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Sunshine Coast Airport Expansion Project EIS: Maroochy River Modelling Development and Calibration for Surface Water Hydrology and Water Quality Assessments

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Sunshine Coast Airport Expansion Project EIS : Maroochy River Modelling Development and Calibration for Surface Water Hydrology and Water Quality Assessments

Prepared For:	Sunshine Coast Regional Council and Sunshine Coast Airport
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Title :	Sunshine Coast Airport Expansion Project: Maroochy River Modelling Development and Validation for Surface Water Hydrology and Water Quality Assessments
Author :	Ryan Shojinaga
Synopsis :	This report summarises the baseline model set-up and process of validation of the suite of modelling tools to be used for assessment of impacts on surface water hydrology and water quality from construction and operation of the airport expansion.

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1 INTRODUCTION

As part of the assessment of environmental impacts of the Sunshine Coast Airport Expansion Project (AEP), numerical models were developed to characterise the surface water hydrology and receiving water quality. These models facilitated description of complex interactions of processes, including those not able to be measured directly for practical and logistical reasons, and were used as the key method of assessment of impacts of the proposed reclamation of the AEP at the airport and surrounds.

Two main modelling packages comprised this modelling suite:

- Hydrologic modelling (catchment inflows) was undertaken to quantify flows and sediment loads originating from upstream catchments of the Maroochy River. Development of a Source model (eWater CRC 2010) was performed to summarise hydrology and sediment input of the airport and surrounds and to inform a TUFLOW FV receiving water quality model.
- The TUFLOW FV model is a coupled 3D hydrodynamic (HD), advection-dispersion (AD), and sediment processes. TUFLOW FV handles both HD and AD components within a flexible mesh computational grid format.

Figure 1-1 presents a process diagram of this modelling suite, including the input/output and general flow of the work.

These models have been applied and verified as reliable for the purpose of impact assessment by BMT WBM on several other major studies involving catchment and receiving water modelling, including:

- Caloundra South Public Environmental Review;
- The Hawkesbury-Nepean River in NSW; and
- Townsville Port Expansion Project.

Formal calibration/validation of the numerical modelling system (TUFLOW FV and Source) was undertaken as part of the EIS study and is described herein.

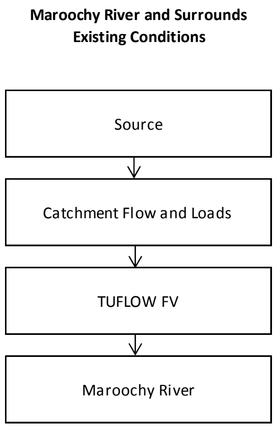


Figure 1-1 Surface Water Modelling Tools Suite and Processes

2 MODEL DEVELOPMENT

2.1 Source (Catchment) Model

Source was used in this study to define catchment derived daily flows of water and associated loads of diffuse pollutants (sediments) entering the Maroochy River estuary system from upstream catchments. Catchment inflows are an important aspect of estuarine hydrology and water quality.

Source was developed by the eWater CRC (www.ewater.com.au), a federally funded Cooperative Research Centre combining Australia's pre-eminent research organisations, State Government water regulators and industry practitioners. The model's 'pedigree' stretches back some 10 years, and is based on the original Environmental Management Support System (or EMSS) developed for the SEQ Healthy Waterways Partnership (HWP) to define diffuse loads to Moreton Bay and other South East Queensland (SEQ) waterways.

The Source model used in this modelling suite was originally developed from a whole-of-SEQ catchment modelling study (BMT WBM 2010a). The model parameters and inputs used are discussed briefly here.

2.1.1 Catchment Map

The catchment map uses for this EIS has been developed over several years as a base of the SEQ region in our role as a key service provider to the HWP. The catchment map defining the topographical boundaries and preferential travel routes are shown in Figure 2-1. The total catchment area is approximately 620 km2. Figure 2-1 also shows the gauges to which the flows predicted by the catchment model were validated.

2.1.2 Land Use

Land used in the Source model represents the most recent (2006) regional land use mapping data for the Maroochy River catchment developed by DEHP. This data was classified by functional units for the purpose of catchment modelling for efficiency as similar land use designations have similar hydrologic and pollutant export characteristics. The functional units for the entire catchment are illustrated in Figure 2-2. Summary of these functional units is also provided in Table 2-1 in terms of gauge catchment areas (see Figure 2-1).

Table 2-1 Maroochy Catchment Functional Unit Areas

Functional Unit	141003C	141008A	141009A	Total
Broadacre Agriculture	4.7	2.2	5.6	12.5
Dense Urban	2.8	5.3	0.5	8.6
Green Space	92.8	33.6	35.0	161.4
Grazing	122.1	56.2	46.0	224.2
Water	5.7	6.8	0.6	13.2
Intensive Agriculture	11.4	16.4	11.4	39.2
Rural Residential	30.1	26.4	43.5	100.0
Urban	25.5	30.7	2.3	58.5
Total	295.1	177.7	144.9	617.7

2.1.3 Rainfall and Evapotranspiration

Daily synoptic rainfall and potential evapotranspiration data sets across the entire catchment of the Maroochy River from the DEHP SILO database were used as daily and regional climate data inputs to the catchment model. These data encompassed the period from 1950 to 2011.

