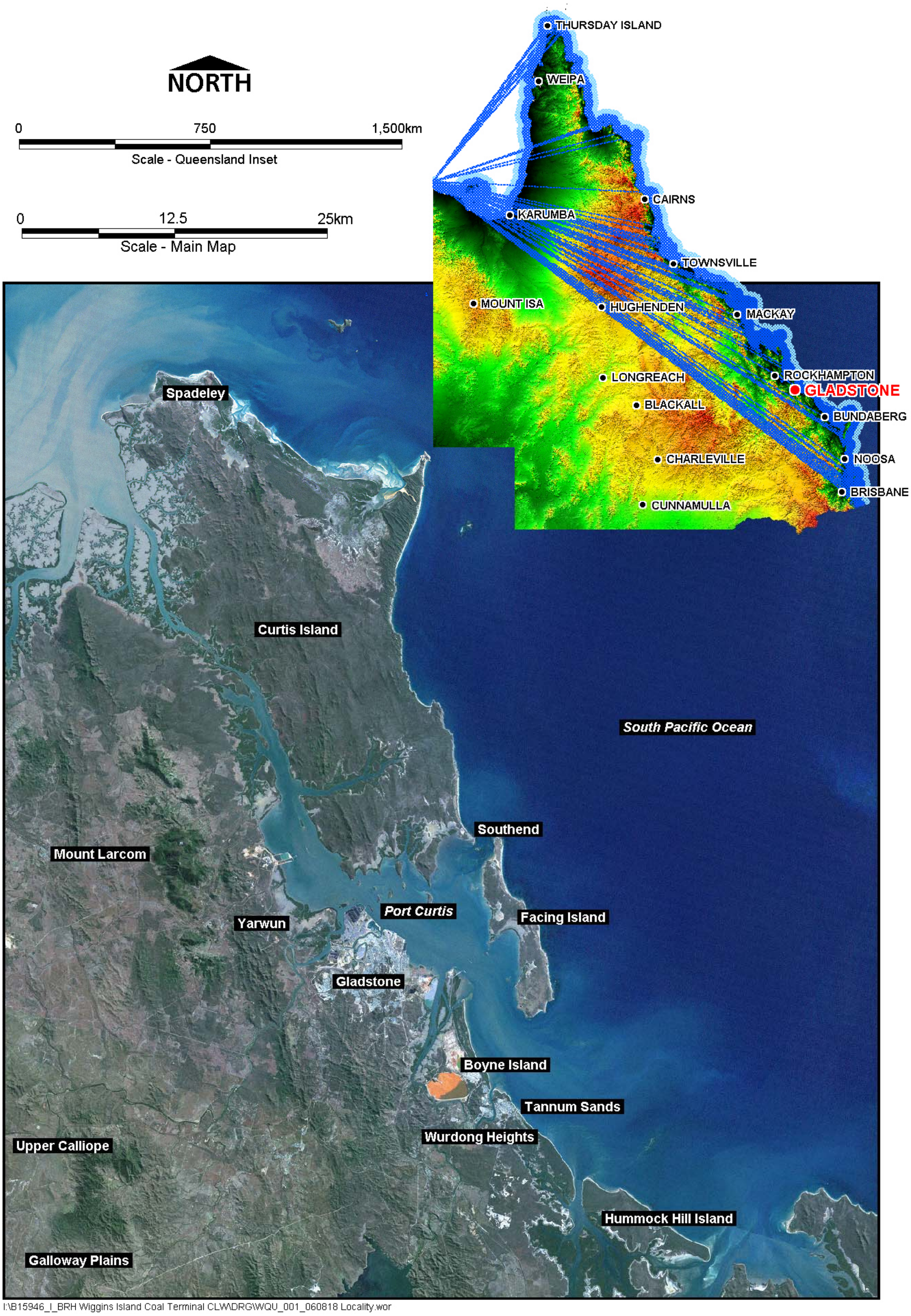
Gladstone Pacific Nickel (GPN) has proposed to establish a nickel plant at Gladstone, QLD (Figure 1-1). As part of the operations of the plant, a primary wastewater stream has been proposed to discharge through a diffuser, into Port Curtis.

WBM has been commissioned by URS Australia to define the near and far field distribution and extent of the discharge plume from the Nickel Plant waste water outfall, for inclusion in an EIS. The specific scope of works that this report covers includes:

- An assessment of the far field extent and distribution of the pollutant plumes generated by the discharge;
- An assessment of the likely dilutions to be achieved for a range of particular pollutants of concern; and
- Likely behaviour of the near field plume and assessment of the associated dilutions.

A modelling approach has been developed and employed to this end. The following presents a description of the development and calibration of a hydrodynamic model for the greater region of Port Curtis and subsequent utilisation of a coupled hydrodynamic-advection dispersion model to investigate the resulting plume distribution in the far field. Near field modelling of the detailed diffuser plume is also described.

It is noted that WBM recommends further detailed modelling be undertaken at a later stage to improve the understanding of specific near field effects, including dynamic behaviour and currents associated with intakes and dilutions. These have not been undertaken here.



Gladstone Regional Map Figure 1-1

2 FAR FIELD HYDRODYNAMIC MODELLING

2.1 Model Development

2.1.1 Background

A hydrodynamic and water quality model of the Port of Gladstone was developed to investigate the hydraulic conditions within the Port and the advection-dispersion characteristics of various water quality constituents.

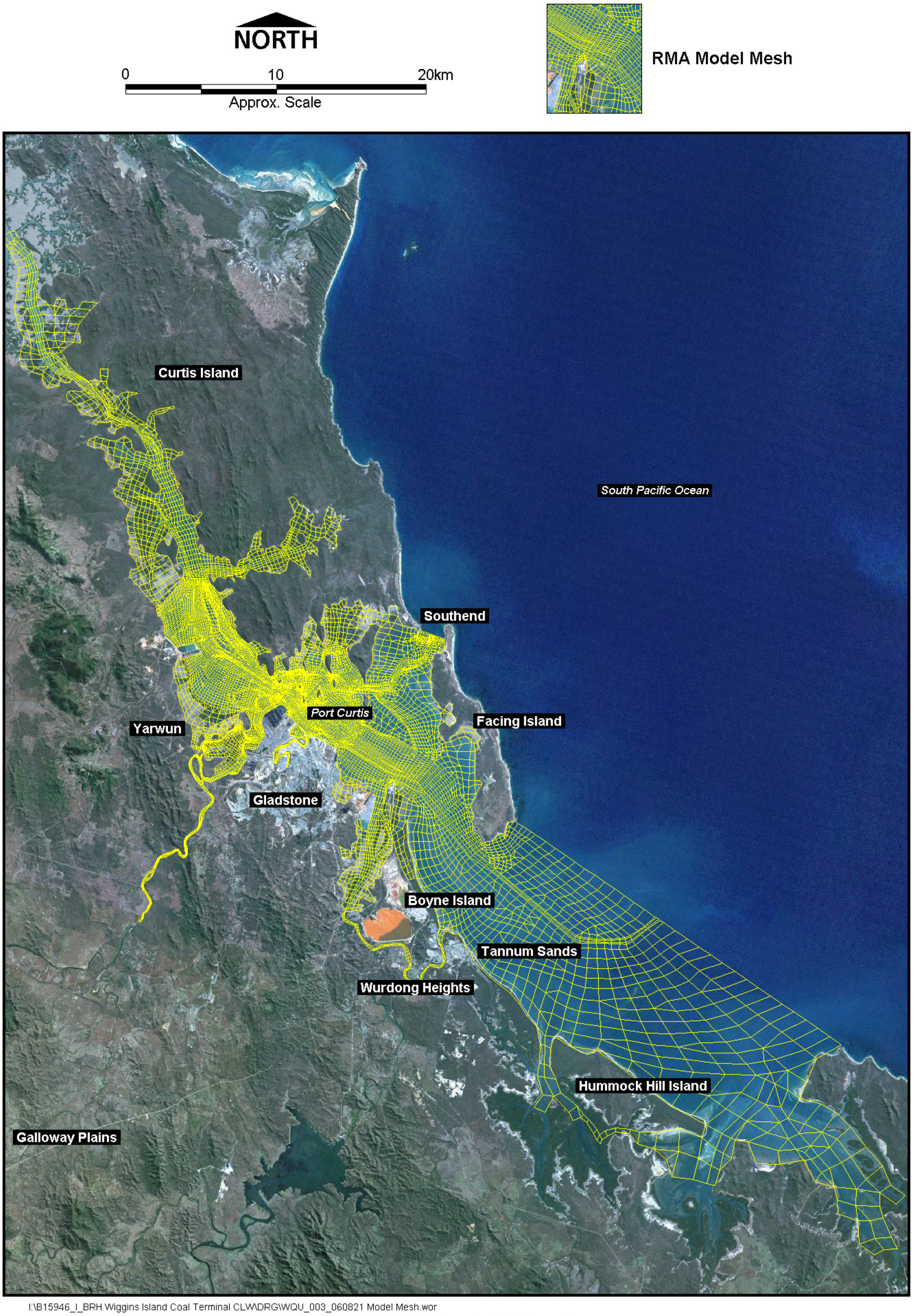
The RMA-10 hydrodynamic model, developed by Resource Modelling Associates, has been applied in this study. RMA-10 is a two-dimensional finite element model. The major advantages of the finite element method in comparison with finite difference based models (such as Mike-21 and TUFLOW) is the functionality of boundary fitted co-ordinates and variable spatial resolution without the requirement for model nesting. This method is particularly appropriate for the Gladstone model given the large study area where the resolution of far field areas remote from the key areas of interest may be decreased, and the computational expense can be concentrated on the key focus areas of the study. Also the boundary fitting capabilities are ideal for the extremely non-uniform footprint of the modelled area and the complex boundaries defined by mangrove/saltpan areas and channel alignments.

2.1.2 Model Extent and Mesh Definition

The model network extends over an area of some 635 km^2, incorporating Port Gladstone and the main inter-tidal areas between Curtis Island and the mainland. The modelled area represents a reach length of approximately 80km extending from Richards Point at the eastern extent to Division Point at the west. The developed model mesh for the study area showing the extent of the model coverage is shown in Figure 2-1. The mesh demonstrates the advantages of the finite element approach with accurate boundary fitting and the ability to vary the spatial resolution.

The model extent includes all the predominant tidal flows into the Port being the main ocean entrance at the eastern model boundary, the North Channel and through the Narrows.

There are a number of tidal tributaries of the Port including the Calliope River, Auckland Inlet, South Trees Inlet and the Boyne River, which are incorporated into the model. The normal fluvial component of flows within these river systems is generally insignificant in relation to the tidal flux. Thus the modelling of the tributaries focuses on representation of the tidal storage and exchange within the system.



RMA Model Mesh for the Port Curtis Region

Figure 2-1

In developing the model mesh, particular focus was given to a number of key areas to ensure a suitable model representation of flow conditions. Where appropriate the resolution of the model mesh was increased to provide a more accurate representation of local conditions. Some key areas are discussed below.

- The flow through the Port is dominated by the main ocean boundary, however the smaller channels of the North Entrance and the Narrows have an impact on the flow distribution within the modelled area. The model resolution has been adapted to define the main channel alignment and bathymetry to adequately define the flow contribution from these channels, particularly at low tides when flows are restricted to narrow channels.

- Within the modelled area there are a number of dredged areas for shipping channels, turning areas and berth pockets. The DEM developed from the bathymetric survey clearly identifies the extents of these features. The model mesh has been developed accordingly to achieve a good representation of conditions within the channels.

- There are numerous islands within the study area (eg. Tide Is., Witt. Is.), some of which have a significant influence on flow distribution. Local adjustment of the mesh resolution has been made to define the land boundaries, and the adjacent flow channels around the islands typically characterised by rapid changes in bathymetry.

- A significant proportion of the model area covers the mangrove and salt pan areas on the tidal fringes. Whilst generally not in critical areas requiring detailed analysis, their influence on tidal hydraulics within the system is important. The major objective in defining these intertidal areas is to represent the contribution to bulk tidal storage volume, which has an impact on the tidal exchange in the system. Thus a relatively coarse resolution has been adopted, sufficient to define the temporary volumetric storage and release over a tidal cycle.

- The Calliope River is a major tributary of the Port of Gladstone. The model has been extended for approximately 25 km upstream of the confluence with the main port channel. This provides the opportunity to adequately define the tidal storage within the river system and simulate the tidal flux. The model mesh has been developed with sufficient detail to enable the flow distribution within the main channel and anabranch to be simulated.

- The confluence of the Calliope River with the main port channel in the vicinity of the berth infrastructure is a key point of interest. The interaction of flows from the river and the main port channel result in complex velocity distributions, which vary considerably in relation to the relative magnitude and timing of flows within the channels.

- Further to the hydraulic interaction at the confluence, the presence of Wiggins and Mud Islands adds complexity to the local hydraulics. This is particularly the case at low tide where low flow channels form around the islands. The resolution of the mesh has been adapted to represent these features and simulate the wetting and drying characteristics of the islands and associated development of low flow channels, impacting on the local hydraulic conditions.

2.1.3 Bathymetry

A Digital Elevation Model (DEM) of the study area was derived from various survey components. A plot of the DEM representing the bathymetry of the model region is shown in Figure 2-2.

In developing the hydrodynamic model, consideration was given to the underlying bathymetry in defining the mesh configuration. For example, model resolution was enhanced at locations of rapidly varying bathymetry or expected high velocity/flow regions based on main channel definition.

A point inspection of the DEM was used to define the bed level at the model computation points (nodes) located at the vertices of the individual elements of the mesh.

2.1.4 Boundary Conditions

The developed model extent included a number of open boundaries requiring the definition of boundary conditions. These boundary conditions defined the forcing functions to drive flow in and out of the modelled area. Flow within the model area was dominated by tidal conditions and the main tidal fluxes across the model boundaries were located at:

1 Main Ocean Boundary – extending from Richards Point on the Rodds Peninsula to East Point on Facing Island.

2 North Entrance – located across the North Channel entrance between Facing Island and Curtis Island.

3 Division Point – located across the entrance to The Narrows providing a tidal connection between Port of Gladstone and the Fitzroy River Estuary.

Concurrent recording of tidal elevations at the boundary locations enabled water level time series to be applied at each boundary as the model forcing condition.

The main ocean boundary was approximately 26 km in length between Richards Pt and Facing Island. Over this length the tidal elevations between the end points were expected to show variations both in magnitude and timing. In this instance a common water level time series for each model point across the entire length of the boundary was not appropriate. A better representation of this boundary, which was applied in the model, utilises a linear variation in tidal elevation between the end points.

The North Entrance and Division Pt boundaries, being much shorter than the ocean boundary, apply a common water level across the length of each boundary line, representative of the tidal elevation at each location.

There were a number of tidal tributaries incorporated in the model, examples being the Calliope and Boyne Rivers. The normal fluvial component of flow within these river systems was insignificant in relation to the tidal flux. As such no additional inflows at the upstream model boundaries of these tributaries were included in the model.

2.1.5 Material Properties

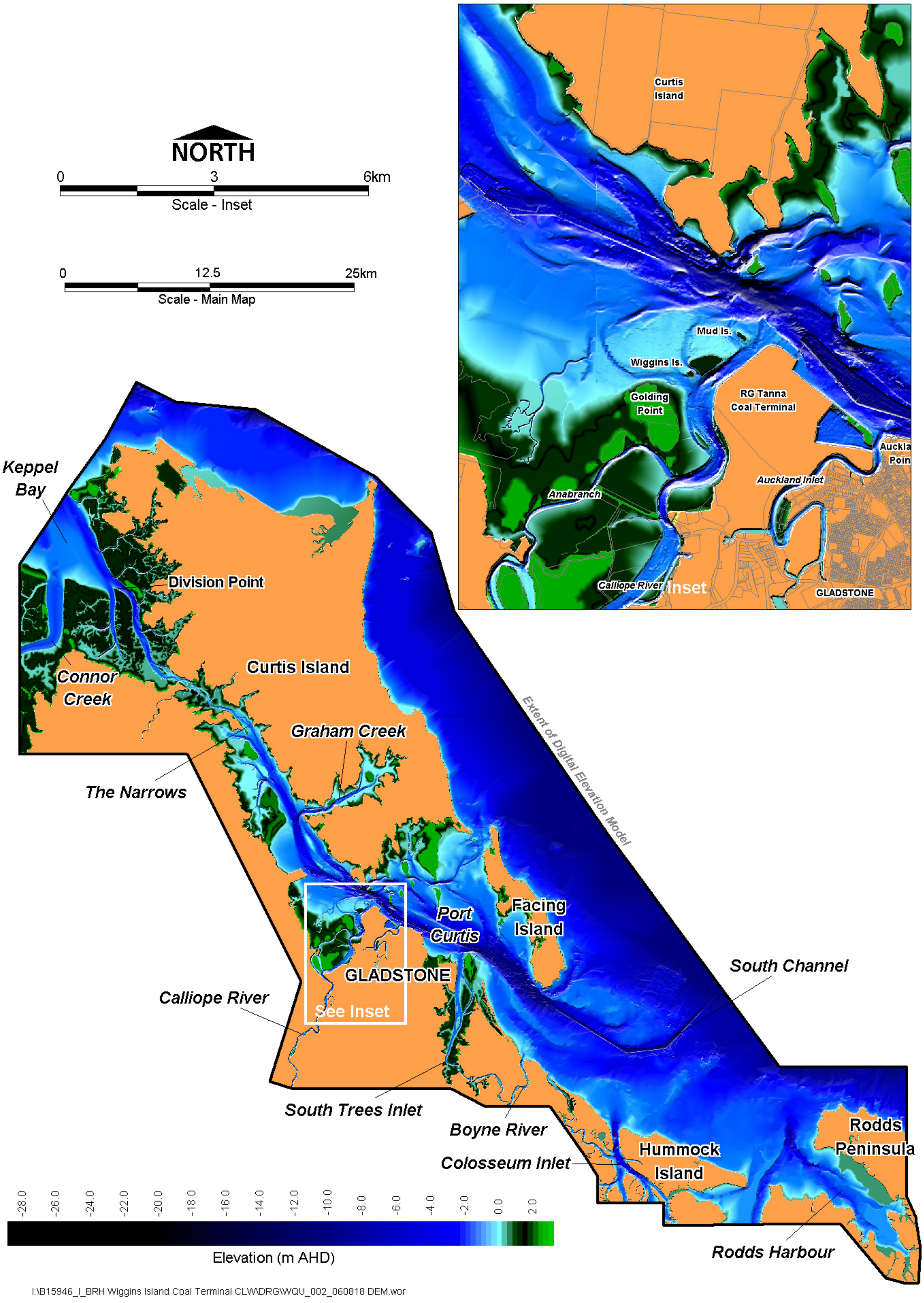
Within the RMA model, various hydraulic properties, for example hydraulic roughness, can be assigned to groupings of model elements. This involves the specification of a spatial distribution of various material types with common properties. For example all model elements representing mangrove areas can be given a material type classification, from which it is possible to prescribe a common Manning's roughness coefficient. A representation of this material classification adopted for the model is shown in Figure 2-3. The figure shows a detail area of the model within the main Port region with a central inset displaying the material distribution over the entire model domain.

2.1.6 Continuity Checks

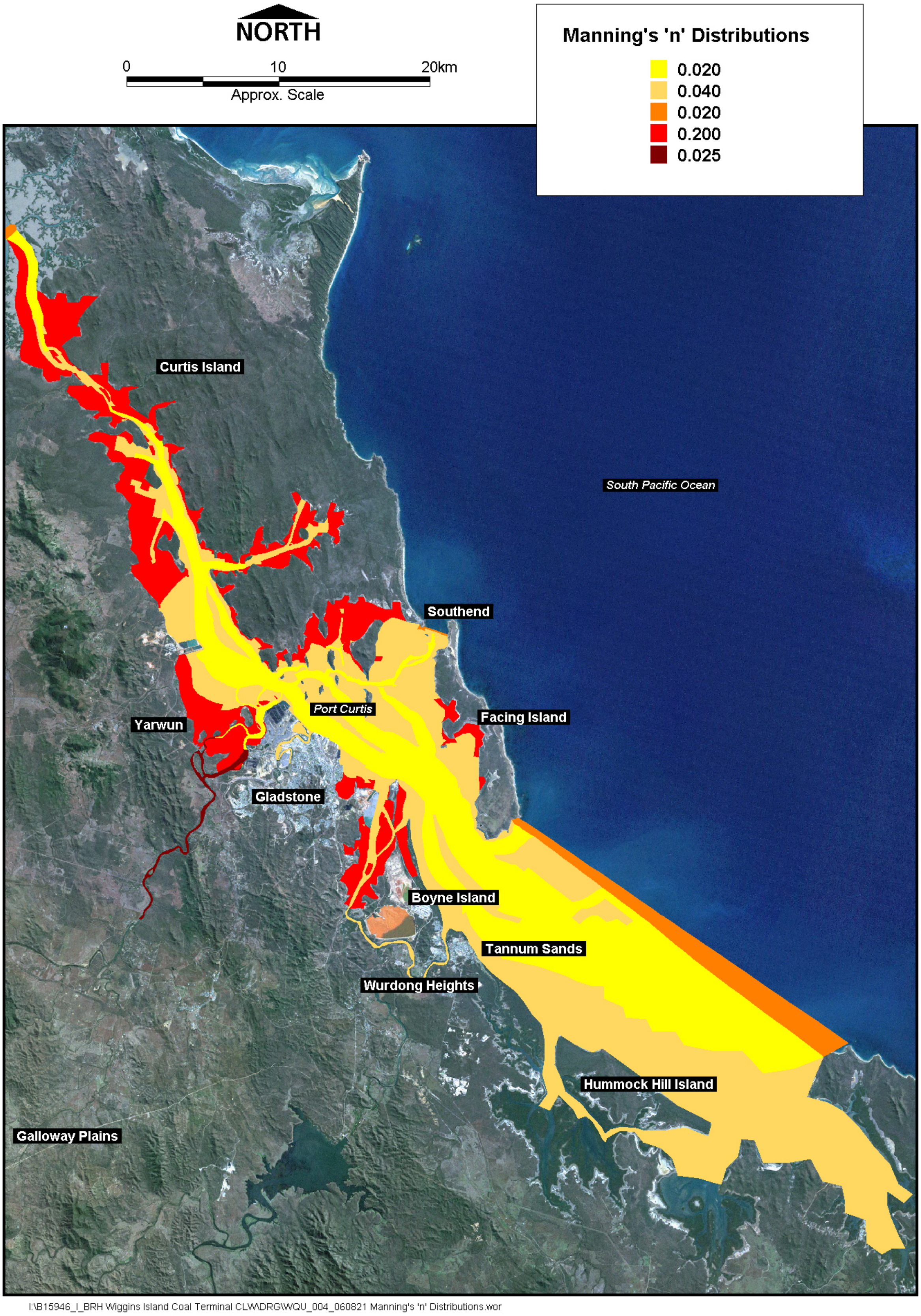
A validation exercise of the model network was undertaken to ensure mass continuity. This is important to verify that the numerical solution provides a good representation of the total mass/flow balance in the system without spurious losses or gains. This process utilises a steady-state model simulation using defined boundary inflows. Various continuity lines can be defined to check the flow balances for cross sections of the model domain.

The boundary conditions adopted for the continuity checks include a steady state inflow of 10,000 m^3/s at the main Port Gladstone boundary and a 1,000 m^3/s outflow for the Calliope River at its upstream model extent. These flows are representative of the peak spring tide flows in the system. A constant water level of 2.5m AHD was adopted at the North Entrance and Division Point boundaries, ensuring all mangrove/saltpan areas of the model are wet.

The locations of continuity lines are shown in Figure 2-4 with flow continuity results summarised in Table 2-1. The total flux through the system is 10,000m^3/s being the adopted ocean boundary inflow, with a fixed proportion of 10% taken through the Calliope River (simulated as 997 m^3/s). The flow split at the outflow boundaries at the North Entrance and Division Pt is 8,611m^3/s (86.1% of total flow) and 392 m^3/s respectively (3.9% of total flow). The combined model outflow of 10,000 m^3/s matches the total inflow. The flow distributions at intermediate sections of the model also indicate good model continuity (+/- 5% variation from expected flow).



