

Section 7

Assessment of Potential Impacts

Criterion	Project Impact
An outstanding example representing significant ongoing geological processes, biological evolution and man's interaction with his natural environment.	<p>Examples given of the values of the Great Barrier Reef which relate to this criterion include its size and morphological diversity; the process of accretion and erosion of coral reefs; extensive Halimeda beds; dispersion and evolution of hard corals; diversity of flora and fauna; coral colonies and communities; floristic regions; and morphological and genetic changes in mangroves and seagrass. The project area is located in Port Curtis which contains one of Queensland's busiest ports. In 2004/05 the Port of Gladstone had a throughput of over 60 million tonnes of cargo and in 2005/06 it was visited by over 1,100 commercial ships. The GNP will reinforce this existing commercial nature of Port Curtis.</p> <p>As discussed above, the project will not result in any further physical disturbance to the area's marine features beyond those which already exist or have been approved. While there are no coral reefs or cays in the project vicinity, the diversity of marine flora and fauna has been described and the only potential disturbance to this will be from the discharge of the refinery's waste water. The assessment described in Section 7.1 shows that all relevant water quality objectives will be met and that no significant impacts on Port Curtis are expected.</p>
Contains unique, rare and superlative natural phenomena, formations and features and areas of exceptional natural beauty.	<p>Examples given of the values of the Great Barrier Reef which relate to this criterion include its vast extent and variety of reefs and islands; coastal mangrove systems of exceptional beauty; rich variety of landscapes and seascapes; spectacular breeding colonies of seabirds and butterflies; and migrating mammals.</p> <p>The project does not interfere with any reefs or islands. While there is a coastal mangrove system in the vicinity of the refinery, there will be no disturbance to these mangroves. The project is located in a port and industrial landscape and will add further to this landscape character.</p> <p>There will be no disturbance to breeding colonies of seabirds nor to migrating mammals as a result of this project.</p>
Provides habitats where populations of rare and endangered plants and animals still survive	<p>Examples given of the values of the Great Barrier Reef which relate to this criterion include structurally and ecologically complex coral reefs; large number of islands providing extensive habitats; mangroves and seagrass beds; inter-reefal and lagoonal benthos; and plants and animals of conservation significance.</p> <p>As discussed, in the project vicinity there are no reefs or islands that will be affected by the project. Nor are there any inter-reefal or lagoonal areas within Port Curtis. While there are mangrove and seagrass areas in the vicinity of the refinery, these are not predicted to be significantly disturbed by the project. There are no threatened or significant species that have key or important habitats in Port Curtis that will be lost or damaged due to the GNP.</p>

Proposed Ongoing Studies and Monitoring

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GPNL is committed to implementing a comprehensive program of ongoing studies and monitoring in relation to Port Curtis. An outline of the proposed program which incorporates the approval conditions proposed by the Queensland EPA is given below.

Release to waters

- Monitoring of contaminants released to Port Curtis will be undertaken for the quality characteristics and parameters, at the monitoring point(s), and at the frequency specified in Tables 8-1, 8-2 and 8-3.

Table 8-1 Release Quality Limits

Release Point	Monitoring Point	Quality Characteristics	Release Limit (At S1)	Limit Type	Minimum Monitoring Frequency
Diffuser 1 & Diffuser 2	S1 ¹ and S2 ²	Dissolved Oxygen	6.0 mg/L	Minimum	Weekly
		Chemical Oxygen Demand	No Limit	No Limit	
		Temperature	3 degrees	Maximum above receiving waters	
		pH	6.5 to 8.5	Range	

Table 8-2 High Tidal Velocity Release Trigger Limit- Toxicants

Release Point	Monitoring Point	Quality Characteristics	Trigger Limit ($\mu\text{g}/\text{L}$) (At S1)	Trigger Type	Minimum Monitoring Frequency
Diffuser 1 & Diffuser 2	S1 and S2	Cadmium	2	Maximum	Weekly
		Chromium (Cr III)	250		
		Chromium (Cr VI)	44		
		Cobalt	18		
		Manganese	1,000		
		Nickel	56		
		Zinc	4		

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Table 8-3 Low Tidal Velocity Release Trigger Limit- Toxicants

Release Point	Monitoring Point	Quality Characteristics	Trigger Limit ($\mu\text{g/L}$) (At S1)	Trigger Type	Minimum Monitoring Frequency
Diffuser 1 & Diffuser 2	S1 and S2	Cadmium	1	Maximum	Weekly ³
		Chromium (Cr III)	125		
		Chromium (Cr VI)	22		
		Cobalt	9		
		Manganese	500		
		Nickel	28		
		Zinc	2		

¹ monitoring point S1 described as the supply pipe from mixing tank to diffusers 1 & 2.

² monitoring point S2 described as the supply pipe from the Gladstone Nickel Refinery to the mixing tank.

³ samples must be taken when receiving water is within 30 minutes before and 30 minutes after slack tide. Flow rates in volume per minute at S1 and S2 must be recorded as well as the time of sampling.

- All determinations of the quality of parameters in the wastewater discharge released will be made on samples that are representative of the discharge.
- All determinations of the quality of contaminants released will be made in accordance with the methods prescribed in the latest edition of the *Environmental Protection Agency Water Quality Sampling Manual*, and be carried out on samples that are representative of the discharge.
- The daily volume of wastewater from the refinery prior to dilution with any seawater will be determined or estimated by an appropriate method with an accuracy of +/- 5%, (e.g. a calibrated flow meter) and records kept of such determinations.
- The daily volume of wastewater released from the refinery to Port Curtis will be determined or estimated by an appropriate method with an accuracy of +/- 5%, (e.g. a calibrated flow meter) for each release point and records kept of such determinations.

Direct Toxicity Assessment (DTA) Procedure

- A written DTA program that effectively measures toxicity of the wastewater discharge will be developed and submitted to the Queensland EPA at least 6 months prior to the discharge of wastewater to Port Curtis.
- The DTA procedure will address all specific methods and protocols to establish that concentrations of toxicants do not exhibit chronic toxicological effects outside the approved chronic toxicity limits (water quality objectives) to the test biota, including but not limited to:
 - a) Specific test organisms to be utilised for DTA testing, in accordance with Section 8.3.6.8 of the ANZECC/ARMCANZ *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000), to provide an accurate indication of actual and chronic toxic effects in the receiving waters, taking into consideration locally occurring species and the nature of any change being investigated;
 - b) Dilution water selection;

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- c) Sampling methodology to ensure that a representative sample is obtained of wastewater prior to release to diffusers under worse case conditions, e.g. highest probable concentration (lowest seawater dilution) and daily process activity.
- d) Characterisation of the discharge wastewater, including temperature and potential toxicant(s) present;
- e) The nature of the contaminant(s);
- f) Acute and chronic DTA testing conducted on end-of-pipe discharge wastewater;
- g) The mixing zone dilution effects likely to be provided by the discharge structure;
- h) Test/biological end points;
- i) Statistical end-points (including No Observed Effect Concentration-(NOEC) and Lowest Observable Effect Concentration (LOEC));
- j) Quality assurance/quality control;
- k) Applicable Toxicity Identification Evaluation (TIE) procedures to be followed should the administering authority require such an evaluation;
- l) Reporting of DTA procedure results promptly to the Queensland EPA, which will include but not be limited to:
 - i) NOEC for all bioassay results;
 - ii) LOEC for all bioassay results;
 - iii) Information on the test sample and dilution water collection;
 - iv) Timing of test sample collection in relation to process performance;
 - v) Details of any water quality-related manipulation of the test sample;
 - vi) Test sample and dilution water delivery details;
 - vii) Results of the chemical analysis of the test sample for known toxicants of concern (i.e. all parameters on Tables 8-1 and 8-2 are a minimum requirement in addition to parameters indicative of any change), receiving environment dilution water, and the test water (wastewater/receiving water) for each of the dilutions;
 - viii) Time between test sample collection and commencement of the DTA (which should be kept to a minimum), and
 - ix) Interpretation of results e.g. relating NOEC to the trigger values, the extent of the mixing zone based on acute and chronic end-points and modelling predictions, and additional dilution of seawater at low current conditions. .

Routine Direct Toxicity Assessment

- GPNL will routinely undertake a DTA to quantify the toxicity of the wastewater discharge. The routine DTA will be undertaken in accordance with the following minimum requirements:
 - During the first 12 months following the commencement of discharge of wastewater to Port Curtis, a DTA will be carried out on a quarterly basis (with approximately 3 months between each routine DTA).
 - After the first 12 months of operation and subject to four consecutive quarterly DTA results showing compliance with the release limits, the minimum frequency of routine DTA shall be annual.

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- If a DTA result shows non-compliance with the release limits, then monitoring will recommence on a quarterly basis as discussed above, unless GPNL can demonstrate with data and information to the Queensland EPA the cause of the non-compliant DTA result and that the cause has been rectified and is unlikely to recur.

Event-based Direct Toxicity Assessment

- GPNL will undertake an event-based DTA where one or more of the trigger limits specified in Table 8-2 are exceeded on four consecutive occasions (weekly sampling) when measured at the monitoring point S1.

When any third consecutive exceedance of such trigger limit is detected, GPNL will make arrangements for priority analysis and reporting of the results of the subsequent sample and also make preparations with the DTA testing laboratories such that, should a fourth consecutive exceedence occur, a DTA can be promptly undertaken. The DTA will occur forthwith following the fourth consecutive exceedance.

Confirmation DTA

- GPNL will undertake a confirmation DTA when any change in the refinery or management of the wastewater stream is likely to increase the toxicological properties of the wastewater discharge.

Receiving Environment Monitoring Program (REMP)

- A REMP, focussing on near-field and further field impacts, will be implemented, based on the outcomes of a background environmental investigation pertaining to the receiving waters (i.e. Port Curtis and connected waters) that address at least the following:
 - Description of potentially affected receiving waters including key communities and background water quality characteristics based on accurate and reliable monitoring data that take into consideration any temporal variation (e.g. seasonality);
 - Description of applicable environmental values and water quality objectives to be achieved (i.e. as scheduled pursuant to the Environmental Protection (Water) Policy 1997);
 - Any relevant reports prepared by other governmental or professional research organisations that relate to the receiving environment within which the REMP is proposed; and
 - Water quality targets within the receiving environment to be achieved, and clarification of contaminant concentrations or levels indicating adverse environmental impacts during the REMP.

Near-field Monitoring Program (NFMP)

- A NFMP will be implemented to monitor and record the effects of the release of contaminants on the near-field receiving environment whilst contaminants are being discharged from the operation of the refinery, with the aims of identifying and describing the extent of any adverse impacts to local environmental values, particularly from potentially toxic contaminants, and monitoring performance of the diffuser to ensure adequate mixing and dilution.

For the purposes of the NFMP, the receiving environment is the waters of Port Curtis and connected waterways within 300 m up-current and down-current of each diffuser.

- The NFMP will address (but not necessarily be limited to) the following:

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- Monitoring for any potential adverse environmental impacts caused by the release;
 - Monitoring performance of the diffuser to ensure adequate mixing and dilution;
 - Sampling to determine the extent of the near-field mixing zone at various tidal phases (including the vertical profile) to validate near-field modelling estimates;
 - Monitoring of selected toxicants (including metals and other toxicants likely to be in the waste stream) to assess the extent of the compliance of concentrations with water quality objectives and the extent of the approved mixing zone;
 - Monitoring of selected physico-chemical parameters (including turbidity, pH, dissolved oxygen percentage saturation and concentration, conductivity, temperature) that would assist in quantifying the mixing and dilution of the diffusers;
 - Monitoring of sediment quality for selected parameters (including metals and metalloids characterised as being likely to be present in the wastewater discharge);
 - The locations of monitoring points including monitoring transects away from the diffuser as well as control locations;
 - The sampling depths;
 - The frequency or scheduling of sampling and analysis;
 - Any historical datasets to be relied upon;
 - Description of the statistical basis on which conclusions are drawn, and
 - Any spatial and temporal controls to exclude potential confounding factors.
- The NFMP will be prepared and submitted in writing to the Queensland EPA for approval not more than one year from the issue of the refinery's development approval.

Far-field Monitoring Program (FFMP)

- A FFMP will be implemented to monitor the effects of the release of contaminants on the receiving environment outside the near-field whilst contaminants are being discharged from the refinery, with the aims of identifying and describing the extent of any adverse impacts to local environmental values.

For the purposes of the FFMP, the receiving environment is the waters of Port Curtis and connected waterways.

- The FFMP will address (but not necessarily be limited to) the following:
 - Monitoring for any potential adverse environmental impacts caused by the release;
 - Monitoring sediments for contaminants of concern, including those described by not limited to those in Table 8-2;
 - Monitoring of selected physicochemical parameters (at least turbidity, pH, dissolved oxygen percentage saturation and concentration, conductivity, temperature and total suspended solids);

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- Monitoring of biological indicators that detect the extent of influence of the discharge on the far-field environment and ensure that environmental values are protected (including seagrass and coral monitoring);
 - The locations of monitoring points including monitoring transects away from the outfall of the designated release point as well as control locations;
 - The sampling depths;
 - The frequency or scheduling of sampling and analysis;
 - Any historical datasets or water quality objectives/guidelines to be relied upon;
 - Description of the statistical basis or approaches on which conclusions are drawn, and
 - Any spatial and temporal controls to exclude potential confounding factors.
- The FFMP will be prepared and submitted in writing to the Queensland EPA for approval not more than one year from the start of discharge of the wastewater to Port Curtis.

Port Curtis Integrated Monitoring Program

GPNL has sponsored several Port Curtis monitoring programs through the Port Curtis Integrated Monitoring Program (PCIMP) in order to gather vital baseline conditions. The involvement to date has included sponsorship of:

- Biological monitoring (water quality and oyster metal concentrations).
- Intertidal (mangrove and sediment) monitoring.
- Seagrass monitoring.
- Specific manganese related studies related to toxicity in the marine environment.

Further Research

Due to the paucity of toxicity data for manganese in marine waters reported in the EIS, GPNL is supporting a PhD research program to investigate the dynamics of trace metals in Port Curtis under naturally occurring environmental conditions, and the bioaccumulation potential and toxicity of trace metals to biota. The study will consist of the following two phases:

- Initially through laboratory assessments, the project will investigate the binding capacity of manganese oxides for trace metals under various simulated natural conditions (pH and dissolved oxygen). The bioaccumulation of trace metals in biota (oysters, prawns etc.) and passive sampling devices (DGT) through spiking manganese aggregates will also be assessed under similar conditions. Environmental harm to biota through toxicity testing will also be determined concurrently. An assessment of the light reducing properties and settling rates of the aggregates will also be determined.
- Secondly, in-situ field studies and/or through the use of mesocosms will be undertaken to validate the results of the laboratory studies. (A mesocosm has been defined as an experimental system that simulates real-life conditions as closely as possible, whilst allowing the manipulation of environmental factors).

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GPN Advection Dispersion Modelling Report

Appendix A



Gladstone Pacific Nickel Advection Dispersion Modelling FINAL REPORT

Reference: R.B16019.004.09.doc
Date: July 2008

Gladstone Pacific Nickel Advection Dispersion Modelling FINAL REPORT

Prepared For: URS Australia Pty Ltd

Prepared By: BMT WBM Pty Ltd (Member of the BMT group of companies)

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Title :	Gladstone Pacific Nickel Advection Dispersion Modelling FINAL REPORT
Author :	Fanny Houdré, Dr Emma Gale, Dr Darren Lyons, Dr Michael Barry, Tony McAlister
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 pollutants.

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1 INTRODUCTION

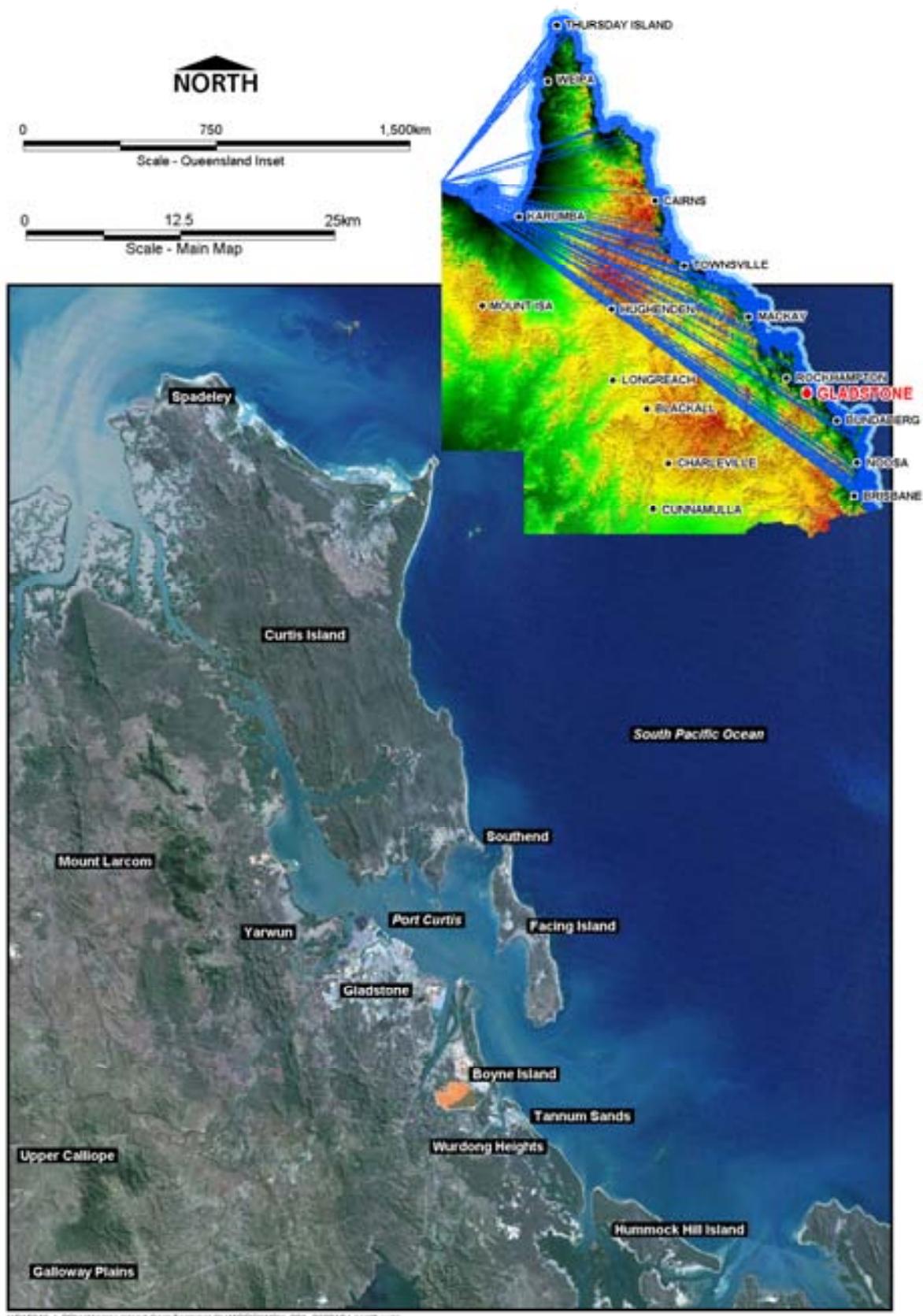
Gladstone Pacific Nickel (GPN) has proposed to establish a nickel plant at Gladstone, QLD (Figure 1-1). As part of the operations of the plant, a primary wastewater stream has been proposed to discharge to Port Curtis.

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 and use of the current tools, in line with standard industry practise. Such improvement would utilise water quality monitoring and detailed design data as it becomes available.



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 km², 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

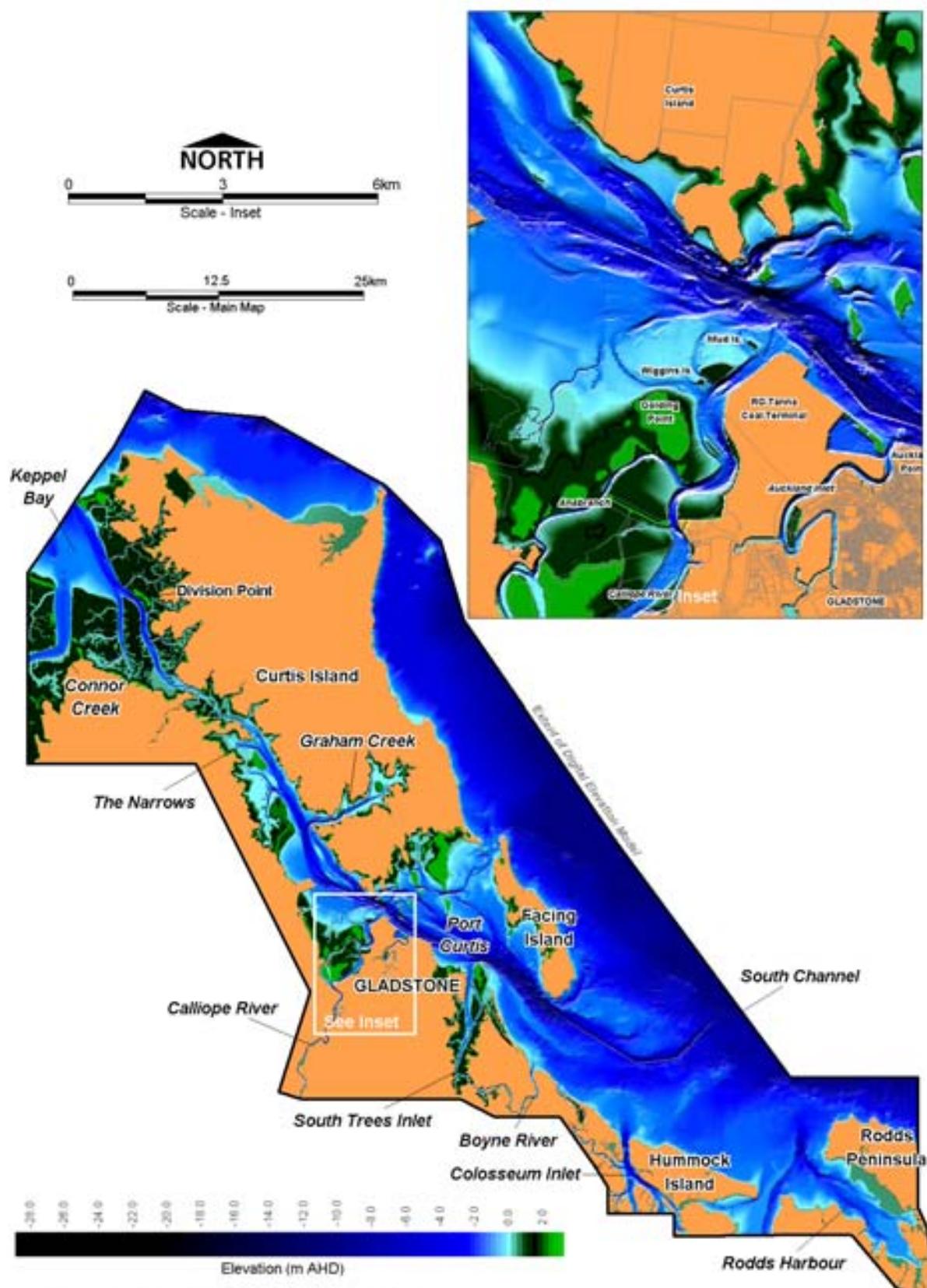
the model is shown in Figure 2-3. The figure shows a detail area of the model within the main Port region with a central inset displaying the material distribution over the entire model domain.

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.

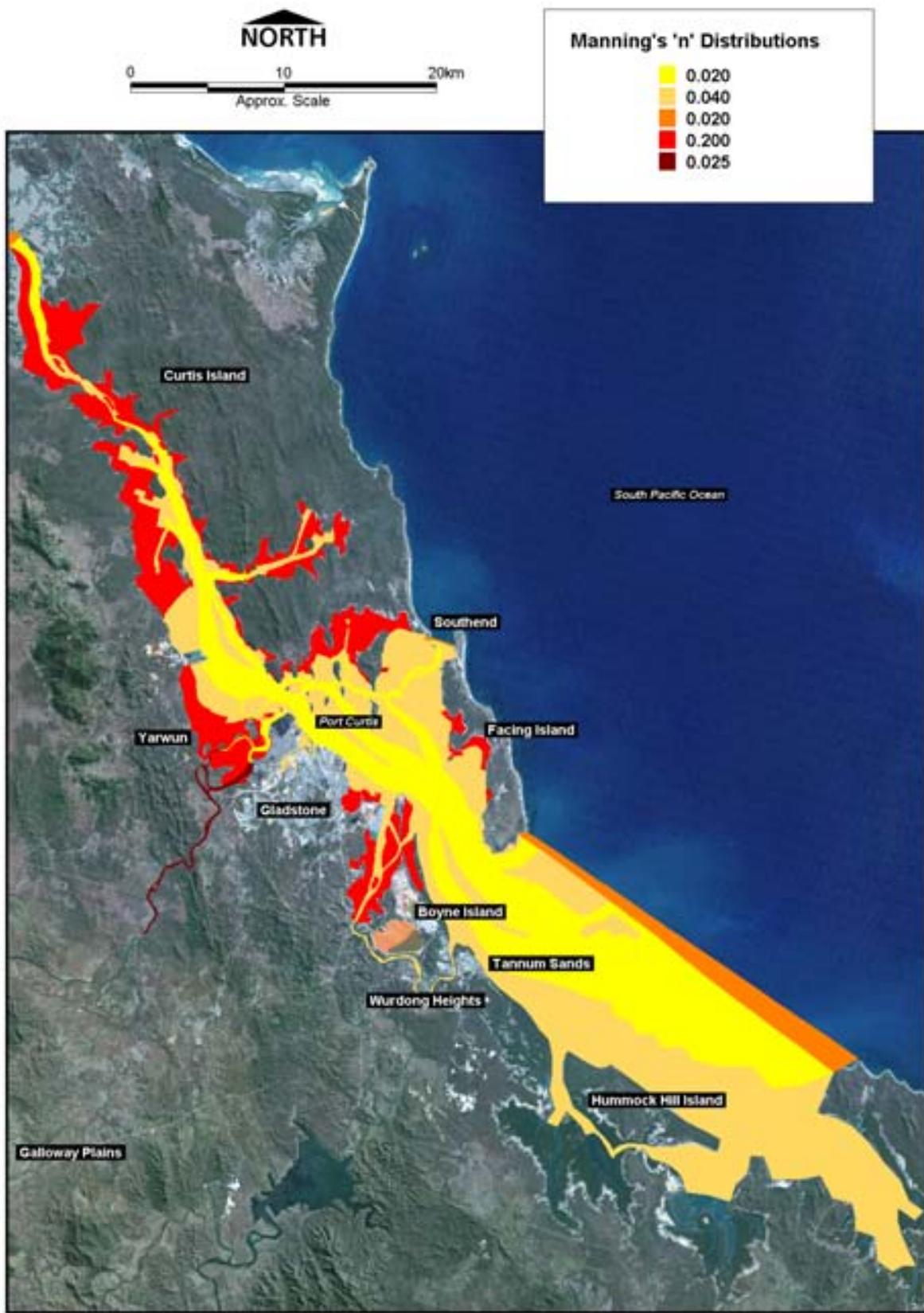
The boundary conditions adopted for the continuity checks include a steady state inflow of 10,000 m³/s at the main Port Gladstone boundary and a 1,000 m³/s outflow for the Calliope River at its upstream model extent. These flows are representative of the peak spring tide flows in the system. A constant 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 10,000m³/s being the adopted ocean boundary inflow, with a fixed proportion of 10% taken through the Calliope River (simulated as 997 m³/s). The flow split at the outflow boundaries at the North Entrance and Division Pt is 8,611m³/s (86.1% of total flow) and 392 m³/s respectively (3.9% of total flow). The combined model outflow of 10,000 m³/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.