2.1.4 Hydrologic Parameterisation

The hydrologic model used in the Source model was the SIMHYD conceptual model, a lumped daily rainfall-runoff model with several hydrologic parameters characterising, for example, infiltration, baseflow, and areas of perviousness. The hydrologic parameterisation of the Source model was performed with the initial whole-of-catchment SEQ model (BMT WBM 2010a). Figure 2-1 presents the gauges to which Source modelled flows were validated against, and it shows the regions defined by those gauges. Table 2-2 presents an example of the parameterisation of the gauge/area for gauge 141003C.

Table 2-2 Maroochy Hydrologic Parameterisation for Region Around Gauge 141003C

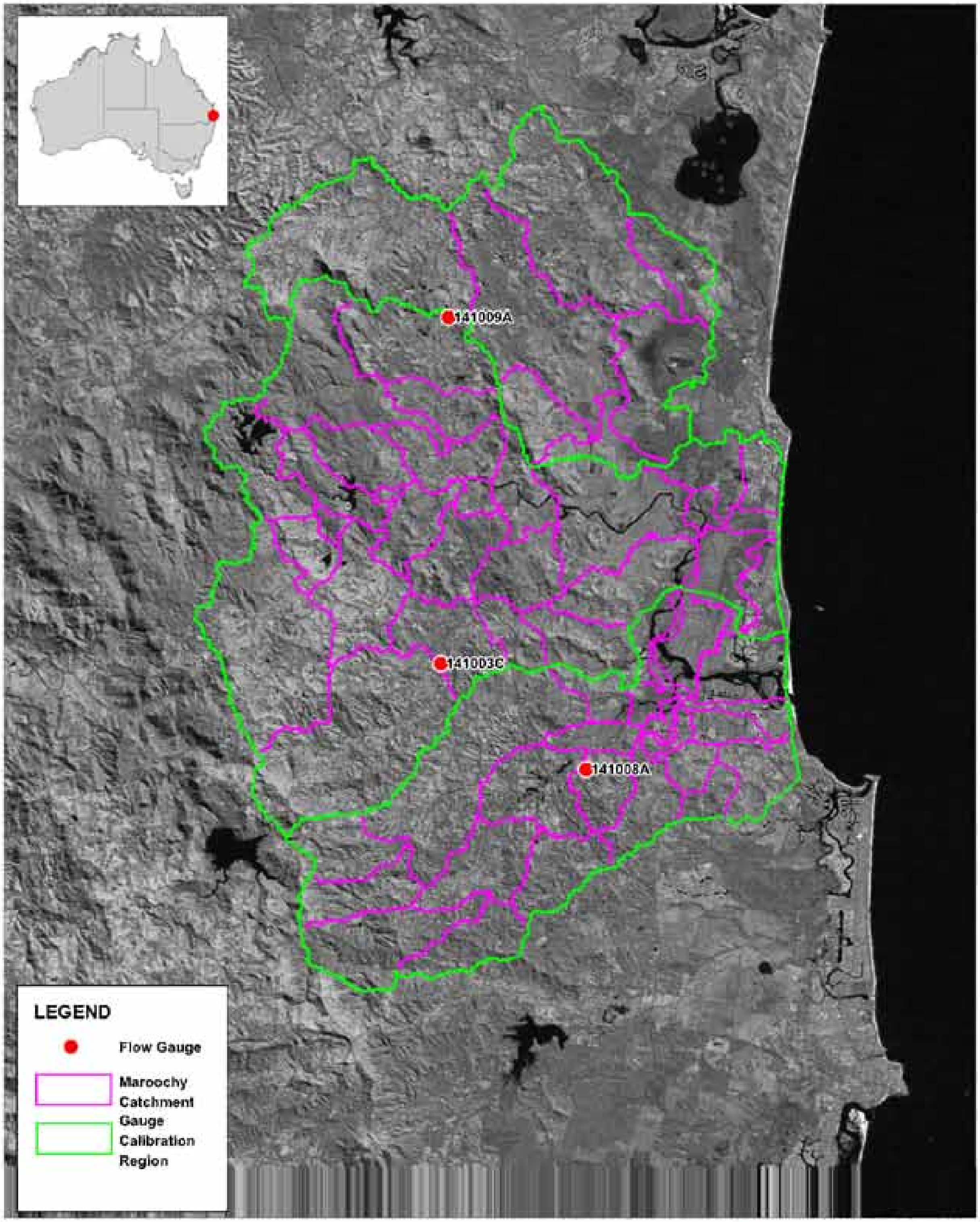
Functional Unit	Broadacre Ag.	Grazing	Green Space	Intensive Ag.	Rural Residential	Urban and Dense Urban
Baseflow	0.26	0.26	0.06	0.26	0.30	0.06
Impervious Threshold	1.00	1.00	1.00	1.00	1.00	0.61
Infiltration Coefficient	209	209	269	209	199	108
Inlfiltration Shape	2.20	2.20	2.31	2.20	1.48	1.64
Interflow Coefficient	0.19	0.19	0.99	0.19	0.35	1.00
Pervious Fraction	1.00	1.00	1.00	1.00	0.87	0.99
Recharge Coefficient	0.21	0.21	1.00	0.21	0.69	1.00
Interception Storage (mm)	1.74	1.74	5.00	1.74	2.04	5.00
Soil Moisture Storage (mm)	105	105	426	105	198	350