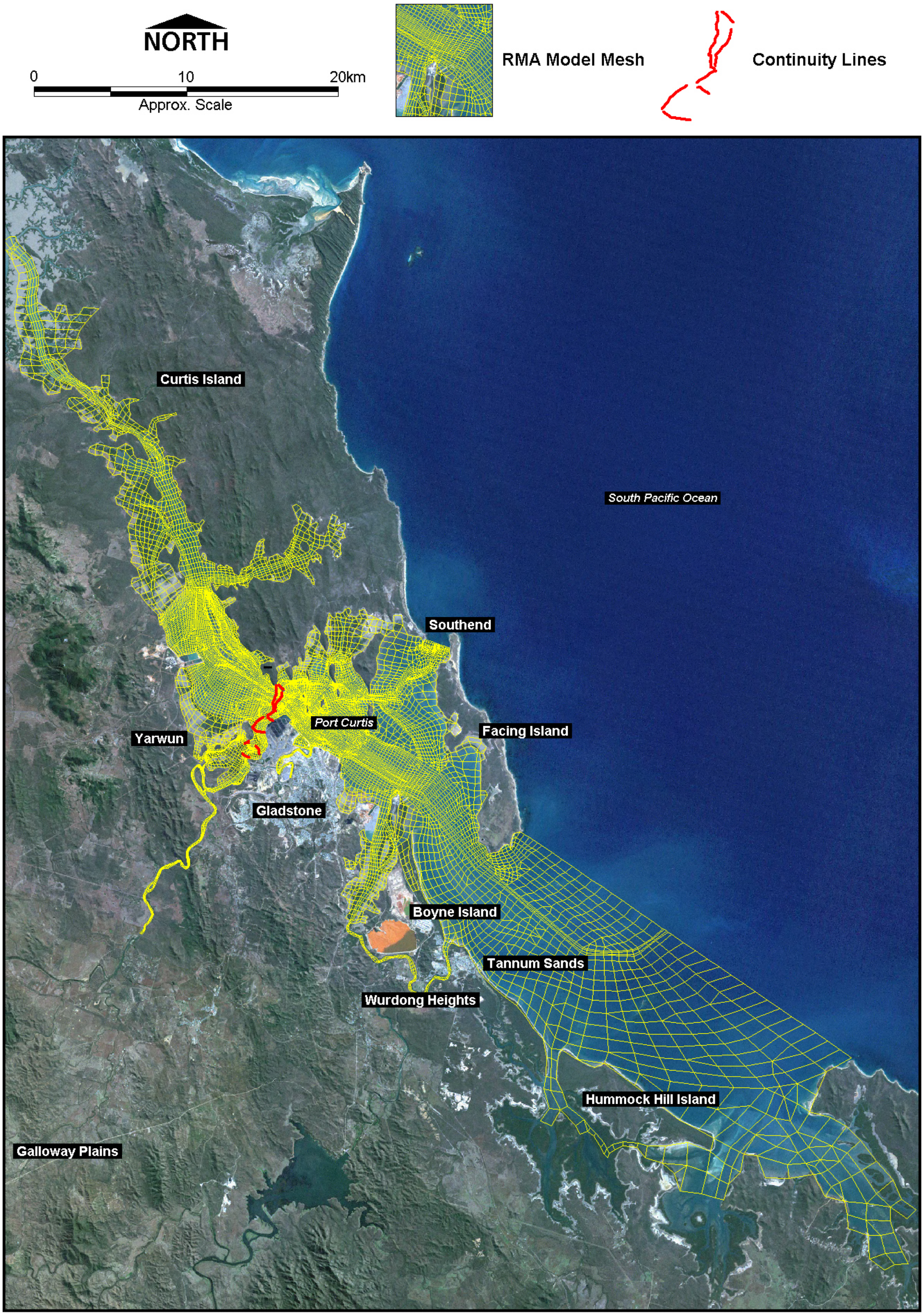
Bathymetry of the Model Area **Figure 2-2**



Material Distributions **Figure 2-3**

Table 2-1 Model Continuity Checks

Continuity Line	Simulated Flow (m^3/s)	Flow Summations		
		Combination	Expected Flow	Combined Flow
A	10,000	C + D	10,000	10,042 (+0.4%)
B	9,910	E + F + G	10,000	10,005 (+0.1%)
C	6,509	E + K + M	10,000	10,000 (+0.0%)
D	3,535	H + I	1,000	1,026 (+2.6%)
E	8,611			
F	927			
G	467			
H	733			
I	293			
J	992			
K	997			
L	389			
M	392			



Continuity Lines Locations

Figure 2-4

2.2 Calibration

2.2.1 Calibration Data

Field data were collected over a period between 26th April 2006 and 08th May 2006 to provide information for model calibration. The data collected included continuous time series of tidal water elevations using fixed point tide gauges and flow/velocity distribution data for defined transects using Acoustic Doppler Current Profiler's (ADCPs). Further calibration data was obtained from a bottom mounted ADCP in the main channel. The location of tide gauges, the ADCP transects and the bottom mounted ADCP location are shown in Figure 2-5.

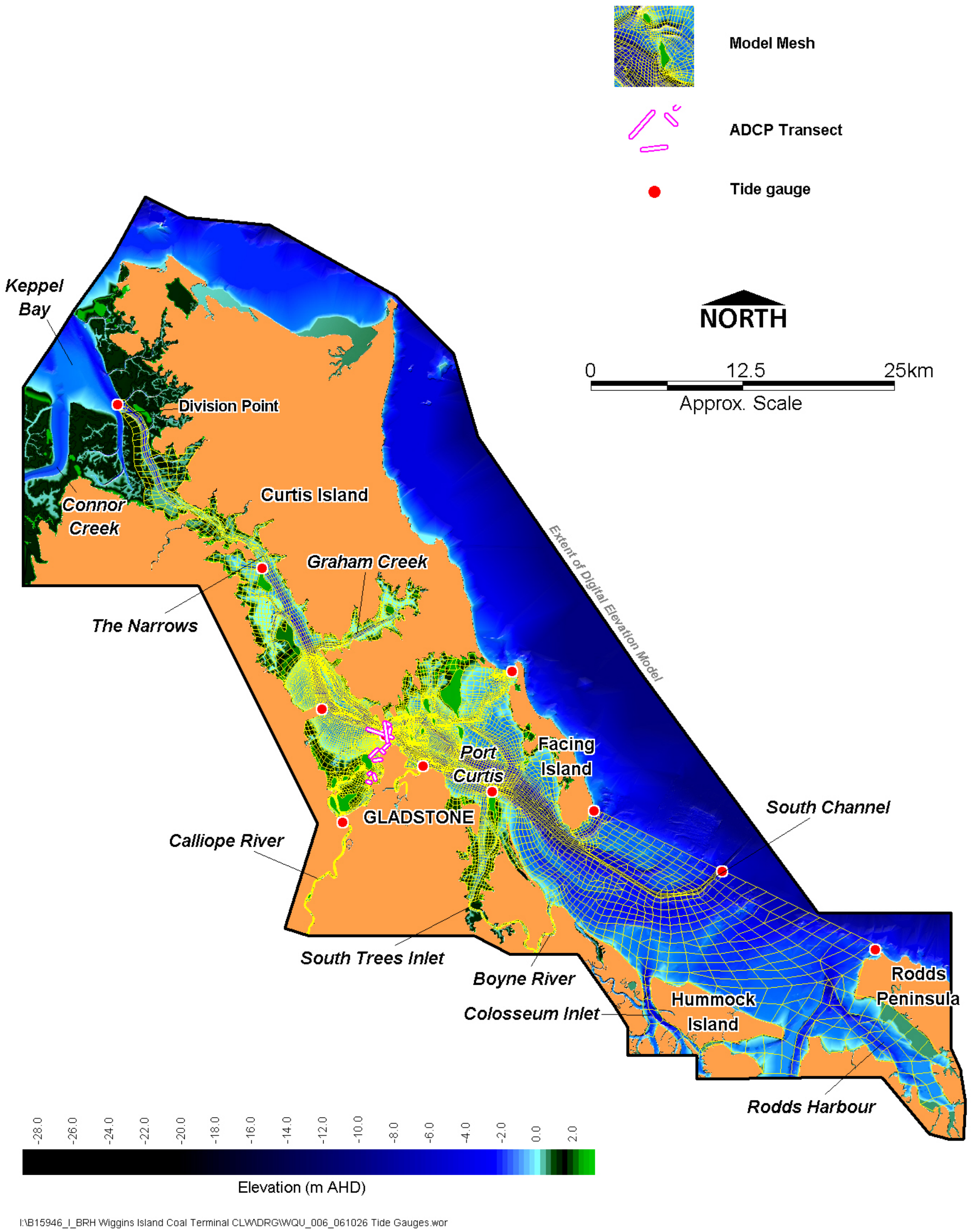
2.2.2 Tidal Water Levels

The extents of the model mesh have been selected to coincide with the location of tide gauge data, providing for direct application of the recorded field data for model boundary conditions. Each of the observed data locations either serve as a model boundary condition, or an internal model calibration point as indicated below:

Boundary Data – Richards Point, East Channel, North Entrance, Division Point

Internal Calibration Points – Black Swan Island, Fisherman's Landing, Calliope River, Auckland Point

The recorded time series of water level at the model boundary locations are shown in Figure 2-6. For the data period collected, both representative spring and neap tide conditions are covered. As discussed earlier, a linear variation in tidal elevation between Richards Pt and the East Channel was applied to the main ocean boundary of the model. The North Entrance and Division Point model boundaries apply the respective observed tidal conditions as a constant profile for each node across the model boundary. A detail of a sample period within the recorded data set is shown in Figure 2-7 that indicates the variation of magnitude and timing for the water level profiles at the adopted model boundaries.



Location of Tide Gauges and the ADCP Transects for Model Calibration

Figure 2-5

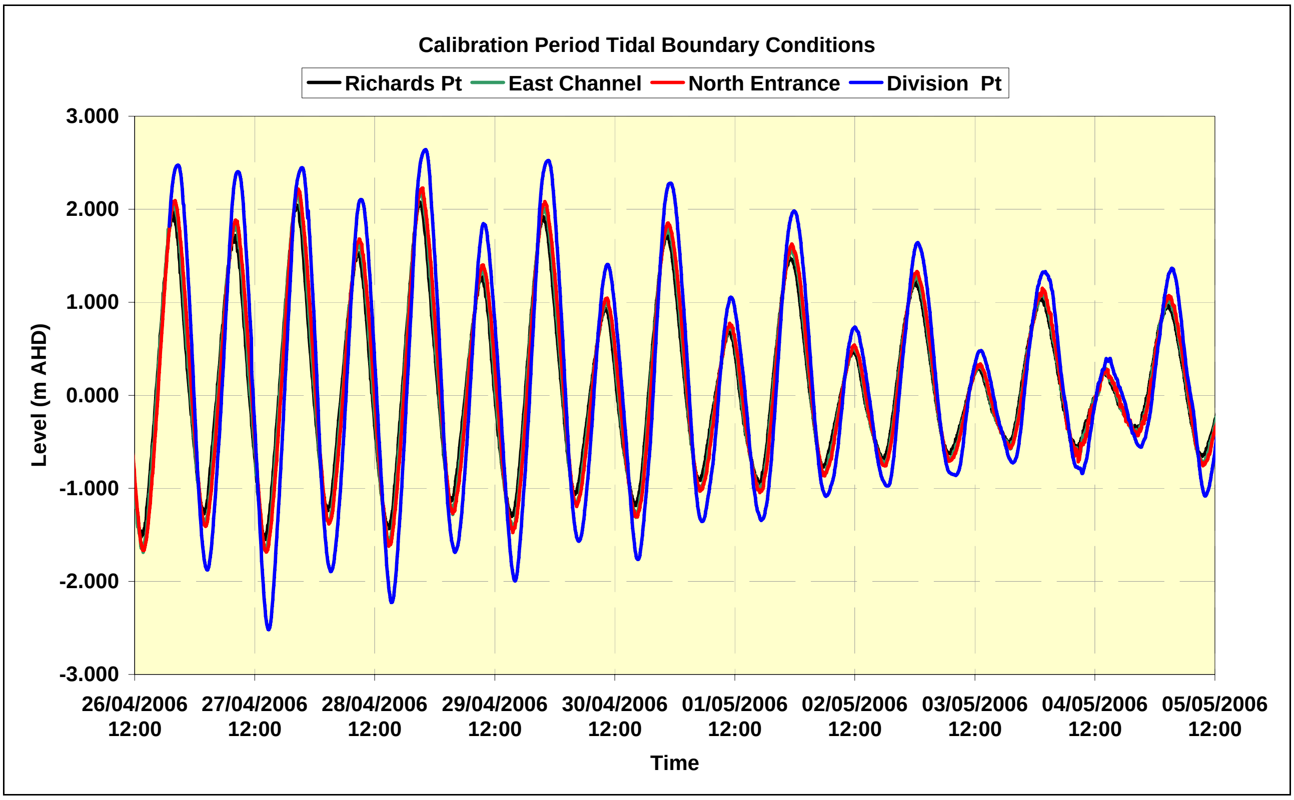


Figure 2-6 Observed Tidal Boundary Conditions for Calibration Period

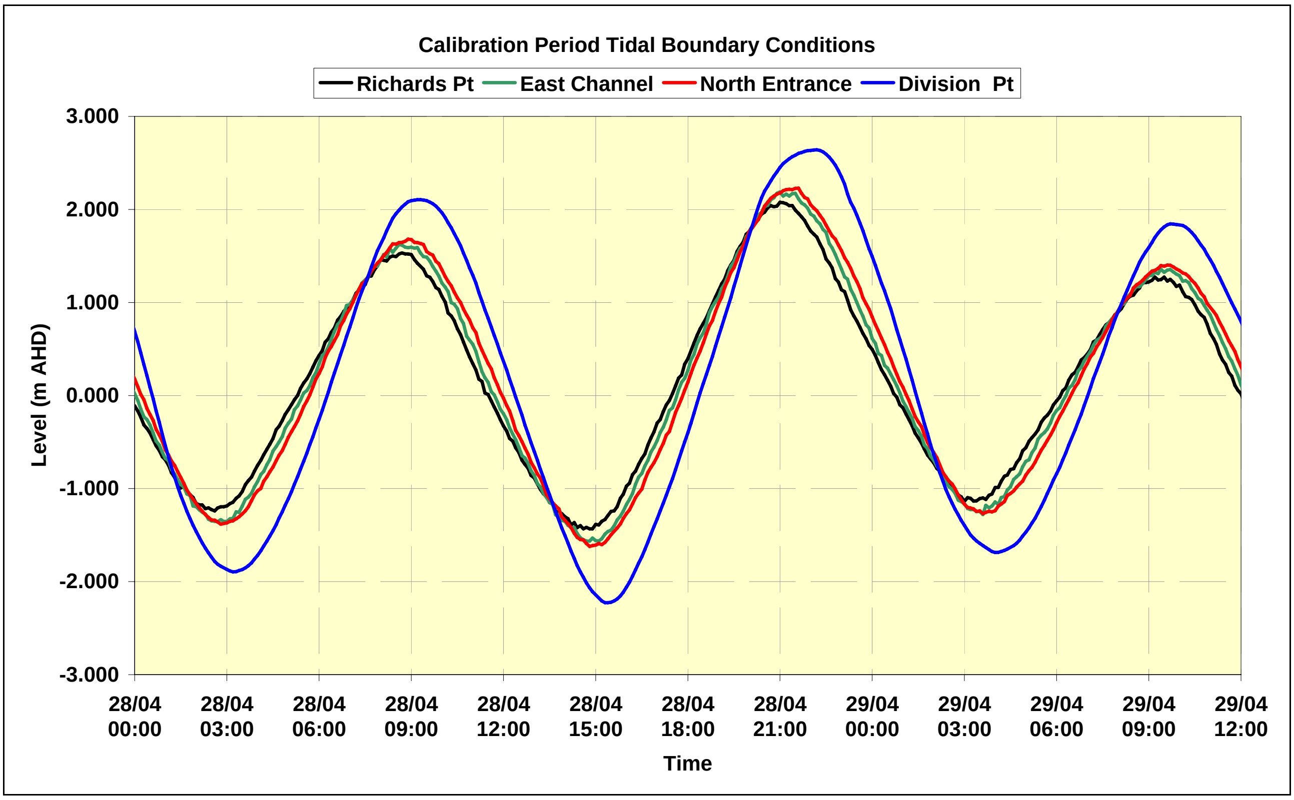


Figure 2-7 Sample Comparison of Tidal Data at Model Boundaries

2.2.3 ADCP Transects

The locations of the ADCP transects were selected to provide information on the flow distribution across various reaches of the study area. The data collected provide flow profiles for the defined sections, current velocities and directions.

A key focus of model calibration is the prediction of the main tidal flows in the system under spring and neap tide conditions and the relative distribution in key model areas such as the Calliope River in the vicinity of the Anabranch and toward the Port confluence around Wiggins Island and the Clinton Coal terminal. The simulated flow distributions at the location of the transects are compared with the observed flow profiles, with the objective being to provide a good match in terms of peak flows, relative timing and total volume exchange. These results are discussed in the following sections.

2.3 Calibration Results

The model was simulated over the calibration period from 26th April 2006 to 4th May 2006. This period incorporates numerous tidal cycles with representative spring and neap tide conditions. The calibration process utilised the initial spring tide conditions at the start of the data collection period for model calibration, with the subsequent neap tide conditions providing for validation of the model. This enabled assessment of the ability of the model to adequately represent a range of tide conditions and its suitability for design condition assessment.

The calibration results in terms of comparison of simulated water levels and flow rates against observed data are presented below.

2.3.1 Water Levels

Calibration plots of observed versus simulated water levels are show in Figure 2-8 to Figure 2-11 for each of the tide recorder calibration points. Each of the figures show a good calibration of water levels both in the magnitude of flood and ebb tide peaks, and the timing of the profiles. The good calibration is achieved for both the representative spring and neap tide conditions.

The accurate simulation of the tidal water profiles is essential to be able to simulate to a sufficient level of accuracy the total tidal volume exchange in the system and the corresponding flows on the ebb and flood tides.