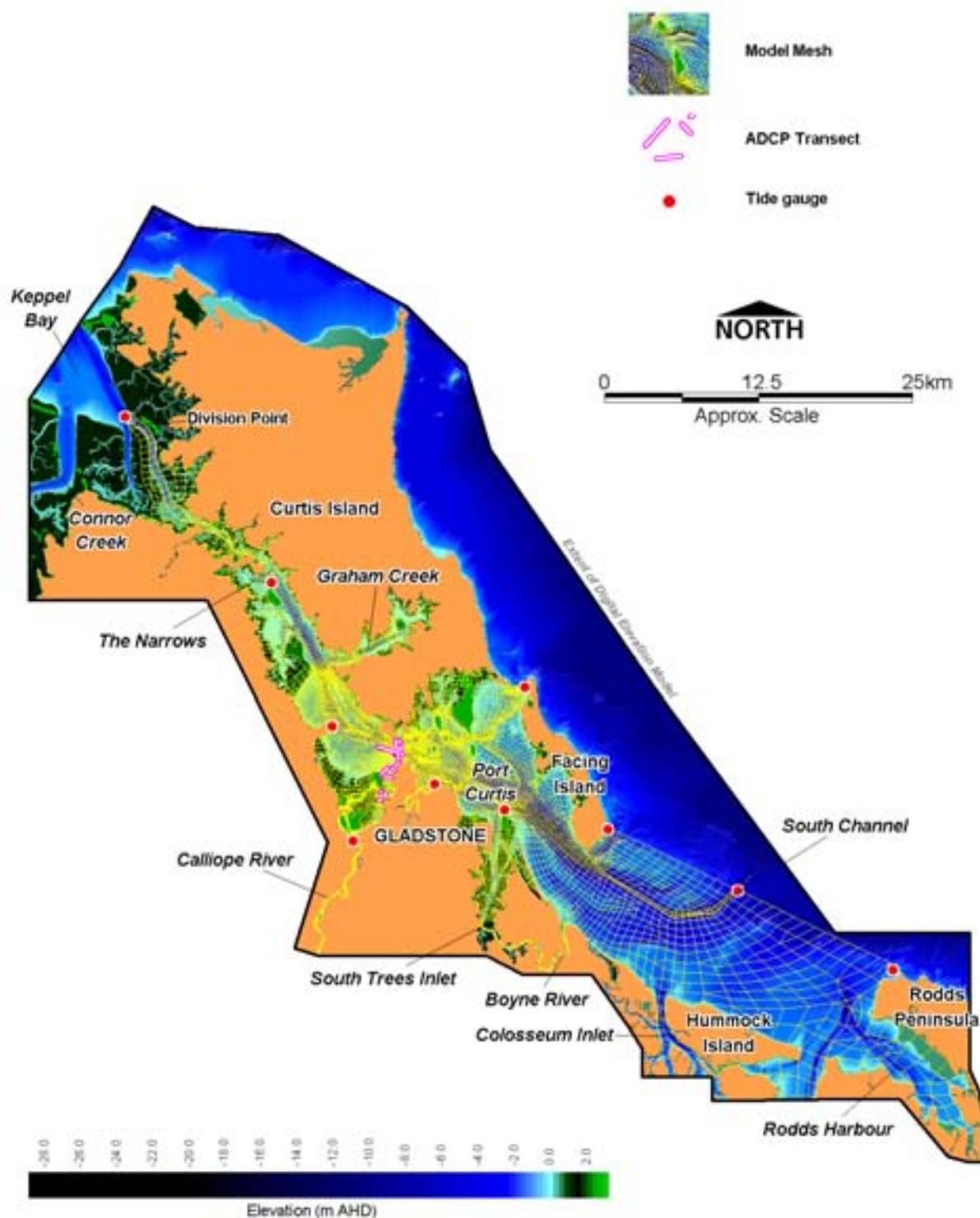
2.2.2 Tidal Water Levels

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

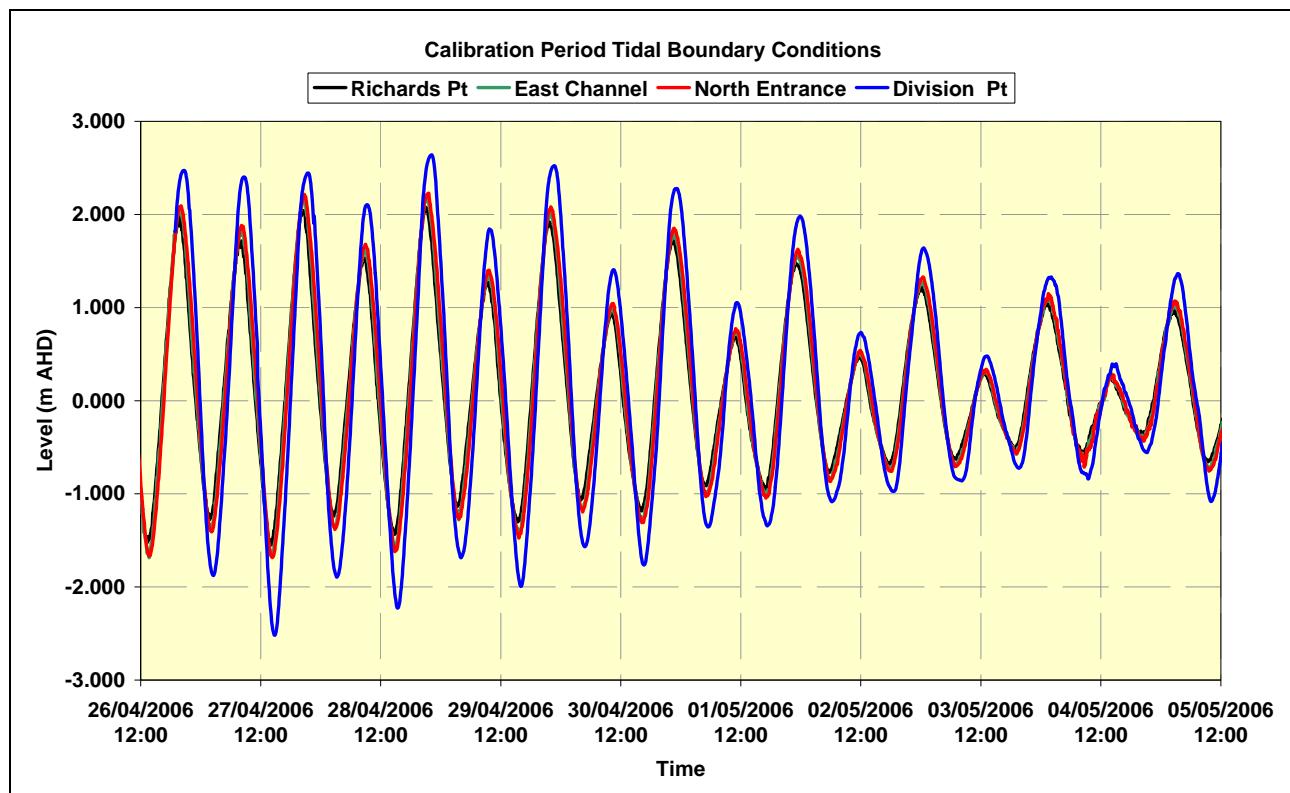


Figure 2-6 Observed Tidal Boundary Conditions for Calibration Period

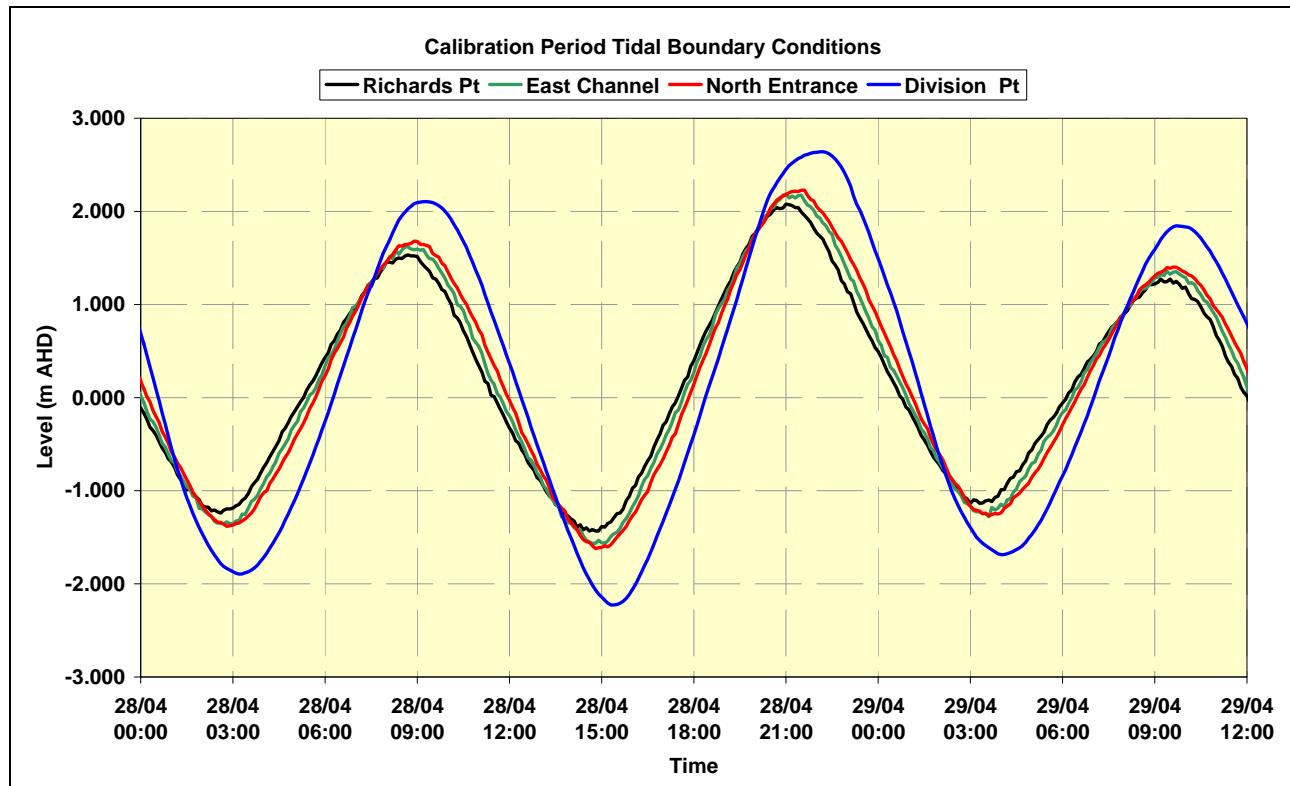


Figure 2-7 Sample Comparison of Tidal Data at Model Boundaries

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.

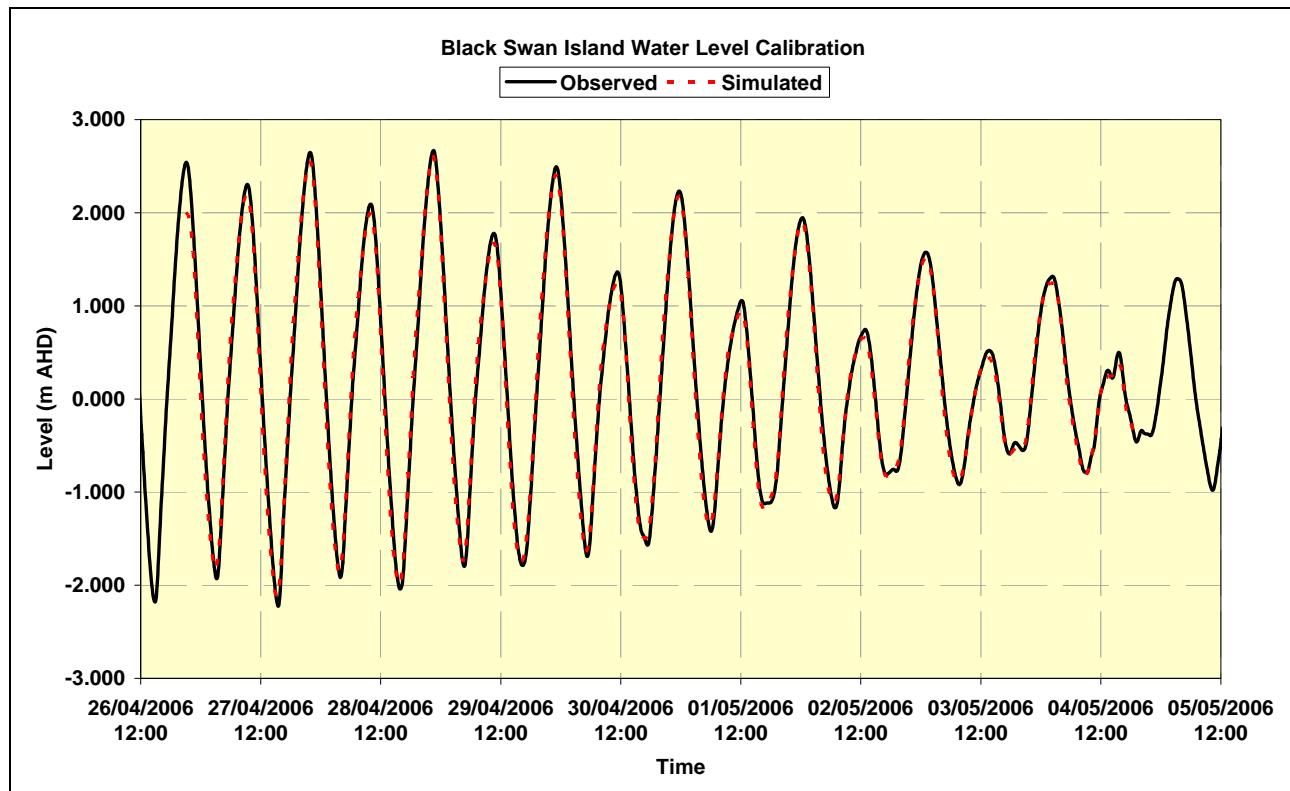


Figure 2-8 Black Swan Island Water Level Calibration

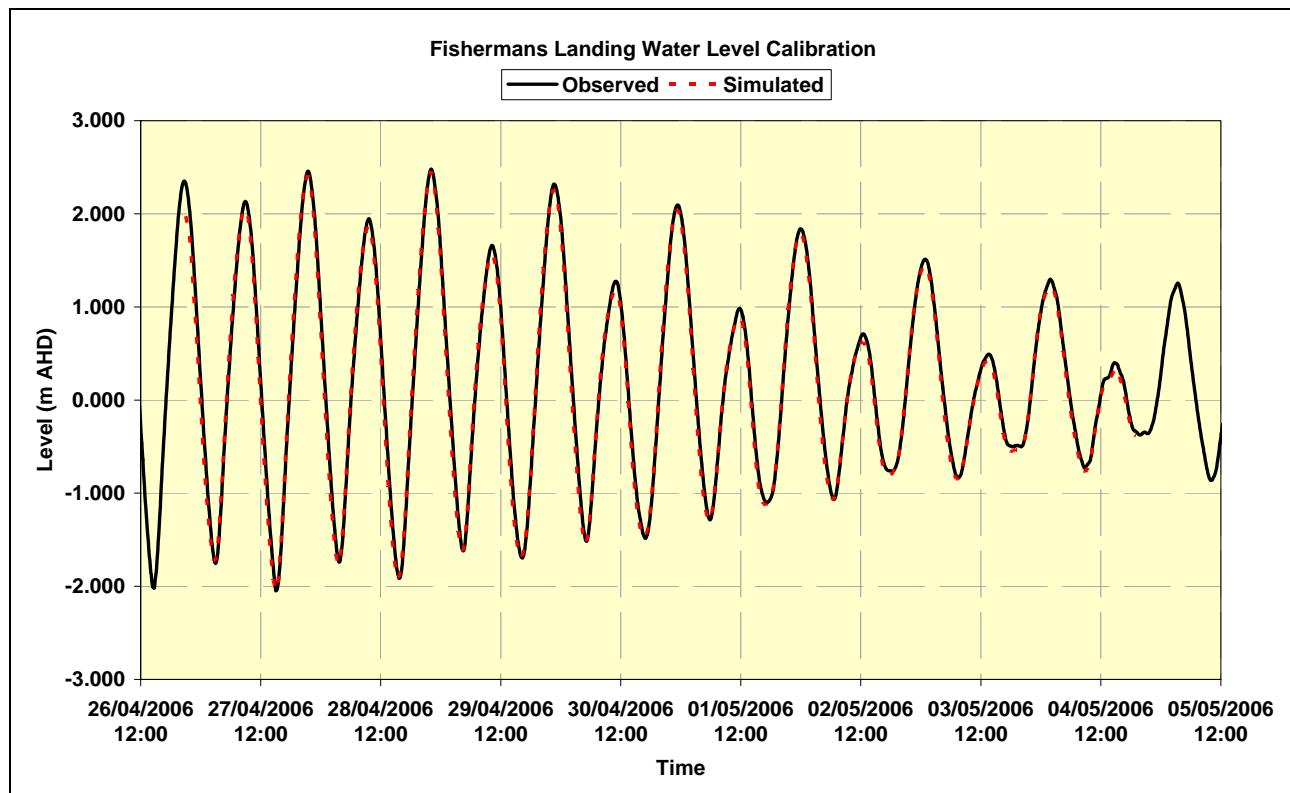


Figure 2-9 Fisherman's Landing Water Level Calibration

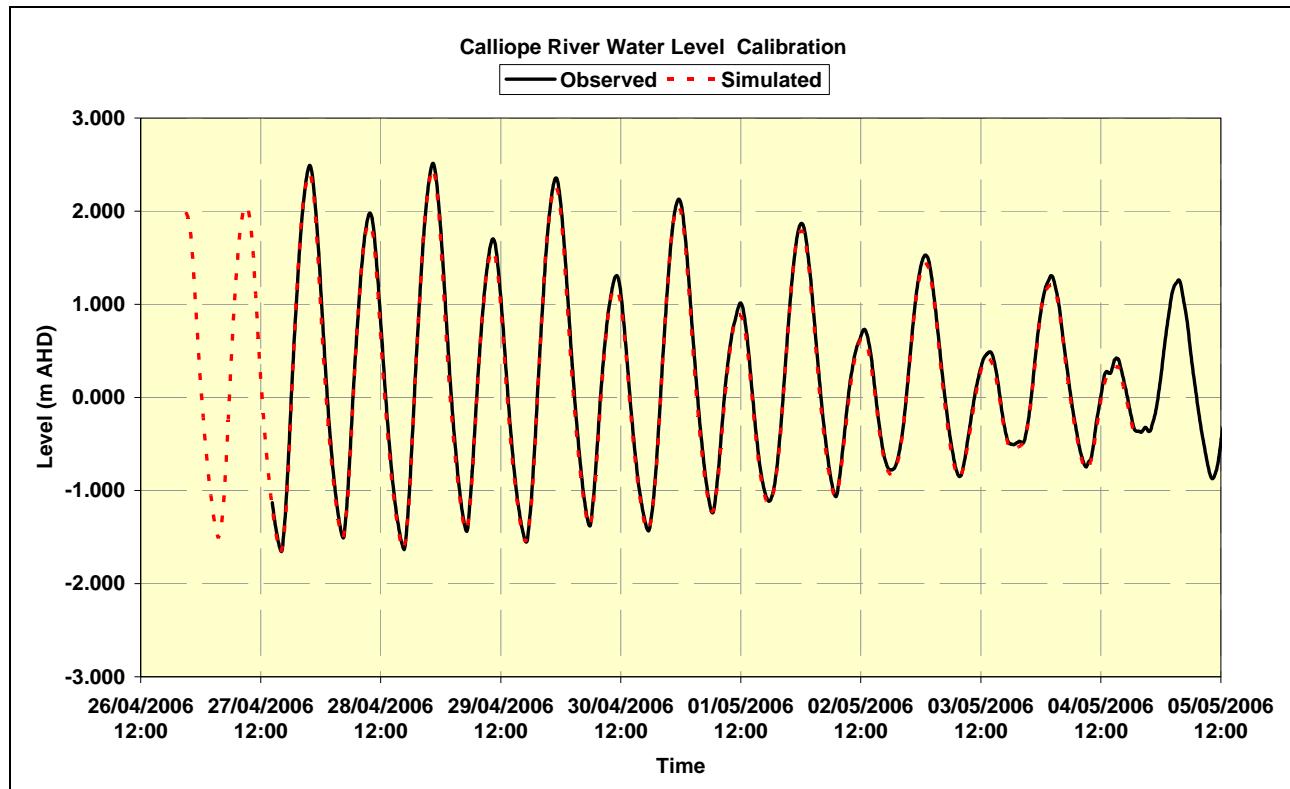


Figure 2-10 Calliope River Water Level Calibration

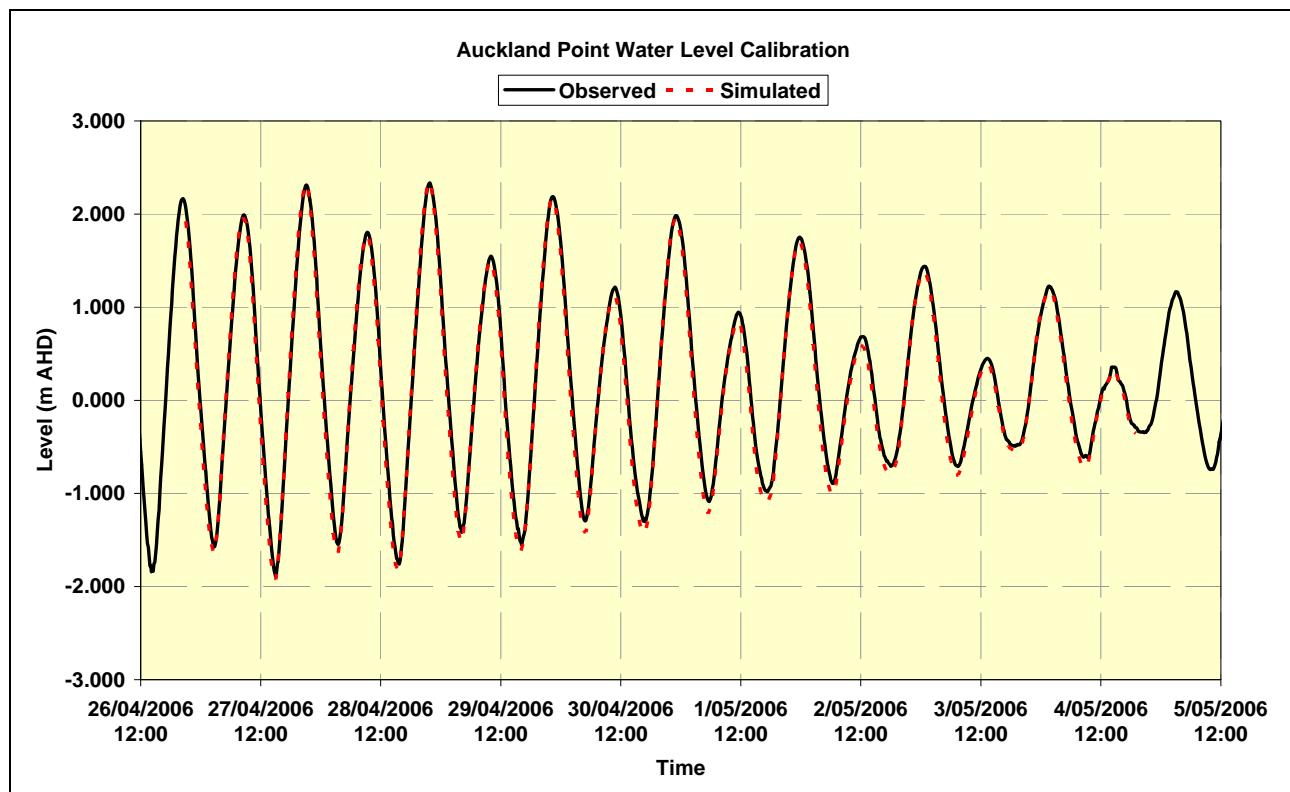


Figure 2-11 Auckland Point Water Level Calibration

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 m³/s and peak ebb tide flow of 20,000 m³/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.