2.1.5 Pollutant Export Rates

Water quality parameterisation (pollutant export rates) used in Source for this study consisted of Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) export process. Literature values were used to derive and allocate EMC/DWC values for each land use represented by the model and these were applied across the entire catchment area. The data used were based on Chiew and Scanlon (2002) but updated through several sources including SEQWater, DERM and WBM as discussed in the original study (BMT WBM 2010b). These values are presented in Table 2-3.

Table 2-3 Suspended Sediment Export Rates (mg/L)

Functional Unit	EMC	DWC
Broadacre Agriculture	10	300
Grazing	10	260
Green Space	7	20
Intensive Agriculture	10	550
Rural Residential	10	130
Urban and Dense Urban	7	130



Title:
Maroochy River Subcatchments

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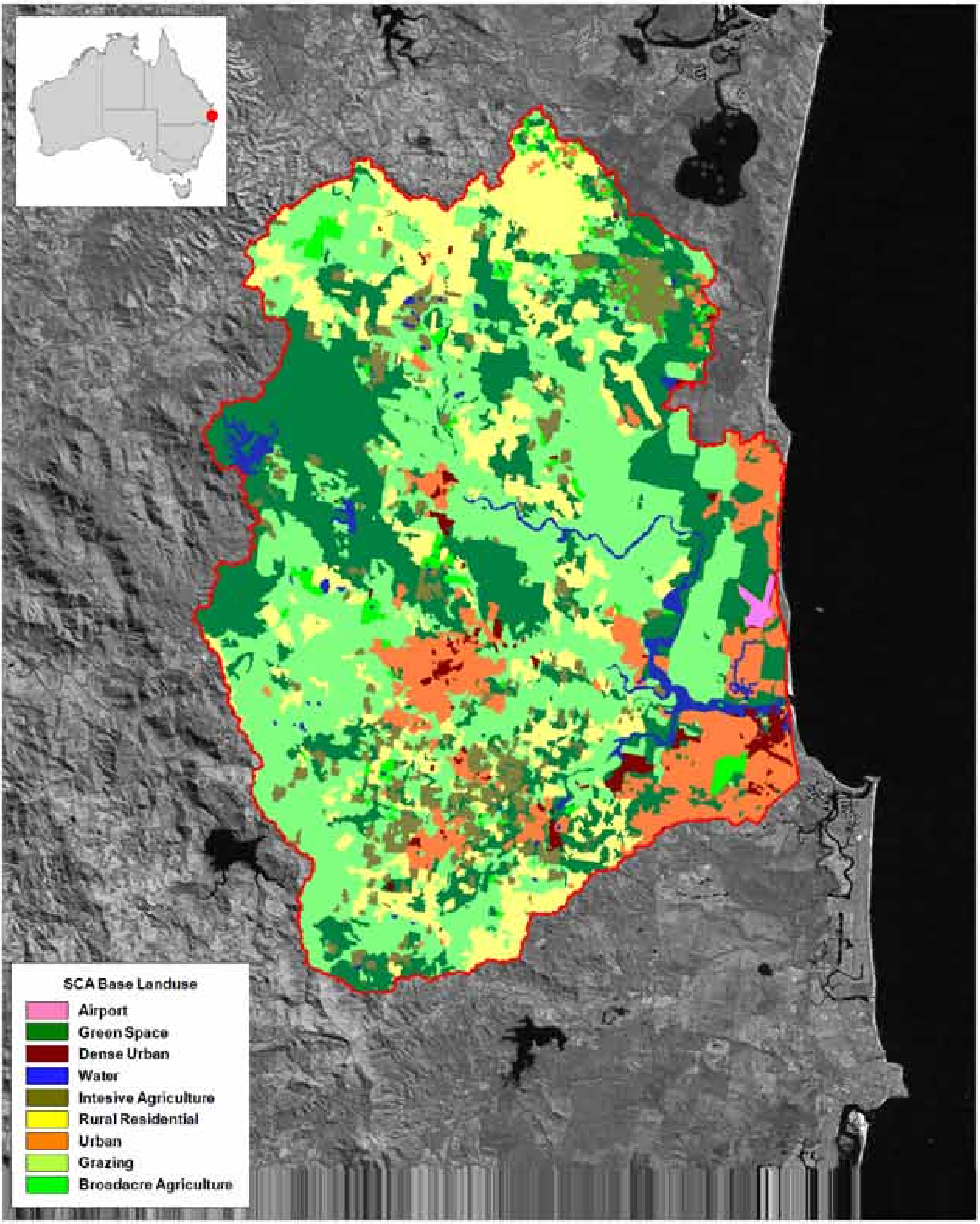