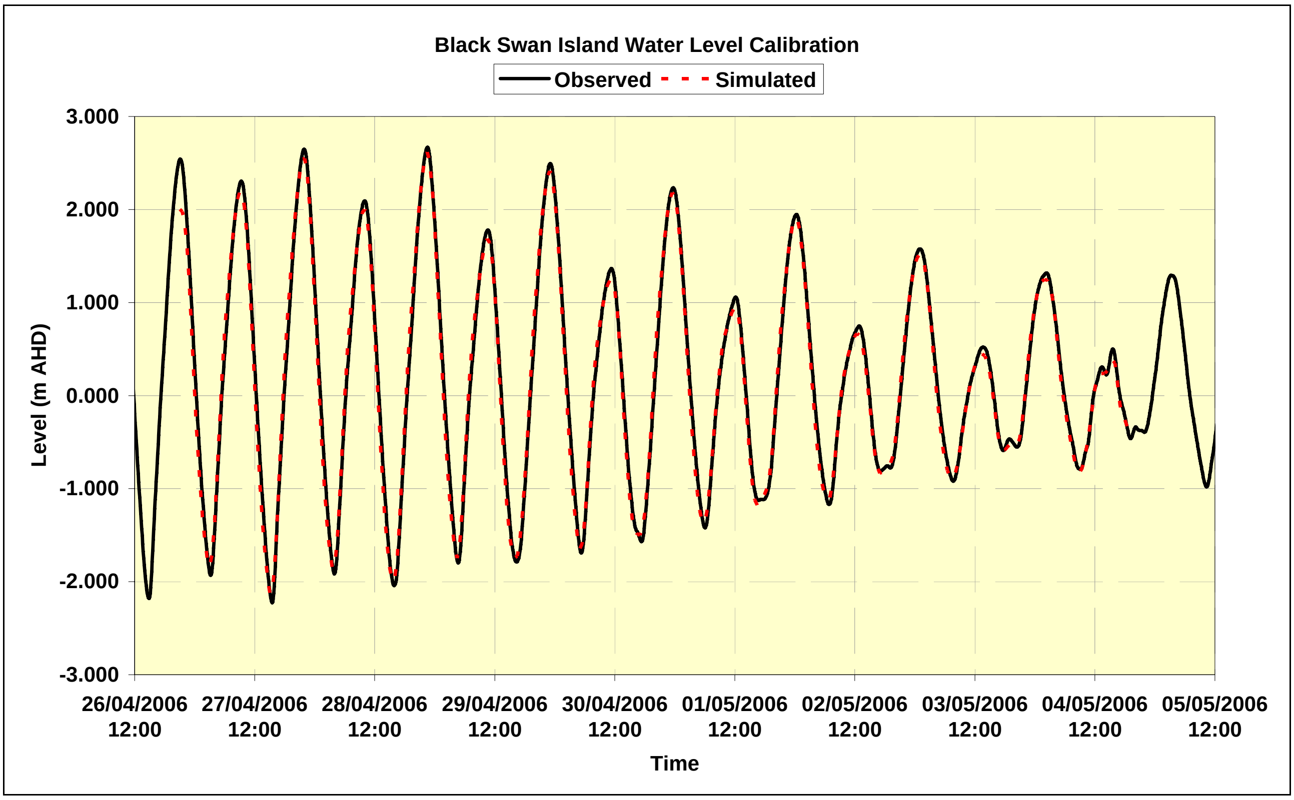


Figure 2-8 Black Swan Island Water Level Calibration

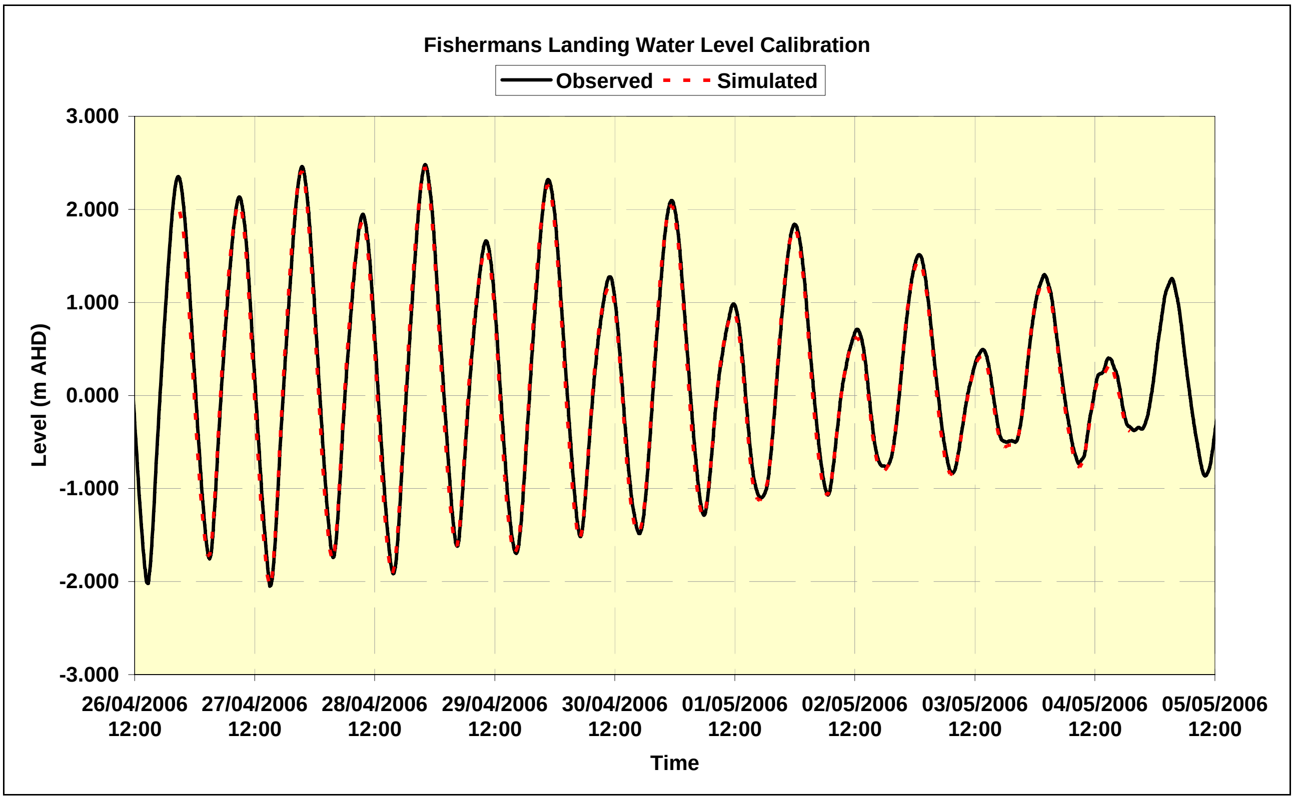


Figure 2-9 Fisherman's Landing Water Level Calibration

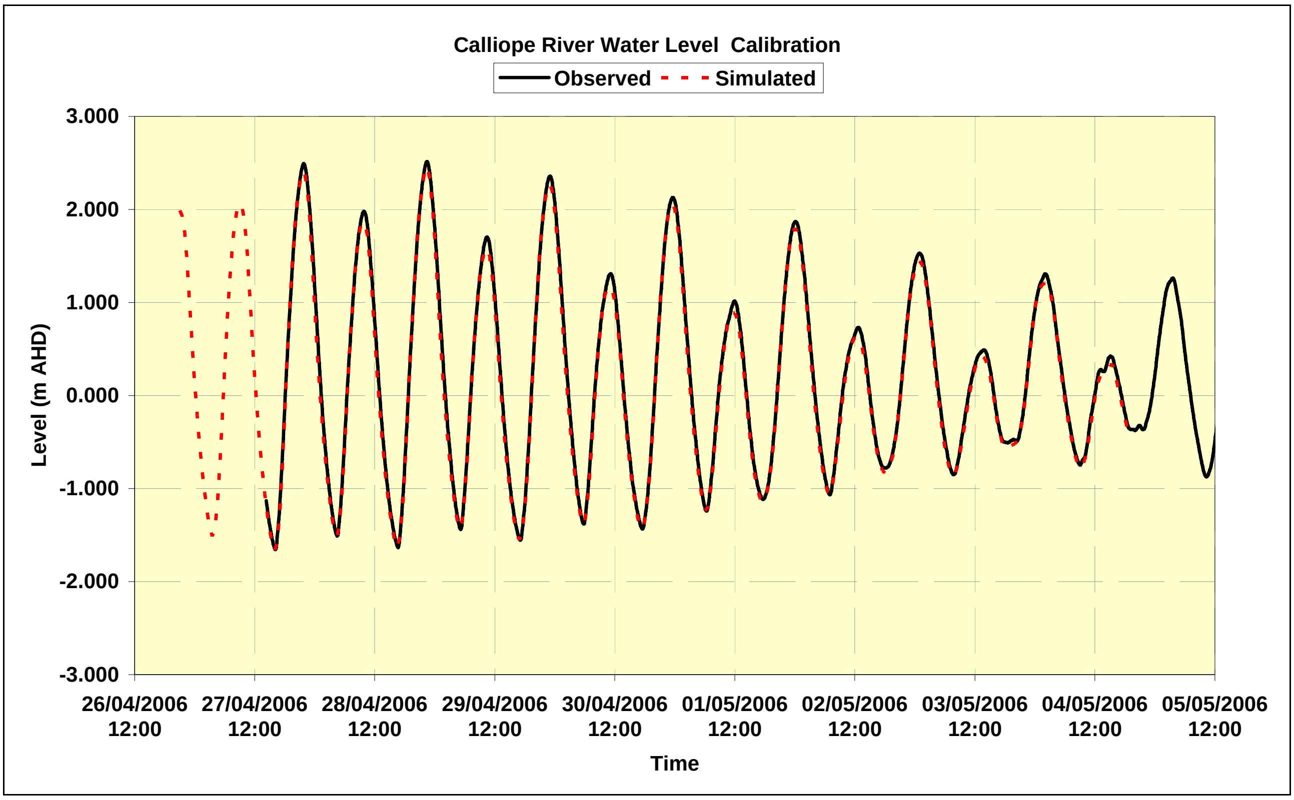


Figure 2-10 Calliope River Water Level Calibration

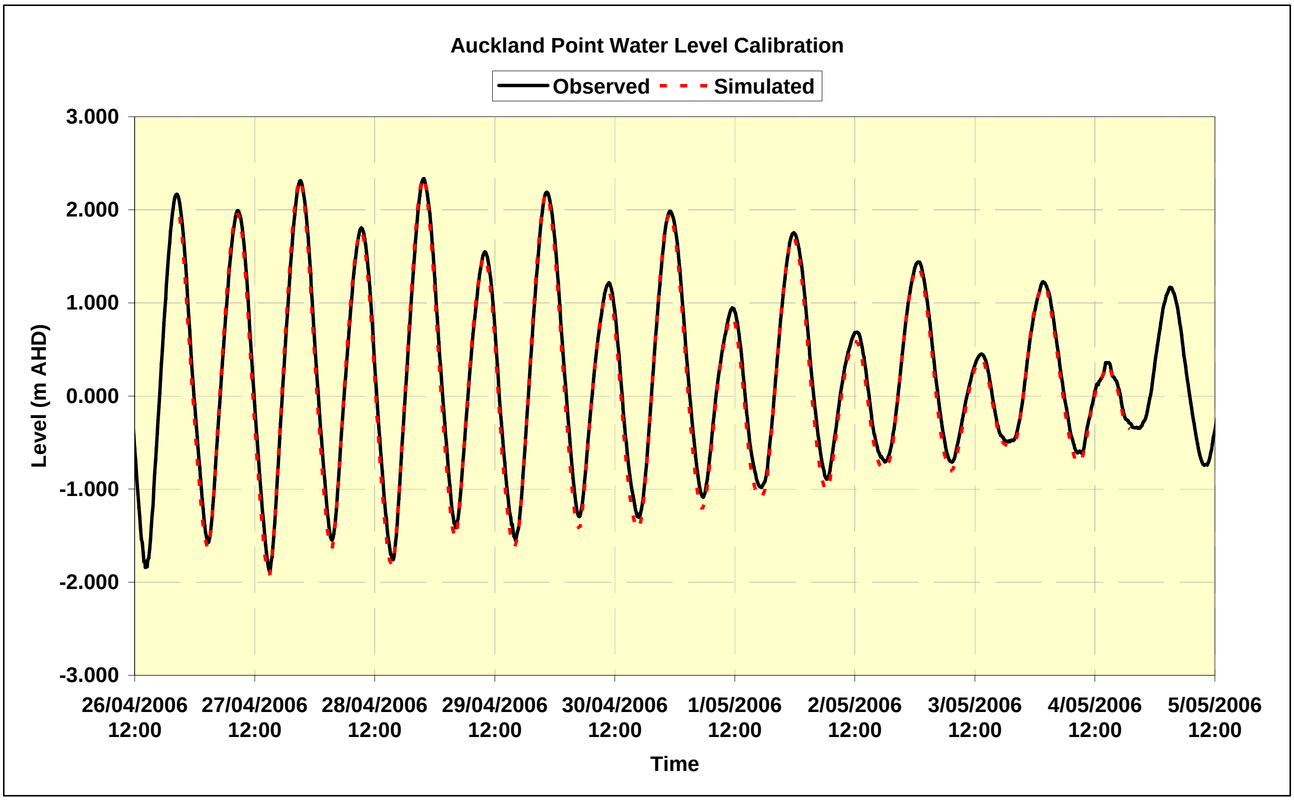


Figure 2-11 Auckland Point Water Level Calibration

2.3.2 Spring Tide Flows

Simulated flows for the ADCP transect locations as shown in Figure 2-4 were extracted from the model. Plots showing the simulated flows with the observed flows at the identified ADCP transect locations are shown in Figure 2-12 to Figure 2-20 for the representative spring tide observation period. The following key points are drawn from the flow calibration:

- The transect from Tide to Mud Island represents the main flow through the Port area, with a peak flood tide flow of approximately 15,000 m^3/s and peak ebb tide flow of 20,000 m^3/s for the calibration period. The bulk of this flow enters the Port through the main ocean boundary. A good calibration has been achieved for these flows (see Figure 2-12), such that the model provides a good representation of the main tidal exchange within the Port.

- A reasonable calibration is achieved for the ADCP transect between Curtis Island and Tide Island (see Figure 2-13). The simulated peak flood tide flows are lower than the observed, with a good match achieved for the peak ebb tide flows. The flow through this narrow channel is characterised by high velocity currents. Local deepening of the channel or changes in the bathymetry could provide for the additional flow capacity which is not reflected in the model. Boating charts indicate a shallow bar approximately 800m to the east of Tide Island that may have an influence on the peak flood tide flows. Nevertheless, the proportion of the total flow through the system conveyed through this location is approximately 15%, such that a minor discrepancy in simulated peak flows will not have a major influence on the total flow distribution across the greater extent of the model.

- Figure 2-14 to Figure 2-20 provides details of the observed and simulated flow distributions in the vicinity of Wiggins Island, including the Calliope River and other low flow channels. The model produces a reasonable representation of the observed flow conditions within this region. The timing and shape of the flow time series is represented well by the model, with some differences indicated in the peaks at some locations. Most notably the model over predicts the peak flood flows within the Calliope River when compared to the ADCP observation. It is important to recognise that the ADCP transects as indicated are representative locations and extents. In terms of the field observations, access may be limited across the entire cross section width, at a particular location, due to the presence of shallow areas on the tidal fringes and / or the presence of mangroves. In these instances the total flow for the cross section may be underestimated by field observations. Whilst some differences in observed and simulated peak flows are indicated, importantly however, the model simulation provides a good representation of the relative flow distributions.

- Similar observations as above can be noted for the flow distributions for the Calliope River in the vicinity of the anabranch. A general agreement in the timing and profiles of the flow time series is apparent for the observed and simulated conditions. Some differences in the peak flow estimates are evident, with the model simulating high flood tide peaks in the Calliope main channel. However again the general flow distribution in the Calliope River main channel and the Anabranch is similar for observed and simulated conditions.

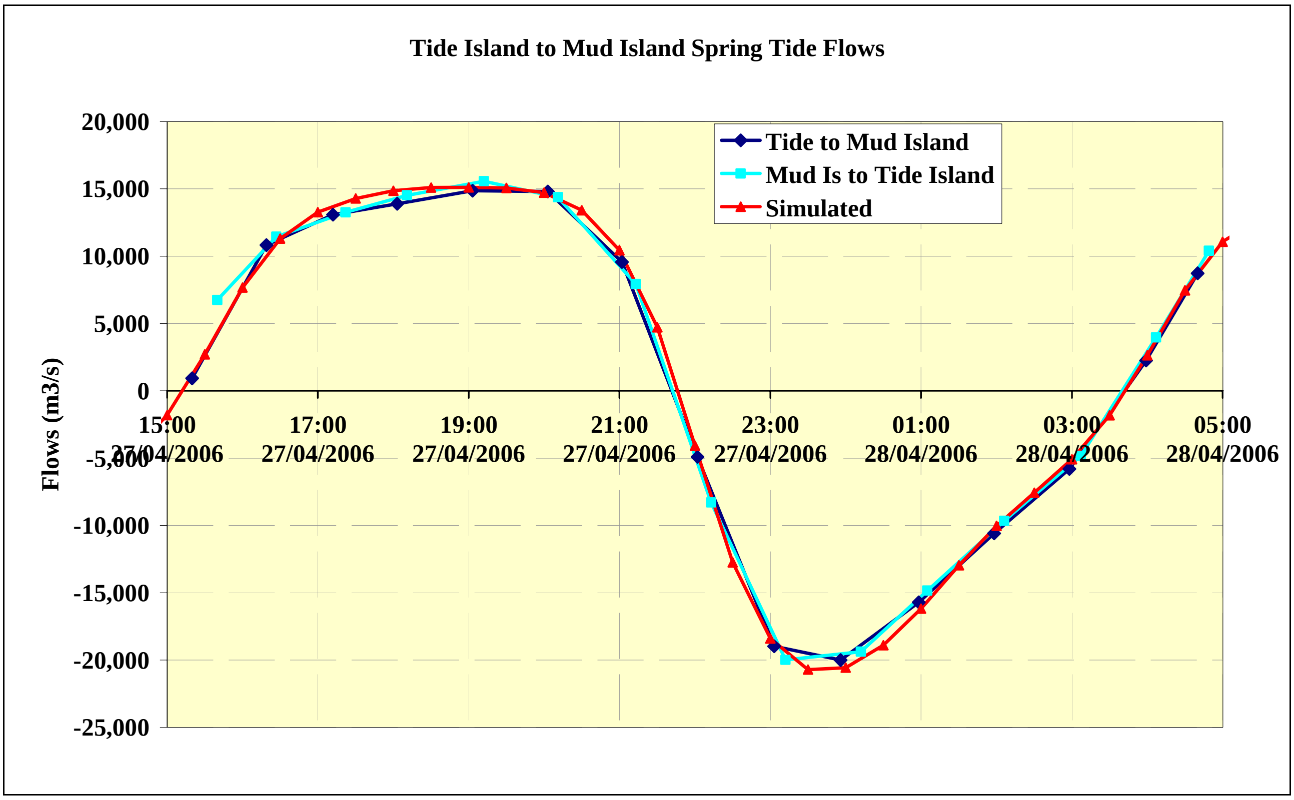


Figure 2-12 Tide Island to Mud Island Spring Tide Flow Calibration

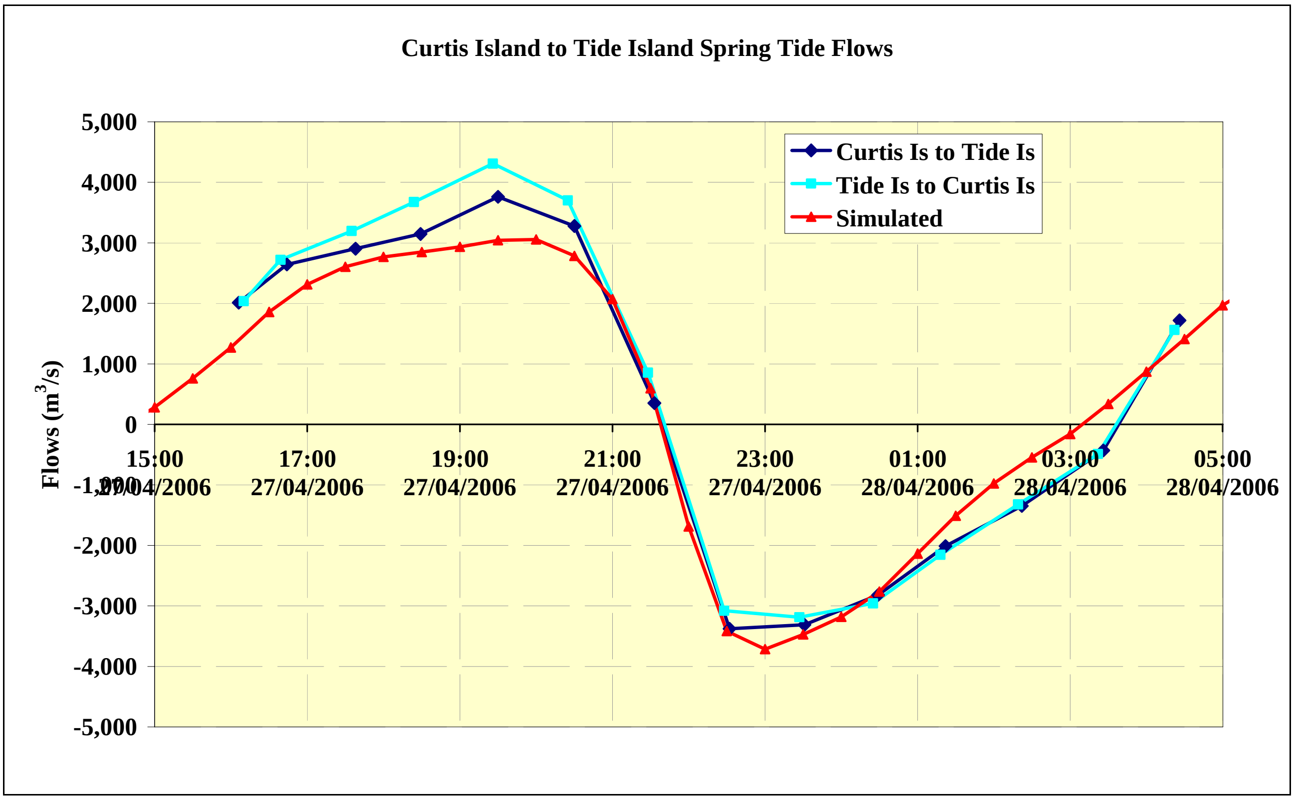


Figure 2-13 Curtis Island to Tide Island Spring Tide Flow Calibration

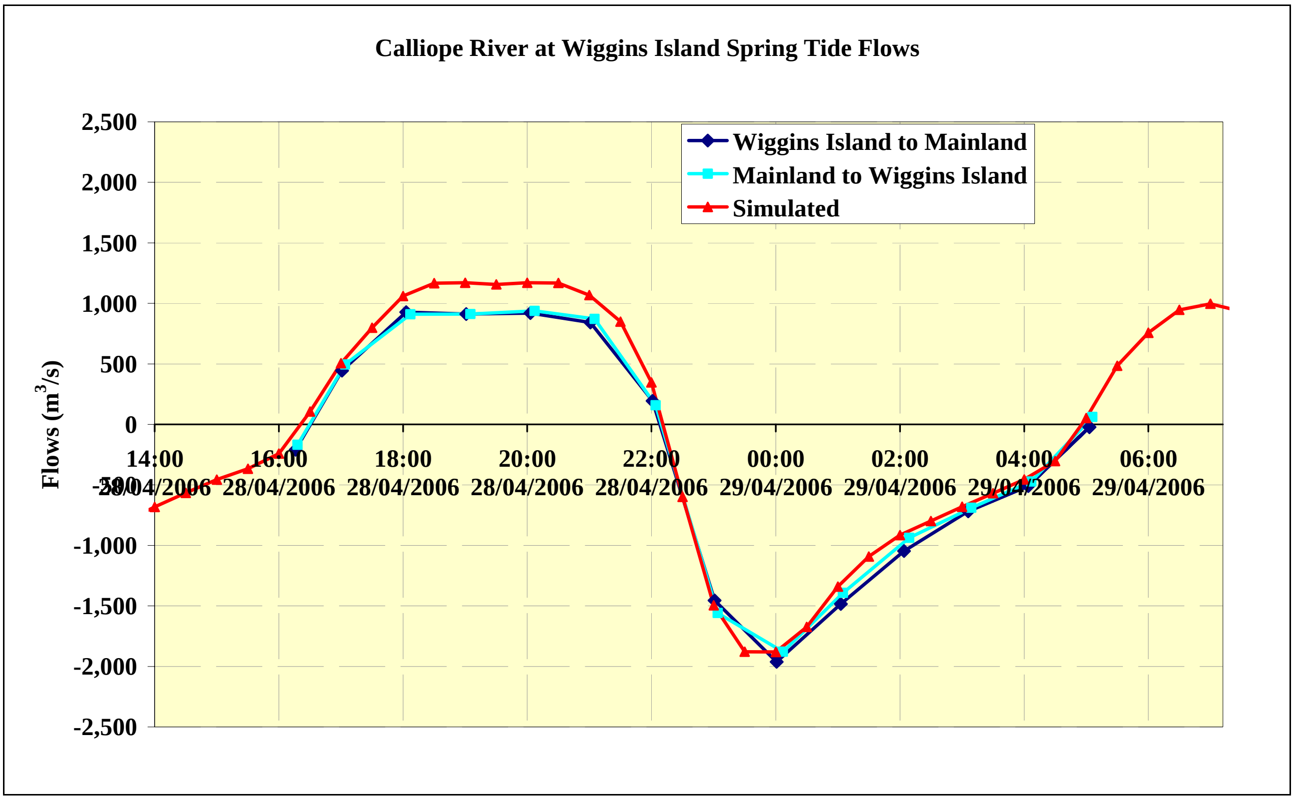


Figure 2-14 Calliope River at Wiggins Island Spring Tide Flow Calibration

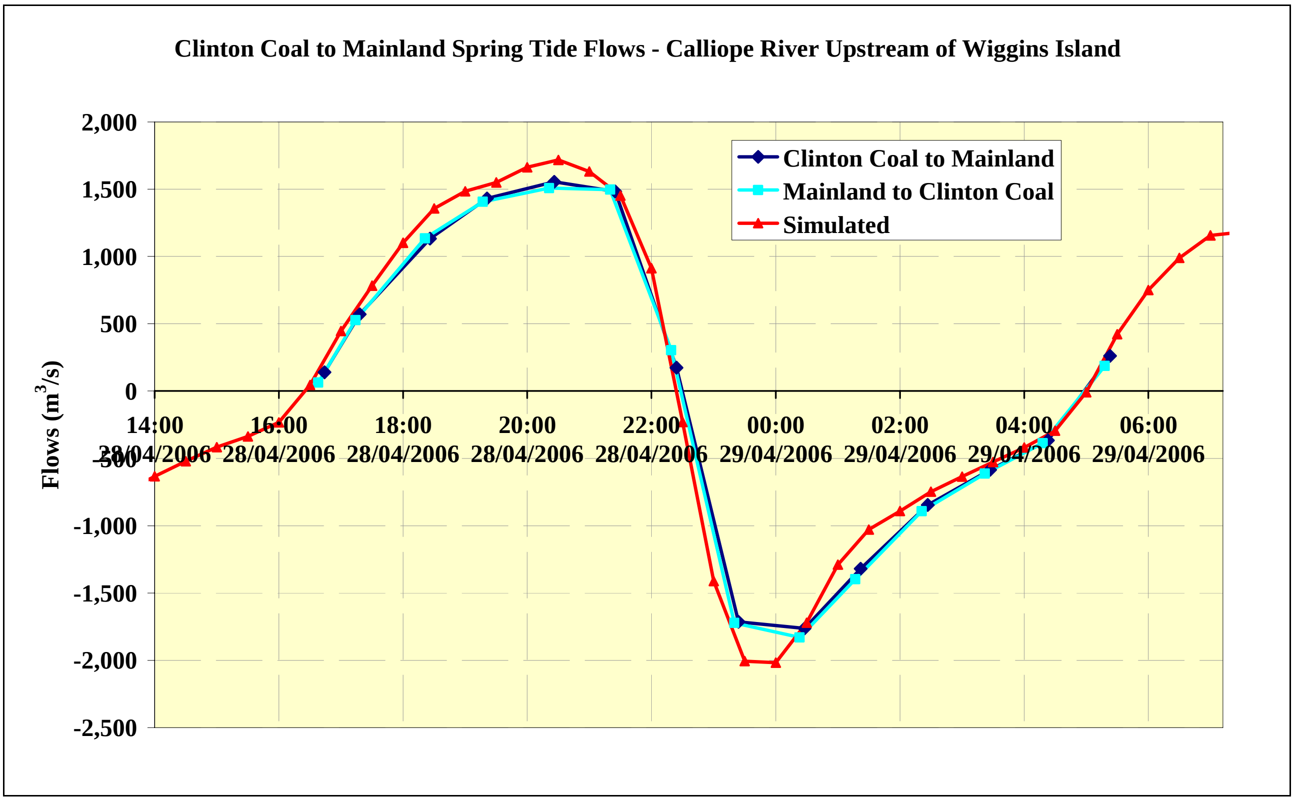


Figure 2-15 Calliope River Upstream of Wiggins Island Spring Tide Flow Calibration