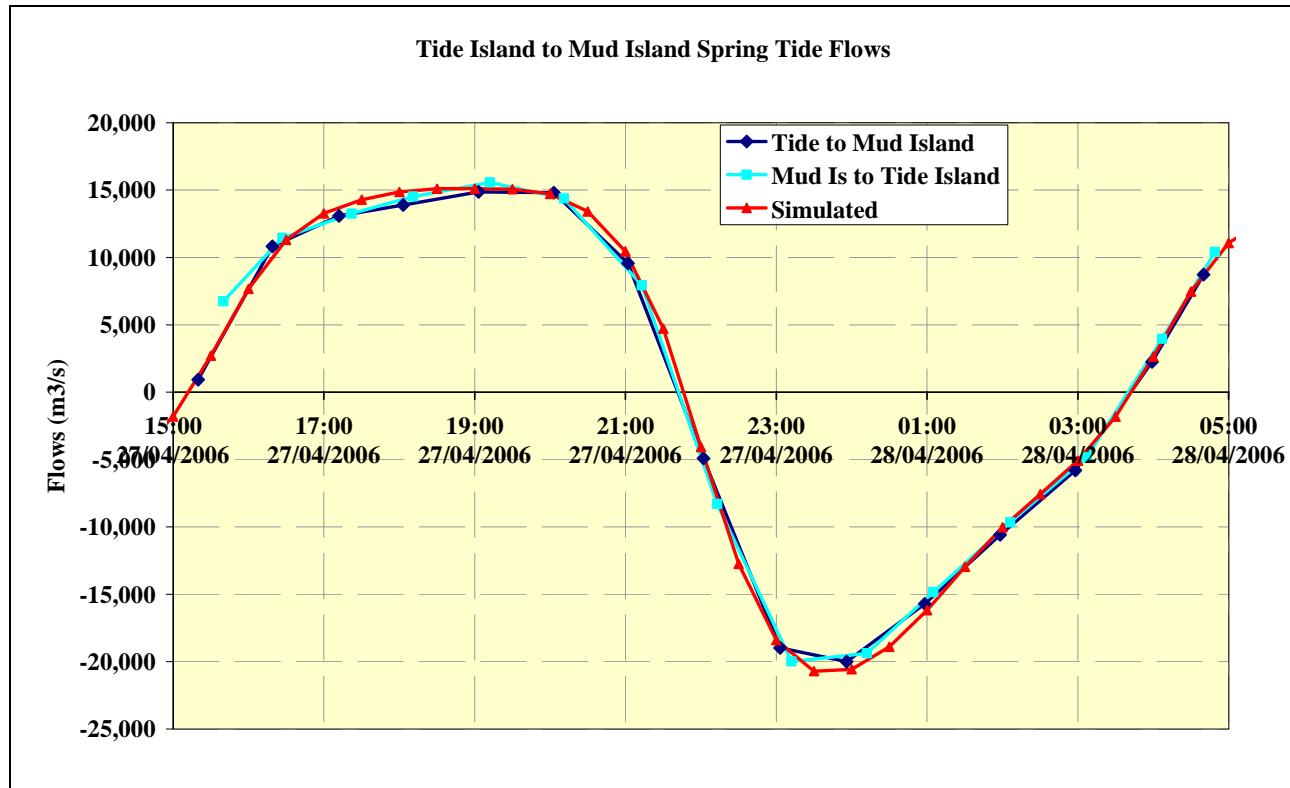


Figure 2-12 Tide Island to Mud Island Spring Tide Flow Calibration

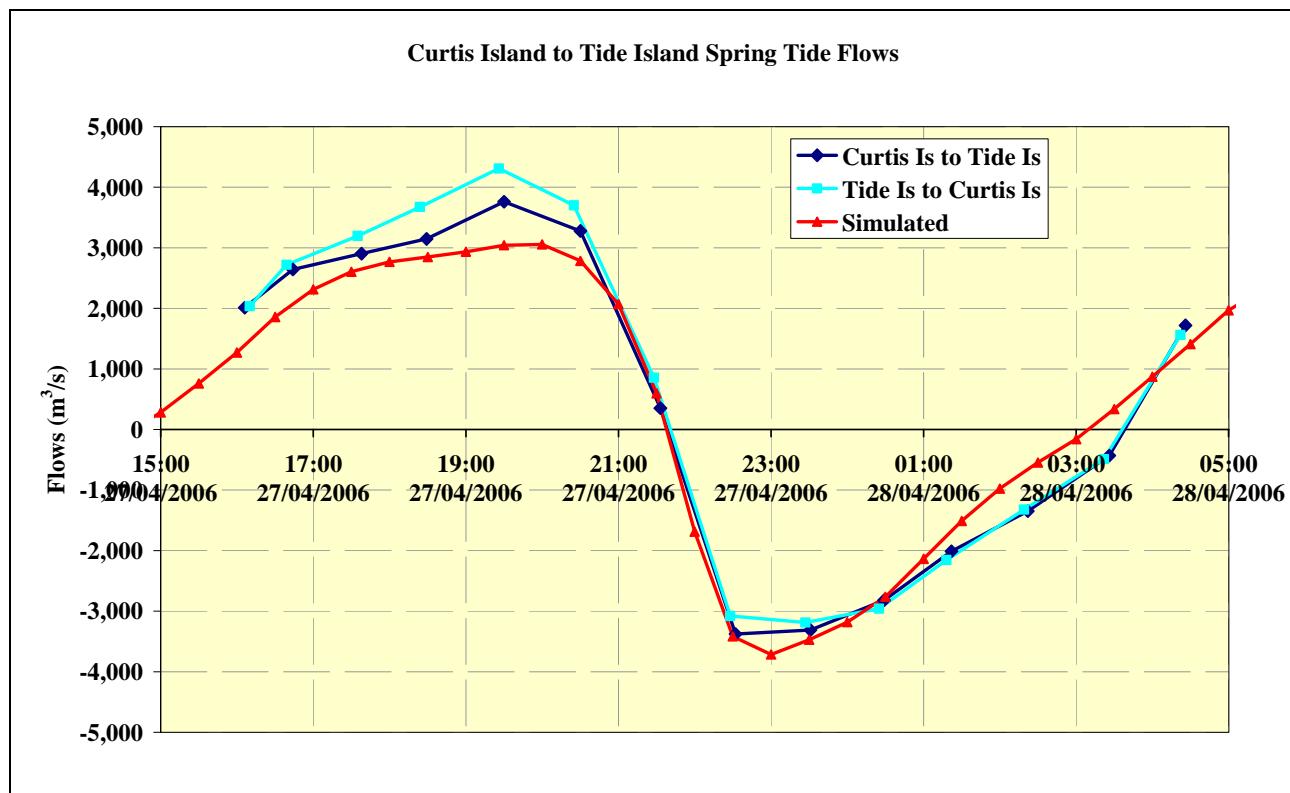


Figure 2-13 Curtis Island to Tide Island Spring Tide Flow Calibration

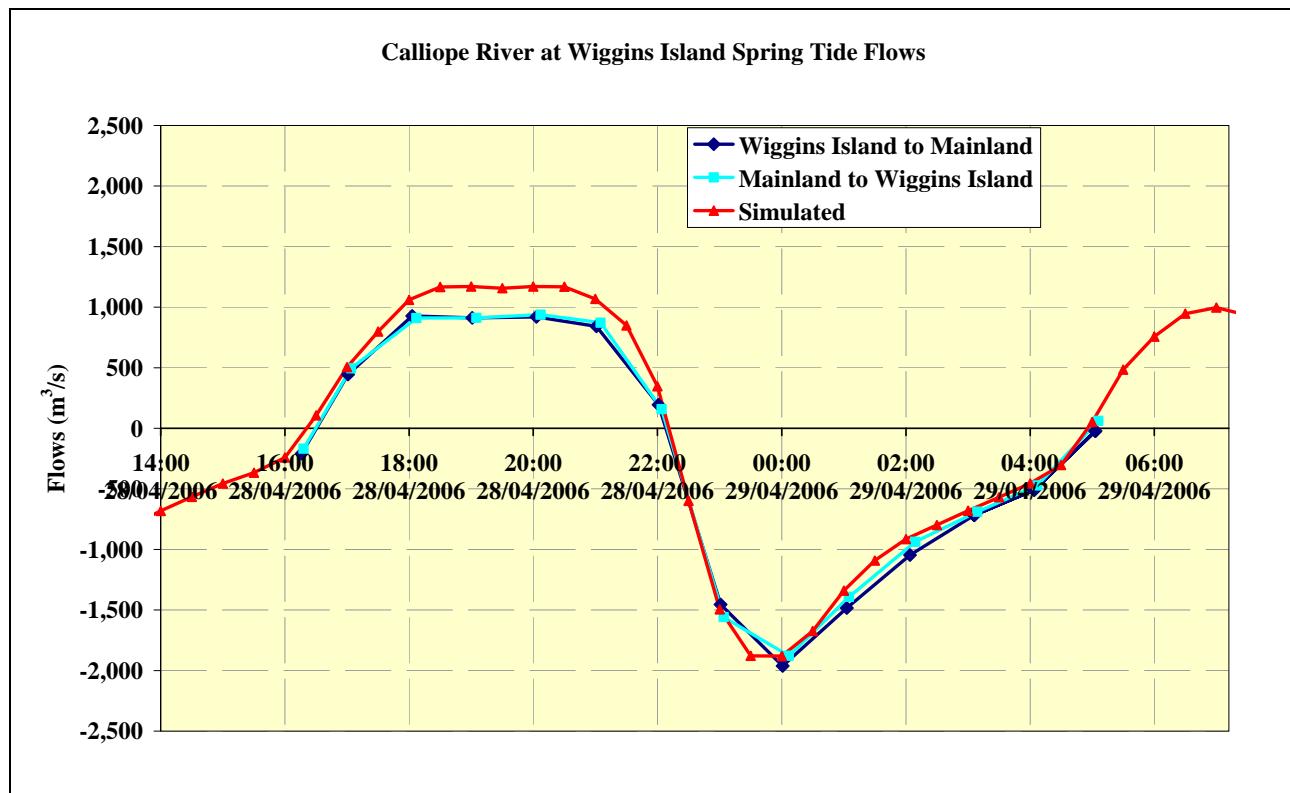


Figure 2-14 Calliope River at Wiggins Island Spring Tide Flow Calibration

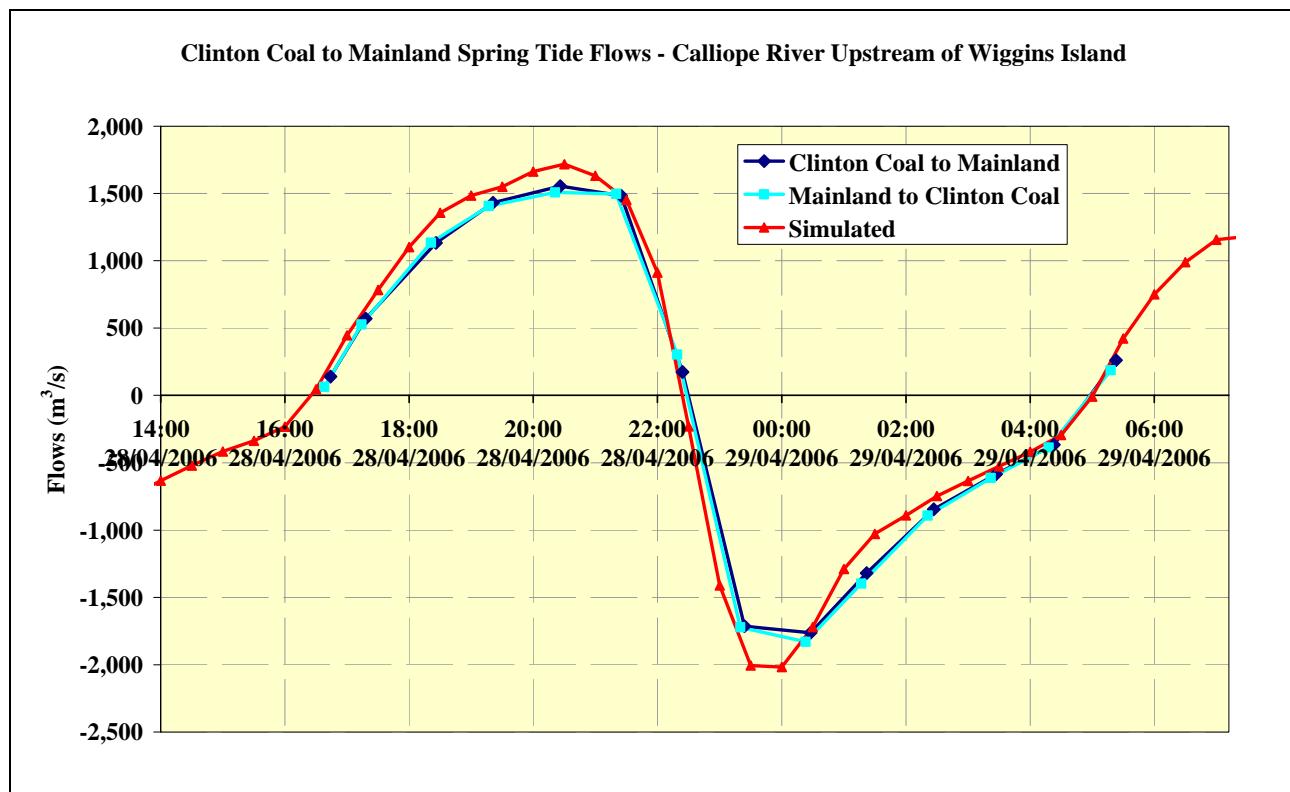


Figure 2-15 Calliope River Upstream of Wiggins Island Spring Tide Flow Calibration

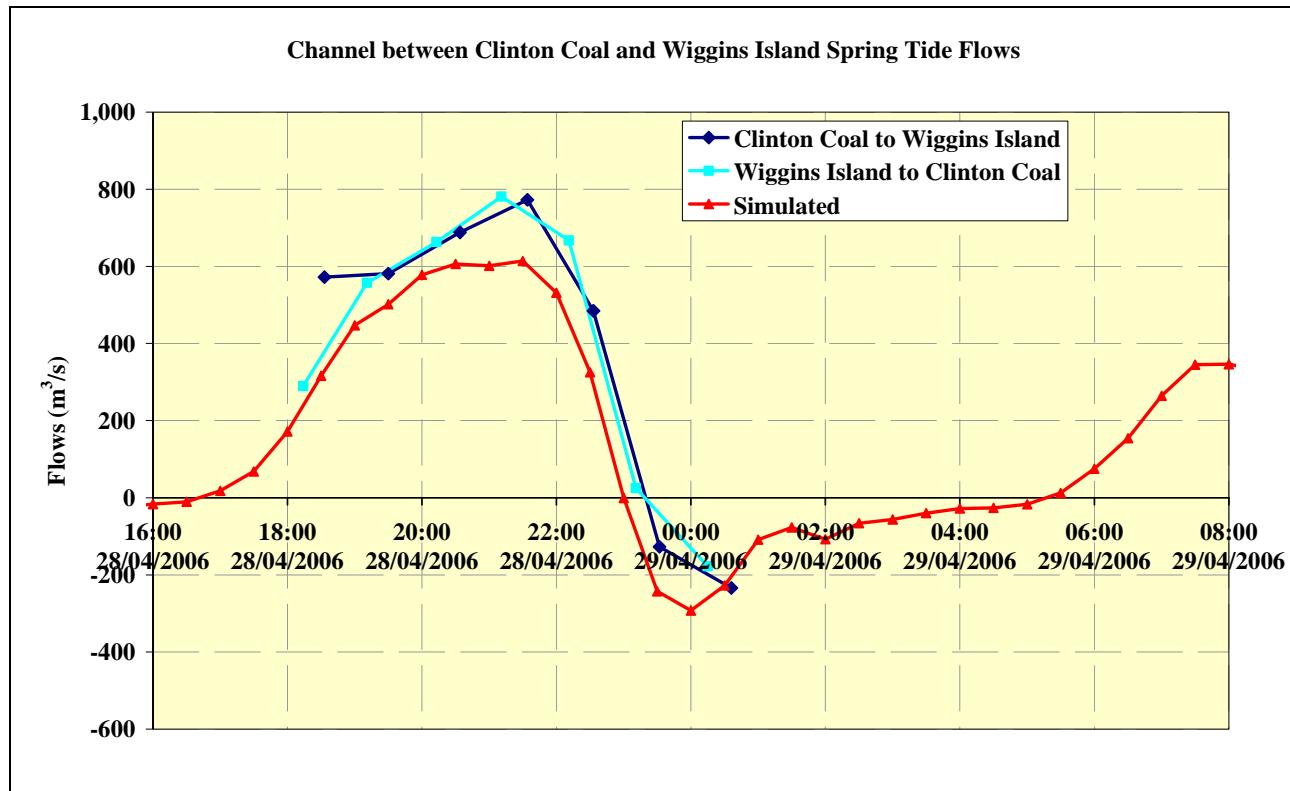


Figure 2-16 Clinton Coal to Wiggins Island Spring Tide Flow Calibration

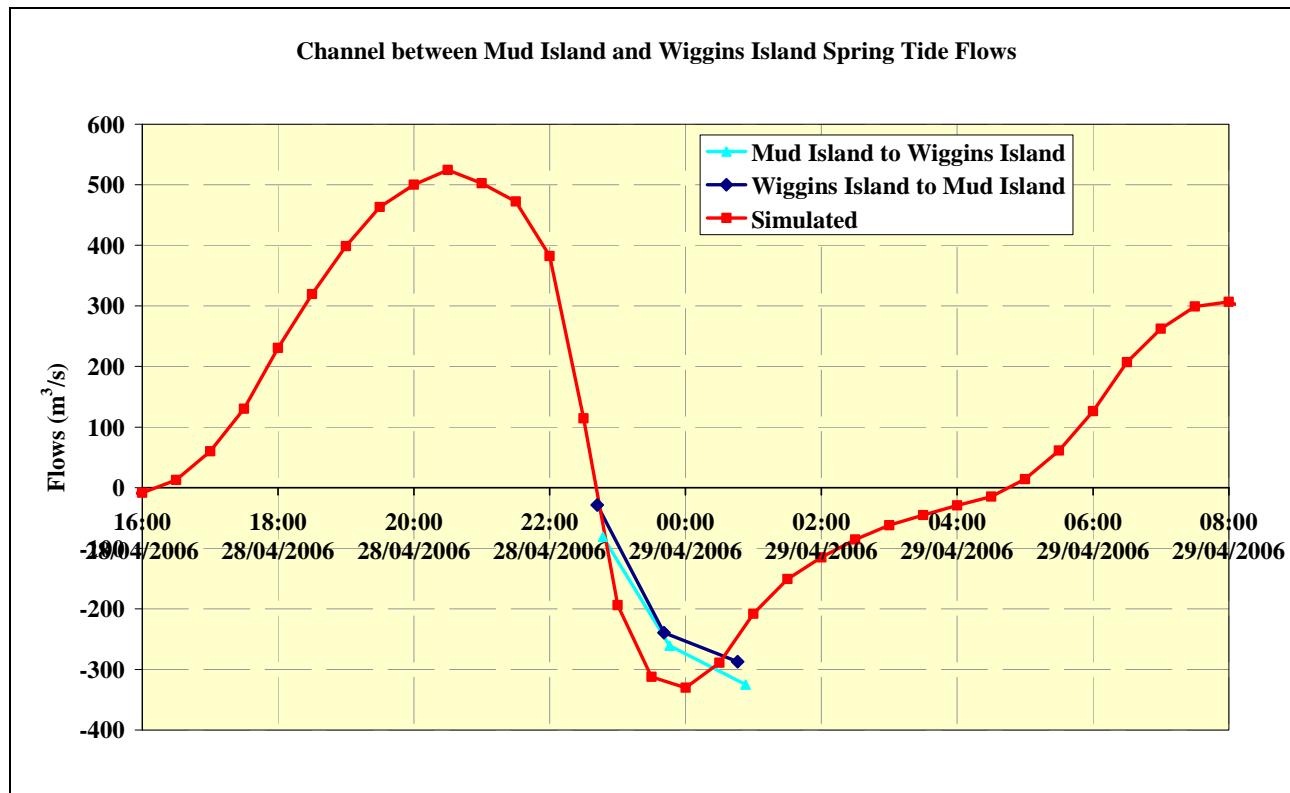


Figure 2-17 Mud Island to Wiggins Island Spring Tide Flow Calibration

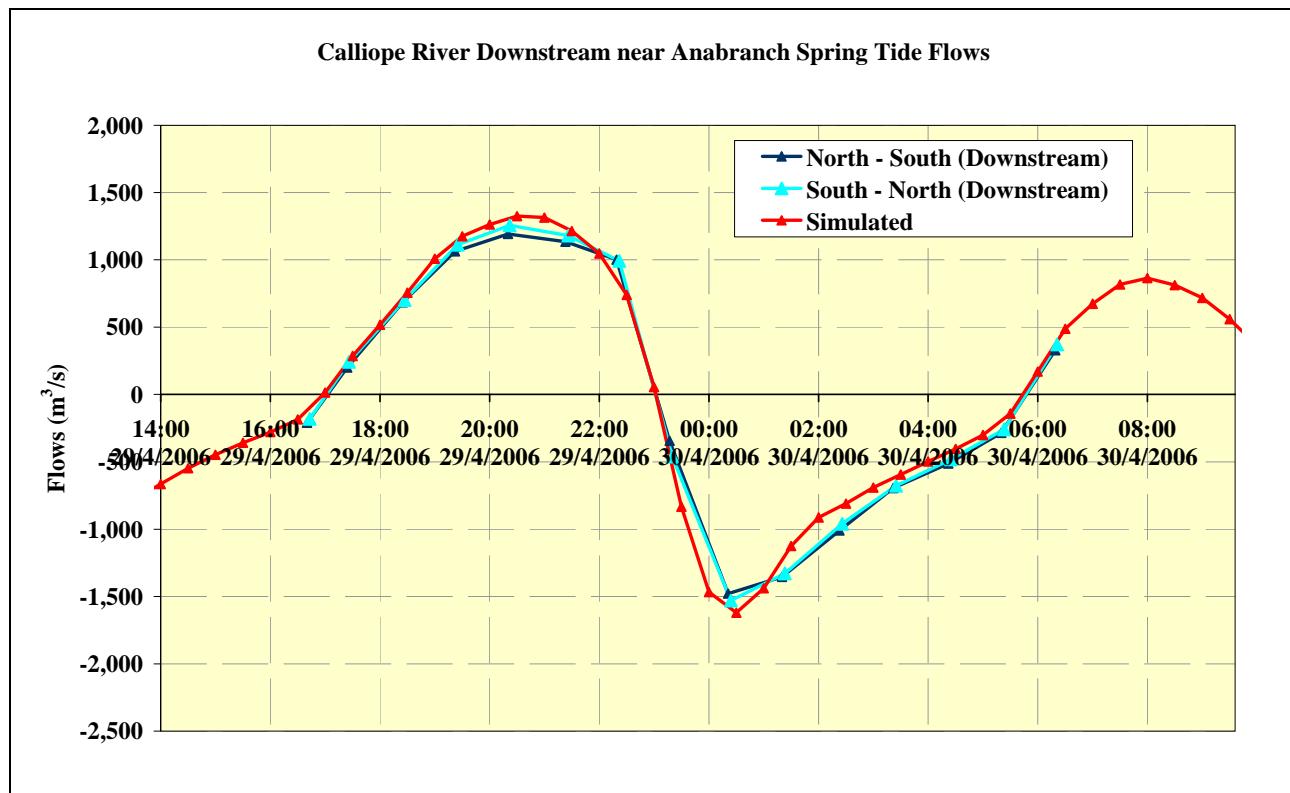


Figure 2-18 Calliope River Downstream near Anabranch Spring Tide Flow Calibration

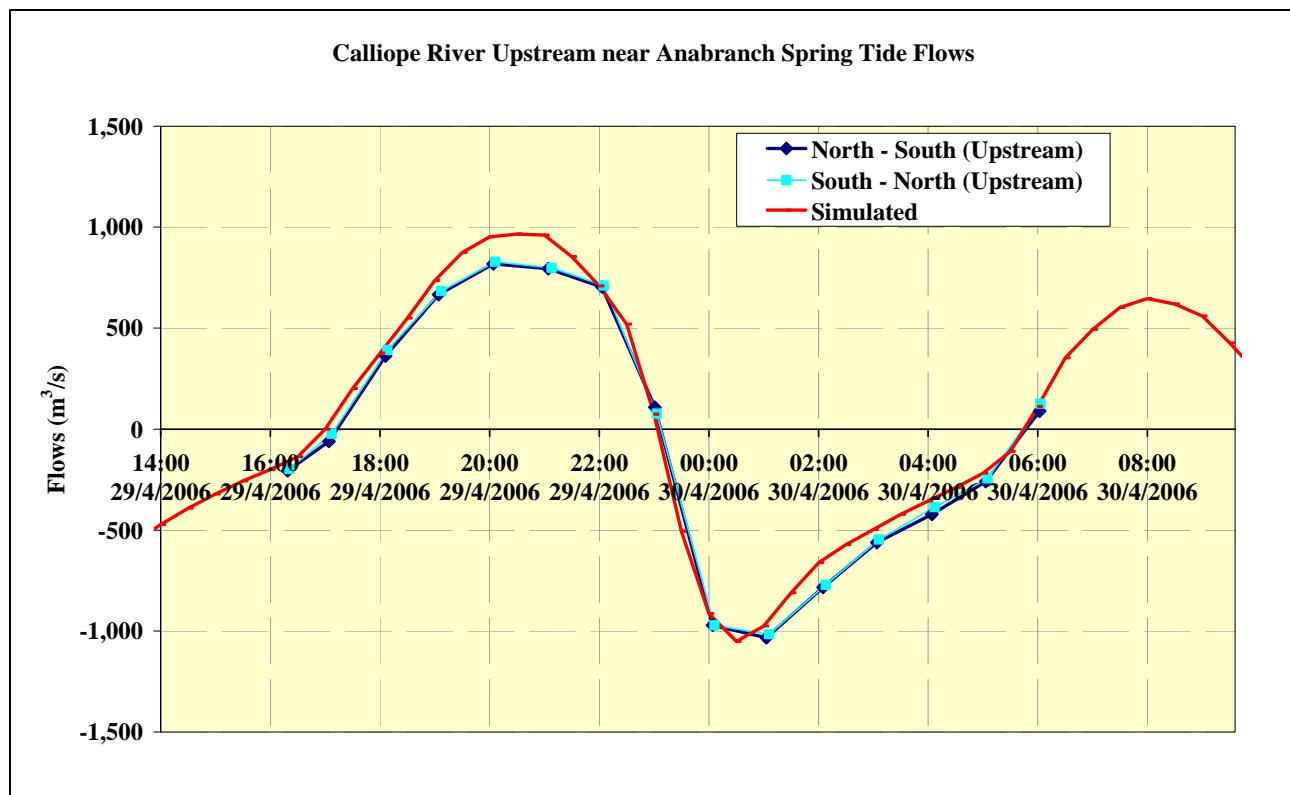


Figure 2-19 Calliope River Upstream near Anabranch Spring Tide Calibration

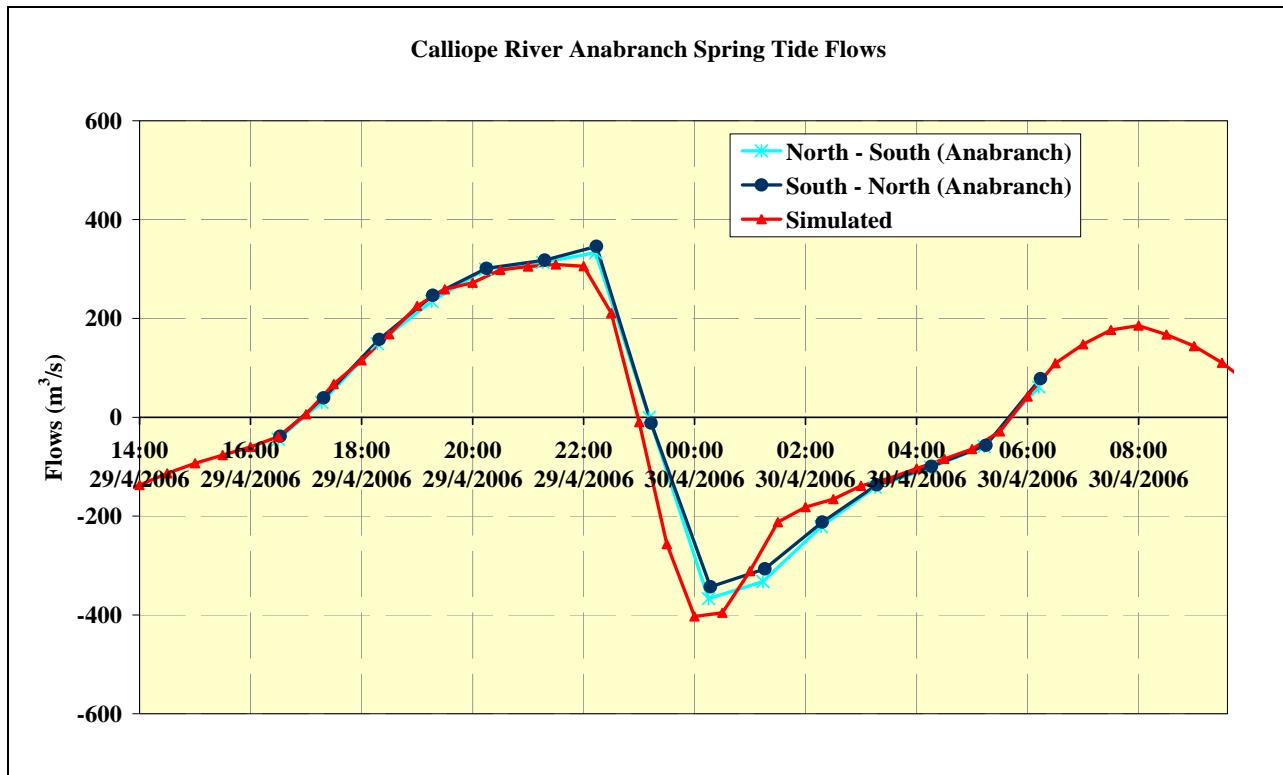
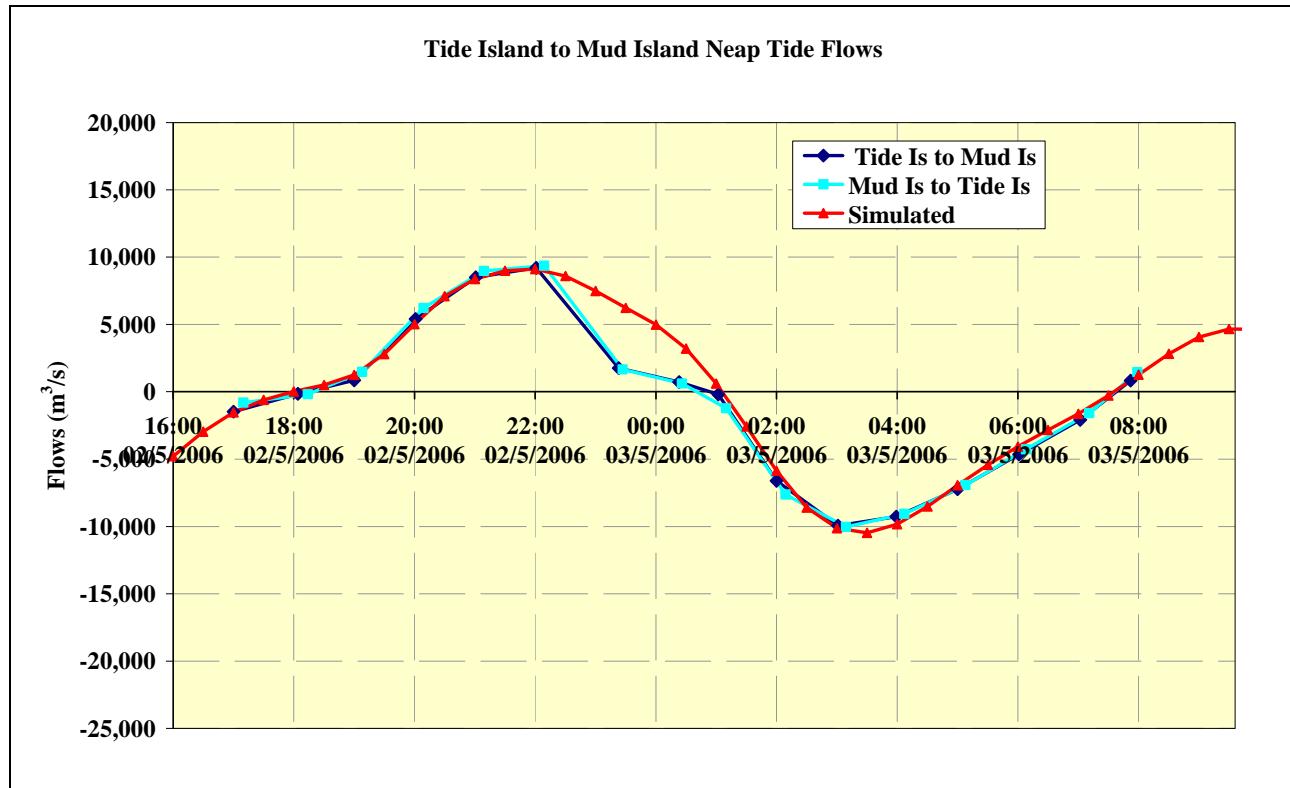
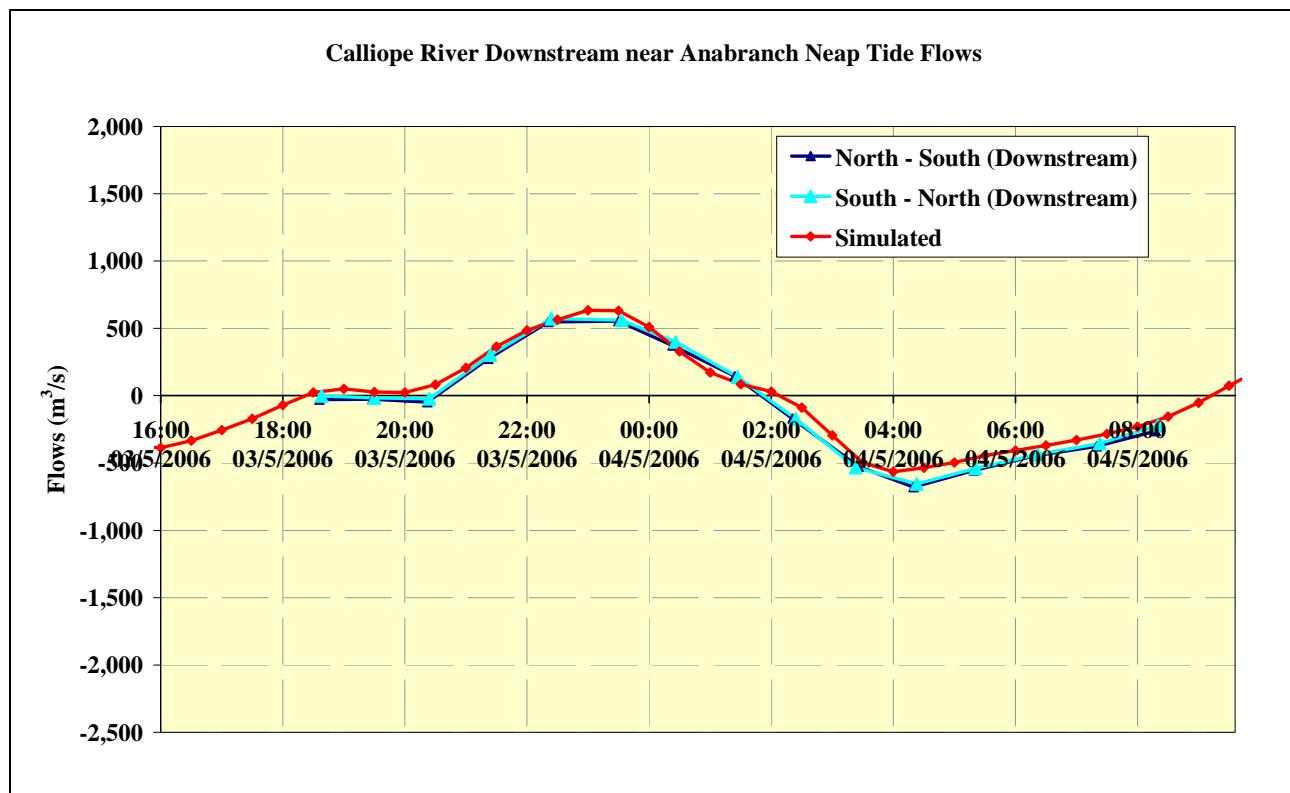