Title: **Maroochy River Functional Units**

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2.2 TUFLOW FV

TUFLOW FV, developed by BMT WBM, is a coupled 3D hydrodynamics (HD) and advection-dispersion (AD) model that adopts a flexible mesh to define the computational domain. A baroclinic model configuration with density coupling from salinity (see below) was applied in order to represent stratification processes. TUFLOW FV solves the Non-linear Shallow Water Equations (NLSWE) using a finite-volume numerical scheme (www.tuflow.com/Tuflow%20FV.aspx).

2.2.1 Model Domain and Mesh Definition

The extents of the model were defined from approximately 3-4km offshore of the Maroochy entrance to the approximate tidal limits in the Maroochy, Eudlo, Petrie and Coolum Creeks. Additionally the Marcoola Drain was included in the model up to 1.8 km from its entrance. The North Drain was also included in the assessment impacts scenarios. Finally, the model includes extensive intertidal and mangrove areas to account for estuarine storage during high tide events. The model mesh with is presented in Figure 2-3.

The flexible mesh specification of TUFLOW FV allowed for the implementation of variable spatial resolution within the model and afforded greater definition within the Maroochy River near the entrance of Marcoola Drain and the north drain. Model resolution was progressively reduced at increasing distance from the Marcoola Drain to improve computation efficiency.

2.2.2 Bathymetry

A critical component of the hydrodynamic model development and calibration is the construction of a sufficiently accurate Digital Elevation Model (DEM) of the study area. For the Maroochy River and surrounds modelling the following bathymetric data sources have been used with order of priority in the order presented:

- 2010 hydrographic survey data of the lower Maroochy River from the entrance up to approximately river kilometre 5.3;
- 2008 terrestrial LiDAR data to define the mangrove and intertidal areas. The terrestrial LiDAR was also important in establishing bathymetry and drainage patterns of the Marcoola Drain and the airport surrounds;
- 2001 hydrographic survey data of the Maroochy River for upstream areas not covered by the 2010 Maroochy River data;
- Mangroves areas were approximated and checked against the terrestrial LiDAR data. Mangroves exist predominantly in the Mean High Water Spring tidal range at from approximately 0.46 to 0.66 mAHD;
- Previous bathymetric (e.g., boating charts, older surveys) for any upstream areas not covered by one of the previously stated bathymetry dataset (e.g., Petrie, Paynter and Eudlo Creeks); and
- 2011 Sunshine Coast Bathymetric LiDAR, Queensland Government.

This bathymetry is presented in Figure 2-4.

2.2.3 Boundary Conditions

2.2.3.1 Tidal Boundary Conditions

Tidal forcing of the TUFLOW FV model was comprised of surface water elevations and salinities. The surface water elevations were obtained from harmonic constituents at the Mooloolaba standard port and were applied as a constant water level across the tidal boundary. Tidal levels were provided at every 30 minutes through the model updated tidal elevations at higher temporal resolution. TUFLOW FV assumes a linear variation of tidal values with time. Salinity was set at a constant 36psu across the entire boundary. This is consistent with typical oceanic values, and while seasonal variation may be observed, the variations have a negligible effect on water quality. The tidal boundary is shown in Figure 2-3.

2.2.3.2 Catchment inflows

Catchment inflows were estimated using the Source model as described previously. Catchment inflow locations are shown in Figure 2-3.

2.2.3.3 Sewage Treatment Plant inflows

Sewage Treatment Plant (STP) flows were input as boundary inflows to the model accounting for flows and sediment concentrations. Nutrients and other contaminants were not modelled within this study due to low levels of nitrogen, phosphorus and other constituents present in the entrained offshore water at the pump-out location. It is not anticipated these have the potential to degrade or otherwise impact Maroochy River water quality. There are three STP the discharges to the Maroochy River, the locations of which are shown in Figure 2-3:

- The Coolum STP;
- The combined Maroochydore and Nambour STPs; and
- The Suncoast STP.

Flows used in the model validation consist of the actual daily flows recorded for that time period (see Section 3.2), however, in order to represent flows consistently regardless of the timeframe modelled, mean monthly flows were calculated for each STP and divided into daily flows. No sediment quality data were available for these STP discharges, however, sediment concentrations of STPs is typically low. As such a mean value was used based on similarly sized STPs in SEQ for which data were available. Table 2-4 presents the flows and TSS concentrations of the Maroochy STPs.