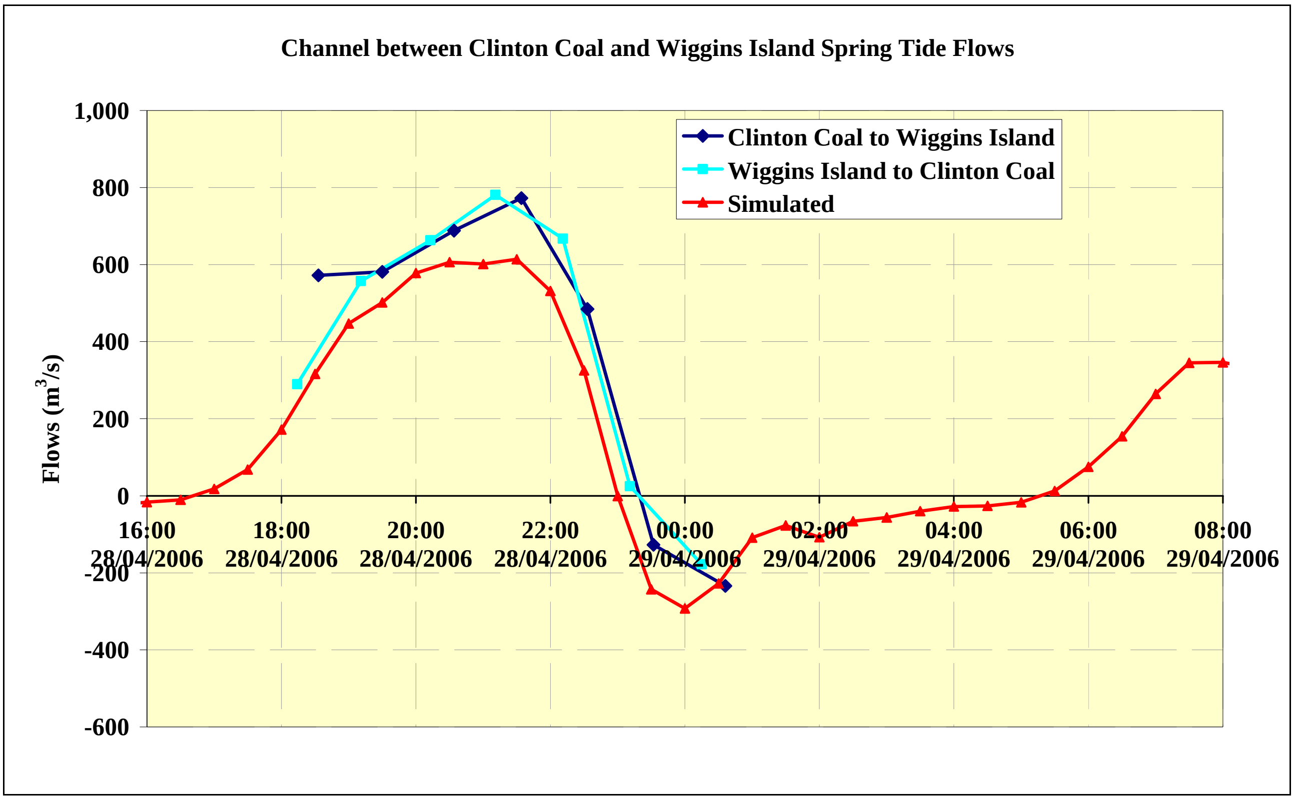


Figure 2-16 Clinton Coal to Wiggins Island Spring Tide Flow Calibration

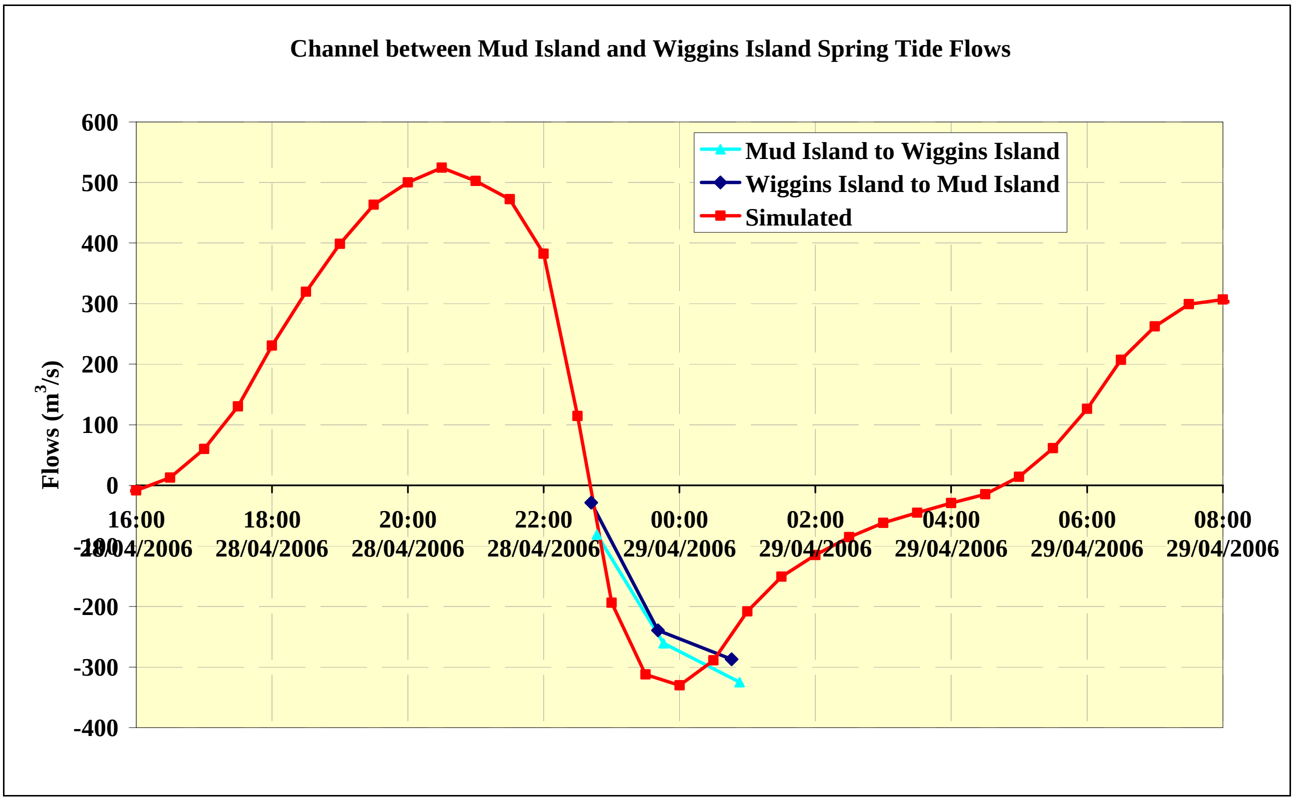


Figure 2-17 Mud Island to Wiggins Island Spring Tide Flow Calibration

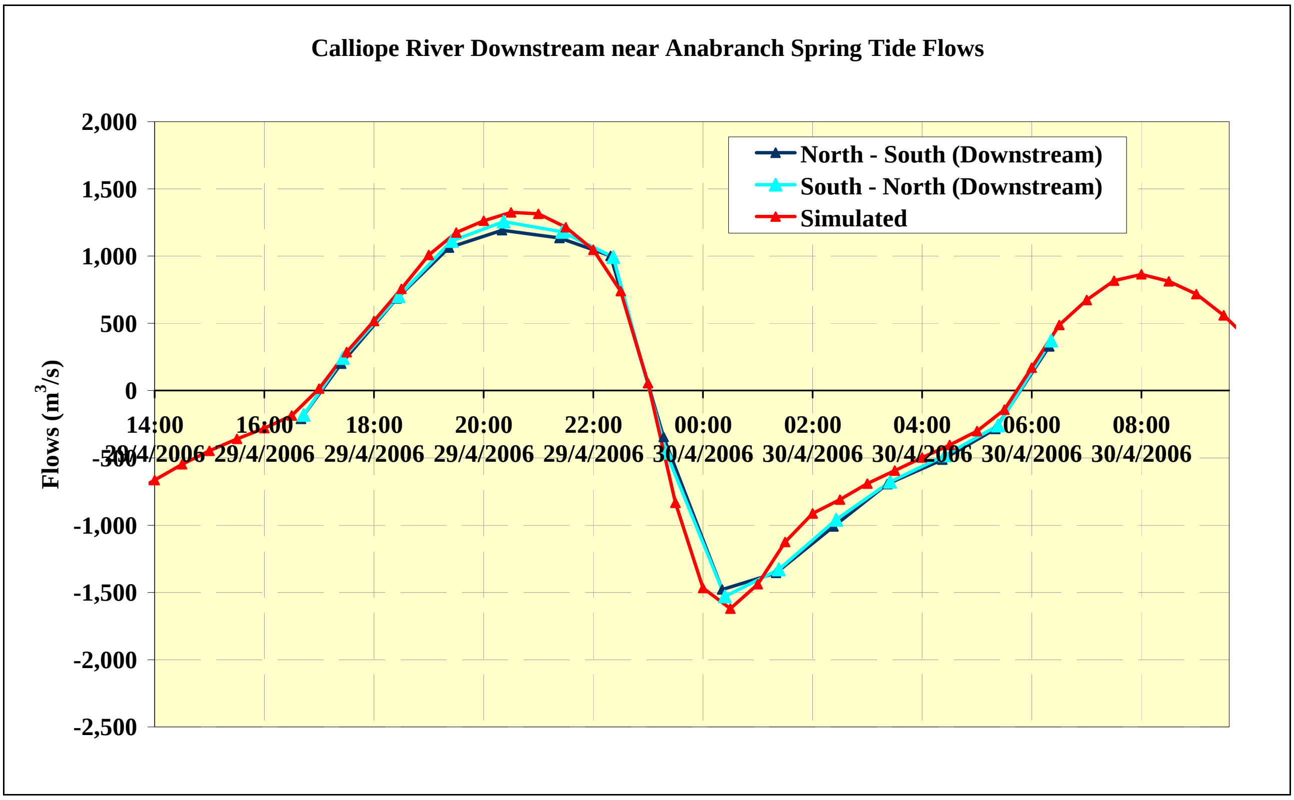


Figure 2-18 Calliope River Downstream near Anabranch Spring Tide Flow Calibration

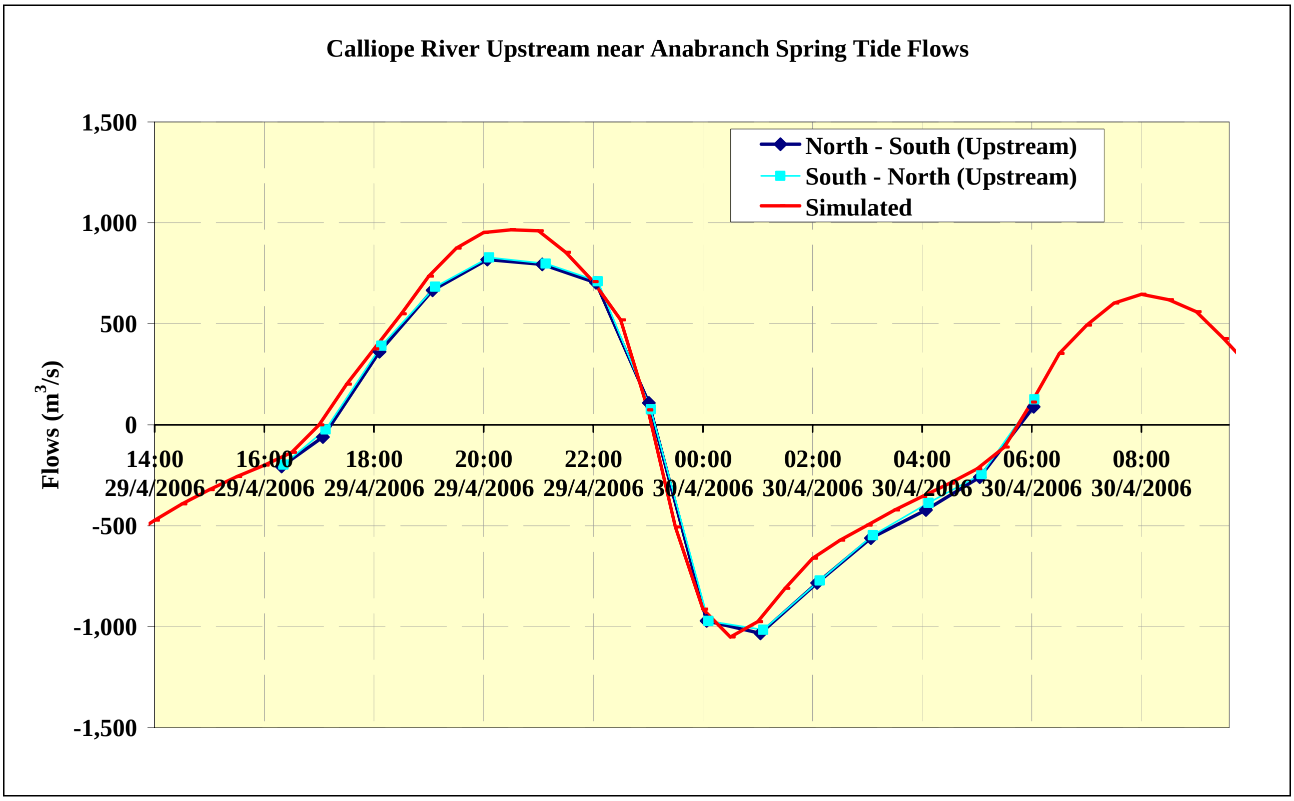


Figure 2-19 Calliope River Upstream near Anabranch Spring Tide Calibration

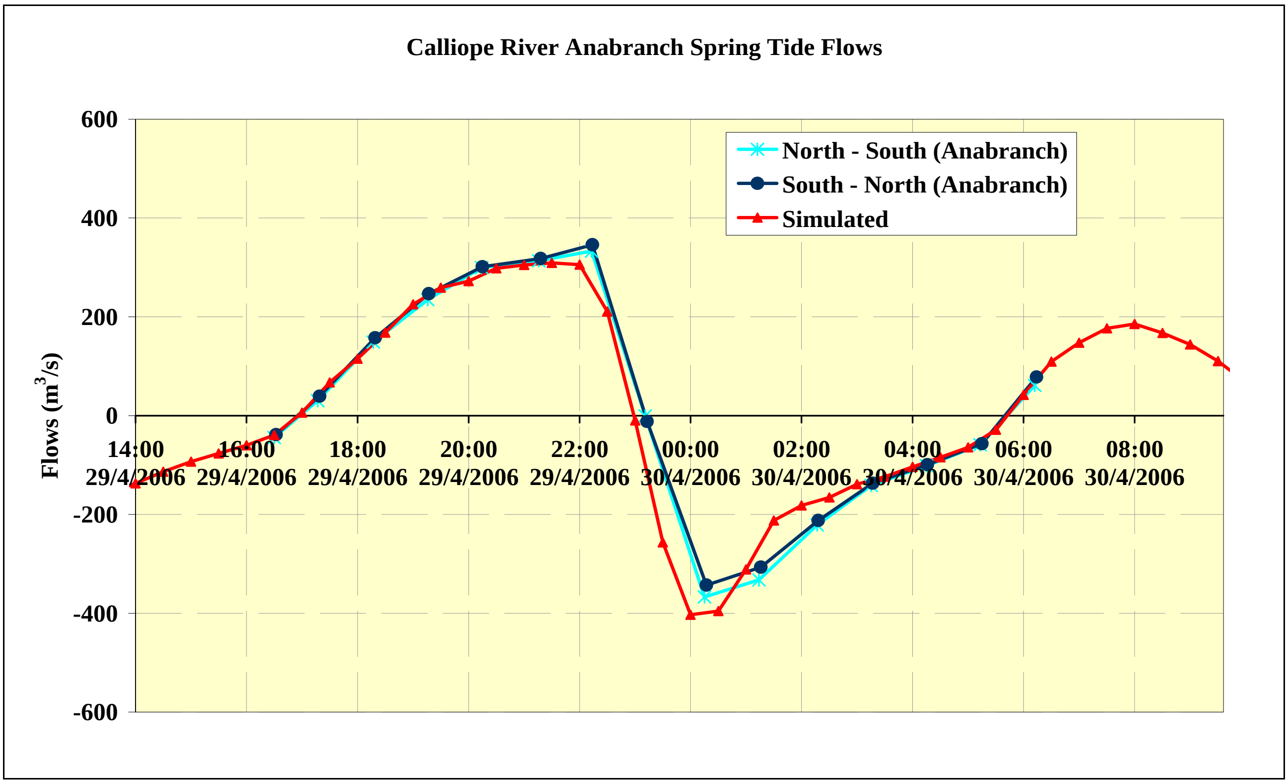


Figure 2-20 Calliope River Anabranch Spring Tide Flow Calibration

2.3.3 Neap Tide Flows

The main model calibration focused on the spring tide flows, such that the observed periods of neap tide flows serve as useful model validation data. Observed and simulated flow profiles for the neap tide period where field data was obtained are shown in Figure 2-21 to Figure 2-24. The comments below highlight some key conclusions from the neap tide flow comparisons:

- The flows between Tide and Mud Islands represent the major proportion of flow through the Port area. The simulated profile (see Figure 2-21) shows a good agreement with the observed conditions. There is some doubt as to the reliability of two of the readings on the observed profile which result in a major deviation in the flow profile, otherwise the simulated profile provides a good fit to the observed conditions. Thus the model adequately represents the bulk flow exchange through the Port for both spring and neap tide conditions.

- The flow distribution for the Calliope River in the vicinity of the Anabranch is shown in Figure 2-22 to Figure 2-24. A reasonable agreement is found between observed and simulated conditions. The timing and shape of the profiles are consistent, with minor variations in flow magnitude. The overall flow distribution between the Calliope main channel and the Anabranch is well represented by the model when compared to the observed flow profiles.