Figure 2-20 Calliope River Anabanch Spring Tide Flow Calibration

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 Anabanch 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 Anabanch 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**

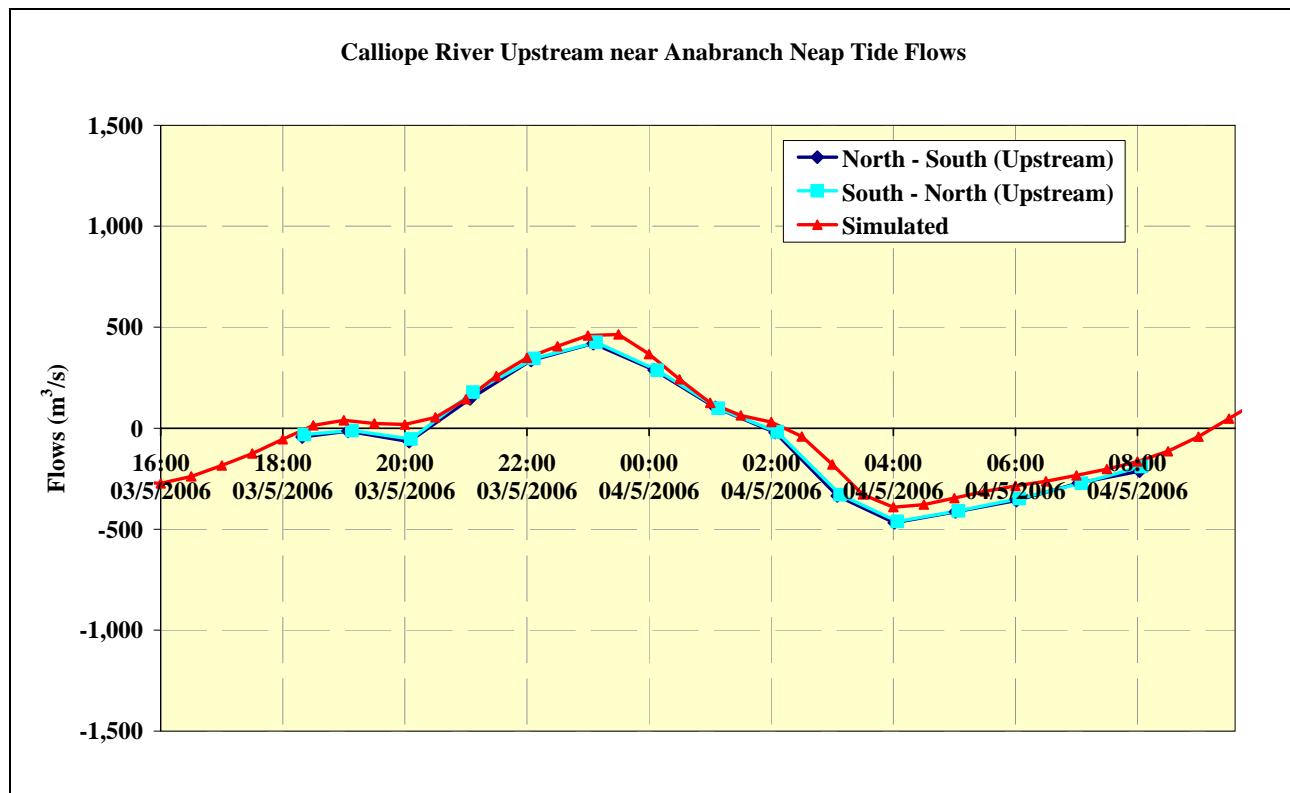


Figure 2-23 Calliope River Upstream near Anabanch Neap Tide Calibration

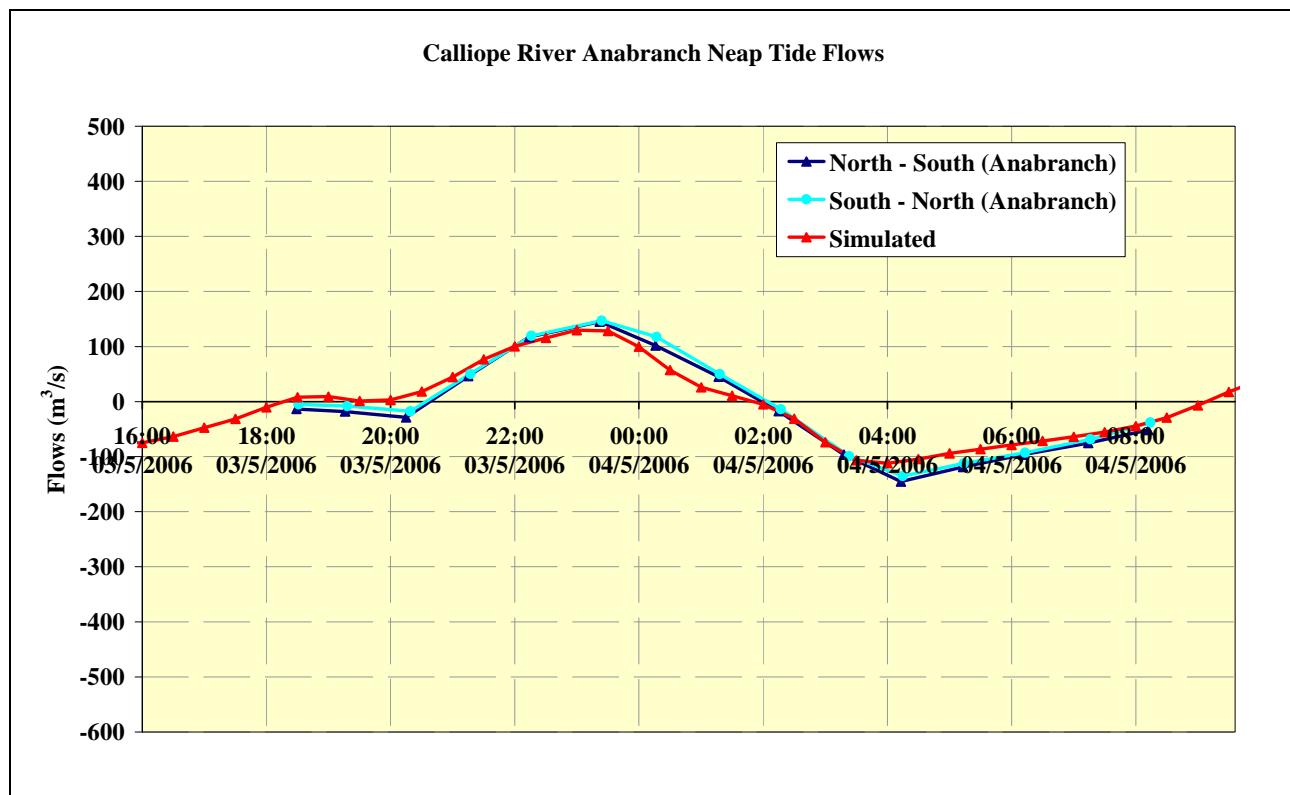


Figure 2-24 Calliope River Anabanch Neap Tide Calibration

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.

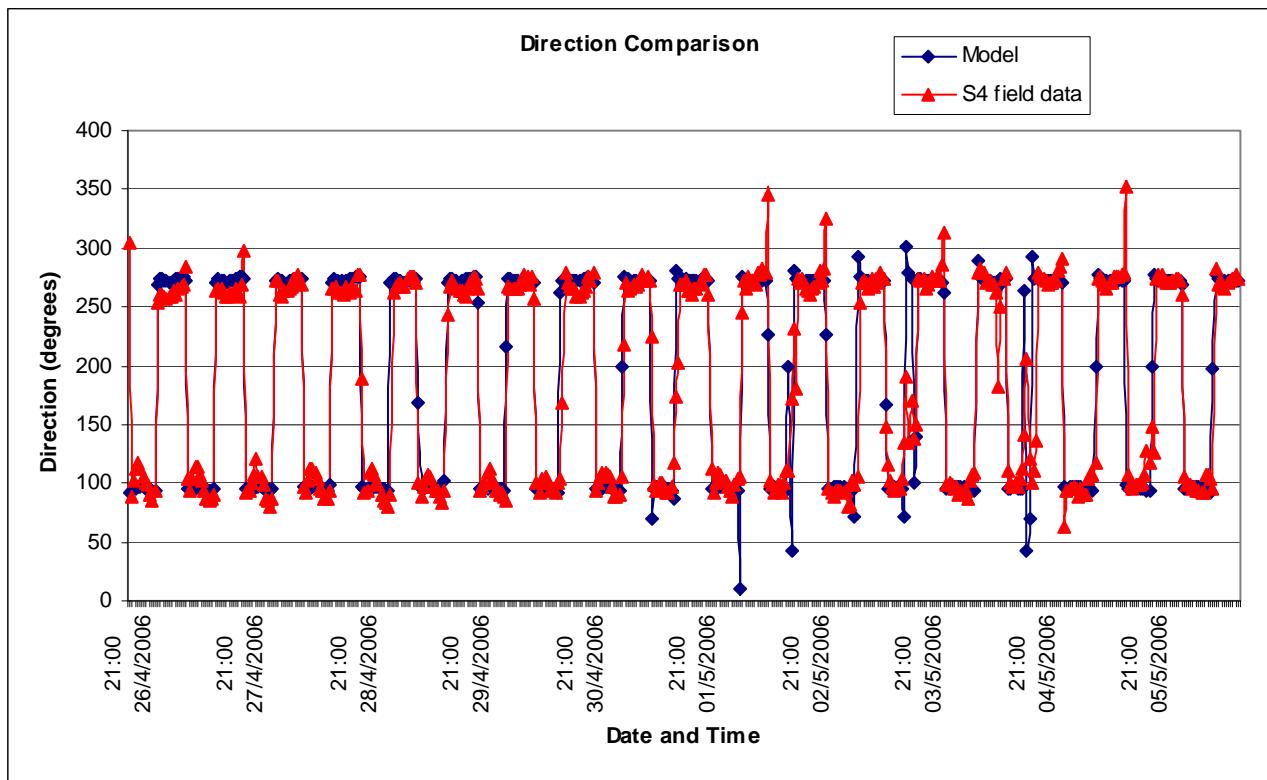


Figure 2-25 Direction Comparison Between Model Data and ADCP Field Data

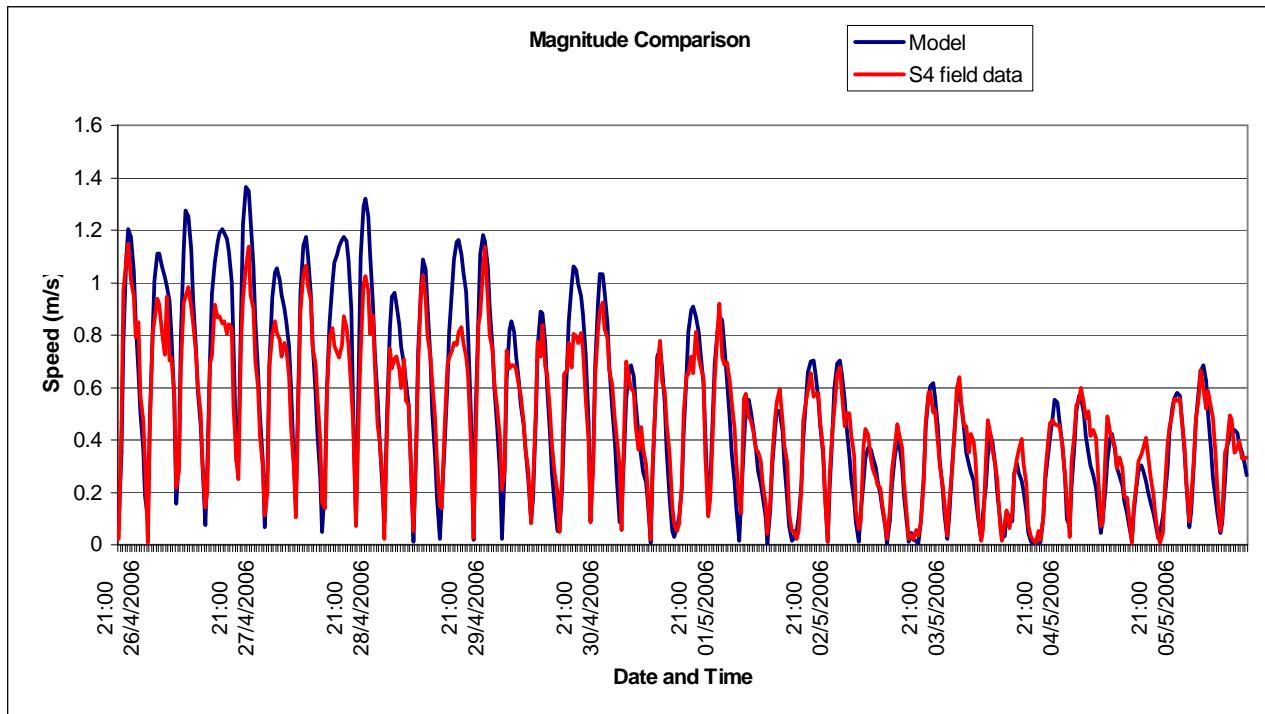


Figure 2-26 Magnitude Comparison Between Model Data and Field Data

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, the model required input of dispersion coefficients. These coefficients are the primary inputs (other than the velocity field from RMA-10) that determine the resultant spread of material throughout the model domain.

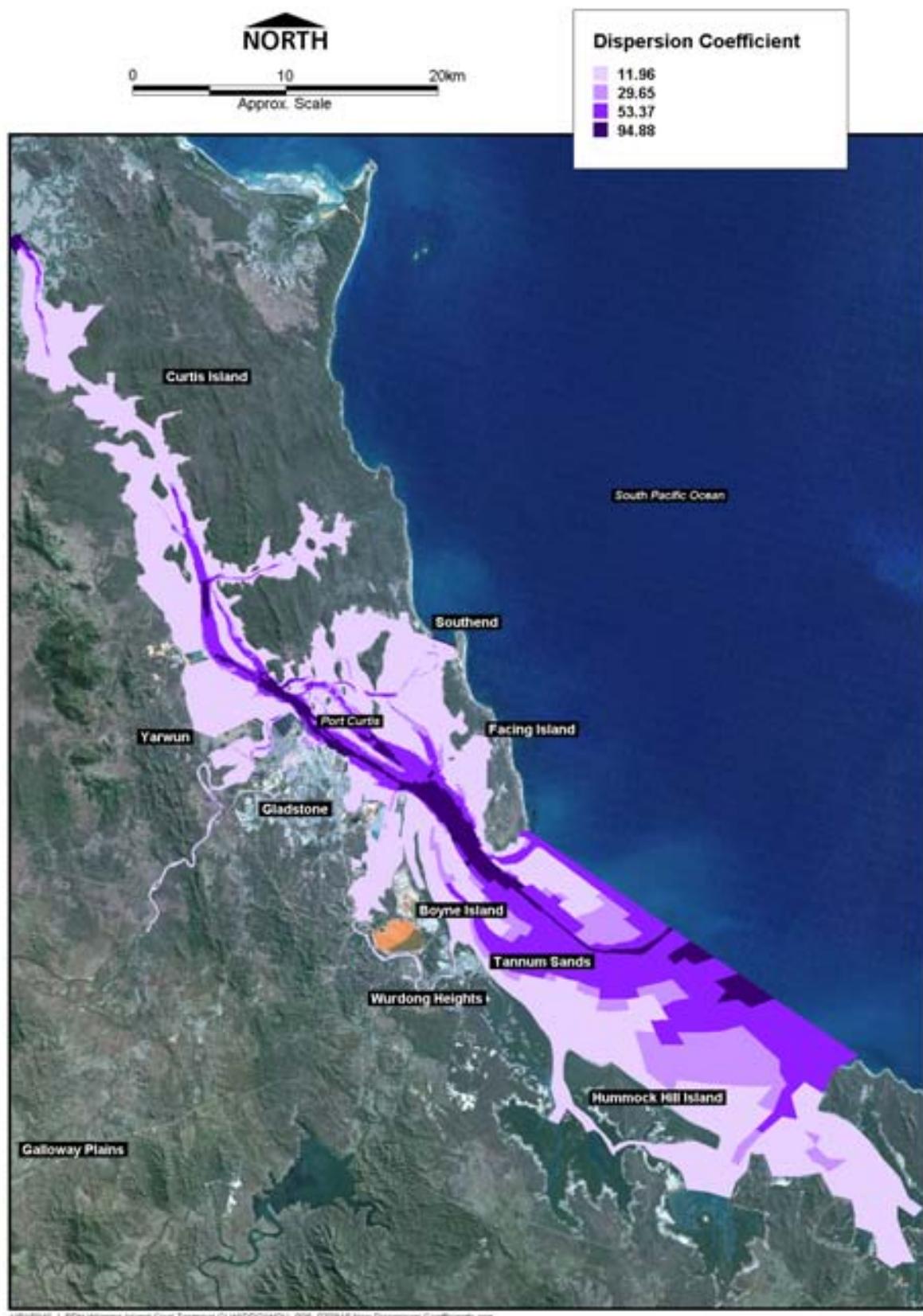
In a typical numerical model setup process, a calibration and validation procedure would be followed whereby available monitoring data (usually salinity) would be used to set and test the dispersion characteristics of a model. Usually these salinity data are selected over a period where a freshwater flushing event has occurred (such as a major storm), and where the subsequent recovery of salt to the modelling domain can be used to estimate diffusion properties. No such data is available for the purposes of this study, and (even if it was) it is expected that a very large event would be needed to provide sufficient freshwater flushing of the domain to facilitate application of this technique. As such, a different technique was applied here. In particular, the Elder equation approach was used.

Elder (1959) proposed that dispersion in turbulent shear flows, D, can be estimated via

$$D = 5.93 u^* d,$$

where u^* is shear velocity and d is water depth. This equation has been further discussed by many others, (e.g. Fischer, 1979) and it is generally agreed that there is a wide variation in the value of the 5.93 coefficient, and it is usually thought to be too small to appropriately capture dispersion in environmental flows. In order to better estimate this coefficient as applied to the current modelling domain, WBM previously executed some dye experiments in the vicinity of Port Curtis as part of a separate study. These experiments found that dispersion can indeed be described using the Elder approach, but that a coefficient of approximately 60 is required to estimate dispersion coefficients in this manner. This coefficient was adopted for this study.

In order to apply this model, the study domain was divided into several regions of approximately similar depth, ranging from -20m AHD to the intertidal areas. Five regions were identified and dispersion computed dynamically by RMA11 in these areas by using the average depth, and assuming that the shear velocity is 10% of the advective velocity magnitude. As such, RMA11 was set to compute dispersion based on the dynamically varying velocity read from the RMA10 results, and an input coefficient, which varied with depth. This variation was captured via spatially varying element types, as shown Figure 3-1. The values correspond to the input coefficients used by RMA11 to compute D dynamically.



Dispersion Coefficients

Figure 3-1

3.2 Flushing Timescale

In order to provide a high level 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 selected tracer (which is the same used for all subsequent simulations reported here) is simply a numerical tracer that acts as a tag to the released inflow water. It is not a real-world substance, and as such has no name or specific gravity: it is purely a numerical tool that allows the advection and dispersion of all pollutants (equally, including heavy metals) to be concurrently assessed. A numerical decay rate is also applied to this tracer in separate simulations, and this accounts for the decay of manganese.

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 normal tidally 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 ($1/e \sim 0.37$). 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

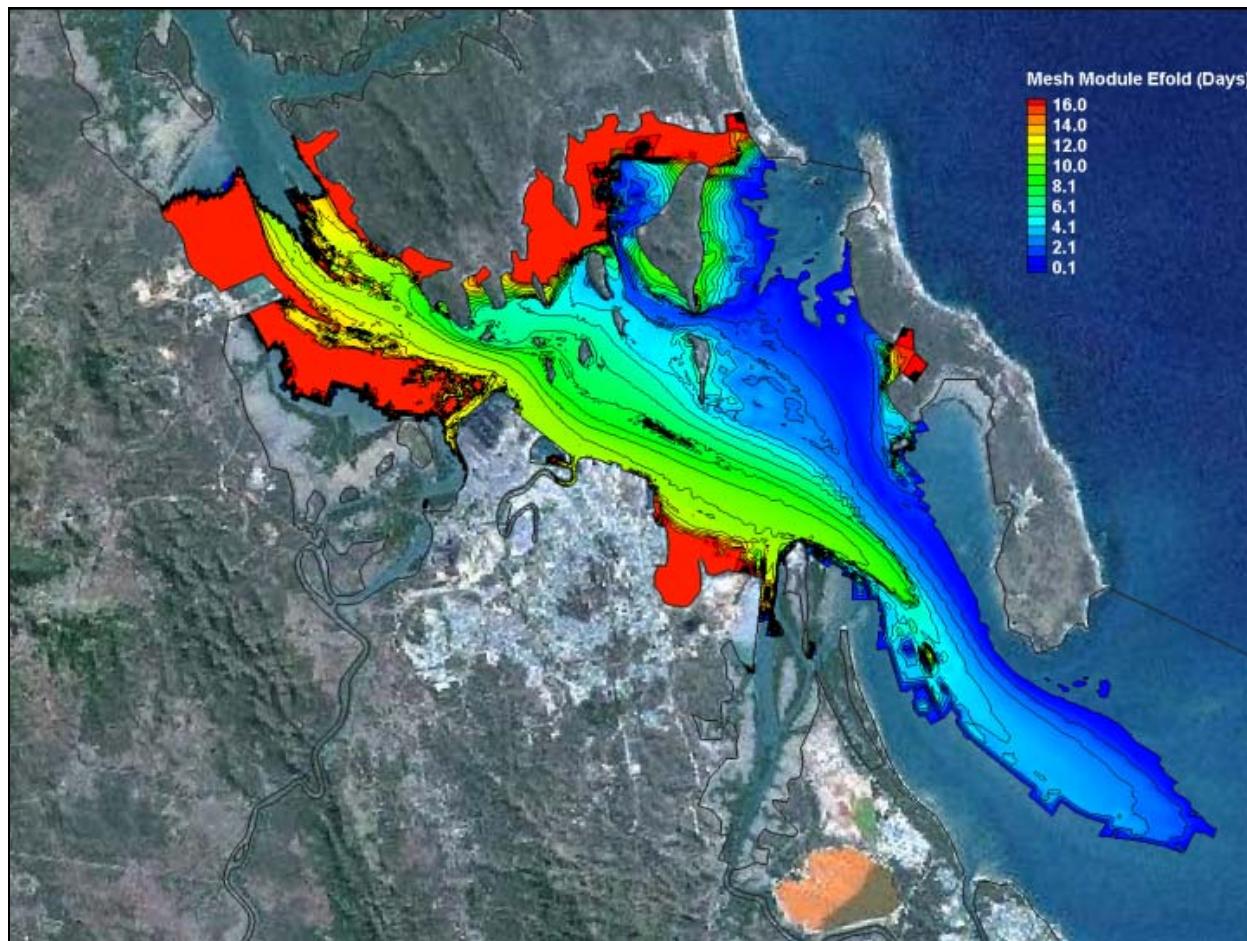


Figure 3-3 Flushing Timescales for Port Curtis

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 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* modelling 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 for completeness.

4 NEAR FIELD MODELLING

As the study progressed, two modelling packages were used to investigate near field plume behaviour. The first model used was CORMIX, but due to limitations becoming apparent in the latter stages of this study, a second, more detailed computational fluid dynamics (CFD) model was adopted to provide more robust assessments of the near field plume dynamics. Both models are described here for completeness, however near field results are only presented from the CFD modelling.

4.1 CORMIX Modelling Package

The CORMIX modelling package (<http://www.cormix.info/>) was initially 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.

4.2 CORMIX Limitations

Under the latest diffuser design (refer to Sections 6 and 7), CORMIX was found to have difficulties predicting pollutant dilutions (and hence concentrations) in the immediate near field zone under low ambient velocity conditions (lower than approximately 0.3m/s). For such ambient velocities, CORMIX provided only global bulk dilutions averaged across an initial mixing zone, rather than the required spatial gradient of dilutions. As such, further investigation of the likely near field plume dynamics was undertaken using a fully three dimensional computational fluid dynamics (CFD) modelling tool. The application of this tool is described below.

4.3 CFD Modelling Package

The CFD package OpenFOAM (Open Field Operation and Manipulation) was used in this study. OpenFOAM can simulate complex fluid flows involving chemical reactions, turbulence and heat

transfer. It is produced by OpenCFD Ltd (<http://www.opencfd.co.uk>), is freely available with open source, and is licensed under the GNU General Public Licence.

The core technology of OpenFOAM is a flexible set of efficient C++ modules. These are used to build solvers to simulate specific problems in engineering mechanics. OpenFOAM is supplied with numerous pre-configured solvers, utilities and libraries and so can be used like any typical simulation package. However, it is open, not only in terms of source code, but also in its structure and hierarchical design, so that its solvers, utilities and libraries are fully extensible.

OpenFOAM uses finite volume numerics to solve systems of partial differential equations ascribed on any three-dimensional (3D) unstructured mesh of polyhedral cells. The fluid flow solvers are developed within a robust, implicit, pressure-velocity, iterative solution framework, although alternative techniques are applied to other continuum mechanics solvers. Domain decomposition parallelism is fundamental to the design of OpenFOAM and integrated at a low level so that solvers can generally be developed without the need for any 'parallel-specific' coding.

An example of an existing OpenFOAM model that simulates spray dynamics is shown below (source: <http://www.opencfd.co.uk/solutions/examples4.html>).

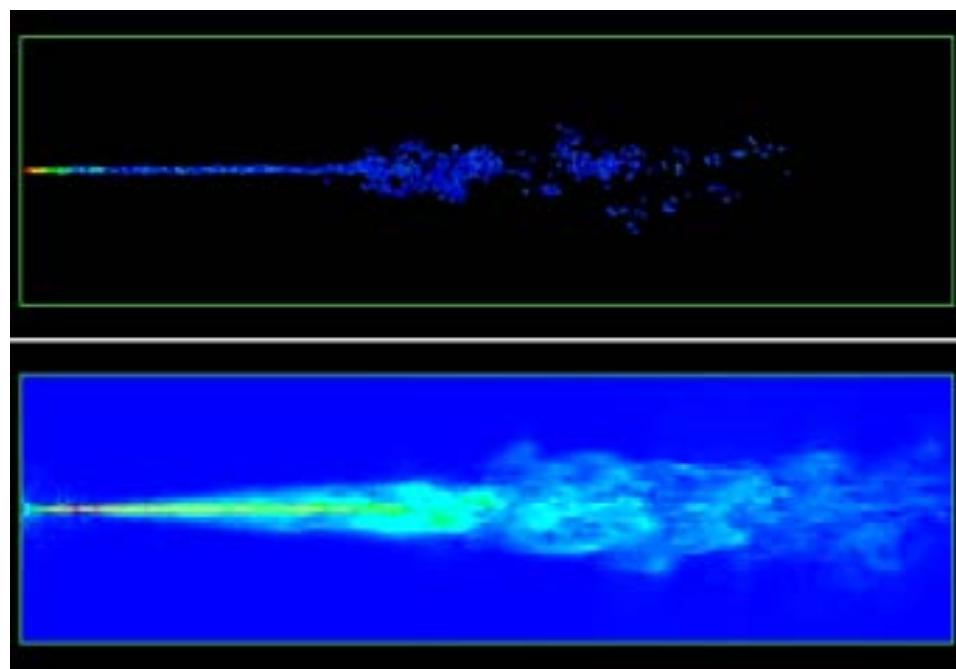


Figure 4-1 Example OpenFOAM Application: Spray Dynamics

Given its flexibility and prior application to similar flow regimes, OpenFOAM is well suited to the needs of the current study, and was used in preference to CORMIX.

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. The CFD modelling was used to examine detailed 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). Use of CORMIX was discontinued towards the latter part of the study.

5.1 Discharge Pollutant Concentrations

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 all 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 were then compared to chronic toxicity trigger values. Specifically, the tracer was inserted at a concentration of 100 units in the far field and 1 unit in the near field, and dilution subsequently traced as a percentage of the original. It is noted that comparison with acute toxicity triggers was not undertaken, as GPN has ensured that effluent concentrations prior to discharge are less than acute trigger values.