Table 2-4 STP Flows and Sediment Concentrations

	Coolum STP	Maroochy and Nambour STP	Suncoast STP
TSS Concentration (mg/L)	5.00	5.00	2.43
Daily Average Flows (MLD)			
January	13.2	65.3	5.7
February	8.7	41.4	3.8
March	8.5	41.4	4.2
April	9.2	47.9	4.4
May	7.5	37.5	3.7
June	6.1	30.1	3.1
July	6.5	29.7	3.0
August	6.2	31.6	3.0
September	5.8	30.9	3.0
October	4.4	27.7	2.3
November	1.8	26.1	1.5
December	6.0	38.2	3.3

2.2.3.4 Atmospheric

Atmospheric forcing was not incorporated into the modelling at the release of the water quality chapter due to technical issues regarding the incorporation of these conditions and model stability. While temperature and heat do influence the estuarine hydrodynamics, salinity is the predominant factor in driving three dimensional flows, and therefore is sufficient to characterise density forced baroclinic conditions in the model..

2.2.4 Initial Conditions

Initial conditions for salinity and TSS were established in the model by running the model for a warm-up period prior to the commencement of the baseline and impacts scenarios. Again, the model simulated TSS, from which turbidity was then calculated. The initial conditions were set at the EHMP values at the date closest to the commencement of the baseline and impacts assessment periods (see Section 3.2.2). The initial concentrations were input within a sufficiently large inflow at the locations of the EHMP sites and run for a week, which was sufficient to establish the initial conditions within the model.

2.2.5 Advection-Dispersion Model

Advection-dispersion is the mechanical and diffusive transport of constituents within the water column. The Smagorinsky diffusivity scheme was used in the TUFLOW FV model for advection-dispersion and the diffusivity coefficient used was 0.1 m^2/s.

The advection-dispersion validation (see Section 3.2.2) was achieved through assessing the recovery of salt in the estuary after medium and large freshwater inflows. The performance of the model was assessed by comparing the rate of recovery in the model to EHMP salinity data.

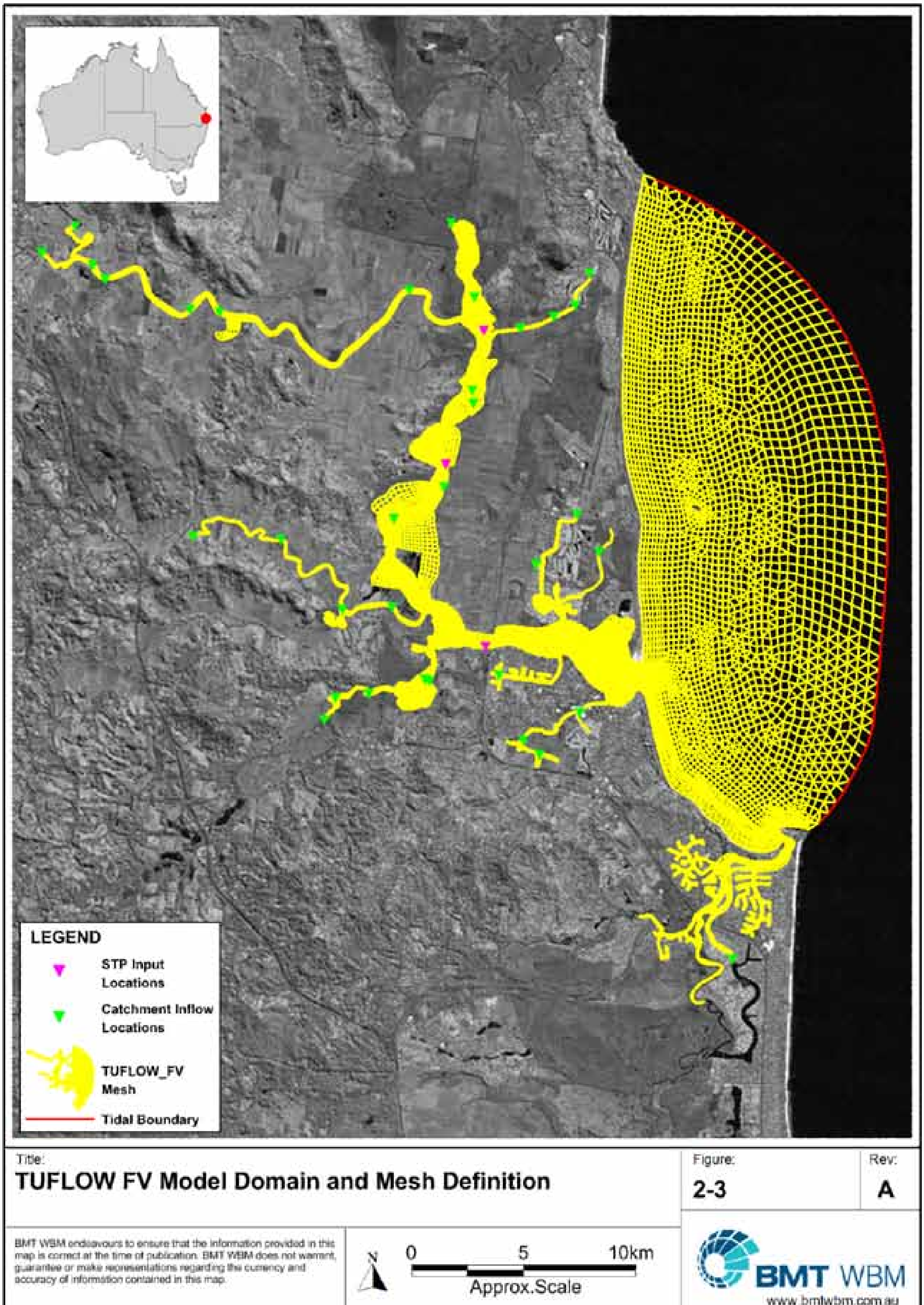
It should be noted that the initial validation demonstrated very slow recovery of salt in the estuary compared to the observed data. Investigation into where salt recovery was limited revealed the slow rate of recovery was the result of morphological features in the model bathymetry, e.g., sand bars or high points restricting flows upstream. Therefore, analysis was undertaken to determine the locations where salt recovery appeared limited by bathymetry and remove these shallow regions to enable a better flow of seawater upstream.