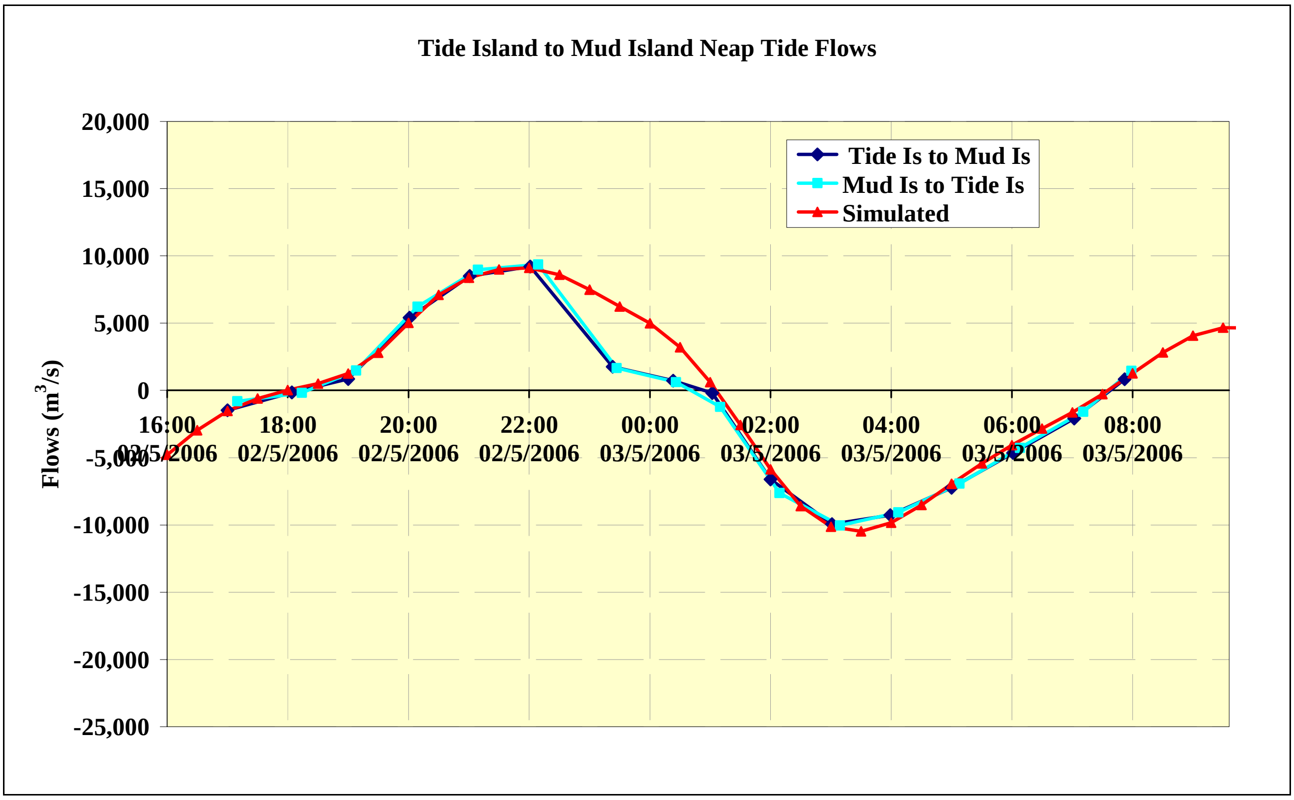


Figure 2-21 Tide Island to Mud Island Neap Tide Flow Calibration

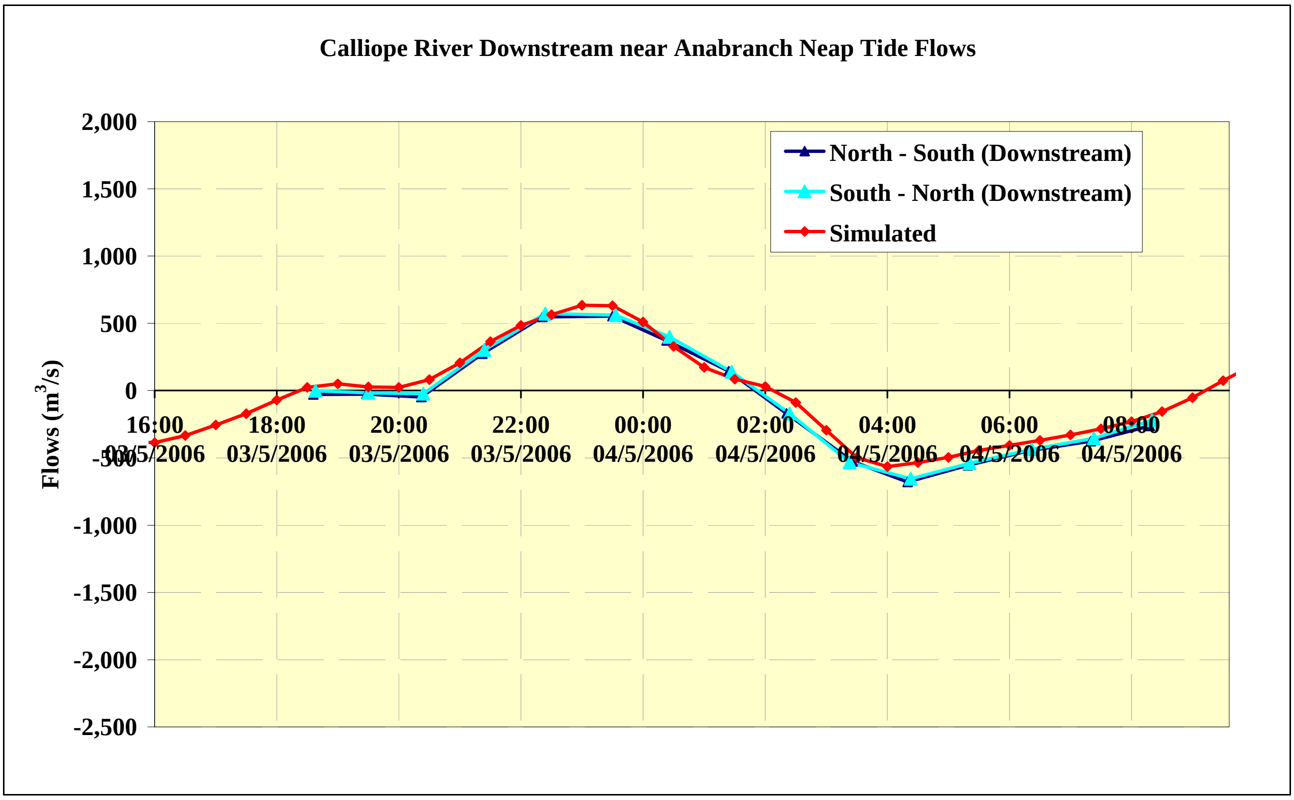


Figure 2-22 Calliope River Downstream near Anabranch neap Tide Flow Calibration

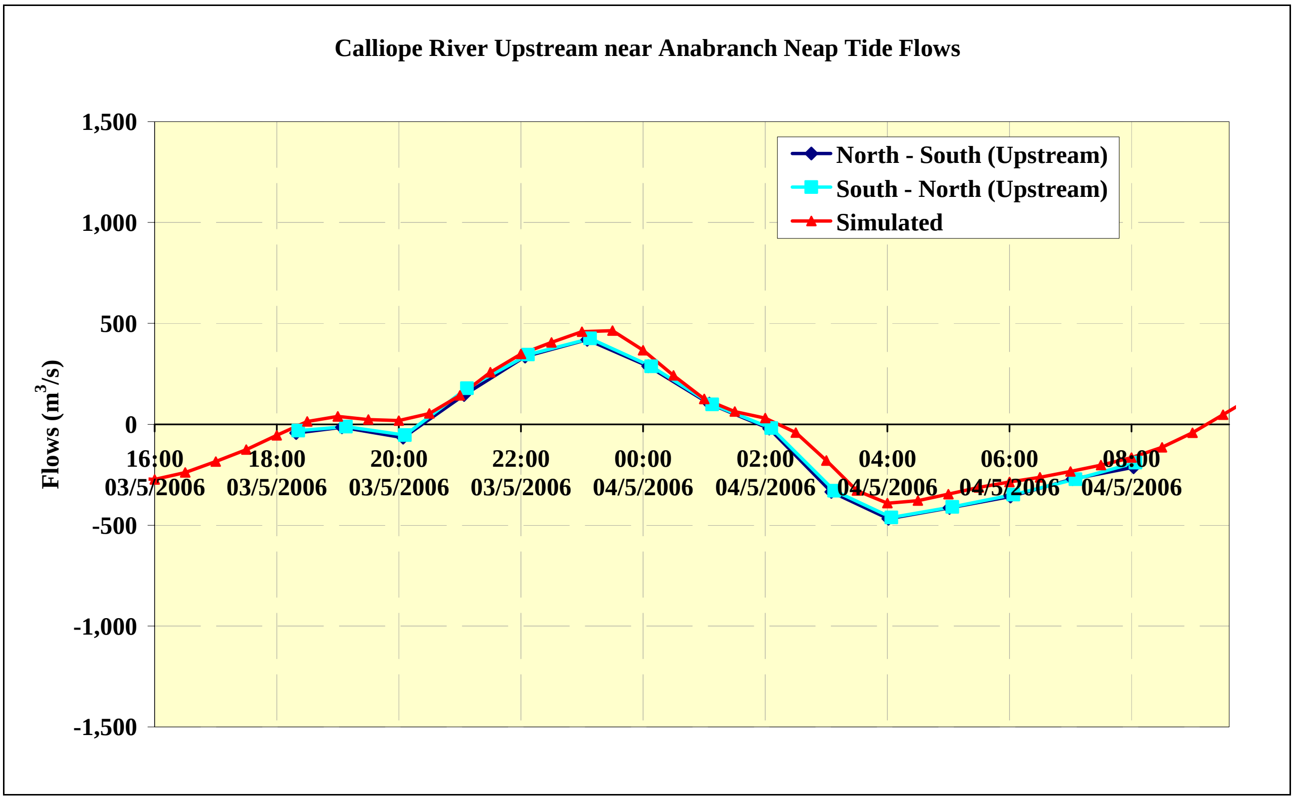


Figure 2-23 Calliope River Upstream near Anabranch Neap Tide Calibration

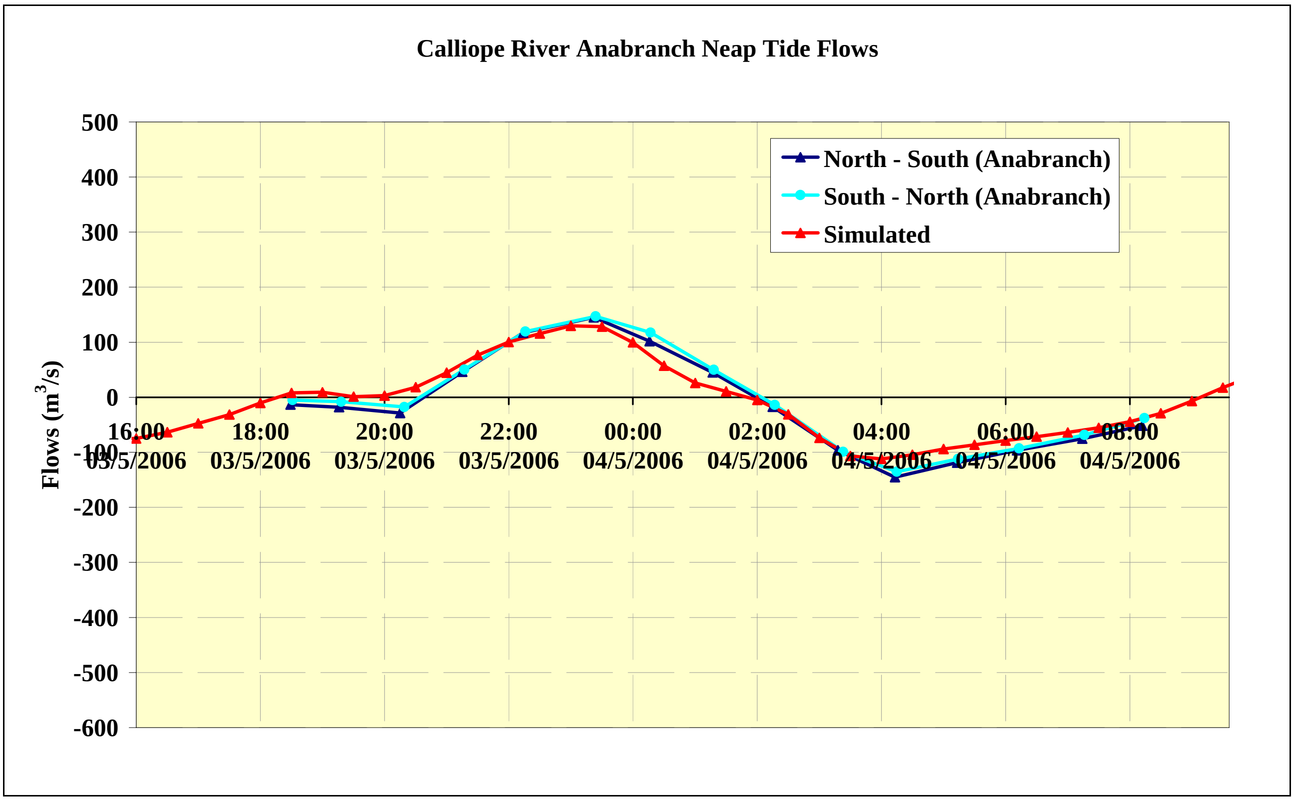


Figure 2-24 Calliope River Anabranch Neap Tide Calibration

2.3.4 Velocities

Further site-specific calibration was undertaken in the main channel, between Tide and Mud Island. The model data was compared against the ADCP field data and compared for velocity direction and magnitude (Figure 2-25 to Figure 2-26). There is a slight variation in the direction of the flow during both the flood tide (approximately 270 degrees) and the ebb tide (approximately 100 degrees), and this variation is not picked up within the model data. The magnitude of the model data shows a slight increase over the field data magnitudes, during the period of spring tides (Figure 2-26). This may be attributed to shading from ships that were berthed (to the south of this location, potentially providing a restriction to the incoming flood tide) during the period of field data capture. During the second week, the model data agrees very well with the field data. Overall the results showed a very good comparison, confirming that the model was accurately predicting the general characteristics of the flow within the region.

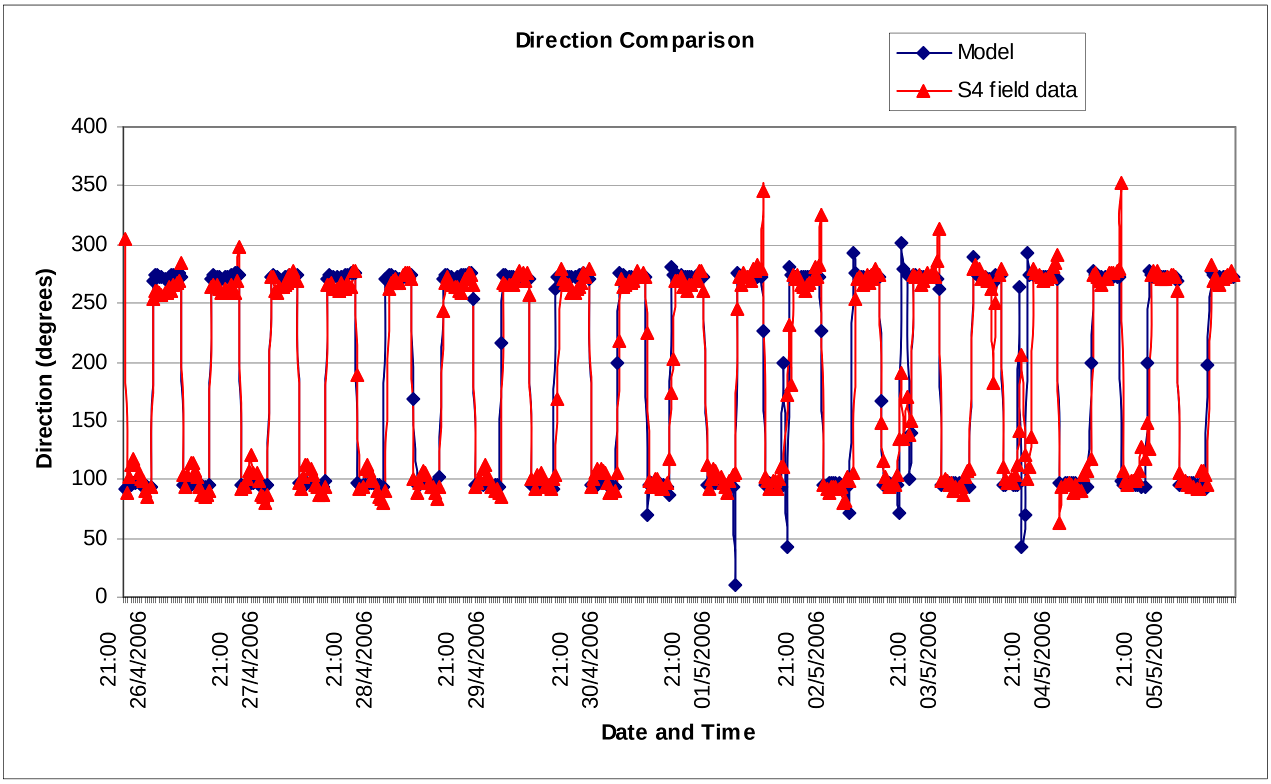


Figure 2-25 Direction comparison between model data and ADCP field data

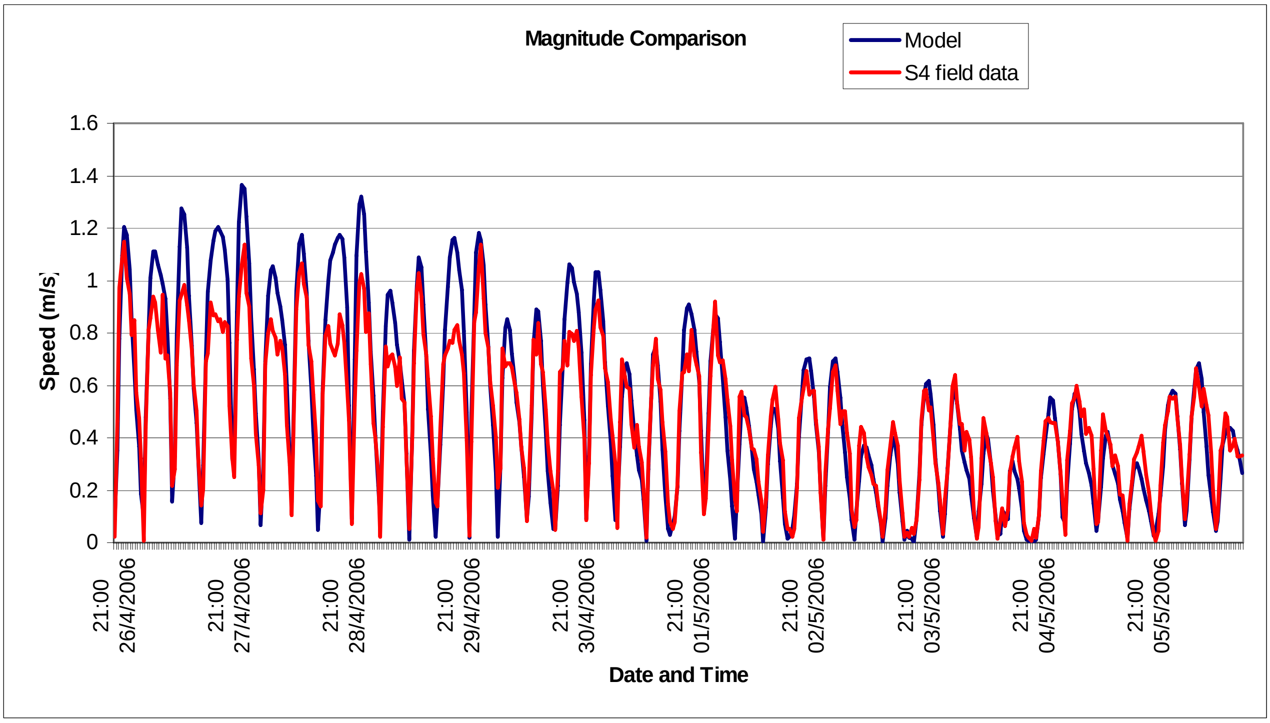


Figure 2-26 Magnitude comparison between model data and field data

2.3.5 Sensitivity to wind

Five different scenarios were simulated to examine the effects of varying wind conditions on the hydrodynamics of Port Curtis. These five scenarios were based on variations in wind magnitude and direction, and were derived in an earlier study of the region (WBM, 2003). The scenarios included:

- No wind scenario
- Naturally varying wind scenario
- 12hrs NE wind, 12hrs no wind
- 12hrs SE wind, 12hrs no wind
- 6hrs SE wind, 6 hrs NE wind, 12hrs no wind

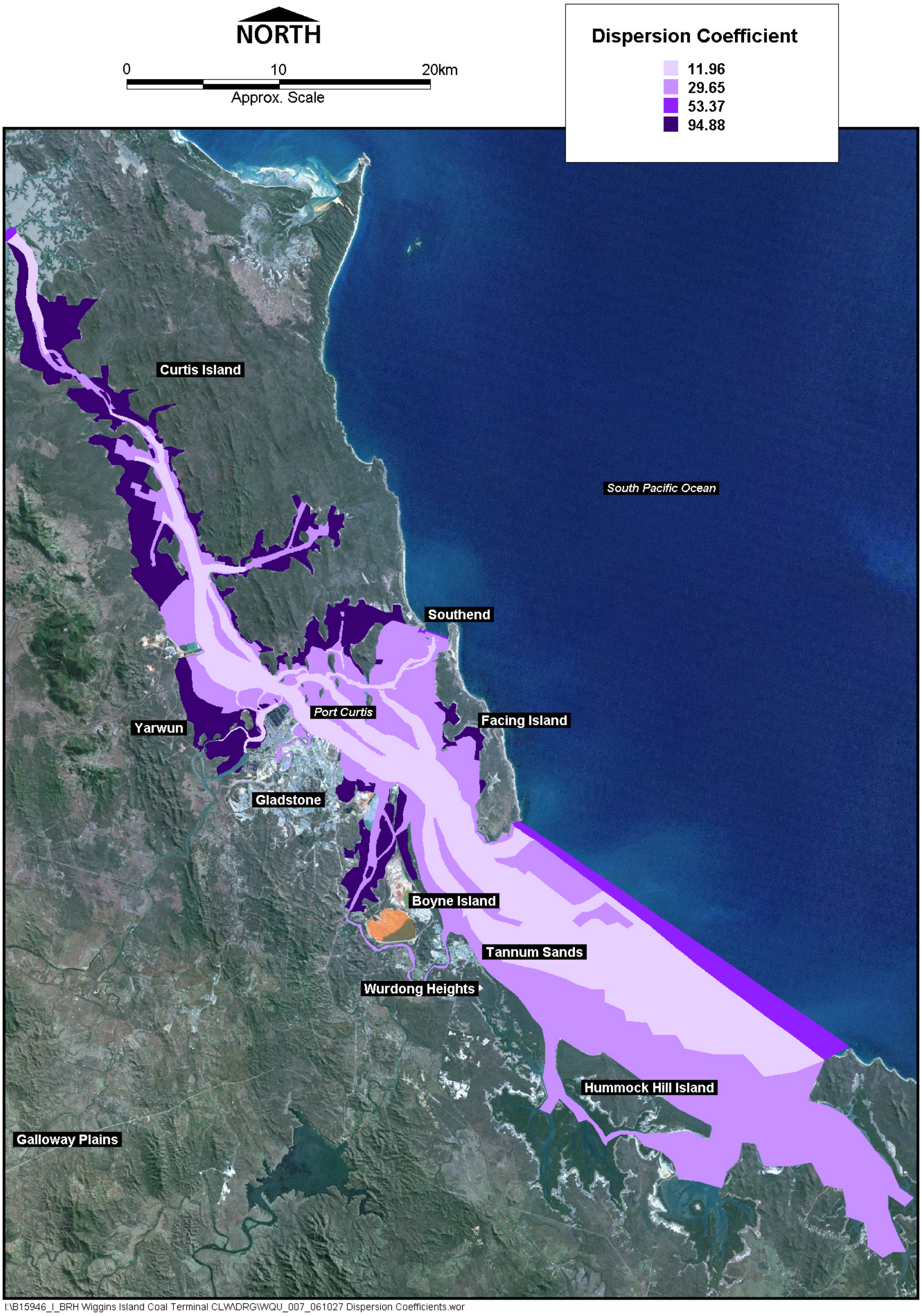
Flow rates were extracted from the model from along the same transects as for the calibration (Figure 2-4) and the results showed that there were no appreciable differences in water velocities, direction and subsequent flow rates between the scenarios. For this reason, and also to reduce repetition, the figures have not been shown. This result agrees with previous work in the region (Herzfeld *et al.*, 2004) and therefore we can be confident in assuming that wind is not a significant driver in the hydrodynamics of Port Curtis.

3 FAR FIELD ADVECTION DISPERSION MODELLING

An advection dispersion model of the greater region of interest was constructed to investigate the advection and dispersion of various water quality constituents of concern. The RMA-11 three-dimensional finite element model, developed by Resource Modelling Associates, was chosen for this purpose as the model utilises the hydrodynamic results obtained from RMA-10. RMA-11 was run in two-dimensional mode for this study. The model also allows the user to simulate a passive tracer only, reducing the computational time often associated with a fully functioning water quality model.

3.1 Advection Dispersion Parameterisation

To accurately capture advection and dispersion within the model, the model required the input of dispersion coefficients. These coefficients are the primary inputs that determine the resultant spread of material throughout the model domain. The dispersion coefficients were set to be varying with water depth (consistent with the recognised Elder approach) and were locally calibrated utilising information obtained from a historical field dye release experiment undertaken within Port Curtis, as well as other existing studies reported in Fischer *et al* (1979). Typical values for the dispersion coefficient inputs within the context of values required by the RMA schematisation ranged from 12 to 95 (Figure 3-1). These values were utilised for the longitudinal direction only (parallel to flow) whilst the transverse values were calculated as a percentage of the longitudinal dispersion coefficient. The resulting dispersion coefficients were then scaled against the velocity magnitude and the depth, where both of the latter values were obtained from the hydrodynamic model.



Dispersion Coefficients **Figure 3-1**

3.2 Flushing Timescale

In order to provide a high order assessment of the model performance, the flushing timescale of Port Curtis was examined. This was undertaken through the utilisation of the passive tracer transport module within RMA-11. The tracer was initially placed within a specified region defining Port Curtis (Figure 3-2) at a nominal concentration of 100 mg/L, then transported under naturally varying conditions over time. All locations outside the extents shown in Figure 3-2 were set to a concentration of 0 mg/L. The flushing timescale simulation spanned representative spring and neap tide periods.

The simulation was allowed to run until initial tracer concentrations had reduced to 37 mg/L at all locations, averaged over a 12 hour tidal period. This concentration was selected as it represents the 'e-folding' timescale associated with flushing (1/*e* ~ 0.37). This approach allows calculation of the flushing timescale at every point in the model domain, rather than a bulk calculation for the entire region. It is noted that the latter approach has been adopted elsewhere (e.g. Herzfeld *et al.*, 2004), but that our preference is for the former method, as it permits investigation of the spatial variation of flushing characteristics, which in turn facilitates identification of areas that may be susceptible to longer term accumulation of pollutants.

The results (Figure 3-3) show a range of flushing timescales from 12 - 16 days within the Port (Figure 3-3). The longest flushing times were found in the intertidal and mangrove regions (16 days), whilst the shortest flushing times were found in the main channel (12 days). These timescales are consistent with previous estimates, providing confidence in the adopted dispersion coefficients.

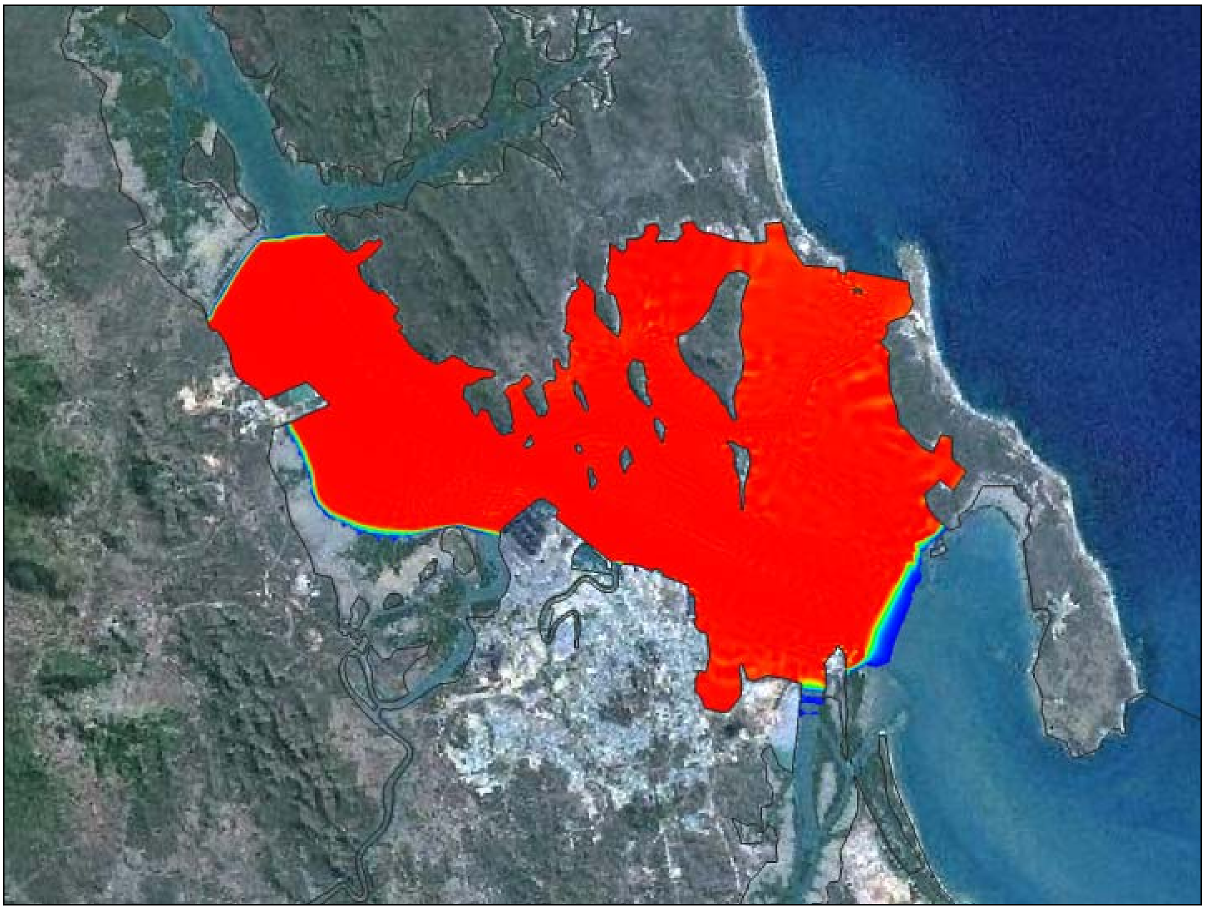


Figure 3-2 Flushing timescales model set-up

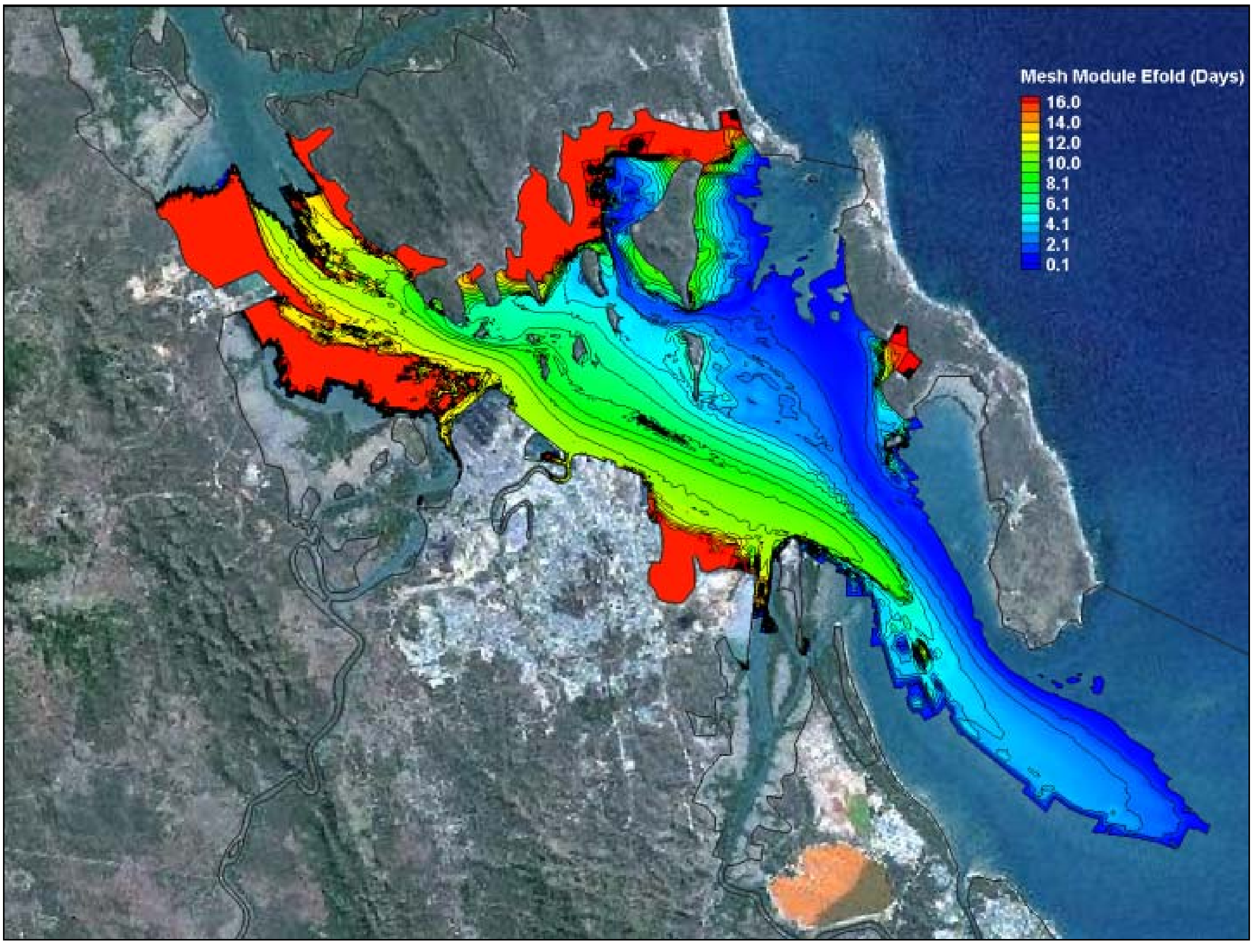


Figure 3-3 Flushing timescales for Port Curtis

3.3 Far Field Assumptions and Limitations

It is stressed that the schematisation of this model requires that the discharged effluent be immediately mixed over the entire water column, *and* laterally across each computational element. This provides an initial artificial mixing, which is a potential over statement of the actual plume dynamics and mixing taking place.