Table 5-1 Total Pollutant Concentrations for the Diffuser Discharge

Constituent	Barren Liquor Concentrations	Discharge Concentration (10-fold Dilution)	Discharge Concentration (20-fold Dilution)	Ambient Concentration	Chronic Toxicity Trigger Value ⁶
Nickel ($\mu\text{g/L}$)	560	56	28	0.5 ¹	7
Cobalt ($\mu\text{g/L}$)	100	10	5	0.1 ⁴	1
Manganese ($\mu\text{g/L}$)	10,000	1,007	507	7.6 ¹	140
Cadmium ($\mu\text{g/L}$)	20	2	1	0.02 ⁴	0.2
Chromium 3+ ($\mu\text{g/L}$)	2,500	250	125	0.15 ⁵	27.4
Chromium 6+ ($\mu\text{g/L}$)	440	44	22	0.15 ⁵	4.4
Zinc ($\mu\text{g/L}$)	40	4	2	0.5 ¹	15
Iron ($\mu\text{g/L}$)	3,000	381	236	90 ¹	n/a
Aluminium ($\mu\text{g/L}$)	2,000	266	169	73 ¹	n/a
Magnesium ($\mu\text{g/L}$)	17,900,000	2,951,700	2,121,000	1,290,000 ²	n/a
Calcium ($\mu\text{g/L}$)	670,000	437,000	424,000	411,000 ²	n/a
Chloride ($\mu\text{g/L}$)	12,080,000	18,670,000	19,037,000	19,400,000 ²	n/a
Sulfate ($\mu\text{g/L}$)	66,400,000	9,061,400	5,875,200	2,688,000 ³	n/a

¹ Median of monitoring data

² Typical seawater value (<http://www.seafriends.org.nz/oceano/seawater.htm>)

³<http://www.enclabs.com/question.html>

⁴Recent monitoring (2006) of the Port Curtis area carried out by the Port Curtis Integrated Monitoring Program (PCIMP) has identified significantly lower ambient concentrations for Cobalt and Cadmium than presented previously (typical seawater values as per note 2). This improves the appreciation of the potential impact to Port Curtis by using more appropriate local ambient data.

⁵Port Curtis Integrated Monitoring Program (PCIMP) of Port Curtis area (2006)

⁶NOEC values (No Observed Effect Concentration)

n/a = no data available

All discharge concentrations have been committed to as per above by GPN, regardless of the seawater intake concentrations. These area all *dissolved* species, so their specific gravity is not relevant

The above approach assumes passive behaviour of all discharged pollutants, with the exception of manganese, which has been modelled with a 10 day half life decay as per advice from others.

5.2 CFD Modelling Methodology

This section describes the methodology applied for the CFD modelling. Details of the diffuser configuration are provided in Section 7 for Stage 1 and 8 for Stage 2. Note that the individual configuration of each diffuser line is similar for both stages.

CFD modelling was undertaken in two stages:

- Steady state analysis; and
- Dynamic (temporally variant tidal velocity) analysis.

The corresponding configurations are described separately in the following sections.

It is noted that an optimisation study was conducted as part of the initial steady state analysis. In this analysis, it was initially assumed that the diffuser ports would be 5 metres apart, with 240mm diameter openings. The optimisation analysis found, however, that diffuser performance could be improved, in a steady state sense, by halving both the port spacing and cross-sectional area of each port. This optimised configuration thus had a 2.5 metre port spacing and 170mm diameter opening. Both steady state and dynamic results from this optimised configuration only are presented below.

5.2.1 Steady State Solution

5.2.1.1 Mesh Description

- The symmetrical nature of the diffuser arrangement was exploited to allow simulation of only one diffuser port. Appropriate boundary conditions were applied accordingly (see).
- The mesh spanned from 20m upstream of the diffuser port to 50m downstream, and was 10m deep. The cells were more densely clustered in the vicinity of the diffuser port (in all three dimensions) to provide the necessary resolution where the plume dispersion is the greatest.
- The mesh spanned 1.25m in the direction of the main diffuser pipe (i.e. half the port spacing). One face was on the centreline of the diffuser port, and the opposite face was on the centreline between the ports. The boundary condition on these faces was that of symmetry.
- The diffuser port exit point was located 1.6m above the bottom face, to match the proposed pipe diameter. The port was modelled as a 0.15m square (0.15m x 0.075m in the symmetric model), thus representing the correct cross sectional area and injection velocity for the optimised configuration (i.e. a 0.17m diameter circular opening). The plume adopted the correct circular cross section within 0.5m of the injection point.

5.2.1.2 Boundary Conditions

- Ambient velocities chosen for simulation were 0.1, 0.2, 0.3, 0.5, and 1.0 m/s, primarily to maintain consistency with previous CORMIX studies. The ambient velocity on the inlet face was defined as being uniform over the inlet area. The outlet face was defined as having a fixed pressure value after removal of the hydrostatic pressure component. This allowed the outlet velocity to be non-uniform over the outlet face while maintaining a sufficient and physically correct problem constraint.
- The top surface of the model was defined as a slip plane allowing flow along the surface, but not through it. The bottom surface was defined as a wall, having zero velocity at the physical surface.
- The side walls were assigned 'mirror' boundary conditions, so that the proximity and impact of adjacent port discharges could be captured. Importantly, this boundary condition enforced that no tracer be lost from the domain across the side walls, and that water predicted to exit the domain was reintroduced back to the simulation volume as a flow in the opposite direction, with tracer attached.
- The density of the ambient stream was 1024.5 kg/m^3 and the density of the injected flow was 1030 kg/m^3 for the 10:1 dilution of the barren liquor.
- The effluent plume was assigned a tracer concentration of 1 unit.

5.2.1.3 Solution Technique

- The standard k- ε turbulence model was used. The injected stream was initialised with $k=10 \text{ m}^2/\text{s}^2$ and $\varepsilon=20 \text{ m}^2/\text{s}^3$, both of which are consistent with the nature of the flow. Although the turbulence level in the ambient stream is not known precisely, it is likely to be significantly less than that of the injected stream. As a result, a near zero value for the ambient stream turbulence was employed which, if anything, will only cause the model to under-estimate the rate of plume diffusion.
- Gravity was defined at 10 m/s^2 acting vertically.
- The model treated the ambient and injected streams as miscible incompressible fluids, and solved for the mixing fraction of the two on the finite volume mesh. The incoming ambient stream was defined as 100% of fluid one and 0% of fluid two, and vice-versa for the injection fluid. Kinematic viscosity for both streams was set at $1 \times 10^{-6} \text{ m}^2/\text{s}$.
- For consistency with prior work, the plume centreline concentrations were compared with CORMIX results for the $v=0.5\text{m/s}$ and $v=1.0\text{m/s}$ cases. The results were in clear qualitative agreement, though with CORMIX predicting lower plume centreline concentrations at all distances downstream. Consequently, the CFD modelling may be considered as providing a more conservative estimate than CORMIX for plume dispersion.

5.2.2 Dynamic Solution

5.2.2.1 Mesh Description

- The same mesh was used in this case as was adopted in the steady state analysis, except the domain was extended to be 50m length either side of the diffuser pipe. The domain details are shown in Figure 5-1.

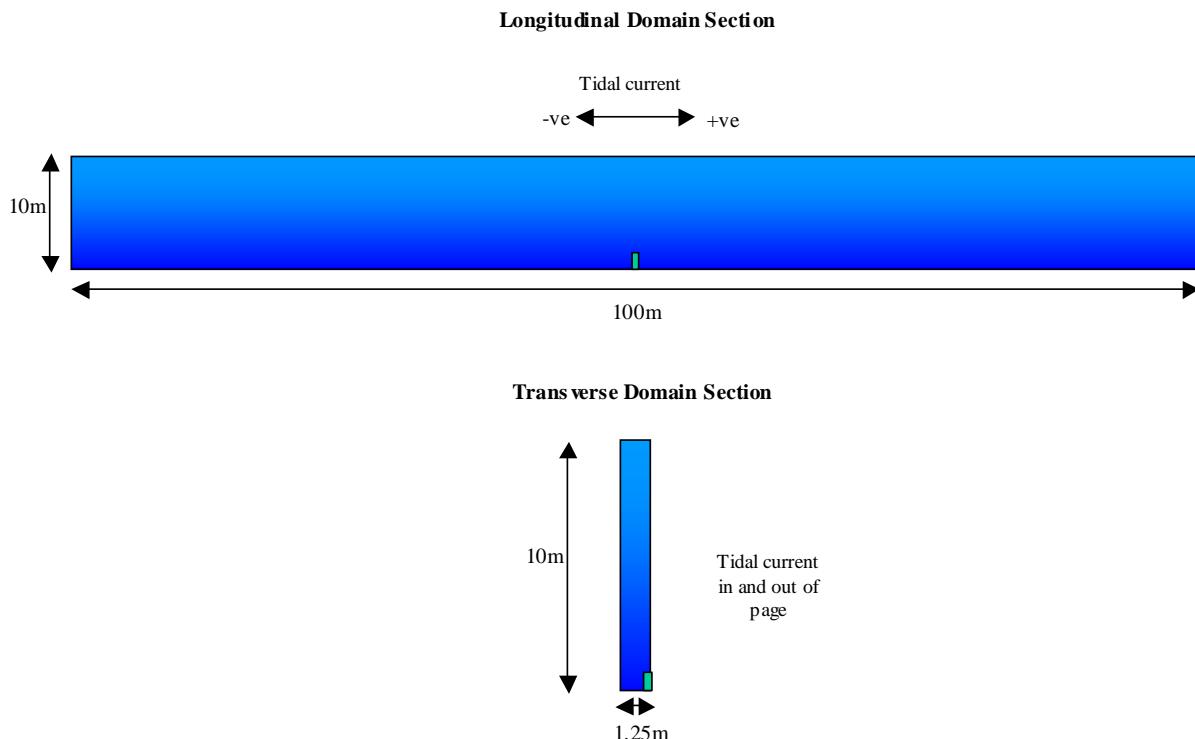


Figure 5-1 CFD Model Domain Arrangement

5.2.2.2 Boundary Conditions

- A temporally varying ambient velocity was chosen for this simulation based on the far field model tidal velocity predictions at the discharge point. A two hour period was simulated where the ambient velocity ranged from $+0.25$ to -0.25 ms^{-1} that included slack water. This permitted examination of plume return effects on ambient concentrations.
- Discharge of a tracer at concentration 1.0 for all times, except where the ambient tidal velocity magnitude was less than or equal to 0.1 ms^{-1} . During these times, the discharge tracer concentration was lowered to 0.5, which was set to represent a doubling of the dilution of discharged effluent from 10:1 to 20:1. The total flow rate was maintained during low tidal velocities, requiring importation of additional seawater to provide this additional dilution. This decision was based to some extent on draft EPA discharge licence conditions, and preliminary feedback based on the steady state analysis results.
- Other boundary conditions were maintained as per the steady state analysis.

5.2.2.3 Solution Technique

- The solution technique was the same as the steady state analysis.

5.3 Near Field and Far Field Results Presentation and Combination

Results from the above models were extracted individually and also combined, to provide an analysis of the cumulative near and far field impacts as related to water quality objectives.

5.3.1 Far Field Model Only

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. 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.

5.3.2 Near Field Model Only

In the case of the near field modelling, only the dynamic results have been analysed for purposes of combination with the far field model, however the steady state results have been presented for completeness. In the dynamic simulation case, dilutions for the tracer have been presented as contour plots and timeseries over the simulation period at three profile locations downstream and across the diffuser axis. These locations are shown in Figure 5-2.

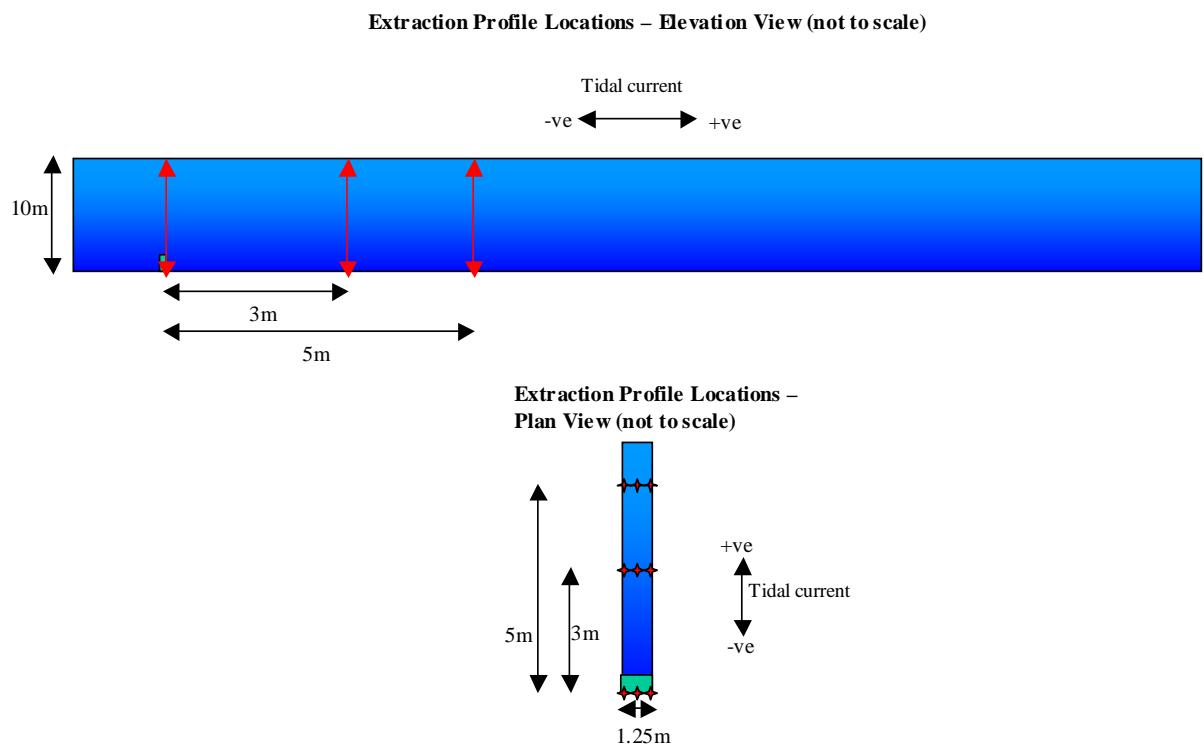


Figure 5-2 Near Field Model Extraction Locations (red stars)

This provided nine locations in total, with dilutions reported over the entire simulation for each. Locations are referred to as '0m', '3m' and '5m' downstream of the diffuser.

5.3.3 Combination Technique

In order to assess the compliance of simulated pollutant concentrations with nominated water quality objectives (or chronic toxicity trigger values), the near and far field model results were considered in combination. Specifically, the long term average concentration of each effluent constituent in the vicinity of the outfall was extracted from the far field RMA11 model as representative of the general increase in background concentrations to be expected as a result of the discharge. Using these values, target dilutions of the tracer discharged in the CFD model were computed for each species, with the targets being based on attainment of chronic toxicity water quality objectives. The spatial and temporal evolution of these dilution targets in the near field was then examined using a variety of contour and timeseries plot analyses. This approach was adopted to account for the cumulative influence of both long term increases in ambient concentrations (i.e. far field model) and transient concentration 'spikes' due to plume discharges (i.e. near field model).

This combinatorial approach was adopted as a rigorous method by which the interaction of the near field and far field dynamics could be captured and reported. Importantly, it provided a means by which to offer assessment of the likely cumulative (ongoing) effects of the discharge on ambient pollutant concentrations, taking into account both near and far field effects, and especially the fact that the near field mixing zone is unlikely to see discharged effluent mixed with previously unaffected background water.

It is noted that this approach, including the use of CFD tools, is a result of an iterative process of diffuser design and investigation, and that this process took place over almost two years. The options progressively considered as part of this process 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 and URS, 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.

The seventh option 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.

The eight option considered a variety of non-linear diffuser arrangements at both the RG Tanner wharf and the proposed Wiggins Island wharf, however dilutions were insufficient and accumulation of pollutants in mangrove areas was predicted.

The ninth configuration adopted consisted of two linear diffuser lines (one for Stage 1, increasing to two for Stage 2) perpendicular to the main direction of flow and located spaced within the area between the proposed tug harbour and the RG Tanner wharf. These diffusers were to have eductors installed at all ports. Again, the dilutions were generally insufficient and other operational constraints precluded adoption of this approach.

After extensive investigations of different configurations, the final diffuser arrangement was set by GPN, and took into account a tenfold onshore dilution of effluent in response to regulatory advice. In contrast to the previous configurations investigated, this final configuration does not implement an eductor arrangement on the outfall pipes, but rather, has adopted a simple perforated pipe installation (as previously described). A transformation rate of a 10 day half-life was simulated for manganese, based on advice from others, and no decay was assumed for all other discharge constituents. In addition to this ten fold dilution, GPN has also committed to increasing this to a twenty fold dilution when ambient tidal velocities fall below 0.1 ms^{-1} . This commitment was made at least partly in response to regulatory feedback. Results are discussed for this option in Chapter 7.

7 PROPOSED CONFIGURATION – STAGE 1

The proposed configuration comprises a single diffuser discharging the total Stage 1 effluent through 70 ports equally spaced along 175m of the 250m long diffuser line and located as per Figure 7-1. This equates to a port spacing of 2.5 m. The Stage 2 diffuser is also shown in the figure. The model setup and results for both the near and far field are described below.

7.1 Near Field Model

7.1.1 Inputs

The diffuser arrangement for the proposed configuration is as follows:

- Diffuser length: 250m;
- Discharge length: 175m;
- Number of ports per diffuser: 70;
- Diffuser type: single unidirectional diffuser with discharge pointing upwards;
- Average water depth: 10 meters. This was calculated as the average depth along the length of the proposed discharge (see Figure 7-2 – Only diffuser 1 is implemented for Stage 1);
- Total flow rate: 17,100 m³/hr;
- Pipe diameter: 1.6m;
- Holes/Ports diameter: 170mm;
- Discharge density: 1030 kg/m³ for the ten-fold dilution of the barren liquor and 1027 kg/m³ for the twenty-fold dilution of the barren liquor (supplied to WBM);
- Background receiving water density: 1024.5 kg/m³ (supplied to WBM);
- Main pipeline elevation: on sea bed;
- Ambient velocity (steady state): Ambient velocities of 0.1, 0.2, 0.3, 0.5 and 1.0 ms⁻¹ have been assumed as representative of tidal currents. Tidal velocity percentiles are shown graphically in Figure 7-3.
- Ambient velocity (dynamic): Ambient velocity ranging from +0.25 to -0.25 ms⁻¹ over several hours, based on the far field RMA model predictions.



Figure 7-1 Diffuser Location

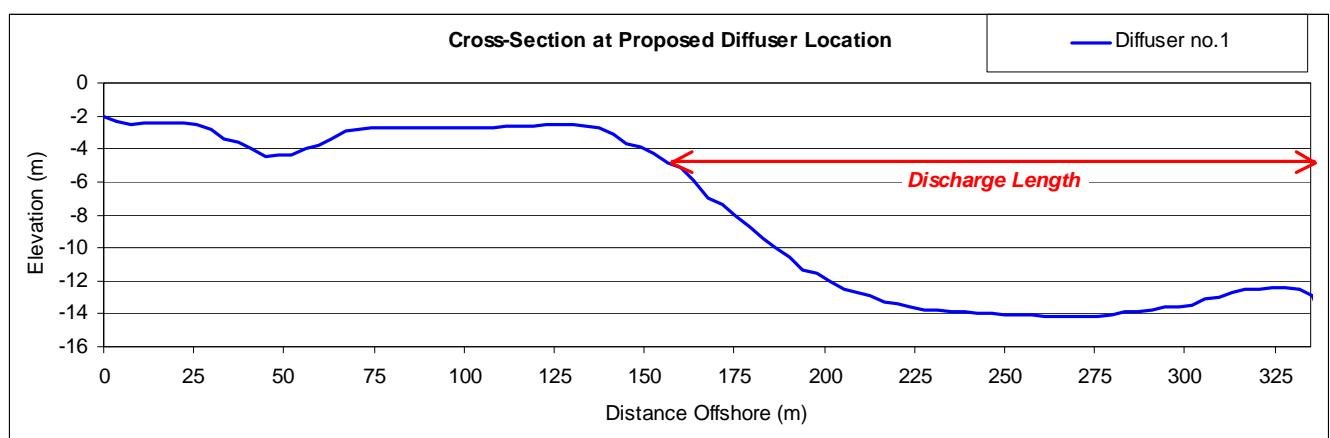


Figure 7-2 Cross Section of the Water Depth for Diffuser Pipeline – Stage 1

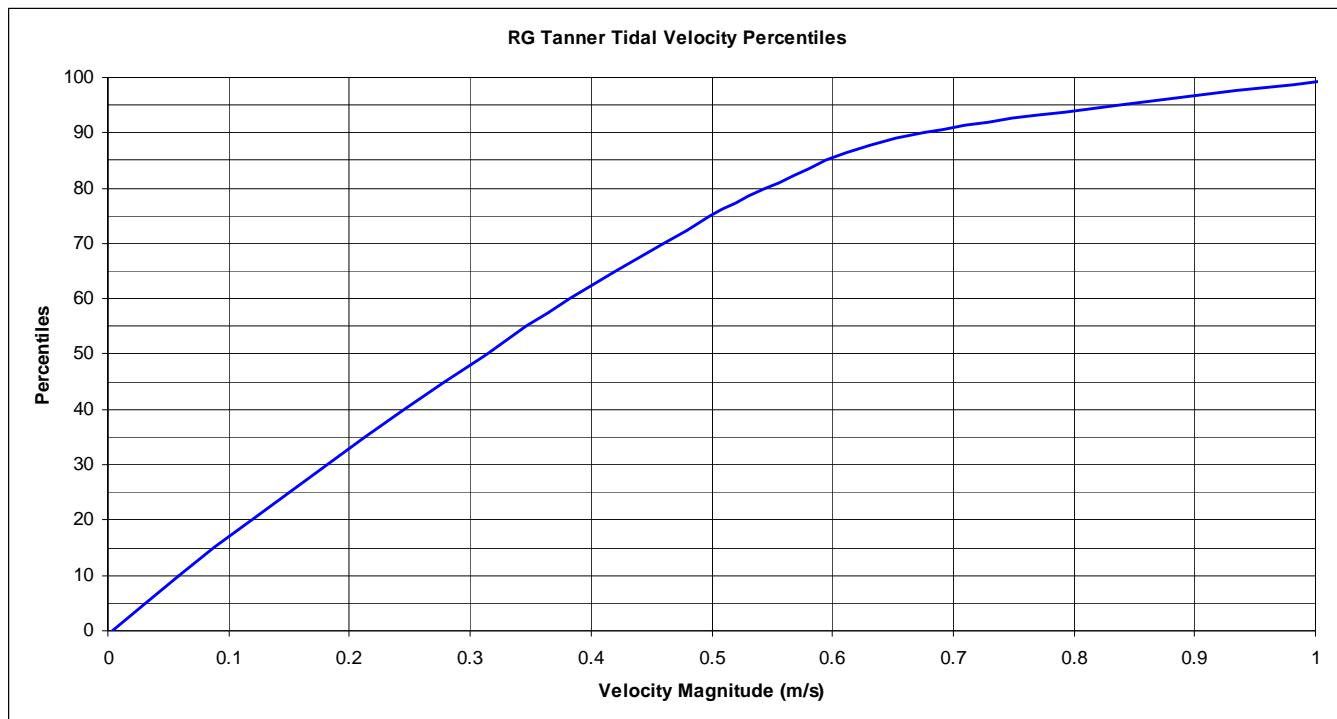


Figure 7-3 RG Tanner Tidal Velocity Percentiles

The proposed discharge concentrations are reported in Table 5-1. It is noted that these concentrations were provided by GPN, and that it has been assumed here that these have already taken into account ambient (i.e. intake) conditions, and the impact that these might have on processing and discharge concentrations.

7.1.2 Results

OpenFOAM explicitly simulates the plume evolution, from exiting the diffuser hole to interacting with the ambient flow. To illustrate this simulation approach, screen grabs from the steady state analysis are presented first to provide visual appreciation for the model results. Data from the dynamic simulation is subsequently presented.

7.1.2.1 Steady State Longitudinal Cross Sections

Following is a series of figures showing the plume evolution downstream of the diffuser exit point for the steady state simulation. The ambient velocity is always from left to right, and plume colours represent a tracer concentration, as per the colourbar. The injection concentration was 1.0, so for example, a plume concentration of 0.1 represents a dilution of 10:1. Figures are presented in order of decreasing ambient velocity, and the total length of each figure downstream of the exit point is 50 metres.

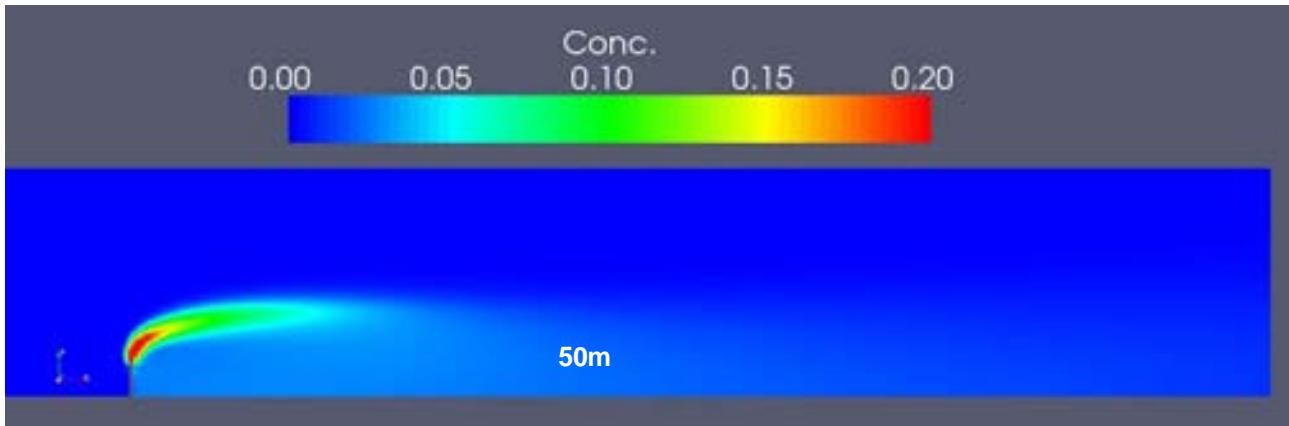


Figure 7-4 Longitudinal Plume Evolution: 1.0 m/s Ambient Velocity

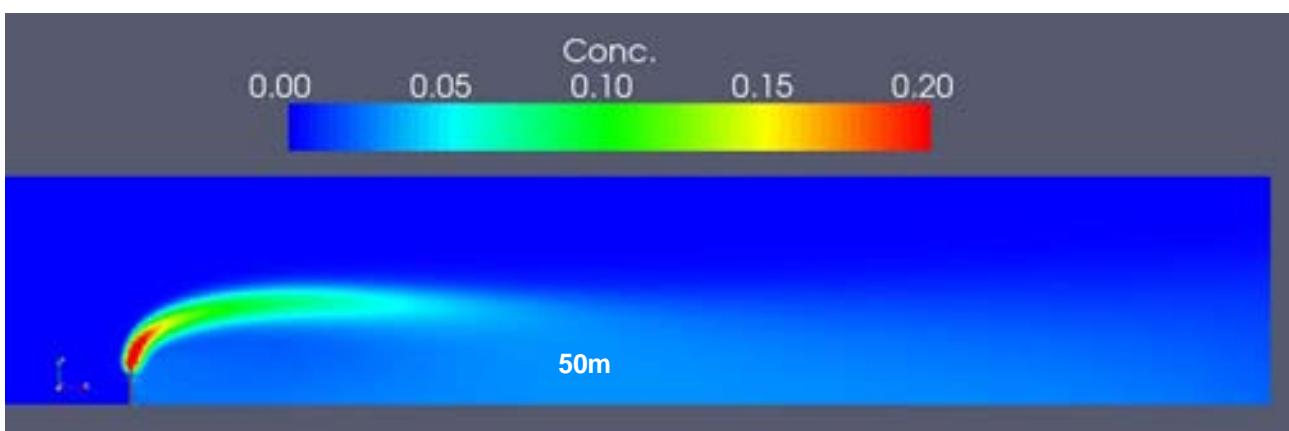


Figure 7-5 Longitudinal Plume Evolution: 0.5 m/s Ambient Velocity

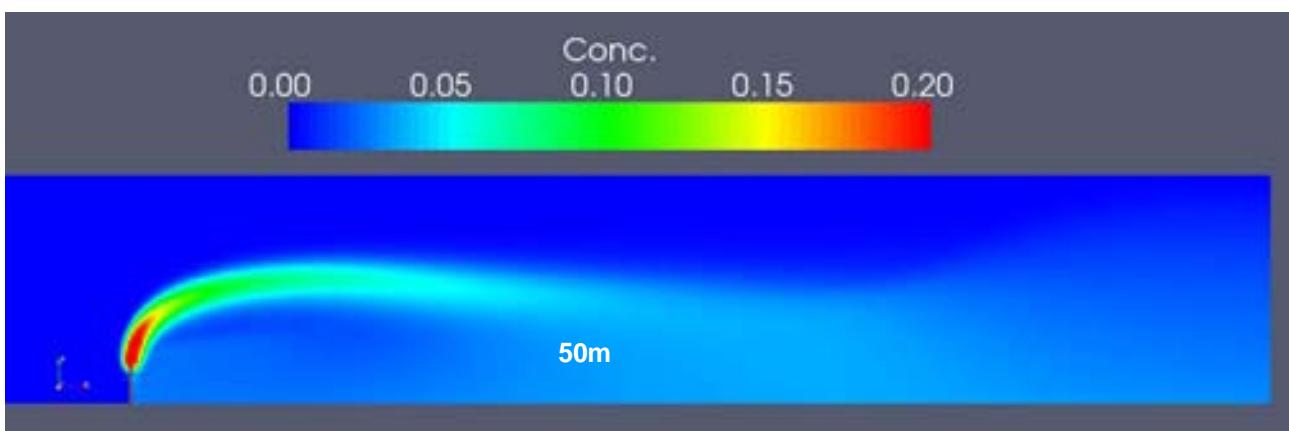


Figure 7-6 Longitudinal Plume Evolution: 0.3 m/s Ambient Velocity

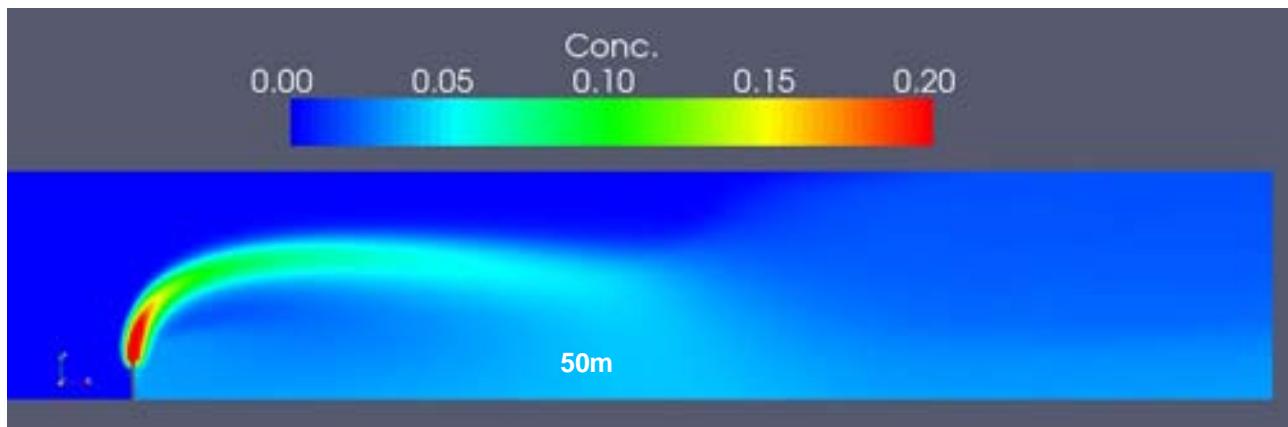


Figure 7-7 Longitudinal Plume Evolution: 0.2 m/s Ambient Velocity

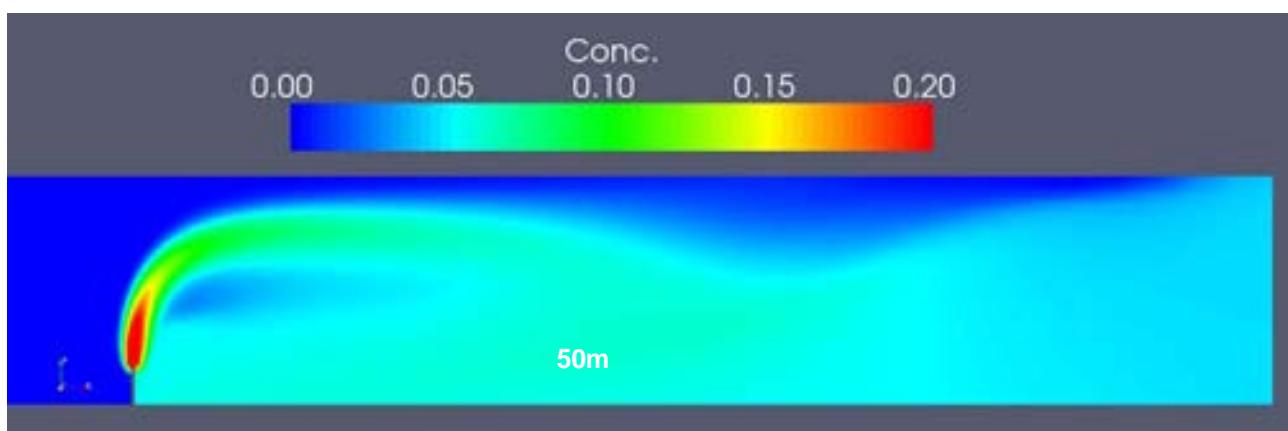


Figure 7-8 Longitudinal Plume Evolution: 0.1 m/s Ambient Velocity

The figures show several key features:

- As ambient velocity decreases, the plumes reach progressively higher into the water column following discharge, with an ambient velocity of 0.1 m/s nearing the free water surface. This is shown graphically in Figure 7-8 and Figure 7-9. ;

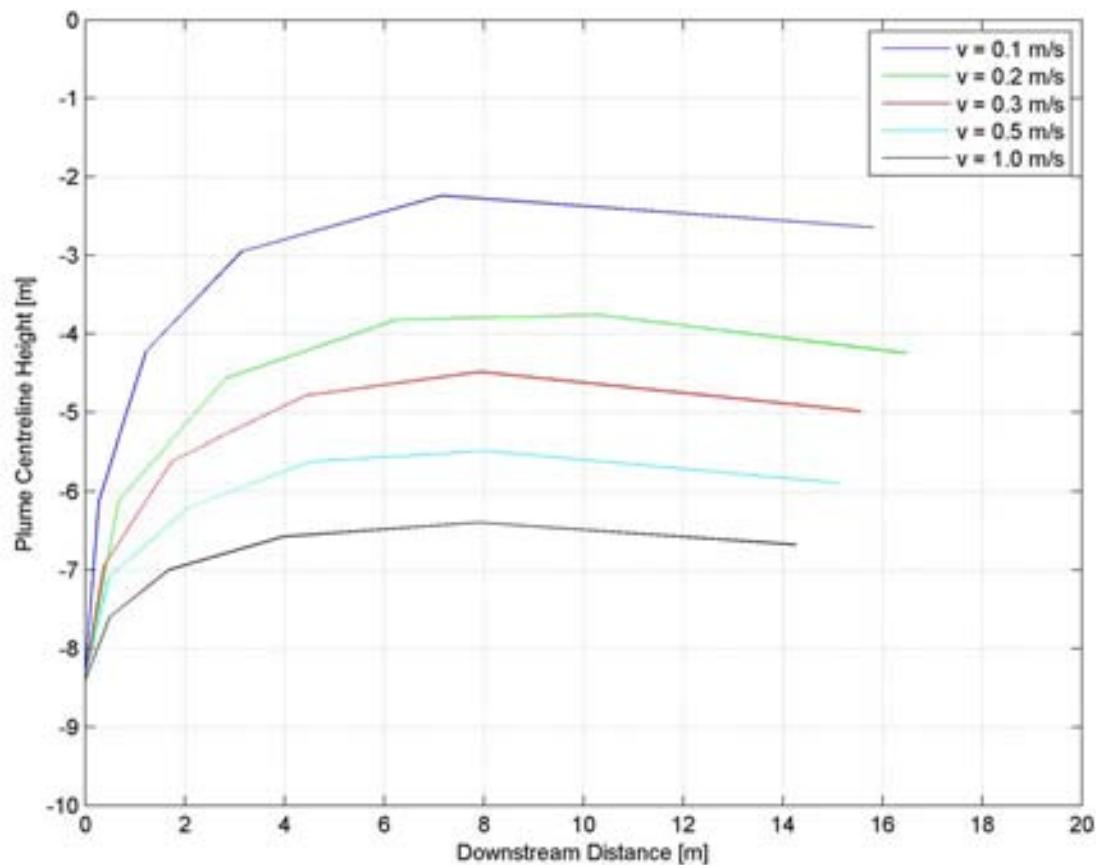


Figure 7-9 Longitudinal Plume Centreline Heights

- Complete mixing over the plume downwards from its peak height, or a close approximation to it, generally occurs by about 25 metres downstream of the exit point, for all velocities; and
- Generally the highest concentrations are within the core of the plume, and do not reach across the entire plume vertical extents.

Some unstable vertical recirculation in the 40 metres downstream of the diffuser was qualitatively predicted by CORMIX for the low ambient velocities (although no details of pollutant concentrations were able to be predicted, hence the move to CFD modelling). This recirculation is evidenced in Figure 7-8, with some discharged tracer appearing near the base of the diffuser pipe.

7.1.2.2 Steady State Transverse Cross Sections

Because the CFD modelling is three dimensional, the transverse behaviour of the plumes can be examined. Following is a series of figures that show, as an example, slices through the plume as it evolves downstream for the 0.5m/s ambient velocity case. The colours again correspond to the tracer concentration, as per the colourbar. The figures are presented in increasing distance downstream of the exit point (as shown in the top left hand corner).

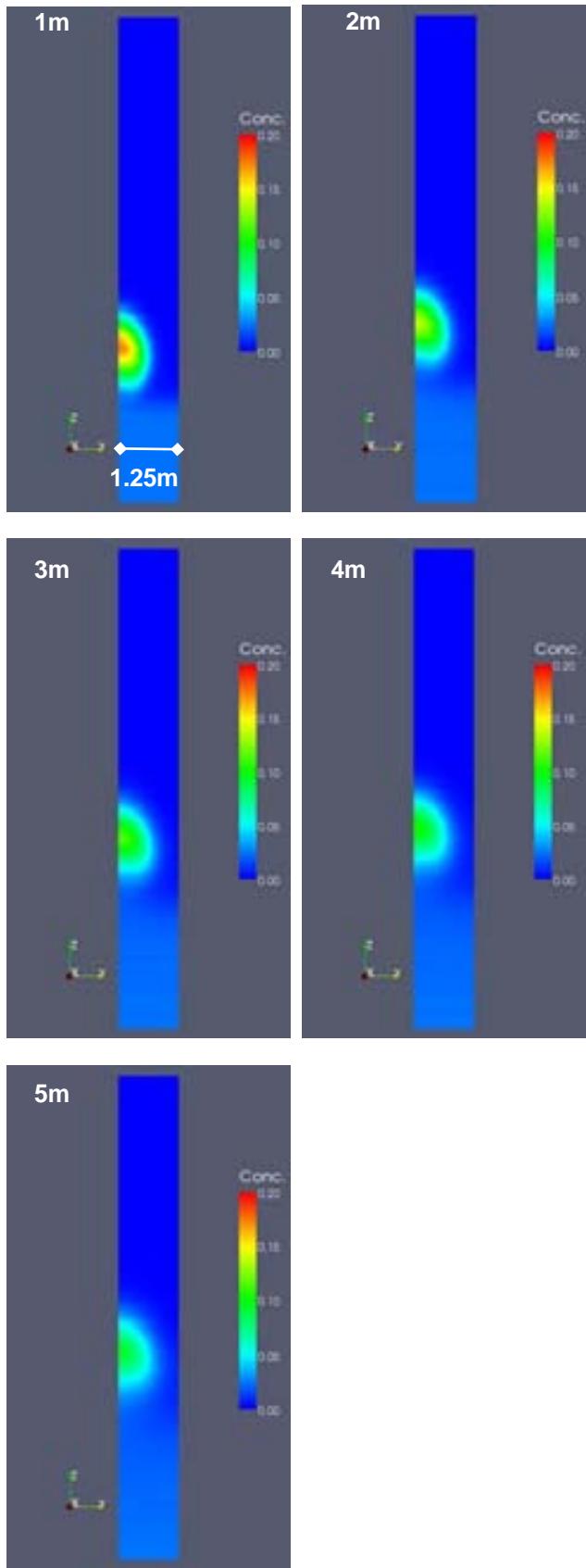


Figure 7-10 Transverse Plume Evolution: 0.5 m/s Ambient Velocity

Figure 7-10 demonstrates that the plume does not occupy the entire water column width or depth. From the results, we estimate that the cross-sectional area of the water column that contains a 0.1 concentration at 2m downstream is less than 4% of the flow area. As such, it is not correct to assume that concentrations greater than or equal to 0.1 occupy a region 175m by 10m depth, primarily because the exceedences are confined to the core of the plume, i.e. the plume centreline. This is a key finding of the CFD modelling study.

7.1.2.3 Steady State Centreline Concentrations

The steady state CFD results allowed extraction of the centreline concentration for all computational cells downstream of the exit point. These have been plotted below for illustrative purposes only – quantitative analysis is presented with regards to the dynamics simulations in subsequent sections. The figure is a log-linear plot, and it is stressed that it presents distance downstream of the exit point on the abscissa, rather than distance along the plume centreline.

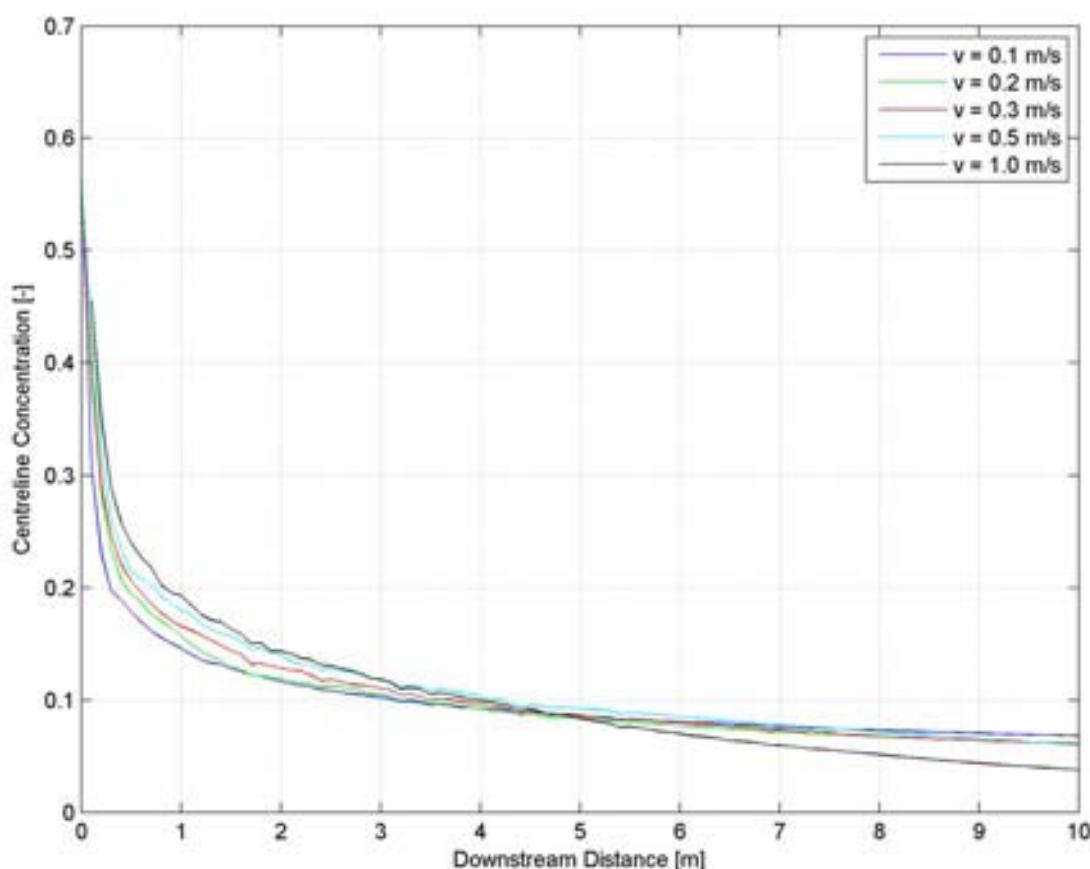


Figure 7-11 Centreline Concentrations with Downstream Distance

The figure shows a rapid decrease in centreline concentration with distance downstream for all ambient velocities, with all cases behaving similarly in this regard. Importantly, the 0.1 m/s case shows excellent performance in this regard, primarily because the ejected effluent has an opportunity to mix with the bulk of the water column without travelling far downstream away from the diffuser line. Because the ambient velocity is low, this opportunity allows the plume to mix relatively quickly (in the

vertical) using the momentum of the jet, rather than the advection induced mixing mechanism that is predicted in the higher ambient velocity cases.

As a guide, all cases show that a centreline dilution of 10:1 is reached in approximately 4 to 5 metres downstream of the exit point, in the core of the plume.

7.2 Far Field Model

The final proposed Stage 1 configuration consists of a single diffuser line running along the approach jetty to the RG Tanna wharf (Figure 7-1).

Within the far field model, three elements along the diffuser line were assigned an inflow accompanied by a tracer (for Stage 1 this was only at diffuser no.1 as per Figure 7-12 below, Stage 2 simulations included all diffusers shown in the figure). As per the near field modelling, the total inflow over the diffuser line was 17,100 m³/hr. The tracer was assigned a half-life transformation rate of 10 days for manganese, and a zero decay rate for all other parameters, as per advice from others. The resulting advection dispersion model simulation covered approximately 10 months, which allowed the tracer to approximate steady state within the Port.

The results are presented below. Note that concentration contours, averages and time series are presented only for the zero decay rate simulation results. These results do not apply for manganese concentration, as this parameter has been applied a 10 day half life rate. Specific results for manganese are only reported in the tables. It should be noted that the contours do not have near field concentrations included.



Figure 7-12 Model Elements Selected to Represent Diffuser Lines. Stage 1 Employed Diffuser 1 Only, and Stage 2 Employed all Diffusers

7.2.1 Spatial and Temporal Concentrations at Steady State

The spatial extent of the tracer covered a large proportion of Port Curtis. However, most of the high concentrations of the tracer were contained between Gladstone Marina, Wiggins Island and the downstream reach of the Calliope River. There was little variation between the 6hrly and 12hrly maximums and the maximum concentration (~0.06%) was found in the immediate vicinity of the diffusers. The remainder of the receiving waters exhibited tracer concentrations of approximately 0.01%.



Figure 7-13 6hrly Maximum Concentrations of the Tracer in Port Curtis – Stage 1



Figure 7-14 12hrly Maximum Concentrations of the Tracer in Port Curtis – Stage 1

The time series data presented in Figure 7-16 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 7-15 Location of Tracer Concentrations Time Series Data at Steady State

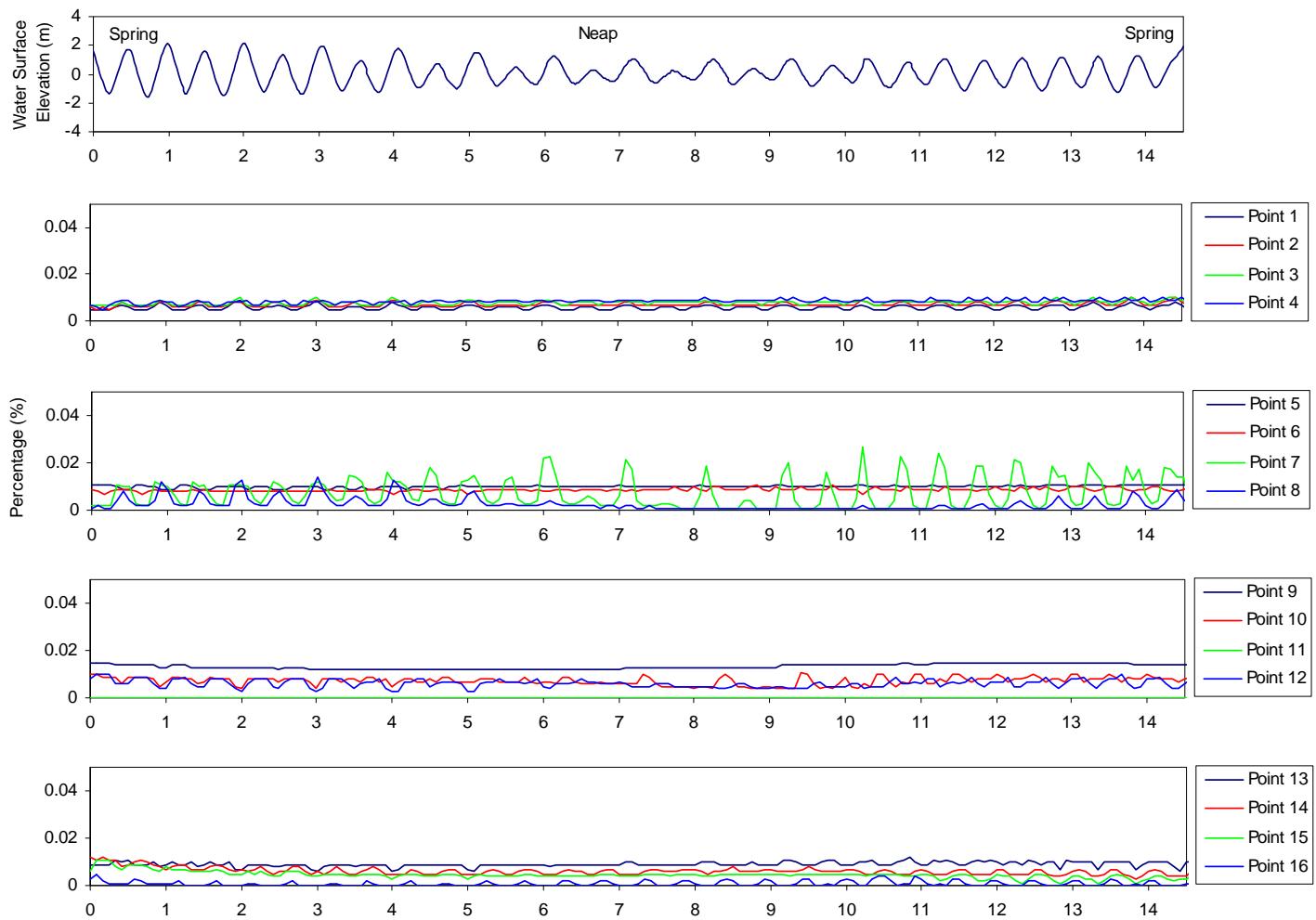


Figure 7-16 Time Series of Concentrations at 16 Locations Within Port Curtis – Stage 1

Data from the 16 far field locations illustrates that the highest instantaneous concentration of the tracer is in the Calliope River (Point 7), with a concentration of 0.022% for the 10 day manganese half life rate and 0.027% for the zero decay rate. These values have been used to calculate the percentages of pollutants likely to be present at this location. The results are tabulated in Section 7.3.

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 7-1. These locations are shown in Figure 7-15. The marina had the highest mean concentration, at steady state, with a value at 0.014%. It should however be noted that the marina is an artificial environment. The second highest mean concentration was situated in location 5.

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

Location	Average Concentration at Steady State (%)
1	0.007
2	0.008
3	0.009
4	0.009
5	0.011
6	0.009
7	0.008
8	0.003
9	0.014
10	0.007
11	0.000
12	0.006
13	0.009
14	0.006
15	0.004
16	0.001

7.3 Stage 1 Pollutant Concentrations

7.3.1 Far Field Only

Table 7-2 Maximum Far Field (Only) Pollutant Concentrations Over Entire Domain – Stage 1

Constituent	Ambient Concentration (ug/L)	Barren Liquor (ug/L)	Discharge Concentration (ug/L)	Maximum Additional Far Field Concentration (ug/L)	Total Maximum Far Field Concentration (ug/L)	Chronic Toxicity Trigger Value (ug/L)
Nickel	0.5	560	56	0.015	0.52	7
Cobalt	0.1	100	10	0.003	0.10	1
Manganese	7.6	10000	1007	0.272	7.9	140
Cadmium	0.02	20	2	0.001	0.02	0.2
Chromium 3+	0.15	2500	250	0.068	0.22	27.4
Chromium 6+	0.15	440	44	0.012	0.16	4.4
Zinc	0.5	40	4	0.001	0.50	15
Iron	90	3000	381	0.103	90.1	n/a
Aluminium	73	2000	266	0.072	73.1	n/a
Magnesium	1290000	17900000	2951717	797	1290797	n/a
Calcium	411000	670000	437006	118	411118	n/a
Chloride	19400000	12080000		see note 1		n/a
Sulfate	2688000	66400000	9061402	2447	2690447	n/a

Note 1: The Chloride discharge concentration is below the background receiving water concentration. This means that the discharge and dilution of this constituent into Port Curtis will, to a certain extent, reduce ambient salinity. In addition, no chronic trigger value was provided for this constituent. Hence, the Chloride maximum concentrations downstream of the diffusers have not been reported in the results tables.

7.3.2 Near Field

The dynamic near field simulations were used to combine with the far field results, and these dynamic simulations included a doubling of discharge dilutions for tidal velocities less than 0.1 m/s. Based on the above tabulated far field concentrations, resultant target dilutions for the near field simulations have been computed, with these dilutions (and greater) indicating compliance with chronic water quality objectives. These target dilutions for Stage 1 are presented below to the nearest integer value, with the corresponding tracer concentrations included.

Table 7-3 Target Dilutions and Tracer Concentrations – Stage 1

Constituent	Chronic Toxicity Trigger Value (μg/L)	Dilution Required	Target Tracer Concentration
Nickel	7	9	0.12
Cobalt	1	11	0.09
Manganese	140	8	0.13
Cadmium	0.2	11	0.09
Chromium 3+	27.4	9	0.11
Chromium 6+	4.4	10	0.10
Zinc	15	0	3.67

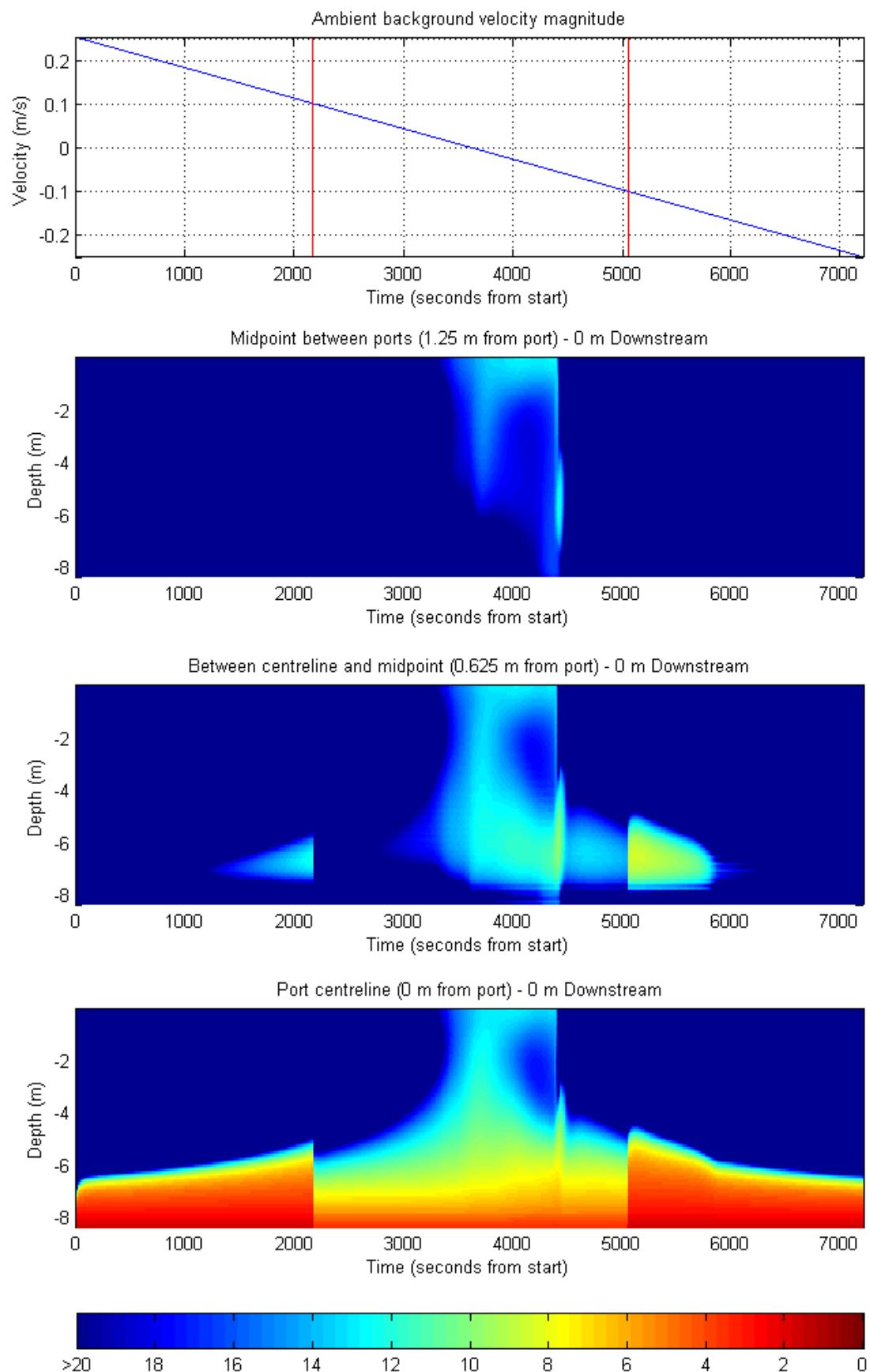
Dynamic near field results to compare with the above target dilutions are presented in two ways:

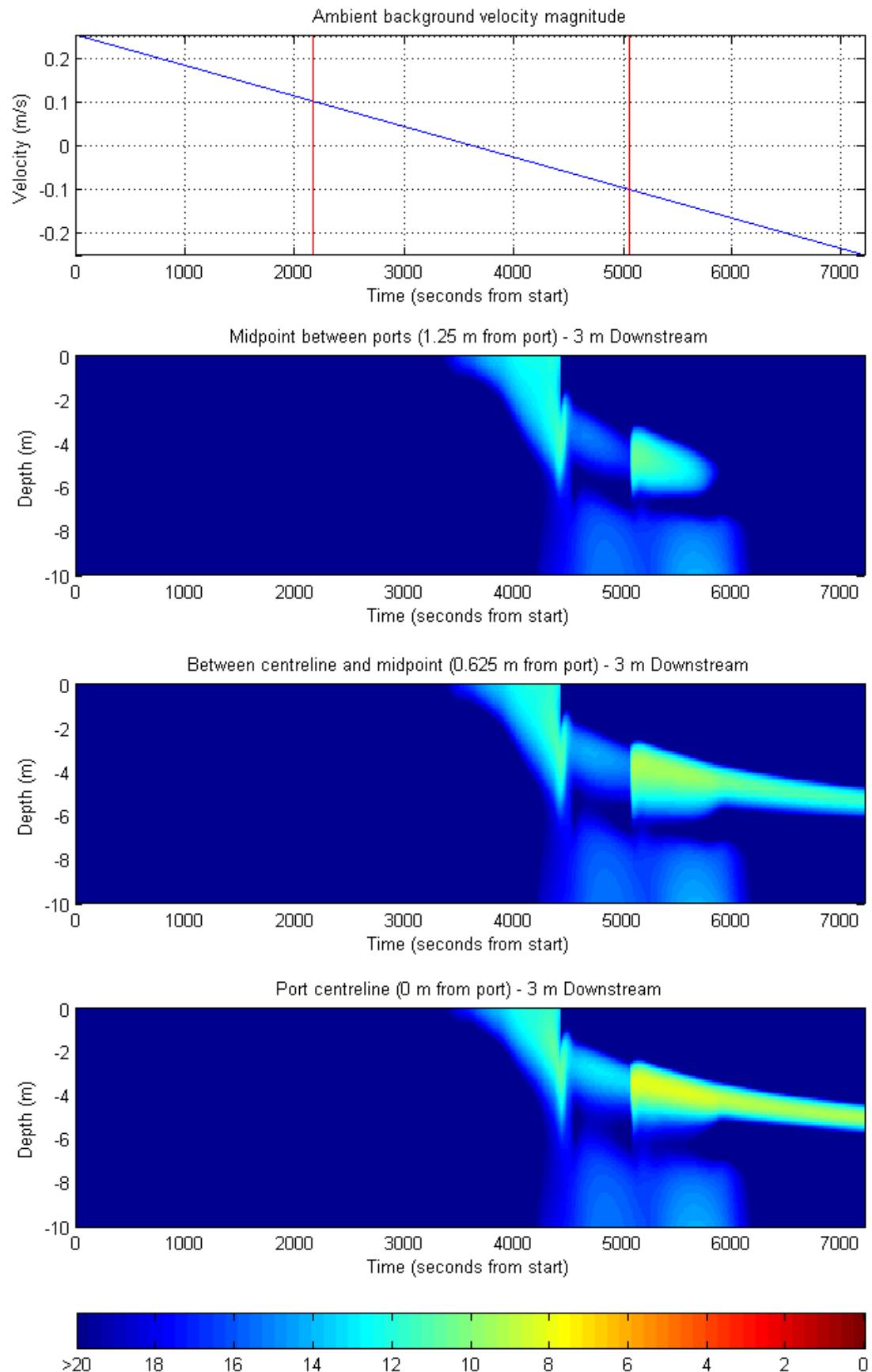
- Colour contour plots of tracer dilution across all depths and all times at each profile location (as shown in Figure 5-2). Each colour contour figure has four panels. The first presents a line plot of the background ambient velocity with time, as applied at the model boundaries. This came from a typical tidal cycle from the far field model. The vertical red lines bound the period where the discharge concentration drops to half the normal, (i.e. 20:1 dilution and an injected discharge tracer concentration of 0.5 units) for tidal velocity magnitudes less than 0.1ms^{-1} . The subsequent three panels show the evolution of tracer dilution (as per the colour bar at the bottom of the figure) at a fixed distance away from the port, depending on the figure, with these distances being 0, 3 and 5 m for Figure 7-17, Figure 7-18 and Figure 7-19, respectively. Given the dynamic nature of the simulations, each profile location is initially upstream of the diffuser, with the obvious exception of the 0 m downstream case which is over the diffuser line itself. In particular, the vertical profile of tracer dilution is plotted at every timestep, with increasing time along the abscissa, and depth on the ordinate, over the simulation duration. As such, it is akin to a prediction for the time variation of results of a field monitoring program that involves taking vertical profiling casts at a set distance (either 0, 3 or 5 m) away from the diffuser, and converting measurements to dilutions. The three panels within each figure differ in their lateral location relative to the diffuser port. The first is exactly between ports (i.e. 1.25 m along the diffuser axis from the port), the last is at the port centreline, and the second last panel is at the midpoint between the second and last panels (i.e. 0.625 m along the diffuser axis from the port). The colour contours at 0 m from the diffuser extend only to a depth of 8.4 m as the diffuser pipe occupies 1.6 m vertical extents in the 10 m domain.
- Timeseries of dilutions at 1 m height intervals for each profile location, and correspond to the colour contour figures. These timeseries are grouped into three figures: one each for the location across the diffuser line, i.e. parallel to the discharge port, and 0.625 and 1.25 m along the diffuser away from the port. These correspond to Figure 7-20, Figure 7-21 and Figure 7-22, respectively. Each figure consists of 12 panels. The top two contain the same data: the time variation of ambient tidal velocity, with the vertical red lines encompassing the period over which the tidal velocity magnitude is less than 0.1 ms^{-1} . The remaining 10 panels show the timeseries of tracer dilution at 1 metre height increments from the surface downwards. Each of the 10 panels has three timeseries lines, with the blue, green and magenta linecolours corresponding to 0, 3 and 5 m downstream of the diffuser pipe, respectively. The horizontal red line on each dilution timeseries plot shows the 11:1 dilution as a reference marker. Data at 9 m below the surface cannot be presented for the 0 m downstream case as this depth is inside the diffuser pipe. Green and magenta (3 and 5 m downstream data) are still presented at that depth.

These figures allow direct visual comparison with the target dilution values for each discharge constituent presented in The dynamic near field simulations were used to combine with the far field results, and these dynamic simulations included a doubling of discharge dilutions for tidal velocities less than 0.1 m/s. Based on the above tabulated far field concentrations, resultant target dilutions for the near field simulations have been computed, with these dilutions (and greater) indicating compliance with chronic water quality objectives. These target dilutions for Stage 1 are presented below to the nearest integer value, with the corresponding tracer concentrations included.

Table 7-3. It is noted that the reason that 0, 3 and 5m data has been presented here is that the draft Queensland EPA (QEPA) licence conditions were targeted towards WQO compliance based at locations 3 m downstream of the diffuser, for Stage 1. These locations, in turn, came from the best

estimates of the CORMIX modelling at the time the conditions were released. Subsequent investigation and interrogation of the CORMIX modelling gave rise to the need to move to CFD near field modelling, with the view to then reporting relative to the initial license conditions. As part of the ongoing discussions around the CFD modelling results, QEPA subsequently requested data at 0 and 5 m from the diffuser to be presented, and as such, this report is a summary of all QEPA data requests regarding the CFD results.

**Figure 7-17 Tracer Dilutions - 0m Downstream Of Diffuser**



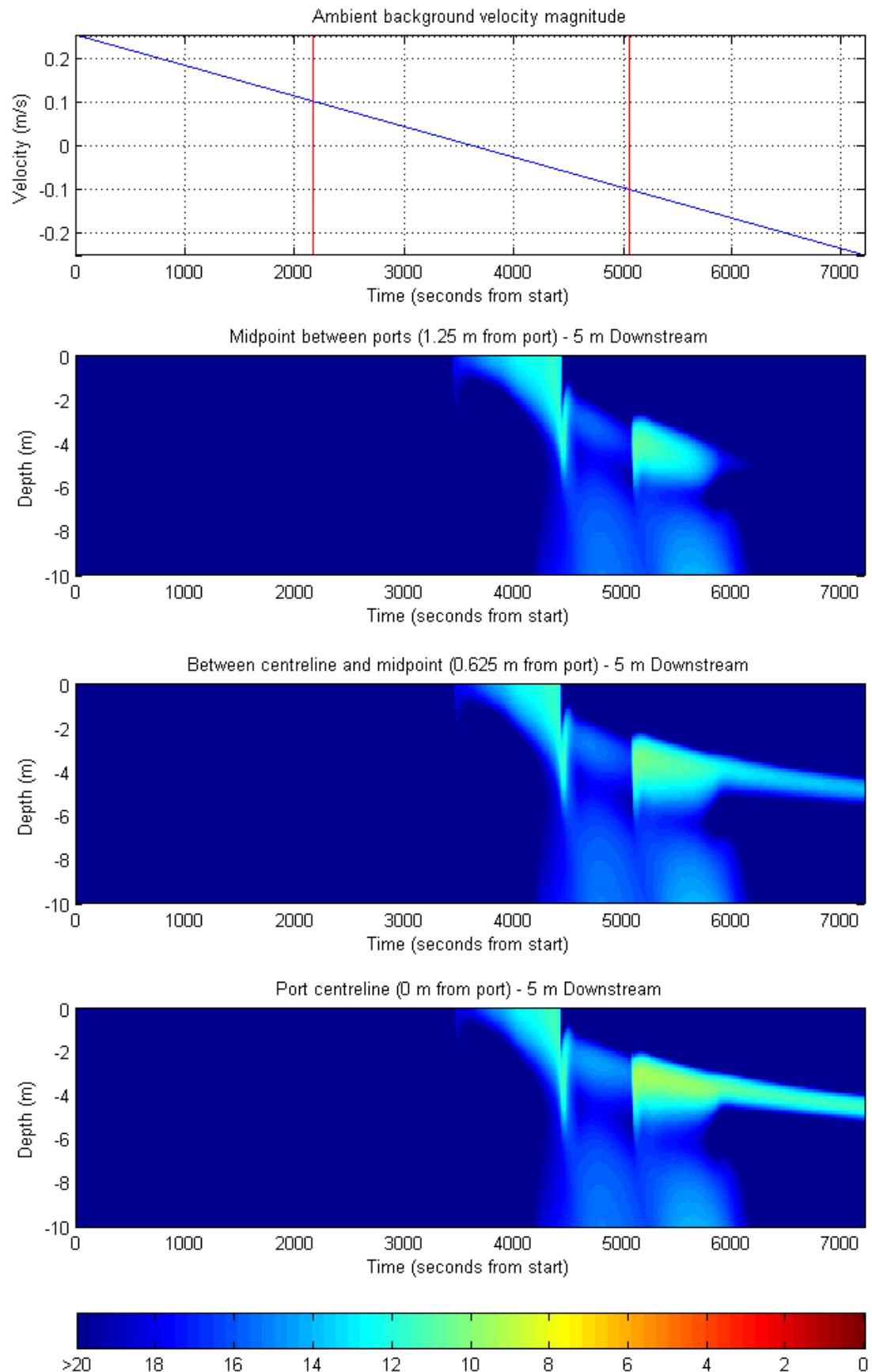


Figure 7-19 Tracer Dilutions - 5m Downstream Of Diffuser

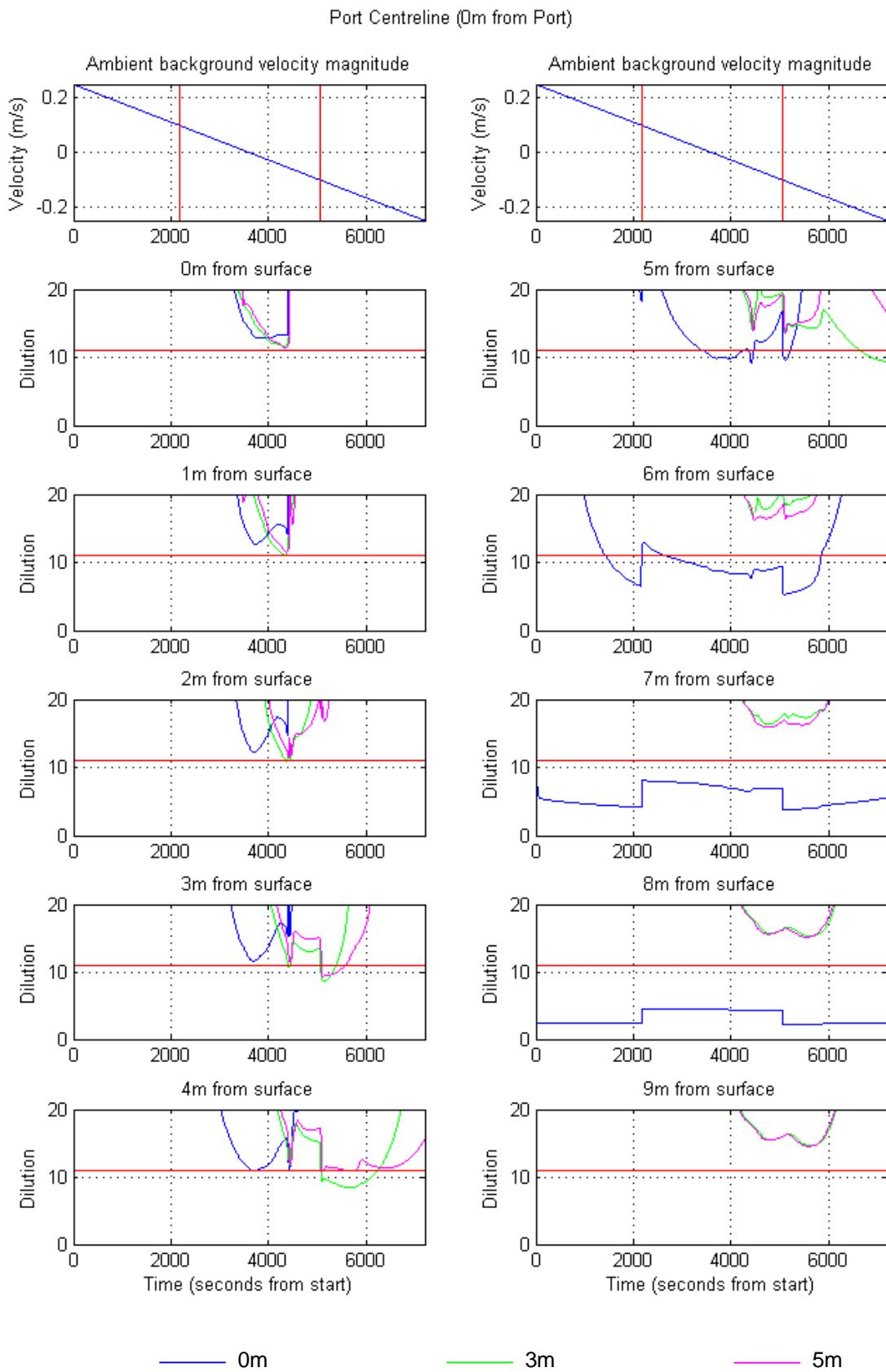


Figure 7-20 Tracer Dilutions – Port Centreline

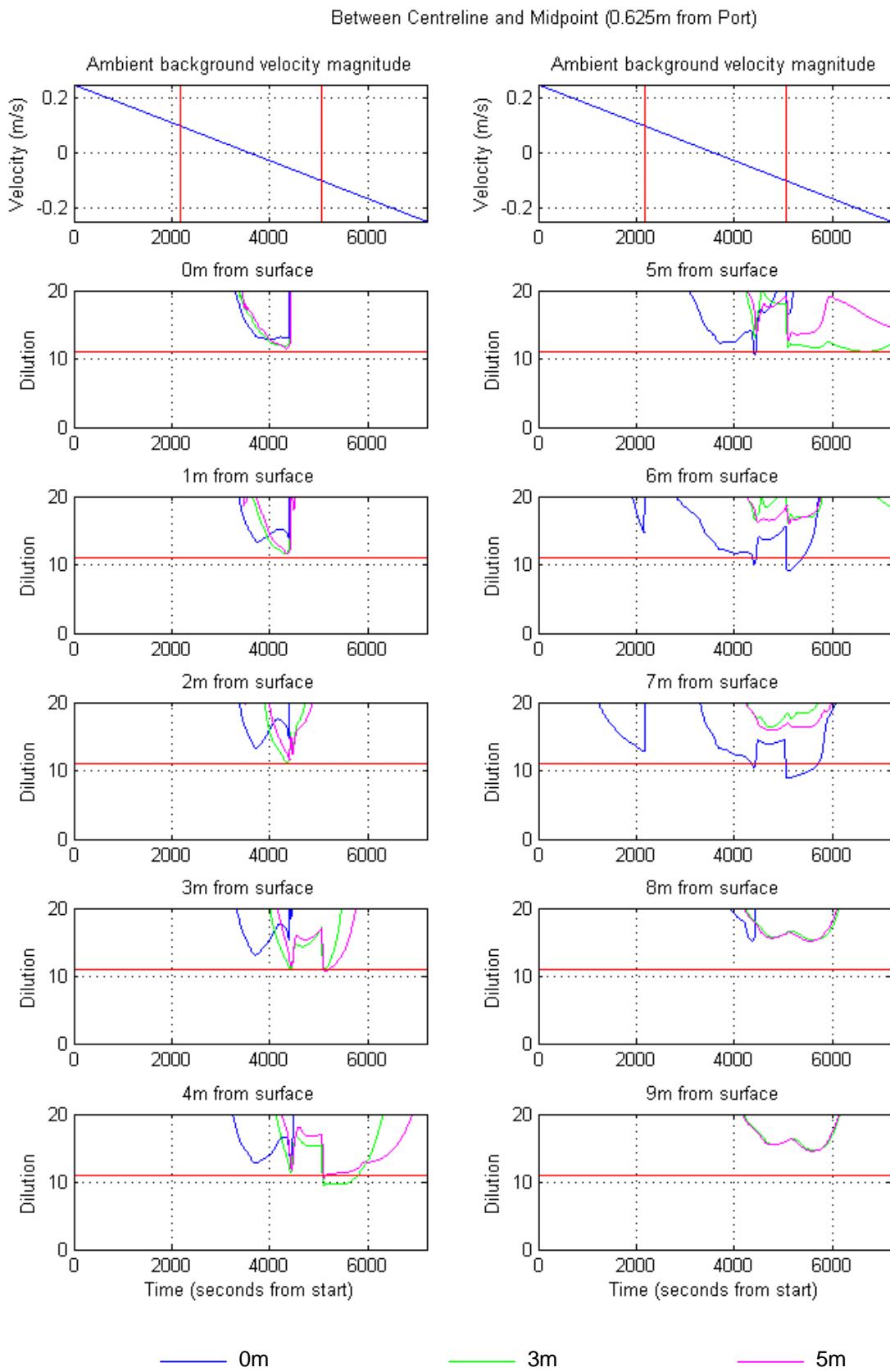


Figure 7-21 Tracer Dilutions – 0.625 m from Port

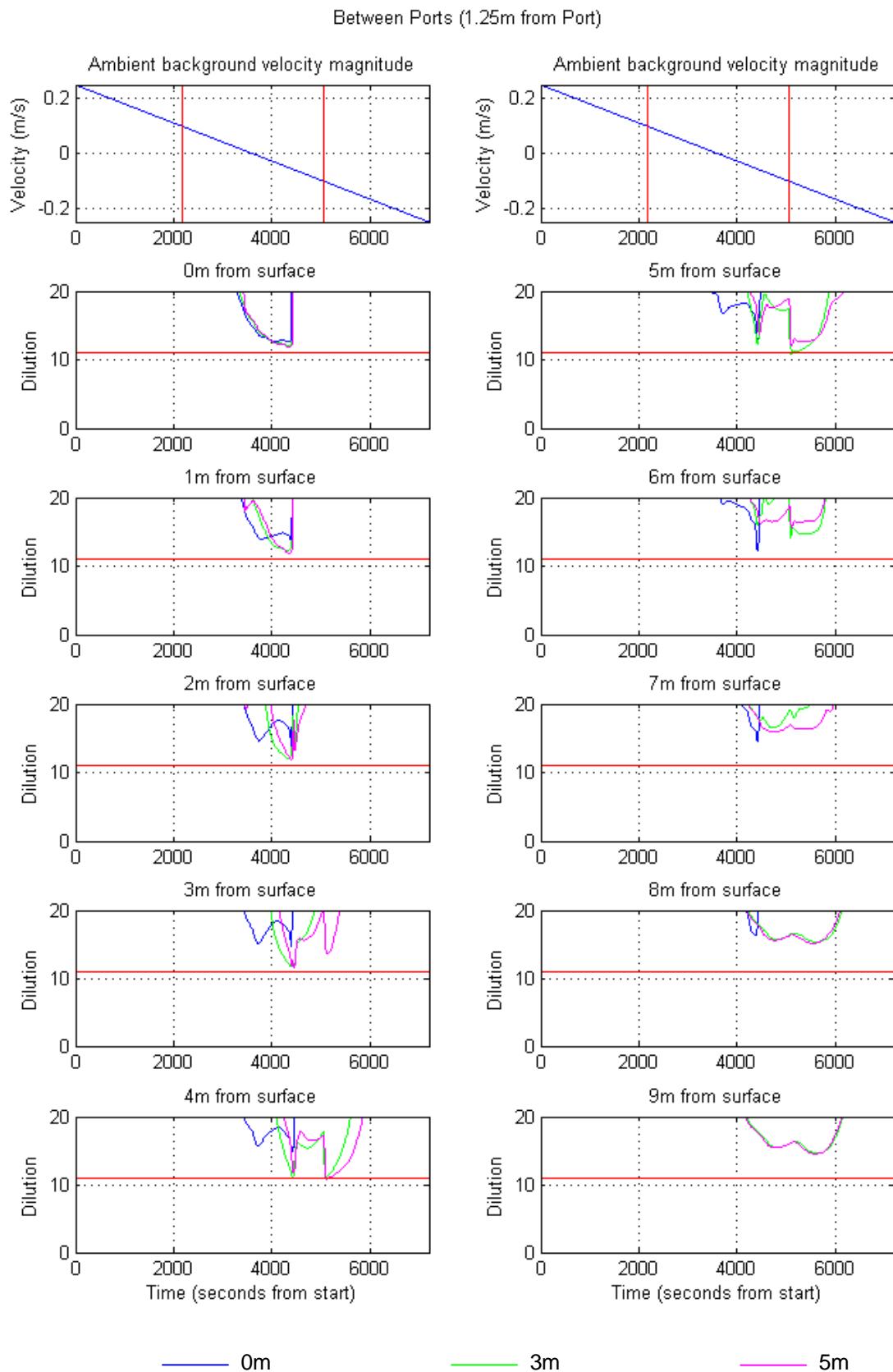


Figure 7-22 Tracer Dilutions – 1.25 m from Port

7.3.3 Discussion

Careful interpretation of the results is required, particularly in light of the information revealed by the dynamic CFD modelling. Key points are as follows.

- Peak concentrations (minimum dilutions) predicted by the dynamic and steady state CFD modelling occur primarily in the core of the effluent plume. Importantly, these lower dilutions are not representative of bulk (or even ‘typical’) downstream concentrations: they are the highest expected concentrations at any time, and only occupy the very central core of each diffuser port plume. As such, they should not be interpreted as characteristic concentrations, and the corresponding computed distances downstream to achieve WQOs do not apply to the entire diffuser length, or water depth;
- Dilutions below 11:1 occur at specific heights in the water column, and persist for very short periods of time. For example, the longest time for which the dilution falls below this level at 3 m from the diffuser (and directly downstream of the port as per Figure 7-20) is approximately 1,000 seconds, or 16 minutes, and this occurs only at 4 m from the water surface. Typically, these lower dilutions are short lived and are not generally reflective of typical downstream dilutions;
- Extending the above, the CFD modelling has shown that the individual plumes (of which the central cores are a subset) occupy a small fraction of the total cross-sectional flow area, even at very short distances downstream of the exit point;

Concentration peaks do not occur during slack flow periods, at least at 3 m away from the diffuser. The highest tracer concentration observed at the plume centreline location during discharge at 20:1 dilution is 0.093, i.e. almost 11:1 dilution, and this occurs only for a few minutes at a specific height in the water column. Referring to The dynamic near field simulations were used to combine with the far field results, and these dynamic simulations included a doubling of discharge dilutions for tidal velocities less than 0.1 m/s. Based on the above tabulated far field concentrations, resultant target dilutions for the near field simulations have been computed, with these dilutions (and greater) indicating compliance with chronic water quality objectives. These target dilutions for Stage 1 are presented below to the nearest integer value, with the corresponding tracer concentrations included.

- Table 7-3, this dilution is in the vicinity of the maximum required to meet WQOs for Stage 1. The reason for this high dilution is that at these low background velocities, the jet from the port mixes well with the entire water column under the influence of the ejected plume momentum. The results show also that some large scale recirculation occurs during these times as tracer signals appear 3m from the diffuser at the time when the ambient velocity approximates 0 ms^{-1} . This large scale eddying was predicted qualitatively by CORMIX;
- Overall concentration peaks occur only in the core of the effluent plumes following increase in ambient velocities, and ejected tracer concentrations. These core concentrations occupy a very small fraction of the water column cross-sectional area;
- The recommencement of discharge at 10:1 dilution following slack water is clearly visible in the results at approximately $t=5,000$ seconds; and
- The CFD modelling was set to have almost zero background (ambient flow) turbulence, with a relatively smooth bottom surface. In reality, there will be considerable background turbulence generated both naturally and as a result of flow interaction with existing infrastructure such as the

RG Tanner approach wharf piles. As such, the CFD modelling has, if anything, under-predicted the capability of the background flow to further mix the plume and dilute the discharged effluent, and as such has overestimated centreline concentrations.

8 PROPOSED CONFIGURATION – STAGE 2

The proposed configuration for Stage 2 comprises two cross current diffusers discharging a total discharge double that of Stage 1 and located as per Figure 7-1. The model setup and results for both the near and far field are described below.

8.1 Near Field Model

8.1.1 Inputs

No additional CFD simulations were executed for Stage 2 as the two proposed diffusers are the same, and it is thus expected that the near field dynamics will be similar for both. Refer to Figure 7-1 for location of the two diffusers. Figure 8-1 shows the existing cross section at the proposed Diffuser 2 location.

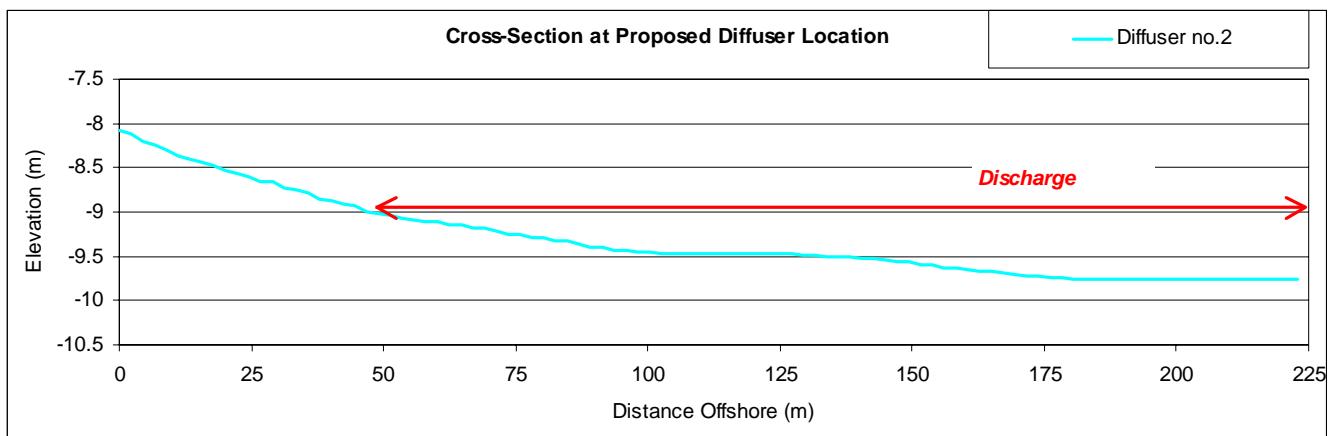


Figure 8-1 Cross Section of the Water Depth for Diffuser Pipeline – Stage 2

Discharge water quality, existing ambient concentrations and water quality objectives (Chronic Toxicity Trigger Values) were not modified. Refer to previous sections for details.

8.1.2 Results

No new results exist for Stage 2 near field, but the target dilutions change slightly based on increases in the likely far field long term average constituent concentrations. These are shown in Table 8-1.

Table 8-1 Target Dilutions and Tracer Concentrations – Stage 2

Constituent	Chronic Toxicity Trigger Value (ug/L)	Dilution Required	Target Tracer Concentration
Nickel	7	10	0.10
Cobalt	1	13	0.08
Manganese	140	8	0.12
Cadmium	0.2	13	0.08
Chromium 3+	27.4	10	0.10
Chromium 6+	4.4	12	0.08
Zinc	15	0	3.71

8.2 Far Field Model

Within the model, three elements along each diffuser line were assigned an inflow accompanied by a tracer (see Figure 7-12). As per the near field modelling, the total inflow over the two diffuser lines was 34,200 m³/hr (ie 17,100 m³/hr per diffuser line). The tracer was assigned a half-life transformation rate of 10 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, concentration contours, averages and time series are presented only for the zero decay rate simulation results. These results do not apply for manganese, as it is subject to a 10 day half life rate. Specific results for manganese are only reported in the pollutant concentrations tables.