This is an appropriate measure to implement in the modelling because of the highly transient nature of sand within the estuary, especially lower in the estuary. While the AD validation was conducted over a period approximately concurrent with when the bathymetric data were collected (2010), the exact bed elevations over the period during which the model was validated are unknown.

2.2.6 Sediment Model

Catchment inflows carry associated sediment loads which are input into the TUFLOW FV model as a boundary condition. The sediment model within TUFLOW accounts for sediment primarily through settling of the sediment out of the water column. The slower the sediment settles, the longer higher concentrations persist in the water column resulting in generally higher turbidity in the water over time.

The TUFLOW FV sediment module was validated by adjusting the settling velocity of catchment sediments. The value used in the modelling was 0.3 m/d, which corresponds to a silt/clay in terms of particle size (Ferguson and Church 2004).



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TUFLOW FV Model Domain and Mesh Definition

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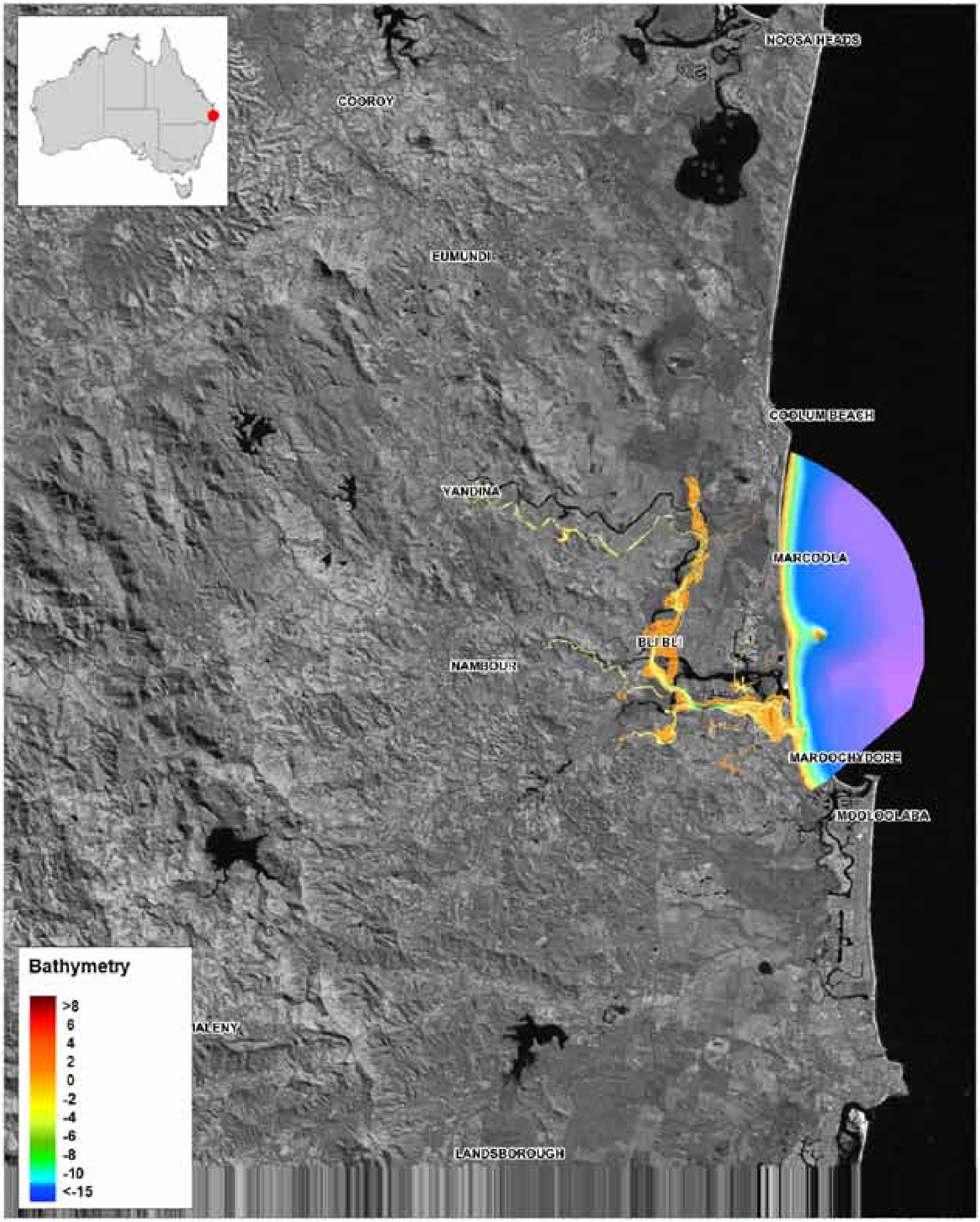