It is also important to note that the far field modelling undertaken in this study uses *depth-averaged* tools in RMA-10 and RMA-11. As such, introduced tracers of the type used in this study are simulated as well mixed over the entire water column at all times and locations. This may introduce some errors in the reporting of dilution coefficients if this depth averaged approximation is not satisfied at all times. If this is the case then the results presented here will be *over-statements* of the dilution achieved, i.e. upper limits. The only way to fully investigate the general validity of this assumption is via executing three-dimensional simulations of the area, which is beyond the scope of this study.

Nonetheless, the correct mass flux has been provided to each simulation, so that in a far field sense, the correct mass loading of the system has been replicated.

It is also noted that the advection dispersion model was constructed over such a spatial extent as to minimize the impact of boundaries on model results of interest, i.e. dispersion around the effluent discharge point and in the Calliope River. To this end, the main exchange boundaries were set to be some 25km from the RG Tanner wharf.

On review of the results (described in later sections) there is evidence of effluent exchange with the boundary in the current suite of simulations (albeit at very low concentrations, approximately 1000 times dilution). This exchange can be partially controlled within the modelling framework by specification of a parameter that is dynamically included in an expression to estimate the likely return concentration of tracer leaving the model domain. In the simulations described below, the effective exchange was in the order of 0.8 to 0.9, which is likely to be a conservative estimate. In light of this, we believe that this return of effluent back into the model domain warrants further investigation, which has not been possible within the study timeframes.

Given this, we recommend that some sensitivity testing be undertaken in the future regarding this return at the boundary, and that a range of coefficients be considered from zero (i.e. all material leaving the model boundary does not return) to 1. Whilst it is not expected that these tests will reveal large changes in the immediate vicinity of the outfall (the key issue for this study), it is an issue that we recommend be pursued.

4 NEAR FIELD MODEL

The CORMIX modelling package (http://www.cormix.info/) was used to describe the near field plume dynamics. It is a one dimensional model that uses flow regime parameters and outfall design characteristics to predict the steady state evolution of effluent plume dynamics. CORMIX can simulate a variety of diffuser configurations, including single and multiport arrangements. Both were employed in this study.

The model has the ability to capture the following key phases of plume evolution:

- Near field: the region where plume dynamics are dominated by the momentum of the discharge.
- Buoyant spreading: the region where the buoyancy of the effluent stream is dynamically important. Depending on ambient flow conditions, this regime may lead to either restratification or full vertical mixing.
- Ambient spreading: the region where full vertical mixing has occurred and the effluent stream is largely controlled by the ambient flow regime.

The locations and characteristics of these phases determine the efficacy of the selected diffuser arrangement in dispersing the effluent stream.

It is noted that CORMIX does not require calibration in the same way the far field models do: it is a process based model requiring specification of inputs only.

4.1 Near Field Assumptions and Limitations

It should be noted that CORMIX results are correct to ±50% (as stated by the model developers), and all results should be interpreted accordingly. Similarly, CORMIX cannot capture two and three-dimensional effects associated with the varying hydrodynamic flow field into which effluent is being discharged. Further investigation at a later stage using more sophisticated (three dimensional) modelling tools will most likely be necessary to capture these effects. Further investigation should also account for unsteady effects, which have not been dynamically simulated here. Appendix A provides further details of the CORMIX model and its outputs and limitations.

5 MODELLING METHODOLOGY

The modelling process involved the use of the three models previously described to investigate the behaviour of the pollutant discharge in both the near and far field. CORMIX was used to examine near field effects (i.e. short term – minutes to hours), and the two RMA models (hydrodynamics and advection-dispersion) were used to investigate far field impacts (i.e. longer term – months to a year).

The modelling methodology firstly involved consideration of the near field effects under a given diffuser arrangement. Following any necessary refinement to the near field outfall configurations to achieve satisfactory results (typically full vertical mixing to ensure a valid linkage with the depth averaged RMA model), the far field model was run with the corresponding discharge included in such a way as to correspond to the location of the proposed outfall configuration.

The complete suite of pollutants to be discharged (see Table 5-1) was not specifically simulated in either of the above models. Rather, a 'dilution' approach was adopted where a passive tracer was inserted with the appropriate flow regime into both models, and the dispersion and dilution of that tracer used to back calculate the likely near and far field concentrations of pollutants from a knowledge of the initial values. Resultant concentrations could then be compared to water quality objectives (WQOs). Specifically, the tracer was inserted at a concentration of 100 units, and dilution subsequently traced as a percentage of the original.

Table 5-1 Total pollutant concentrations for the diffuser discharge

Constituent	Discharge Concentration	Ambient Concentration	Water Quality Objective
Nickel (µg/L)	150	<1[2]	70[4]
Cobalt (µg/L)	20	0.39[2]	1[4]
Iron (µg/L)	140	73[1]	196[3]
Magnesium (µg/L)	1700000	1320000[2]	NA
Aluminium (µg/L)	110	69[1]	127[3]
Manganese (µg/L)	3000	8[1]	140[5]
Zinc (µg/L)	1.9	1.25[1]	15[4]
Calcium (µg/L)	420000	411000[2]	NA
Chlorine (µg/L)	19300000	19400000[2]	NA
Sulfate (µg/L)	4100000	2688000[2]	NA

[1] 50th percentile of monitoring data
[2] Typical seawater value. If both 1 and 2 were available, ambient seawater data was selected
[3] WQO from 80th percentile of monitoring data (WBM, 2002)
[4] ANZECC/ARMCANZ http://www.deh.gov.au/water/quality/nwqms/pubs/wqg-ch3.pdf (95% protection of species level)
[5] Provided by URS
NA = no data available

The above approach assumes essentially passive behaviour of all discharged pollutants, with the exception of manganese, which has been modelled with a 28 day half life decay.

In the case of CORMIX, pollutant concentrations were extracted at designated locations downstream, and near field concentrations computed. One thousand metres downstream was selected for the purposes of this report.

In the case of the far field modelling, timeseries of tracer concentrations at a number of randomly selected points throughout the model domain were produced. Contour maps were also produced from far field results. The maps show the 6 and 12 hour moving average maximum concentrations throughout the model domain, at steady state.

CORMIX simulations were run as a 'once off' for a variety of tidal velocities, as it is a steady state model. The far field model was run for approximately 10 months to reach steady state, then hot-started for a two week period over which results were extracted. The underlying hydrodynamic model was run on a two week cyclical basis to support the progression of advection dispersion modelling.

This near field/far field modelling combination was used iteratively to assess a wide range of configurational options for the proposed GPN discharge, and these are briefly described in the following chapter. Based on that iterative investigative work, a final proposed configuration has been arrived at, the results of which are described in Section 7.

6 OVERVIEW OF CONFIGURATIONAL INVESTIGATION

Through the iterative process of near field and far field modelling described above, and under the guidance of GPN, the following options for dispersal of the proposed plant effluent were considered. In terms of the diffuser arrangements, these consisted of either eductors (single stand alone outlets), diffusers (multiport pipes) or combinations of both.

The first configuration of eductors was located at the proposed Wiggins Coal Terminal Wharf, which if it is built, is to be situated in the main channel opposite Tide Island. An investigation was undertaken on the dynamics in the near field (CORMIX) and the far field (RMA). The pollutant discharge from the eductors configuration was aligned perpendicular to the main direction of flow, and a variety of different flow rates and pollutants concentrations were tested. The near field modelling results showed that there was bottom attachment of the plume and the far field results showed that there was poor dilution of the pollutant discharge, especially within the mangrove regions to the north and south of Fisherman's landing. The modelling also suggested there might be recirculation of the pollutant discharge back towards the intake location, and longer term accumulation in the mangrove areas. For these reasons this configuration was not pursued.

The second configuration moved further south to the existing RG Tanna wharf. The configuration consisted of four eductors located along RG Tanna wharf, parallel to the main direction of flow, but discharging perpendicular to ambient tidal flows. The results showed that there was a tendency for the pollutant discharge to accumulate in the marina and disperse up the Calliope River during spring tides. Also, insufficient vertical mixing was attained by the use of these eductors, making the conceptual link between the near field and (vertically averaged) far field modelling difficult.

The third configuration consisted of a diffuser line situated along RG Tanna wharf, extending approximately 1km. The diffuser was aligned parallel to the main currents and within this configuration there were further options of two different flow rates with different concentrations of pollutants. The results from this far field modelling suggested that the dilutions were constrained by the parallel alignment of the diffuser line with the ambient tidal flow regime. In particular, insufficient dilution was attained. Preliminary testing near field modelling was undertaken and the results suggested that there would be greater dilutions if the diffuser line were to be situated perpendicular to the flow, instead of parallel. This option was pursued.

The fourth configuration consisted of a diffuser line situated along the approach jetty to RG Tanna wharf, perpendicular to the main direction of flow. Transformation rates for dissolved manganese were investigated by others and implemented in the far field modelling. These rates consisted of 4- and 30-day rates. Whilst the resultant near and far field concentrations were considerably lower than previously observed, dilutions were still insufficient.

The fifth configuration consisted of two diffuser lines, one situated along the approach jetty to RG Tanna wharf, and another diffuser line 900m east, both perpendicular to the main direction of flow. Implementation of transformation rates for manganese was included in the far field modelling, however the dilutions were still not sufficient.

The sixth arrangement comprised two diffuser lines located as before, but approximately 1.7km apart.

After extensive investigations of different configurations, the final configuration adopted consisted of two diffuser lines as per above for Stage 1, with an additional two diffusers included equi-spaced between those of Stage 1. A transformation rate of 28 day a half-life was simulated for manganese, based on advice from others, and no decay was assumed for all other discharge constituents. Results are discussed in detail for both stages in Chapter 7.

7 PROPOSED CONFIGURATION – STAGE 1

The proposed configuration comprises two cross current diffusers discharging half the total Stage 1 effluent each, located as per Figure 7-1. The model setup and results for both the near and far field are described below.

7.1 Near field

7.1.1 Inputs

The diffuser arrangement for the proposed configuration is as follows (it is noted that CORMIX can only simulate one diffuser line at a time):

- Diffuser lengths: 180m
- Diffusers as per Figure 7-1.
- Distance from shore of beginning of diffuser: 100m
- Number of ports per diffuser: 10 (20m spacing)
- Diffuser type: T diffuser (see Figure 7-2 for schematic)
- Water depth: 10 meters. This was calculated as the average depth along the length of the approach jetty (Figure 7-3)
- **Total** flow rate: 76,267 m^3/hr (38,133 m^3/hr **per diffuser**)
- Pipe diameters: The diffuser will step down in diameter in both stages to maintain port flow rates. This cannot be captured by CORMIX so equivalent diameters have been assumed as follows to represent an average cross-sectional area: 1.48m
- Outlet diameter: 585 mm;
- Diffuser eductor length: < 2m
- Discharge density: 1025 kg/m^3;
- Background receiving water density: 1024.5 kg/m^3 (supplied to WBM)
- Main pipeline elevation: 1/3 of average water depth from the bottom;
- Ambient velocity: Ambient velocities of 0.25, 0.5, 0.75 and 1.0 m/s have been assumed as representative of tidal currents. Steady state conditions have been simulated only. This should be investigated further using three dimensional unsteady dynamics in the future;
- Eductor inlet diameter: 100 mm (not explicitly modelled);
- Eductor plan configuration: Perpendicular to the main diffuser line;

Figure 7-1 Diffuser locations – Stage 1

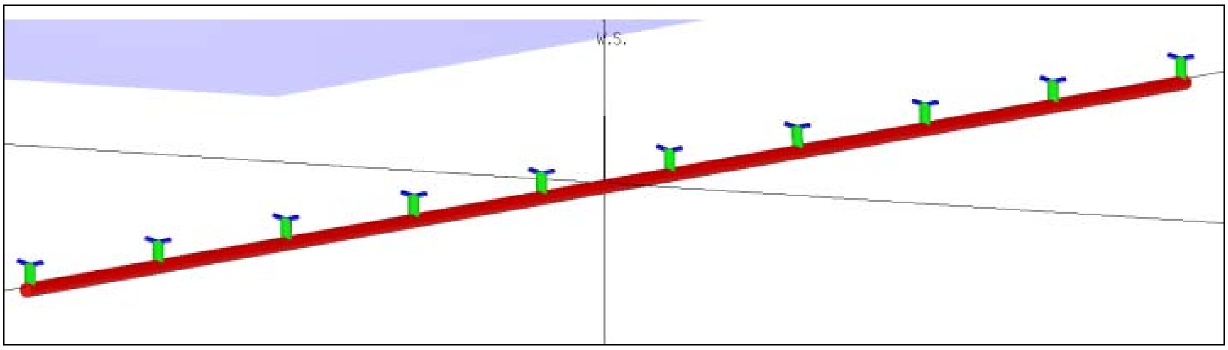


Figure 7-2 Schematic Representation of a Diffuser Line

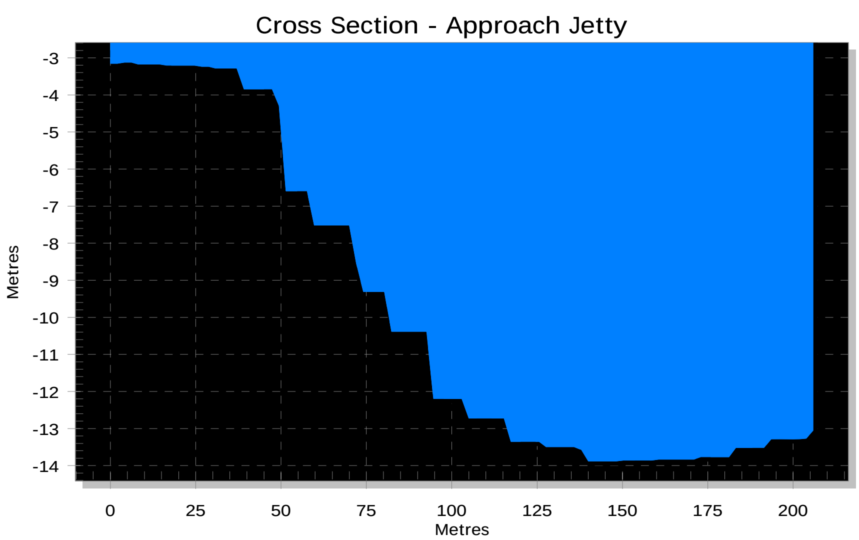


Figure 7-3 Cross section of the water depth for diffuser pipeline along the approach jetty

Discharge water quality is shown in Table 7-1. Existing ambient concentrations and water quality objectives (WQOs) are also shown, with appropriate sources. General advice for diffuser design (as per CORMIX outputs) is provided in Appendix A. Some specific references to the generally expected performance of the proposed GPN diffuser (and means of optimising this performance) are also included.

Table 7-1 Discharge, Ambient and Water Quality Objectives Concentrations

Constituent	Discharge Concentration	Ambient Concentration	Water Quality Objective
Nickel (µg/L)	150	<1[2]	70[4]
Cobalt (µg/L)	20	0.39[2]	1[4]
Iron (µg/L)	140	73[1]	196[3]
Magnesium (µg/L)	1700000	1320000[2]	NA
Aluminium (µg/L)	110	69[1]	127[3]
Manganese (µg/L)	3000	8[1]	340/140[5]
Zinc (µg/L)	1.9	1.25[1]	15[4]
Calcium (µg/L)	420000	411000[2]	NA
Chlorine (µg/L)	19300000	19400000[2]	NA
Sulfate (µg/L)	4100000	2688000[2]	NA

[1] 50th percentile of monitoring data
[2] Typical seawater value. If both 1 and 2 were available, ambient seawater data was selected
[3] WQO from 80th percentile of monitoring data (WBM, 2002)
[4] ANZECC/ARMCANZ http://www.deh.gov.au/water/quality/nwqms/pubs/wqg-ch3.pdf (95% protection of species level)
[5] Provided by URS –340 µg/L for disturbed areas and 140 µg/L for other areas
NA = no data available

7.1.2 Results

The CORMIX modelling typically shows the following key phases of plume evolution:

- Near field region. This zone captures the behaviour immediately above the diffuser line.
- Buoyant ambient spreading. This describes the spread of the plume under the influence of buoyancy and occurs from the edge of the near field region.
- Passive ambient mixing. This describes the behaviour of the plume once it is vertically mixed and no longer driven by buoyancy.

Away from the diffuser line itself, results were extracted at a location 1000m downstream of the diffuser. This distance was chosen as representative of a distance sufficiently removed from the discharge location to allow plume development to be independent of the diffuser characteristics. It is still anticipated that some (presently unquantifiable) hydrodynamic effects impact plume evolution at this distance, and dilution factors should be interpreted accordingly.

The dilutions at this location for the four ambient velocity cases considered here are:

- 0.25 m/s: 62;
- 0.5 m/s: 131;
- 0.75 m/s: 177;
- 1.0 m/s: 227.

Given tidal velocity variations, a representative dilution of 149 has been assumed here. It is emphasised again that this is a result from a steady state one-dimensional model that does not take into account any lateral velocity effects or additional mixing due to bathymetric variations. This is a limitation that needs to be considered in interpreting results. Using this dilution factor of 149, the following concentrations are predicted 1000m downstream of the diffuser.

Table 7-2 Predicted Pollutant Concentrations at 1000m Downstream of Diffuser

Constituent	Discharge Concentration	Concentration at 1000m	Ambient Concentration	Total Maximum Near Field Concentration	Water Quality Objective
Nickel (μg/L)	150	1.007	<1[2]	2.007	70[4]
Cobalt (μg/L)	20	0.134	0.39[2]	0.524	1[4]
Iron (μg/L)	140	0.940	73[1]	73.940	196[3]
Magnesium (μg/L)	1700000	11409	1320000[2]	1331409	NA
Aluminium (μg/L)	110	0.738	69[1]	69.738	127[3]
Manganese (μg/L)	3000	20	8[1]	28	340/140[5]
Zinc (μg/L)	1.9	0.013	1.25[1]	1.263	15[4]
Calcium (μg/L)	420000	2819	411000[2]	413819	NA
Chlorine (μg/L)	19300000	129530	19400000[2]	19529530	NA
Sulfate (μg/L)	4100000	27517	2688000[2]	2715517	NA

[1] 50th percentile of monitoring data
[2] Typical seawater value. If both 1 and 2 were available, ambient seawater data was selected
[3] WQO from 80th percentile of monitoring data (WBM, 2002)
[4] ANZECC/ARMCANZ http://www.deh.gov.au/water/quality/nwqms/pubs/wqg-ch3.pdf (95% protection of species level)
[5] Provided by URS –340 μg/L for disturbed areas and 140 μg/L for other areas
NA = no data available

All pollutants with identifiable WQOs meet guidelines at the selected point downstream of the diffuser. The following table presents the distance downstream of the diffuser where these WQOs are predicted to be met for the four ambient velocity cases considered.

Table 7-3 Compliance with WQOs Downstream of Diffuser

Constituent	Water Quality Objective (µg/L)	Distance downstream of diffuser v=0.25m/s	Distance downstream of diffuser v=0.50m/s	Distance downstream of diffuser v=0.75m/s	Distance downstream of diffuser v=1.00m/s
Nickel	70	0.3m	0.2m	0.1m	0.1m
Cobalt	1	24m	6m	2.7m	1.5m
Iron	196	0m	0m	0m	0m
Aluminium	127	0.2m	0.1m	0.1m	0m
Manganese	140	11.2m	2.9m	1.4m	1.1m
Manganese	340	1.6m	0.8m	0.5m	0.4m
Zinc	15	0m	0m	0m	0m

Constituents being discharged at seemingly high concentrations are magnesium, calcium, chlorine (assumed to be in the form of chloride ions) and sulfate. None have identifiable WQOs. In the absence of WQOs, it is noted that magnesium, calcium, chloride and sulfate all increase background seawater levels by less than 1%. Of these, calcium, chloride and sulfate are least likely to have adverse impacts. The potential impacts of magnesium are unclear. Some researchers, however, have investigated the toxicity of magnesium to shrimp at varying salinities (Pillard *et al.*, 2002). It was found that tolerance to magnesium was related to ambient salinity. This field is generally outside WBM's expertise, so no further advice can be offered at this stage, although investigation by others may be warranted. Further investigation of these WQOs may also be warranted.

Note that these dilutions and resultant pollutant concentration are derived from ***one diffuser only***. Due to CORMIX's inability to simulate more than one diffuser we cannot examine the potential near field additive effects of two diffusers within this modelling framework. This could be the focus of further work, however, the far field modelling does include the two diffuser lines and will partially cover these potential additive effects (to the extent of pure mass addition, rather than detailed plume interaction dynamics).

7.1.3 Total Suspended Sediments

Based on a maximum concentration of 200 mg/L in the return liquor, a TSS concentration differential of 5 mg/L is predicted on discharge from the eductor. Figure 7-4 shows the centreline dilution as a function of downstream distance applied to this TSS differential. The dilution rate has been directly extracted from the near field modelling results (CORMIX) at each location downstream of the diffuser. The figure can be used to estimate this differential at any desired location, within the model limitations.

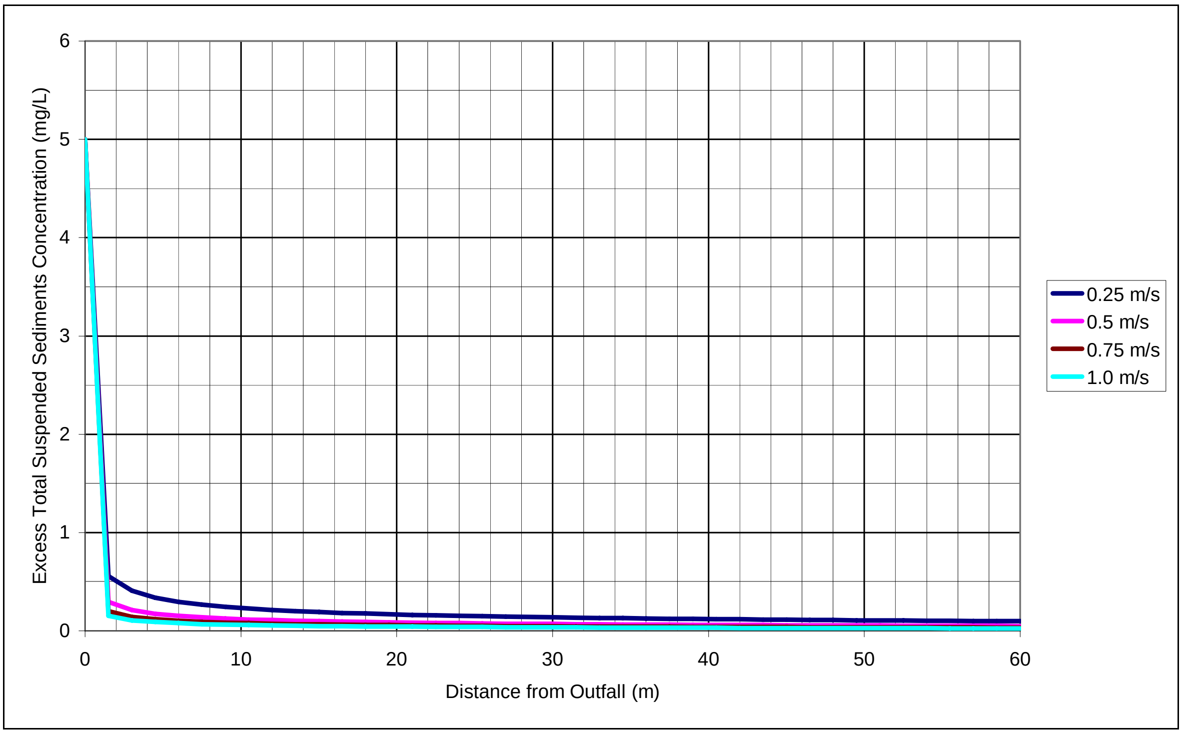


Figure 7-4 Predicted Centreline TSS Differential

7.1.4 Temperature

It is expected that an effluent to ambient temperature differential of 5^{o}C will be present on discharge from the eductor. Figure 7-5 shows the centreline dilution as a function of downstream distance applied to this temperature differential. As previously, the dilution rate has been directly extracted from the near field modelling results (CORMIX) at each location downstream of the diffuser. Again the figure can be used to estimate this differential at any desired location, within the model limitations.