8.2.1 Spatial and Temporal Concentrations at Steady State

The spatial extent of the tracer covers a large proportion of Port Curtis. The 6hrly maximum concentration (approximately 0.1%) was found in the immediate vicinity of the diffusers. The 12hrly maximums were slightly smaller than the 6hrly concentrations, with a value of approximately 0.07% close to the diffusers. The extent was similar in both cases. Concentrations of less than 0.02% extend across the wider receiving waters in Stage 2.

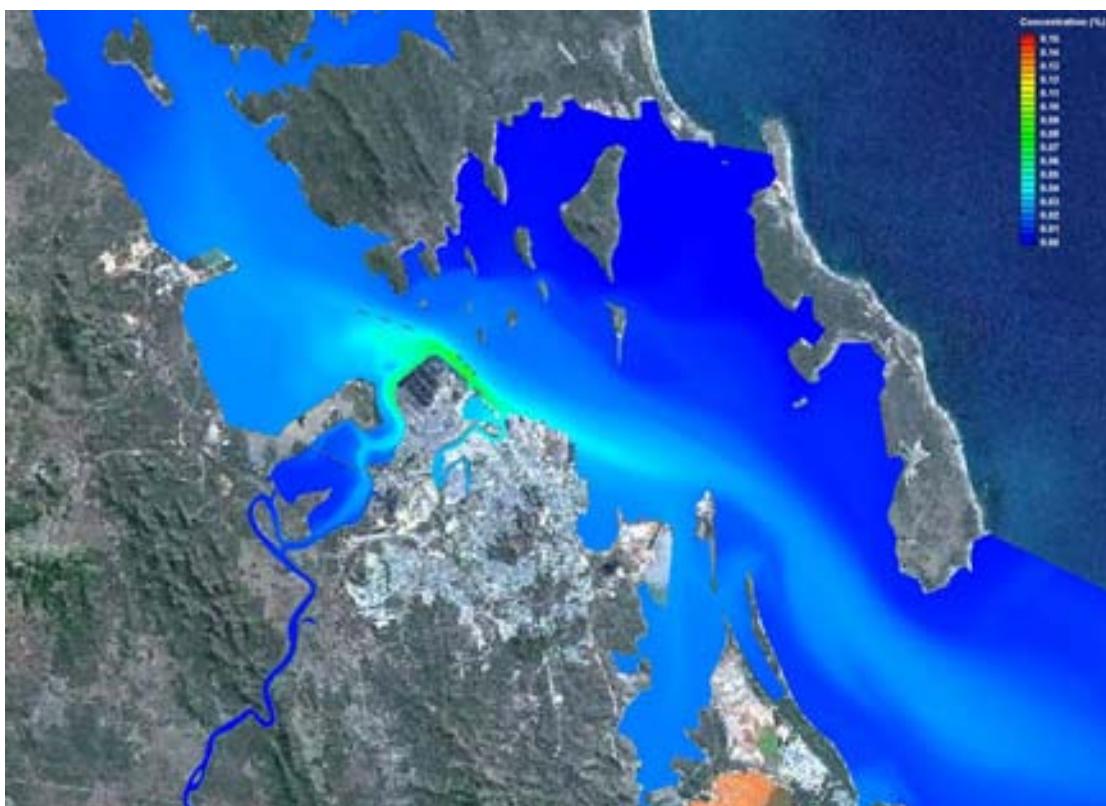


Figure 8-2 6hrly Maximum Concentrations of the Tracer in Port Curtis – Stage 2

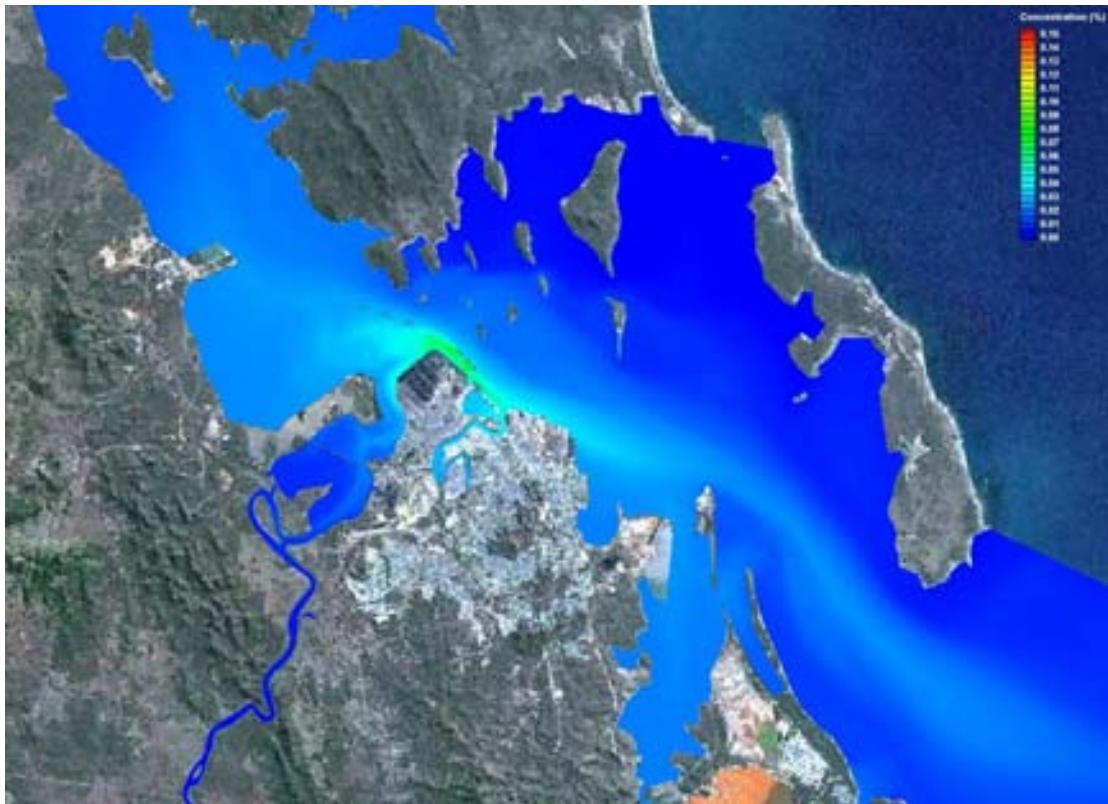


Figure 8-3 12hrly Maximum Concentrations of the Tracer in Port Curtis – Stage 2

The time series data (Figure 8-4) 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 7-15 for location of the 16 far field time series extractions.

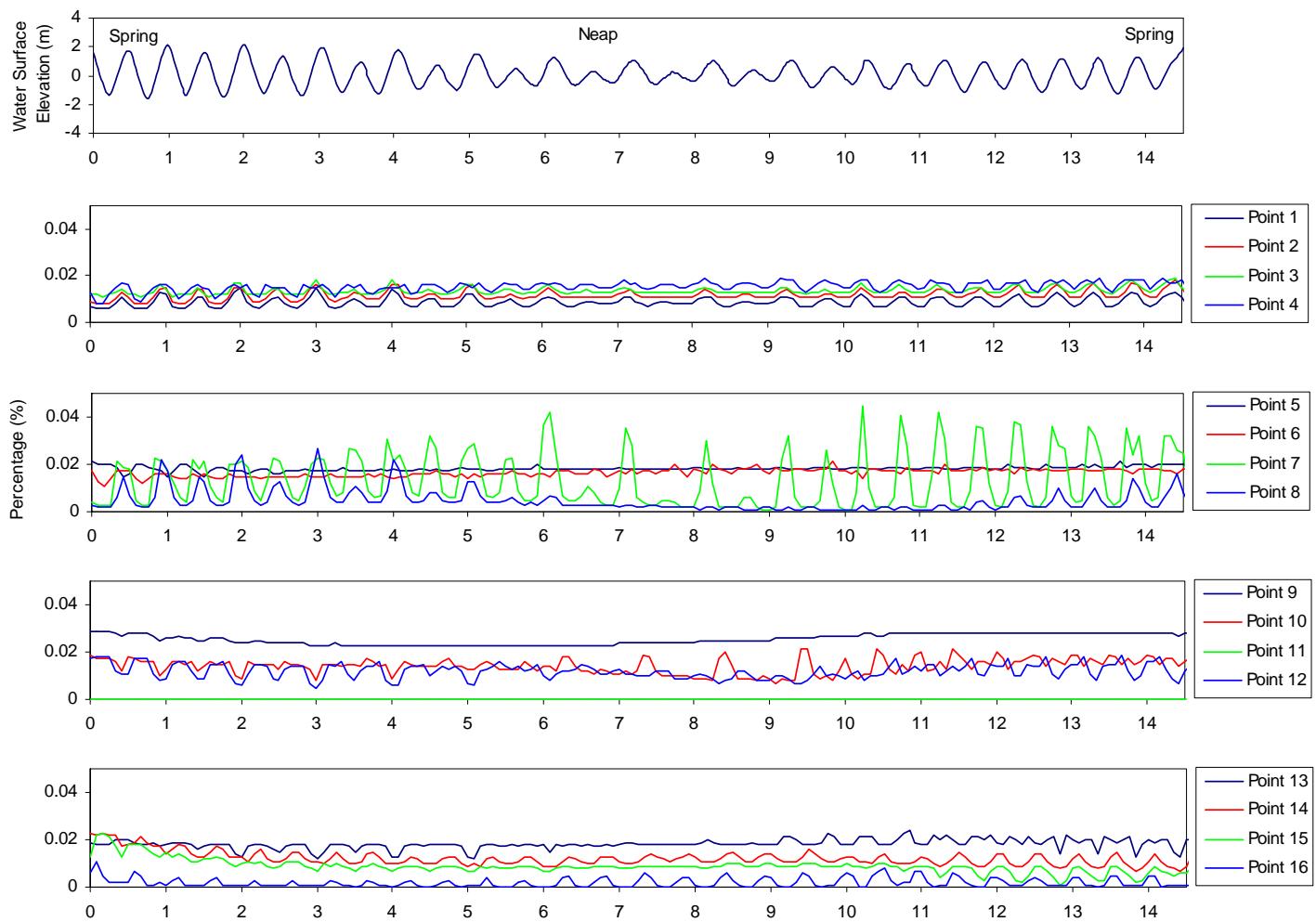


Figure 8-4 Time series of Concentrations at 16 Locations Within Port Curtis – Stage 2

Data extracted from the 16 far field locations shows that the highest concentration of the tracer was found in the Calliope River (Point 7), with a concentration of 0.039% fro the 10 day manganese half life rate and 0.047% for the zero decay rate. These values have been used in Section 8.3 to calculate the percentages of pollutants likely to be present at this location.

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 7-15 for location of the 16 points). The marina had the highest mean concentration, at steady state, with a value at 0.027%. It should however be noted that the marina is an artificial environment. The second highest mean concentration was situated at location 5.

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

Location	Average Concentration at steady state
1	0.011
2	0.014
3	0.016
4	0.017
5	0.020
6	0.017
7	0.014
8	0.005
9	0.027
10	0.015
11	0.000
12	0.012
13	0.018
14	0.011
15	0.008
16	0.002

8.3 Stage 2 Pollutant Concentrations

8.3.1 Far Field Only

Table 8-3 Maximum Far Field (Only) Pollutant Concentrations Over Entire Domain – Stage 2

Constituent	Ambient Concentration (ug/L)	Barren Liquor (ug/L)	Discharge Concentration (ug/L)	Maximum Additional Far Field Concentration (ug/L)	Total Maximum Far Field Concentration (ug/L)	Chronic Toxicity Trigger Value (ug/L)
Nickel	0.5	560	56	0.027	0.53	7
Cobalt	0.1	100	10	0.005	0.10	1
Manganese	7.6	10000	1007	0.473	8.1	140
Cadmium	0.02	20	2	0.001	0.02	0.2
Chromium 3+	0.15	2500	250	0.118	0.27	27.4
Chromium 6+	0.15	440	44	0.021	0.17	4.4
Zinc	0.5	40	4	0.002	0.50	15
Iron	90	3000	381	0.179	90.2	n/a
Aluminium	73	2000	266	0.125	73.1	n/a
Magnesium	1290000	17900000	2952249	1388	1291388	n/a
Calcium	411000	670000	437085	205	411205	n/a
Chloride	19400000	12080000		see note 1		n/a
Sulfate	2688000	66400000	9063033	4260	2692260	n/a

Note 1: The Chloride discharge concentration is below the background receiving water concentration. This means that the discharge and dilution of this constituent into Port Curtis will, to a certain extent, reduce ambient salinity. In addition, no chronic trigger value was provided for this constituent. Hence, the Chloride maximum concentrations downstream of the diffusers have not been reported in the results tables.

8.3.2 Near Field

Similarly to the methodology for Stage 1, the timeseries figures from the dynamic CFD simulations are reproduced with the example target dilution increased from 11:1 to 13:1. These are shown below.

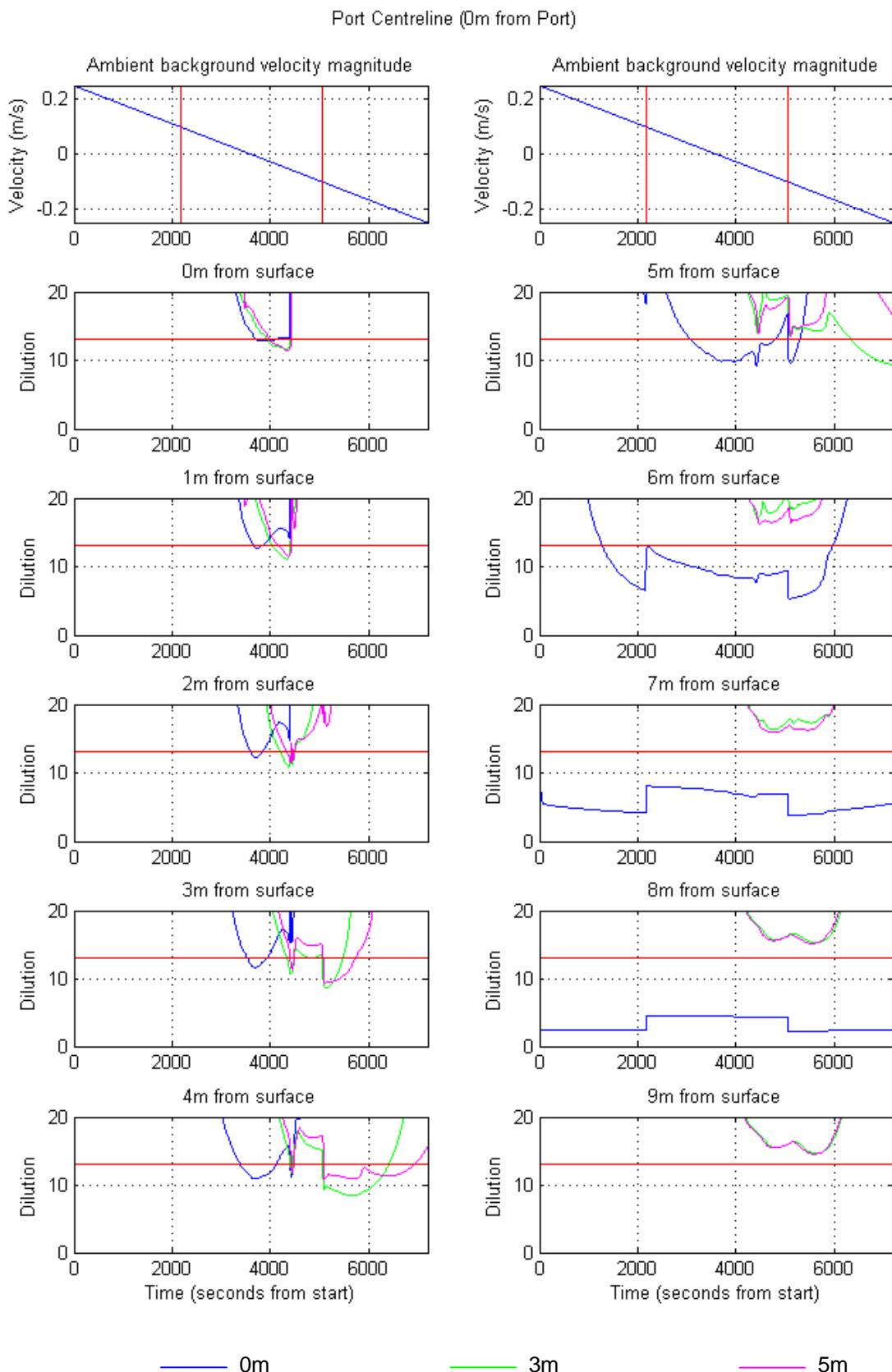


Figure 8-5 Tracer Dilutions – 0 m from Port

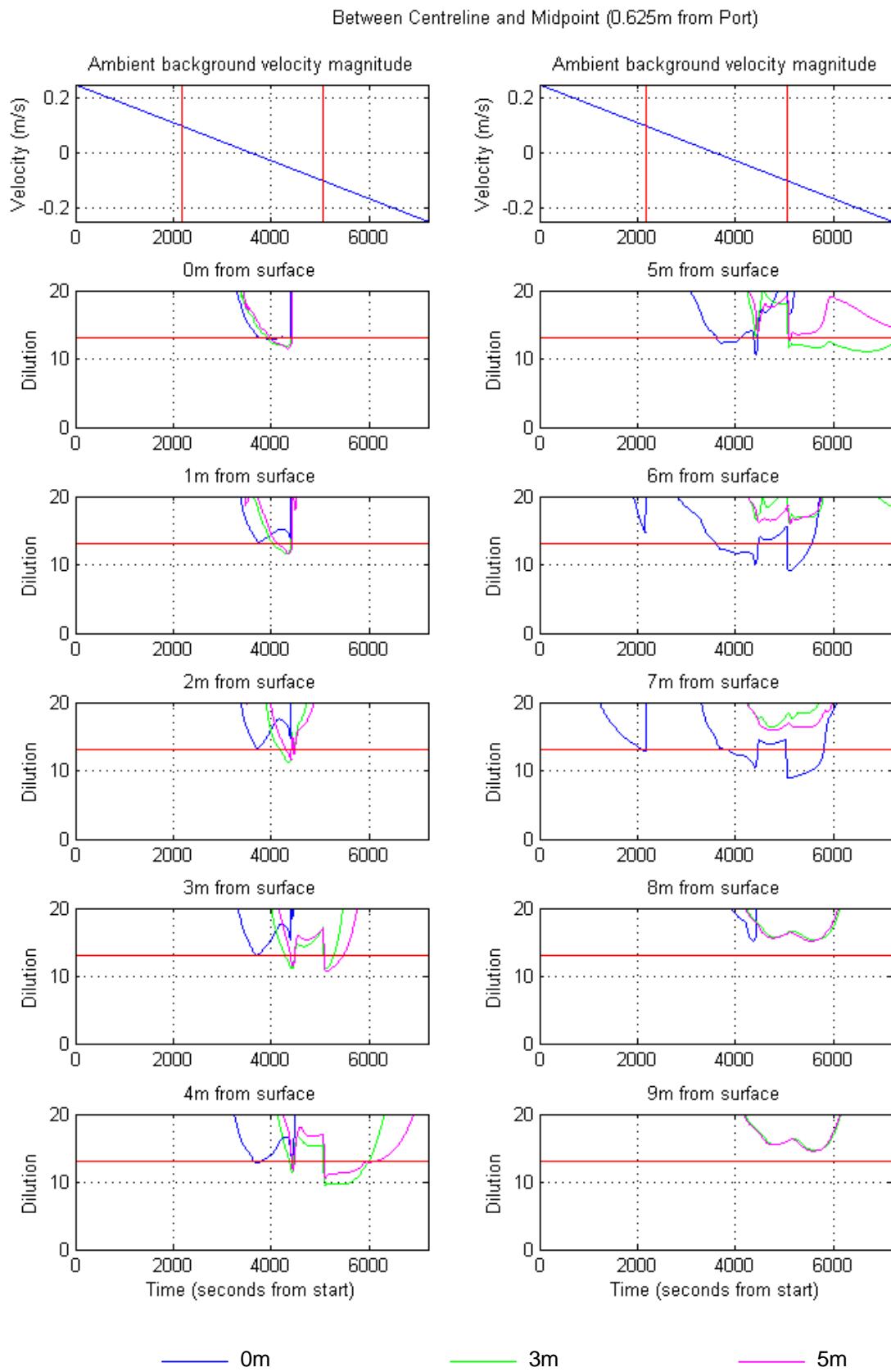


Figure 8-6 Tracer Dilutions – 0.625 m from Port

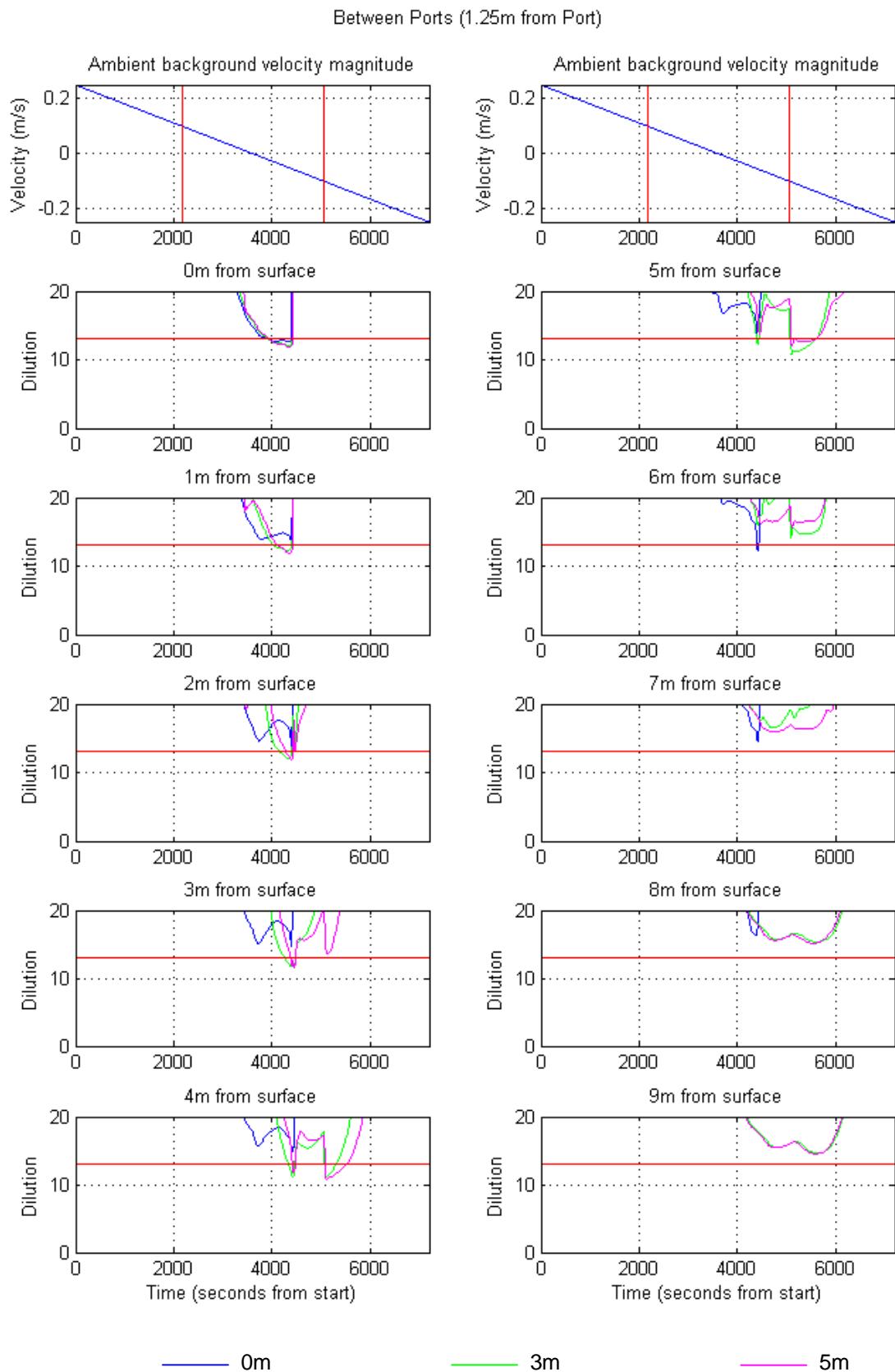


Figure 8-7 Tracer Dilutions – 1.25 m from Port

8.3.3 Discussion

Key points that should be considered when interpreting the results are similar to those for Stage 1 (Refer to Section 7.3.3). Importantly, the results show that dilutions lower than the most stringent requirement still occur for relatively short periods of time, and at isolated heights in the water column.

In addition to the CFD simulations, we have re-interrogated the far field RMA results to qualitatively assess the likelihood of water that initially flows over the diffuser returning at subsequent tidal states. This return flow of all waters is an implicit assumption of the CFD modelling. This investigation has been undertaken by inserting numerical drogues into the RMA hydrodynamic results, and allowing these drogues to be advected by the ambient velocity field over several tidal cycles. Figure 8-8 shows the eventual paths of the numerical drogues. The drogues leave a trail indicating their paths. The first panel is the initial condition (i.e. drogues released over and between the diffusers), and the second panel shows the drogue paths after several tidal cycles.

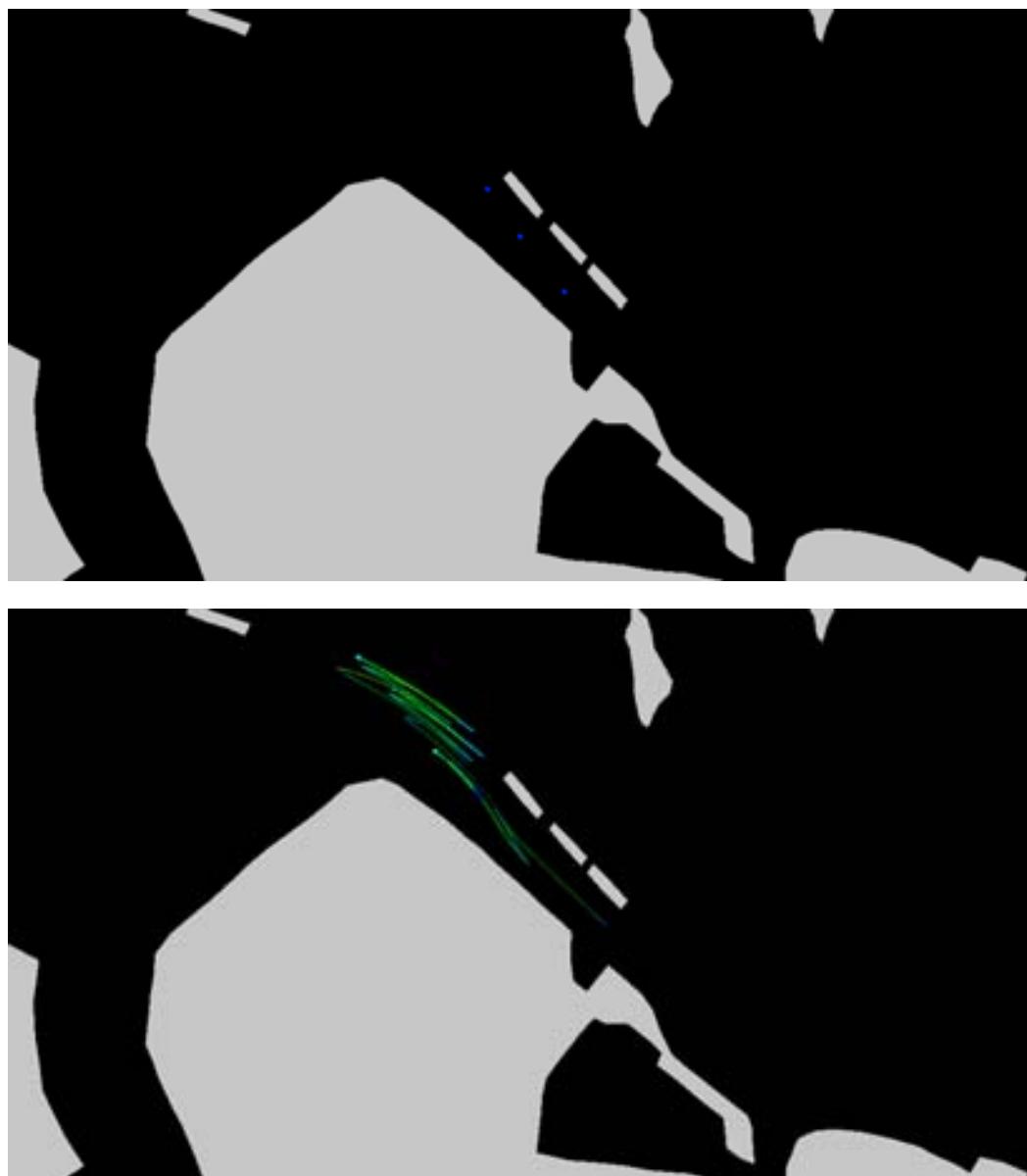


Figure 8-8 RMA Drogue Paths over Several Tidal Cycles

The figure shows that, at least over the period considered, the drogues generally leave the vicinity of the diffusers, and move out to more open waters at the entrance of the Calliope River, where they move back and forth. As such, the potential for return flow is limited to the extent that assuming 100% return flows of waters over each diffuser (as is the case in the CFD modelling) is likely to be a conservative assumption. It is also noted that by the time these drogues (and associated waters) reach this location, it is expected that the high 'core' concentrations from the discharged plumes will have dissipated.