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Maroochy River 2010 Bathymetry

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3 MODEL VALIDATION

3.1 Catchment Model

Quantitative performance measures were used to provide lumped values of average errors in representing observed data. The statistical performance of the hydrological parameterisation process was measured through the following two performance statistics:

1. Nash-Sutcliffe efficiency (NSE) coefficient: The NSE coefficient is commonly used to assess the predictive power of hydrological models (Nash and Sutcliffe 1970). An efficiency of 1 corresponds to a perfect match of modelled flow rates to the observed data. An efficiency of 0 indicates that the model predictions are only as accurate as the mean of the observed data. An efficiency of less than 0 occurs when the observed mean is a better predictor than the model. The NSE coefficient were calculated on the daily and monthly flow volumes using the following equation (from Moriasi et al, 2007):

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2} \right]$$

2. Total volume percent bias (PBIAS): The average tendency of modelled data to be greater or less than the corresponding observed data. PBIAS is calculated on total modelled and observed volumes using the following equation (from Moriasi et al, 2007):

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim}) * (100)}{\sum_{i=1}^{n} (Y_i^{obs})} \right]$$

Table 3-1 summarises the performance of the hydrologic model based on these indicators for the gauge regions used in the validation. Table 3-2 provides some general guidance in assessing these indicators. It should be noted that the performance ratings are for monthly time step values, whereas the model was calibrated to daily and monthly values. Finally, for qualitative comparison, a representative time series plots of observed versus modelled flows

are presented in

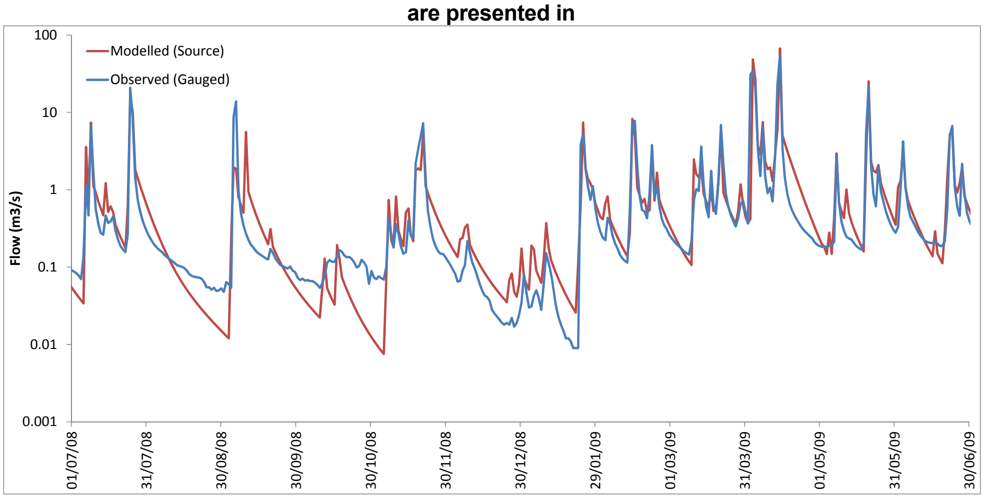


Figure 3-1 through Figure 3-3.

Table 3-1 Daily and Monthly NSE and Total Volume Validation Statistics

Calibration Statistic	North Maroochy 141009A	Petrie Creek 141003C	Eudlo Creek 141008A
Daily NSE	0.75	0.47	0.76
Monthly NSE	0.94	0.95	0.96
Tvol %	0.3%	3.6%	7.2%

Table 3-2 General Performance Ratings for Recommended Statistics for a Monthly Time Step (adapted from Moriasi et al 2007)

Performance Rating	PBIAS (%)	NSE
Very Good	PBIAS < ±10	0.75 < NSE ≤ 1
Good	±10 ≤ PBIAS < ±15	0.65 < NSE ≤ 0.75
Satisfactory	±15 ≤ PBIAS < ±25	0.5 < NSE ≤ 0.65
Unsatisfactory	PBIAS ≥ ±25	NSE ≤ 0.5