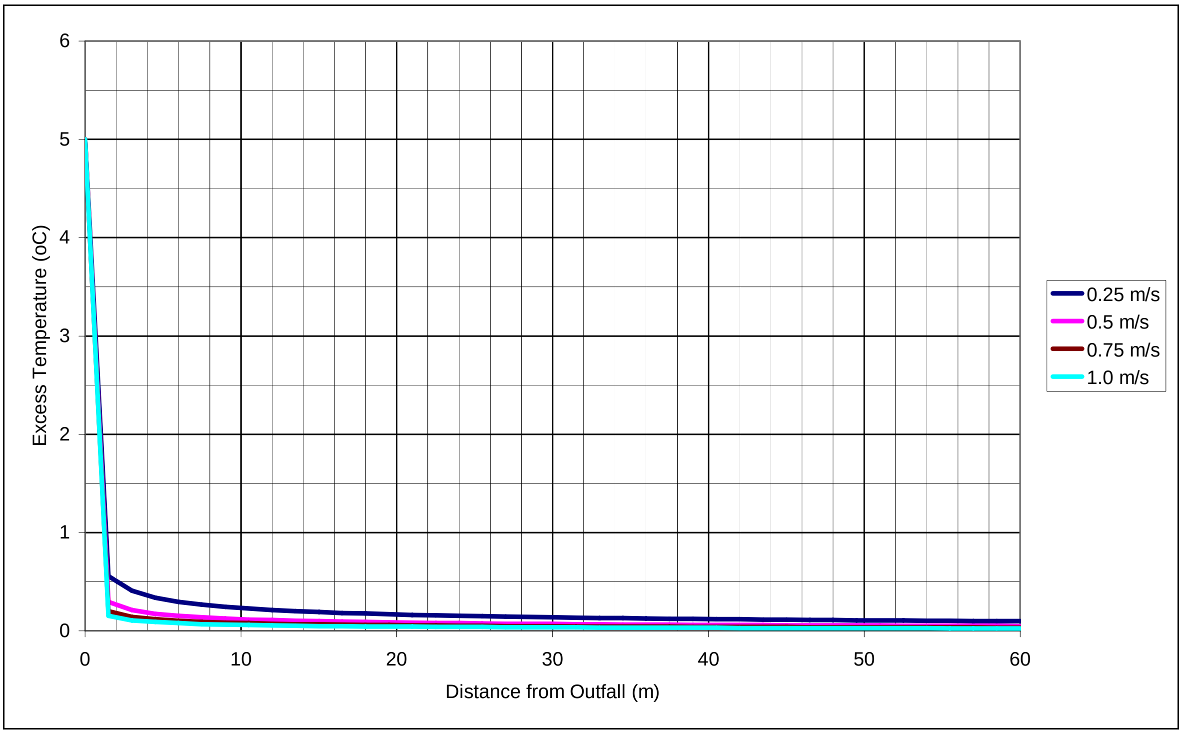


Figure 7-5 Predicted Centreline Temperature Differential

7.2 Far field configuration

The final proposed Stage 1 configuration consists of two diffuser lines running perpendicular to the main flow. One diffuser line is situated next to the approach jetty to the RG Tanna wharf, and the second diffuser line is situated approximately 1.7km downstream (Figure 7-1).

Within the model four elements along each diffuser line were assigned an inflow accompanied by a tracer. As per the near field modelling, the total inflow over the two diffuser lines was 76,267 m^3/hr. The tracer was assigned a half-life transformation rate of 28 days for manganese, and a zero decay rate for all other parameters, as per advice from others. The resulting water quality model simulation covered approximately 10 months, which allowed the tracer to approximate steady state within the Port.

The results are documented below. Note that concentration contours, averages and time series are presented only for the zero decay rate simulation results. It is understood that these results do not apply for manganese concentration, as this parameter has been applied a 28 day half life rate.

7.2.1 Spatial and Temporal Concentrations at Steady State

The spatial extent of the tracer covered a large proportion of Port Curtis, which is directly related to the large volume of discharge cooling water. There was little variation between the 6hrly and 12hrly maximums and the maximum concentration (~2%) was found in the immediate vicinity of the diffusers. The remainder of the Port exhibited tracer concentrations of approximately 1%.

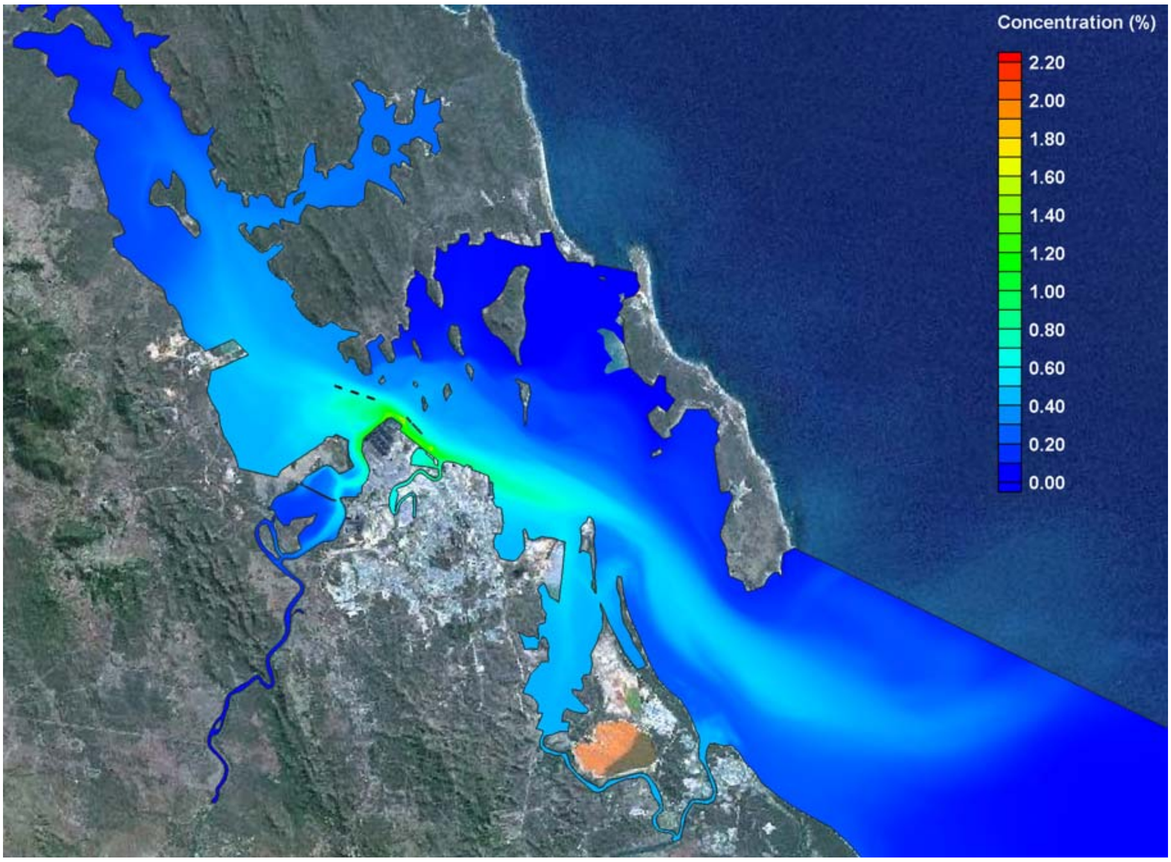


Figure 7-6 6hrly maximum concentrations of the tracer in Port Curtis – Stage 1

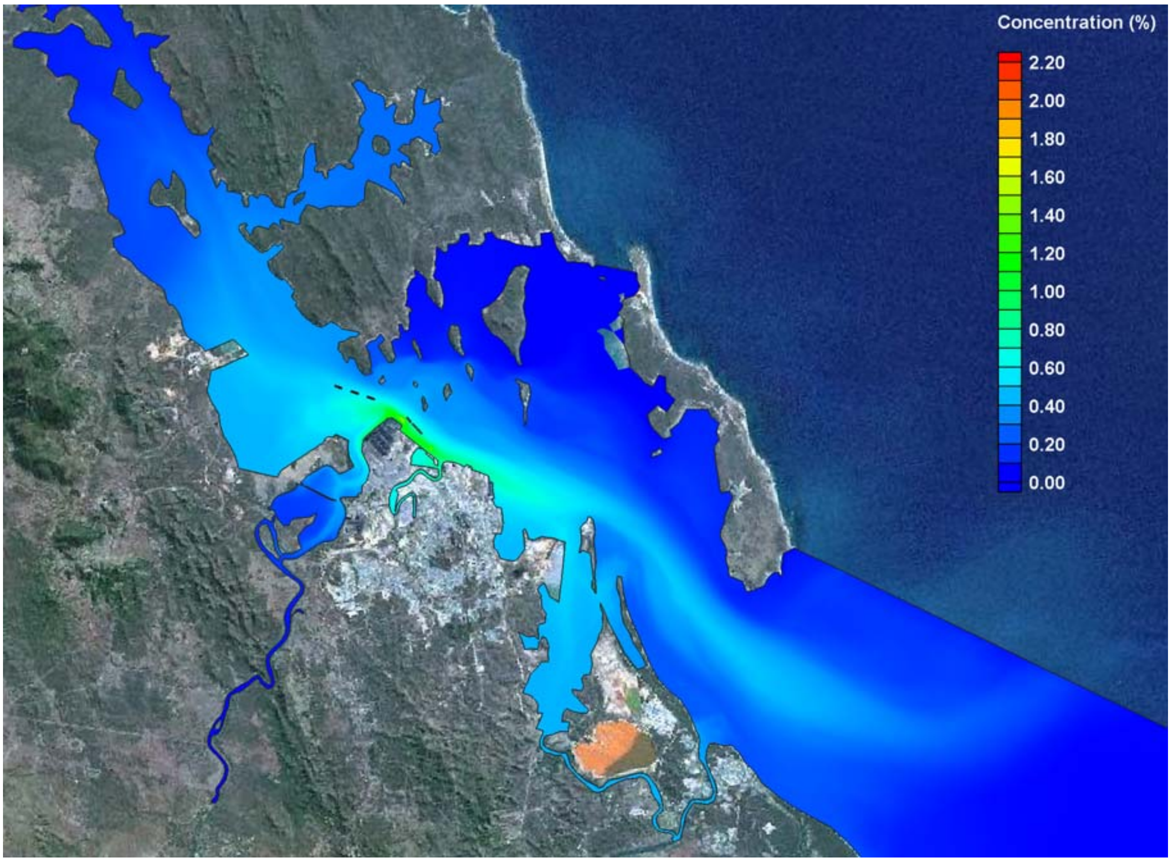


Figure 7-7 12hrly maximum concentrations of the tracer in Port Curtis – Stage 1

The time series data (Figure 7-9) shows the temporal variation in the concentrations, with peaks and troughs occurring due to the flood - ebb tidal cycle and the spring neap cycle. The locations of the timeseries data extraction points are also shown below.

Figure 7-8 Location of tracer concentrations time series data at steady state

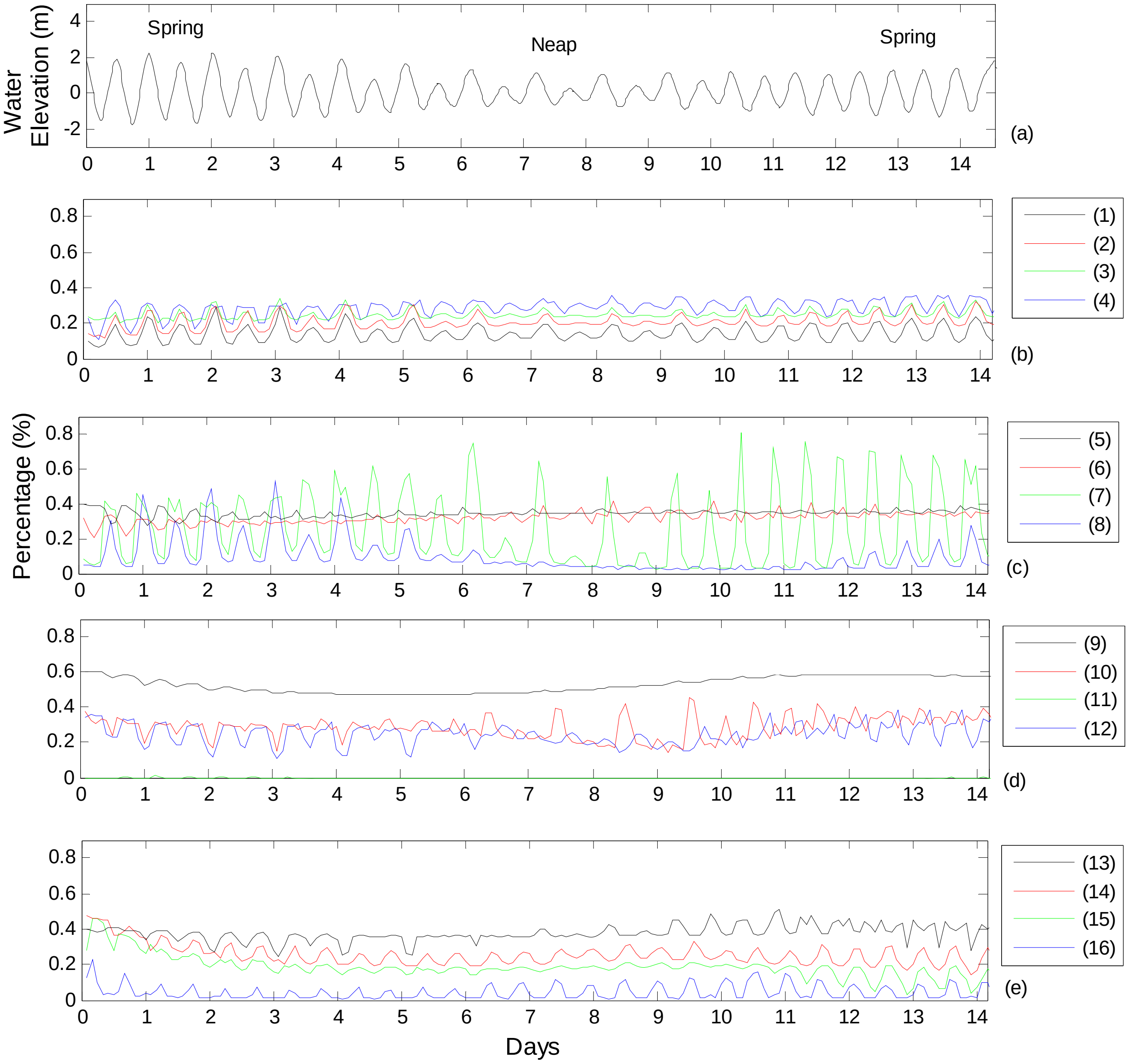


Figure 7-9 Time series of concentrations at 16 locations within Port Curtis – Stage 1

An examination of the 16 far field locations illustrated that the highest concentration of the tracer was found in the Calliope River (point 7), with a concentration of 0.75% for the 28 day manganese half life rate and 0.84% for the zero decay rate. These values have been used in Table 7-4 to calculate the percentages of pollutants likely to be present at this location.

Table 7-4 Far Field Pollutant Concentrations – Stage 1

Constituent	Discharge Concentration	Maximum Additional Far Field Tracer Concentration	Ambient Concentration	Total Maximum Far Field Concentration	Water Quality Objective
Nickel (µg/L)	150	1.25	<1[2]	2.25	70[4]
Cobalt (µg/L)	20	0.167	0.39[2]	0.557	1[4]
Iron (µg/L)	140	1.170	73[1]	74.170	196[3]
Magnesium (µg/L)	1700000	14212	1320000[2]	1334212	NA
Aluminium (µg/L)	110	0.920	69[1]	69.920	127[3]
Manganese (µg/L)	3000	22.4	8[1]	30.4	340/140[5]
Zinc (µg/L)	1.9	0.01588	1.25[1]	1.26588	15[4]
Calcium (µg/L)	420000	3511	411000[2]	414511	NA
Chlorine (µg/L)	19300000	161348	19400000[2]	19561348	NA
Sulfate (µg/L)	4100000	34276	2688000[2]	2722276	NA

[1] 50th percentile of monitoring data
[2] Typical seawater value. If both 1 and 2 were available, ambient seawater data was selected
[3] WQO from 80th percentile of monitoring data (WBM, 2002)
[4] ANZECC/ARMCANZ http://www.deh.gov.au/water/quality/nwqms/pubs/wqg-ch3.pdf (95% protection of species level)
[5] Provided by URS –340 µg/L for disturbed areas and 140 µg/L for other areas
NA = no data available

All pollutants with identifiable WQOs meet guidelines.

7.2.2 Mean Dilution Analysis

To investigate the longer-term background concentrations within the Port, the mean concentrations at all 16 locations were tabulated and are reported in Table 7-5. These locations are shown in Figure 7-8. The marina had the highest mean concentration, at steady state, with a value at 0.55%. It should however be noted that the marina is an artificial environment. The second highest mean concentration was situated at South Trees Inlet (location 13) and in location 5.

Table 7-5 Average Concentrations for 16 Locations in Port Curtis at Steady State – Stage 1

Location	Average Concentration at steady state
1	0.17
2	0.25
3	0.29
4	0.32
5	0.38
6	0.34
7	0.28
8	0.11
9	0.55
10	0.30
11	0.00
12	0.25
13	0.38
14	0.23
15	0.16
16	0.04

8 PROPOSED CONFIGURATION – STAGE 2

The proposed configuration for Stage 2 comprises four cross current diffusers discharging half the total Stage 1 effluent each (eg the total discharge for Stage 2 is doubled compared to Stage 1), located as per Figure 8-1. The model setup and results for both the near and far field are described below.

Figure 8-1 Diffuser locations – Stage 2

8.1 Near field

The individual diffuser arrangement for the proposed configuration is identical to stage 1 configuration, and as such dilutions are as previously presented (refer to Section 7.1). See later sections for discussion on interaction between the four diffuser lines.

The corresponding discharge and diluted concentrations at 1000m downstream are as per Table 8-1.

Table 8-1 Predicted Pollutant Concentrations at 1000m Downstream of Diffuser

Constituent	Discharge Concentration	Concentration at 1000m	Ambient Concentration	Total Maximum Far Field Concentration	Water Quality Objective
Nickel (µg/L)	150	1.007	<1[2]	2.007	70[4]
Cobalt (µg/L)	20	0.134	0.39[2]	0.524	1[4]
Iron (µg/L)	140	0.940	73[1]	73.940	196[3]
Magnesium (µg/L)	1700000	11409	1320000[2]	1331409	NA
Aluminium (µg/L)	110	0.738	69[1]	69.738	127[3]
Manganese (µg/L)	3000	20	8[1]	28	340/140[5]
Zinc (µg/L)	1.9	0.013	1.25[1]	1.263	15[4]
Calcium (µg/L)	420000	2819	411000[2]	413819	NA
Chlorine (µg/L)	19300000	129530	19400000[2]	19529530	NA
Sulfate (µg/L)	4100000	27517	2688000[2]	2715517	NA

[1] 50th percentile of monitoring data
[2] Typical seawater value. If both 1 and 2 were available, ambient seawater data was selected
[3] WQO from 80th percentile of monitoring data (WBM, 2002)
[4] ANZECC/ARMCANZ http://www.deh.gov.au/water/quality/nwqms/pubs/wqg-ch3.pdf (95% protection of species level)
[5] Provided by URS –340 µg/L for disturbed areas and 140 µg/L for other areas
NA = no data available

8.1.1 Total Suspended Sediments

Based on a maximum concentration of 200 mg/L in the return liquor, a TSS concentration differential of 5 mg/L is predicted on discharge from the eductor. Figure 8-2 shows the centreline dilution as a function of downstream distance applied to this TSS differential. The dilution rate has been directly extracted from the near field modelling results (CORMIX) at each location downstream of the diffuser. The figure can be used to estimate this differential at any desired location, within the model limitations.

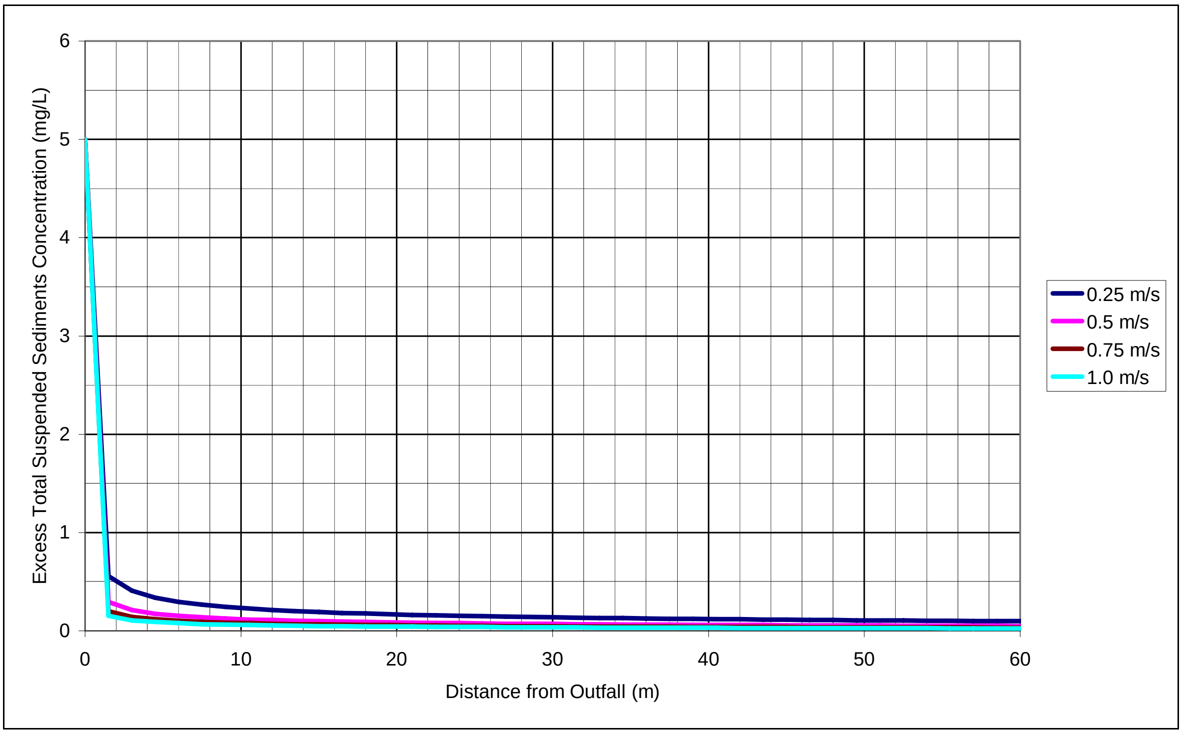


Figure 8-2 Predicted Centreline TSS Differential

8.1.2 Temperature

It is expected that an effluent to ambient temperature differential of 5°C will be present on discharge from the eductor. Figure 8-3 shows the centreline dilution as a function of downstream distance applied to this temperature differential. As previously, the dilution rate has been directly extracted from the near field modelling results (CORMIX) at each location downstream of the diffuser. Again the figure can be used to estimate this differential at any desired location, within the model limitations.

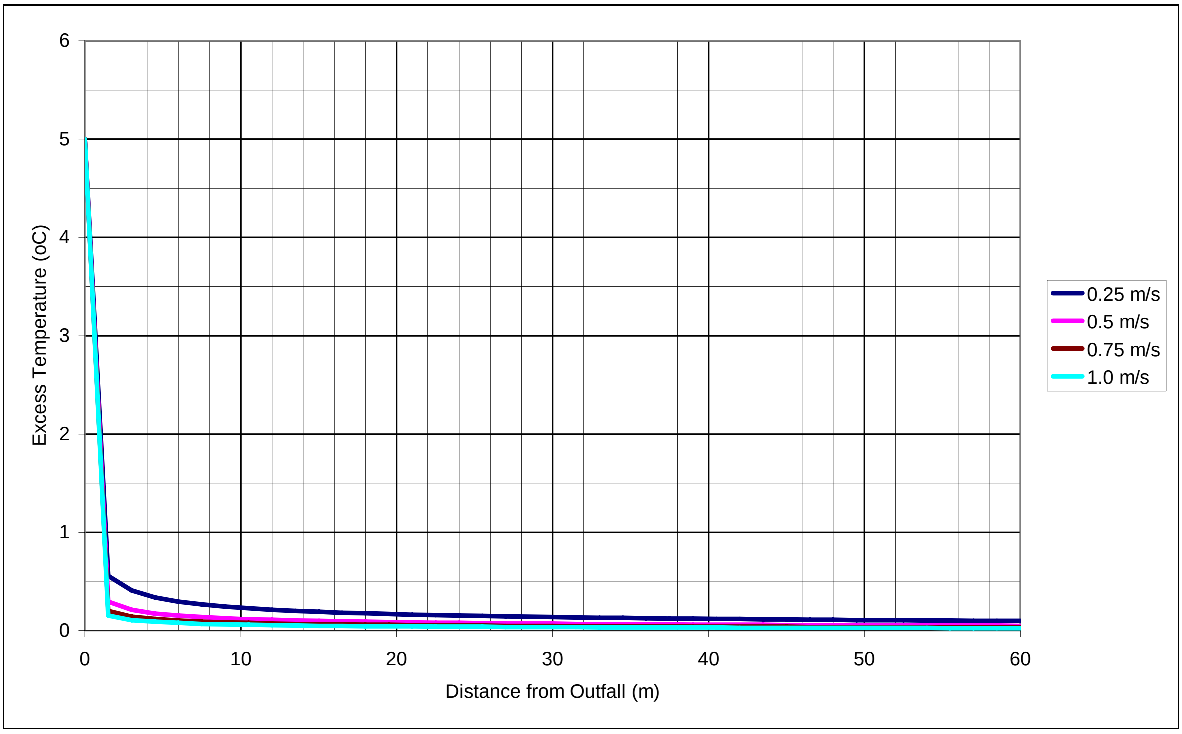


Figure 8-3 Predicted Centreline Temperature Differential

8.2 Far field configuration

The Stage 2 proposed configuration consists of four diffuser lines running perpendicular to the main flow. The first diffuser line is situated next to the approach jetty to the RG Tanna wharf, and the fourth diffuser line is situated approximately 1.7km downstream, with the two intermediate diffuser lines equally spaced in between (Figure 8-1).

Within the model, four elements along each diffuser line were assigned an inflow accompanied by a tracer. As per the near field modelling, the total Stage 2 inflow over the four diffuser lines was 150,000 m^3/hr. The tracer was assigned a half-life transformation rate of 28 days for manganese, and a zero decay rate for all other parameters, as per advice from others. The resulting water quality model simulation covered approximately 10 months, which allowed the tracer to approximate steady state within the Port.

The results are documented below. As for stage 1, note that concentration contours, averages and time series are presented only for the zero decay rate simulation results. It is understood that these results do not apply for manganese concentration, as a 28 day half life has been applied to this parameter.

8.2.1 Spatial and Temporal Concentrations at Steady State

The spatial extent of the tracer covers a large proportion of Port Curtis, which is directly related to the large volume of discharged effluent. The maximum concentration (approximately 2.5%) is found in the immediate vicinity of the diffusers. Concentrations above 1% extend in the Port in Stage 2.

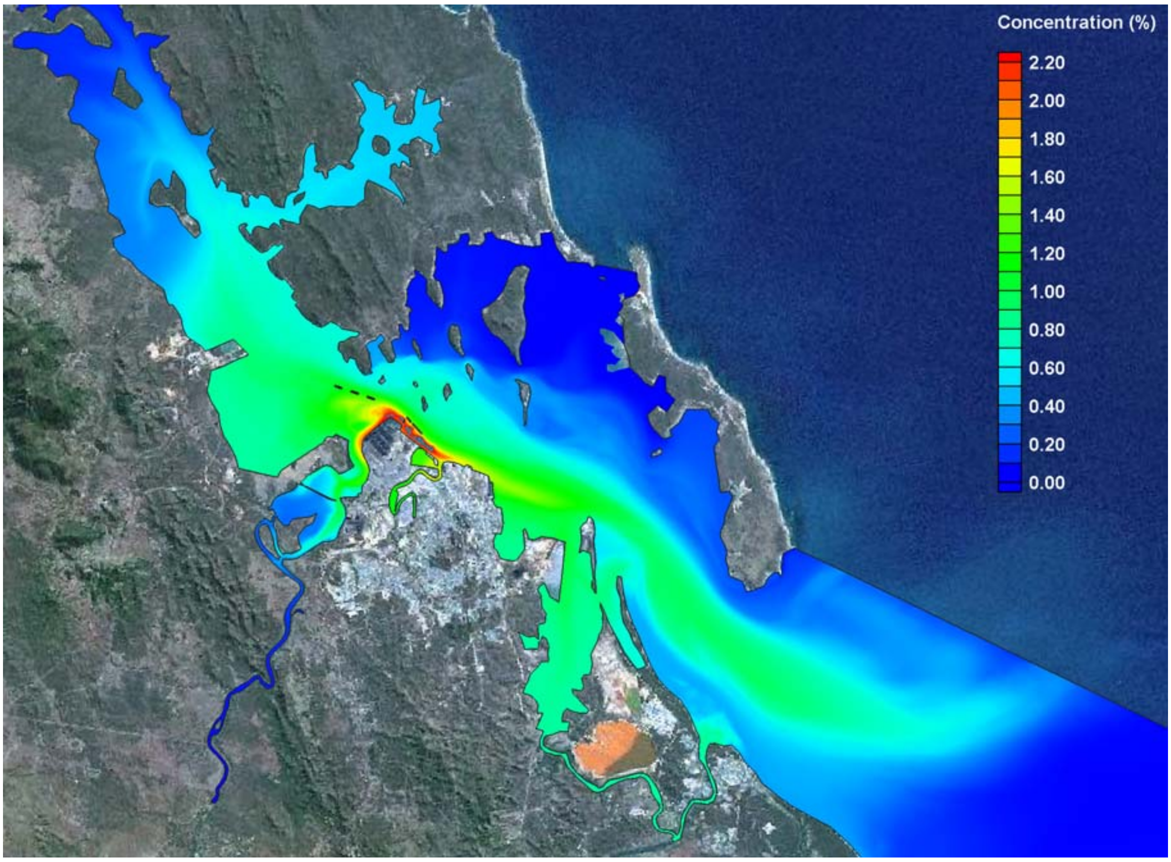


Figure 8-4 6hrly maximum concentrations of the tracer in Port Curtis – Stage 2

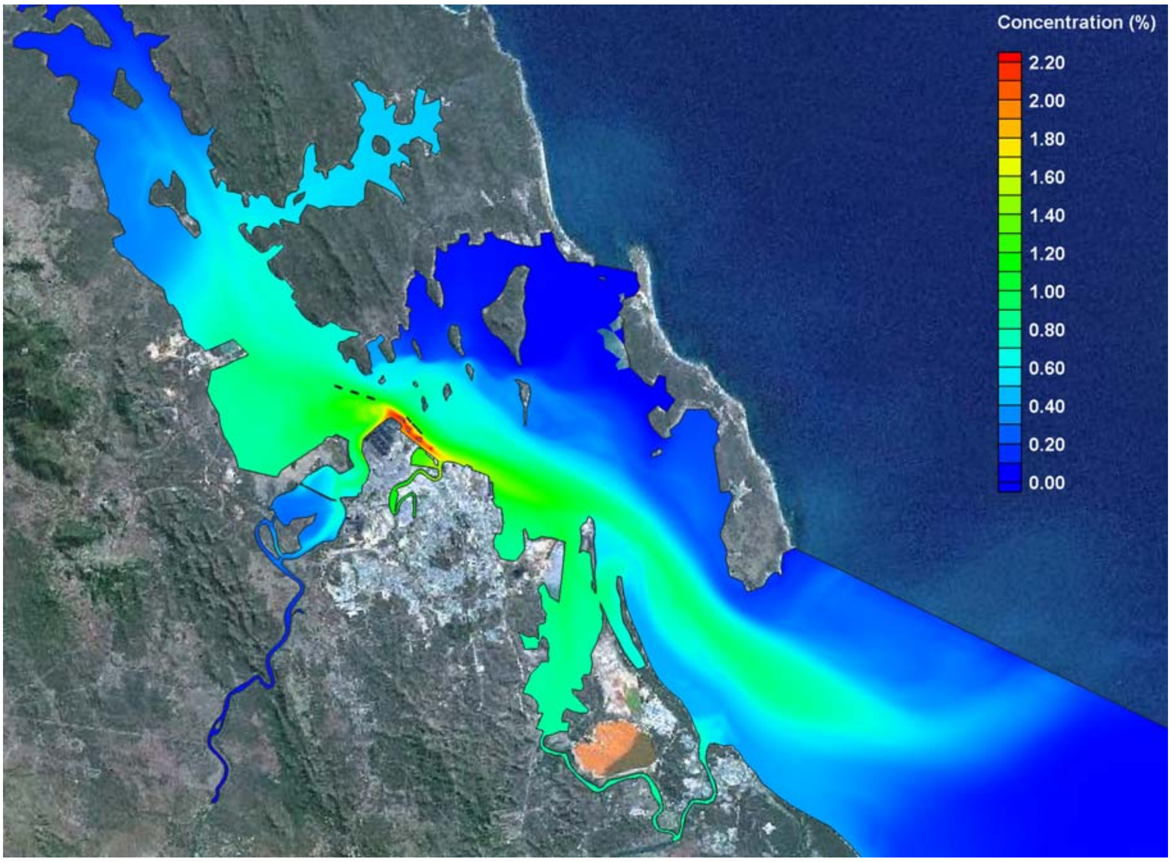


Figure 8-5 12hrly maximum concentrations of the tracer in Port Curtis – Stage 2

The time series data (Figure 8-6) shows the temporal variation in the concentrations, with peaks and troughs occurring due to the flood - ebb tidal cycle and the spring neap cycle. Refer to Figure 7-8 for location of the 16 far field time series extractions.

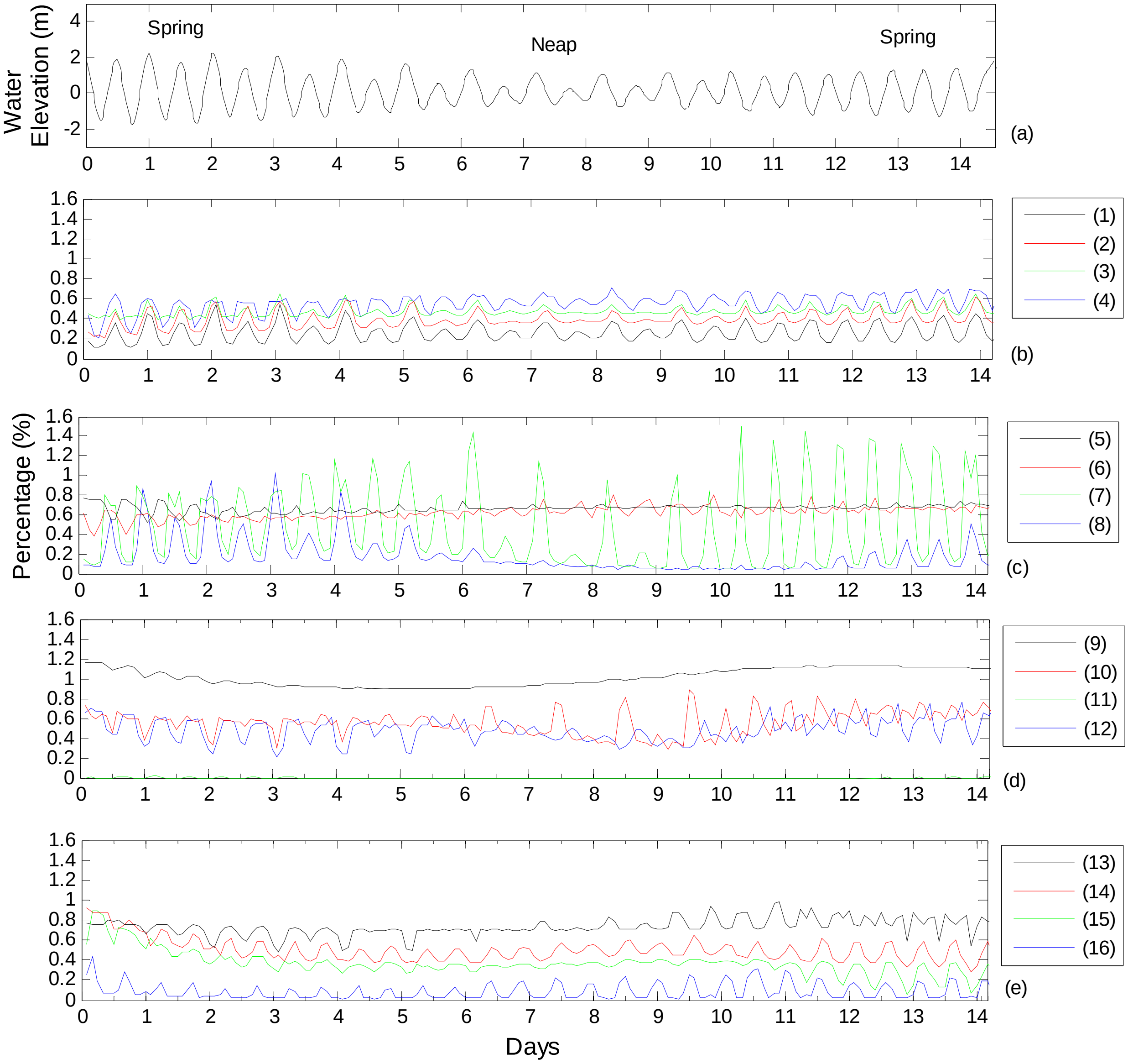


Figure 8-6 Time series of concentrations at 16 locations within Port Curtis – Stage 2

An examination of the 16 far field locations illustrated that the highest concentration of the tracer was found in the Calliope River (point 7), with a concentration of 1.39% fro the 28 day manganese half life rate and 1.55% for the zero decay rate. This value has been used in Table 8-2 to calculate the percentages of pollutants likely to be present at this location.

Table 8-2 Far Field Pollutant Concentrations – Stage 2

Constituent	Discharge Concentration	Maximum Additional Far Field Tracer Concentration	Ambient Concentration	Total Maximum Far Field Concentration	Water Quality Objective
Nickel (µg/L)	150	2.32	<1[2]	3.32	70[4]
Cobalt (µg/L)	20	0.309	0.39[2]	0.699	1[4]
Iron (µg/L)	140	2.164	73[1]	75.164	196[3]
Magnesium (µg/L)	1700000	26282	1320000[2]	1346282	NA
Aluminium (µg/L)	110	1.701	69[1]	70.701	127[3]
Manganese (µg/L)	3000	41.7	8[1]	49.7	340/140[5]
Zinc (µg/L)	1.9	0.02937	1.25[1]	1.27937	15[4]
Calcium (µg/L)	420000	6493	411000[2]	417493	NA
Chlorine (µg/L)	19300000	298378	19400000[2]	19698378	NA
Sulfate (µg/L)	4100000	63386	2688000[2]	2751390	NA

[1] 50th percentile of monitoring data
[2] Typical seawater value. If both 1 and 2 were available, ambient seawater data was selected
[3] WQO from 80th percentile of monitoring data (WBM, 2002)
[4] ANZECC/ARMCANZ http://www.deh.gov.au/water/quality/nwqms/pubs/wqg-ch3.pdf (95% protection of species level)
[5] Provided by URS –340 µg/L for disturbed areas and 140 µg/L for other areas
NA = no data available

All pollutants with identifiable WQOs meet guidelines. Cobalt is approaching the WQO.

8.2.2 Mean Dilution Analysis

To investigate the longer-term background concentrations within the Port, the mean concentrations at all 16 locations were tabulated in Table 8-3 (refer to Figure 7-8 for location of the 16 points). The marina had the highest mean concentration, at steady state, with a value at 1.06%. It should however be noted that the marina is an artificial environment. The second highest mean concentration was situated at South Trees Inlet (location 13) and location 5.

Table 8-3 Average Concentrations for 16 Locations in Port Curtis at Steady State – Stage 2

Location	Average Concentration at steady state
1	0.32
2	0.47
3	0.55
4	0.62
5	0.73
6	0.66
7	0.52
8	0.20
9	1.06
10	0.58
11	0.00
12	0.49
13	0.73
14	0.46
15	0.31
16	0.07

9 CONCLUSIONS

9.1 Summary

This report describes numerical modelling undertaken to determine the near and far field impacts of effluent discharge to Port Curtis from the proposed GPN processing plant at Gladstone. The focus has been water column quality responses to this discharge. As a result of an extensive investigation into a wide range of effluent disposal options, a proposed diffuser arrangement has been adopted that offers the best dilution and dispersal of pollutants considered at present.

This arrangement includes:

- In Stage 1: two almost parallel diffusers aligned perpendicular to the ambient tidal current direction, each discharging half of the expected maximum flow for Stage 1. These are tee-diffusers with eductors fitted as per previous descriptions; and
- In Stage 2: four parallel diffusers aligned perpendicular to the ambient tidal current direction, each discharging one quarter of the expected maximum flow for Stage 2 (double Stage 1).

The results of both near- and far-field modelling exercises have been presented in previous sections. These have been presented in terms of relationships to WQOs, as timeseries and contour maps.

9.2 Modelling Assumptions and Limitations

As previously described, each model used in this study has limitations that need to be considered in interpretation of the results. Key limitations and modelling assumptions are presented in a separate document provided to URS.

In terms of manganese, we have applied a 28 day half life decay to its evolution. Application of no decay would increase reported concentrations.

10 REFERENCES

ANZECC (2000) Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy, Australian and New Zealand Conservation Council

EPA (2006) Queensland Water Quality Guidelines. Environmental Protection Agency, QLD.

Fischer, H.B., List, E.J., Koh, R.C., Imberger, J. and Brooks N.H. (1979) Mixing in Inland and Coastal Waters, Acadmeic press Inc.

Herzfeld, M., Parslow, J., Andrewartha, J., Sakov, P. and Webster, I.T. (2004) Hydrodynamic Modelling of the Port Curtis Region. CSIRO technical report 7. Project CM2.11

WBM Pty Ltd (2003) Modelling of Discharges from the Porposed LG Chem Plant to Port Curtis, Queensland. Final Report

WHO (2004) Concise International Chemical Assessment Document 63: Manganese and its Compounds: Environmental Aspects. World Health Organisation.

APPENDIX A: CORMIX MODEL DIFFUSER DESIGN ADVICE

DESIGN RECOMMENDATIONS: SUBMERGED MULTIPORT DIFFUSER DISCHARGES:

A reliable environmental analysis and mixing zone prediction is possible only if each design case is evaluated through several iterations of CORMIX2. Small changes in ambient or discharge design conditions can sometimes cause drastic shifts in the applicable flow configuration (flow class) and the size or appearance of mixing zones. Iterative use of CORMIX2 will give information on the sensitivity of predicted results on design and ambient conditions.

Each predictive case should be carefully assessed as to:

- size and shape of LMZ,
- conditions in the TDZ (if present),
- bottom impact of the discharge flow,
- water surface exposure,
- bank attachment, and other factors.

In general, iterations should be conducted in the following order:

- Diffuser design changes (geometry variations),
- Sensitivity to ambient conditions, and
- Discharge flow changes (process variations).

DIFFUSER DESIGN CHANGES (GEOMETRY VARIATIONS):

Most of the following recommendations are motivated by the desire for improving conditions in the applicable mixing zones (i.e. minimizing concentrations and/or areal extents):

1) Diffuser location: Consider moving the outfall further offshore to a larger water depth in order to delay flow interaction with the bank/shore, and to improve near-field mixing.

2) Diffuser type: The diffuser type is dictated by its nozzle/port arrangement (angles THETA and BETA with or without fanning) and its alignment (angle GAMMA) relative to the current. Many combinations are possible (see also the advice on discharge conditions in DATIN). No hard and fast rules can be given on the most desirable type and arrangement.

The diffuser choice is often dictated by local bathymetry and other conditions, e.g. clearances for navigation or fishing.

UNIDIRECTIONAL DIFFUSER:

This type has a directed net momentum input. It tends to produce strong currents in the receiving water, especially under shallow conditions, often associated with benthic impacts. A fanned-out port/nozzle design (variable BETA) usually gives somewhat improved dilutions.

Perpendicular alignment ("co-flowing diffuser"): This is the preferred type for non-reversing flows, as in rivers and in some coastal conditions. Note that in riverine situations the river flow provides an upper limit on the achievable dilution.

Parallel alignment ("tee diffuser") as per current GPN specifications: This alignment may be acceptable for weak reversing coastal flows to provide offshore transport for the diffuser plume. It provides poor mixing under strong current conditions.

STAGED DIFFUSER:

This type also provides a directed momentum input. Hence, it can lead to strong induced currents, with plume contact at the bottom.

Perpendicular alignment: This is a good arrangement for shallow water conditions in the coastal environment under weak or strong reversing currents. Under weak currents it gives good offshore transport, and it efficiently captures the ambient flow under strong current conditions.

Parallel alignment: Generally not advantageous.

ALTERNATING DIFFUSER:

This type has no directed net momentum input. Its dilution efficiency is mostly dictated by its buoyancy flux and by the ambient current. It usually has the least benthic impact. A fanned-out (variable BETA) will give somewhat improved dilutions especially under shallow water conditions.

Perpendicular alignment: This is the preferred arrangement for deep water (e.g. sewage) diffusers in coastal environments with variable currents and stratification. It may also be advisable for more shallow conditions if minimal influences on the ambient regime current are desired.

Parallel alignment: May be desirable because of bathymetric or navigational reasons.

3) Diffuser length: By and large, a longer diffuser will give better dilutions. However, this may not be the case for diffusers in parallel (as is the case with the proposed GPN diffuser) alignment, especially with strong ambient currents. Also keep in mind the dilution limitations given by the total flow in riverine situations. Typically, an alternating type will require a longer diffuser than the unidirectional or staged type in order to achieve the same near-field mixing.

4) Number of ports/nozzles and port/nozzle diameter (discharge velocity): Remember that for a given discharge flow rate the port area and discharge velocity are inversely related: a small discharge port implies a high discharge velocity, and a consequently high discharge momentum flux. Typically, a high velocity discharge will maximize near-field mixing. Note, however, that high velocity discharges a) may lead to unstable near-field flow configurations perhaps involving undesirable mixing patterns, and b) usually have little, if any, effect on dilutions over the far-field where a LMZ may apply. Discharge velocities in typical engineering designs may range from 3 m/s to 8 m/s. Very high velocities may lead to excessive pumping energy requirements. Very low velocities (less than 0.5 m/s) may lead to undesirable sediment accumulation within the discharge pipe or tunnel.

5) Port/riser spacing: Given the other constraints on diffuser mixing (i.e. diffuser length and discharge velocity) the spacing is a dynamically unimportant variable that has a limited effect on overall mixing.

However, the spacing plays a role in the merging process of the individual jets/plumes, and thus may affect the very initial mixing, e.g. as of interest in toxic dilution zone (TDZ) predictions. As a rough rule, merging takes place after a distance along the plume path of about three to five spacings. If the TDZ is encountered before then, additional single jet/plume predictions, using CORMIX1, may be needed.

6) Port height: In most cases, this is a dynamically unimportant parameter. However, there are important exceptions: For negatively buoyant discharges, the port height may control the amount of initial mixing prior to benthic contact. More generally, for deep water discharges the port height to water depth ratio has some effect on initial mixing. Finally, in the presence of crossflow, the port height influences the stability of the discharge, i.e. the distinction between deep and shallow water discharges.

SENSITIVITY TO AMBIENT CONDITIONS:

Variations - of the order of 25 percent - of the following ambient design conditions should be considered:

- ambient velocity (or ambient flowrate),
- ambient depth (or river/tidal stage), and
- ambient density structure (notably density differences).

Such variability is important for two reasons:

1) the usual uncertainty in ambient environmental data, and

2) the schematization employed by CORMIX.

DISCHARGE FLOW CHANGES (PROCESS VARIATIONS):

Actual process changes can result in variations of one or more of three parameters associated with the discharge: flowrate, density, or pollutant concentration. In some cases, such process changes may be difficult to achieve or too costly. Note, that "off-design" conditions in which a discharge operates below its full capacity also fall into this category.

Pollutant mass flux: The total pollutant mass flux is the product of discharge flow (m^3/s) times the discharge pollutant concentration (in arbitrary units). Thus, decreasing the pollutant mass flux will, in general, decrease the resulting pollutant concentration in the near-field and far-field. This occurs, of course, during off-design conditions.

Discharge flow: For a given pollutant mass flux, an increase in discharge flow implies an increase in discharge pollutant concentration, and vice versa. For the variety of flow classes contained in CORMIX2 there is no universal rule whether high or low volume discharges are preferable for optimizing near-field mixing. Mostly, the sensitivity is small, and even more so for far-field effects. Note that a change in discharge flow will influence, in turn, the discharge velocity and hence the momentum flux.

Discharge density: The actual density of the discharge flow controls the buoyancy effects relative to the ambient water. Occasionally, the discharge density is controllable through the amount of process heating or cooling occurring prior to discharge. Usually, near-field mixing is enhanced by maximizing the total density difference (positive or negative) between discharge flow and ambient water. In most cases, however, this effect is minor.