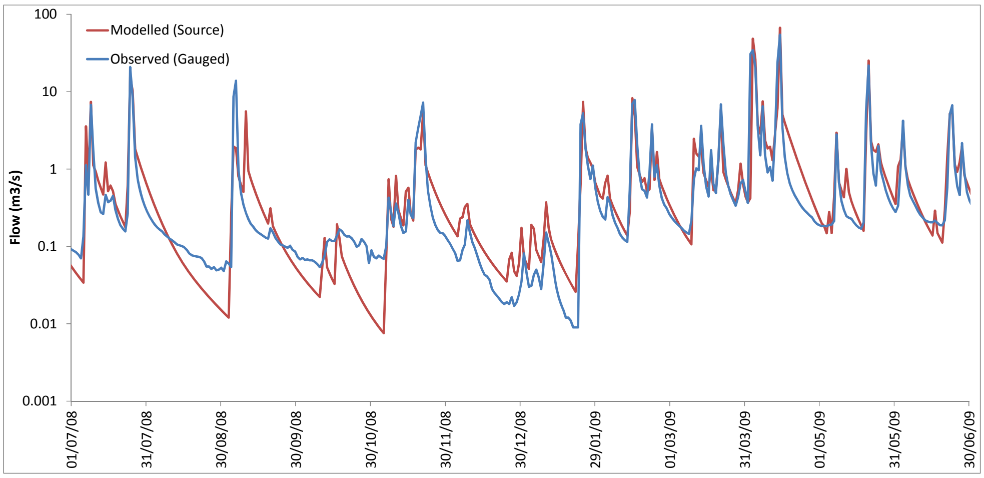


Figure 3-1 Gauge 141009A – North Maroochy River at Eumundi

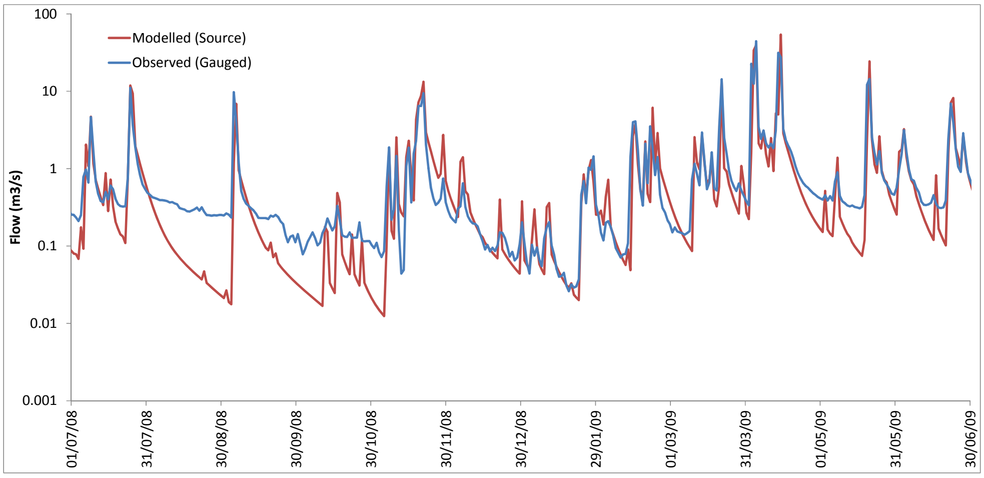


Figure 3-2 Gauge 141003C – Petrie Creek at Warana Bridge

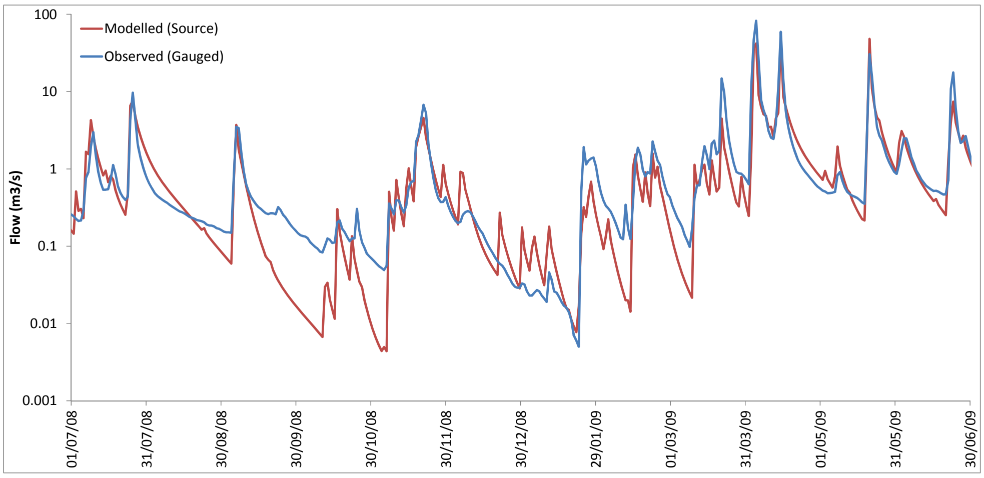


Figure 3-3 Gauge 141008A – Eudlo Creek at Kiels Mountain

3.2 TUFLOW FV Model

3.2.1 Hydrodynamic Model

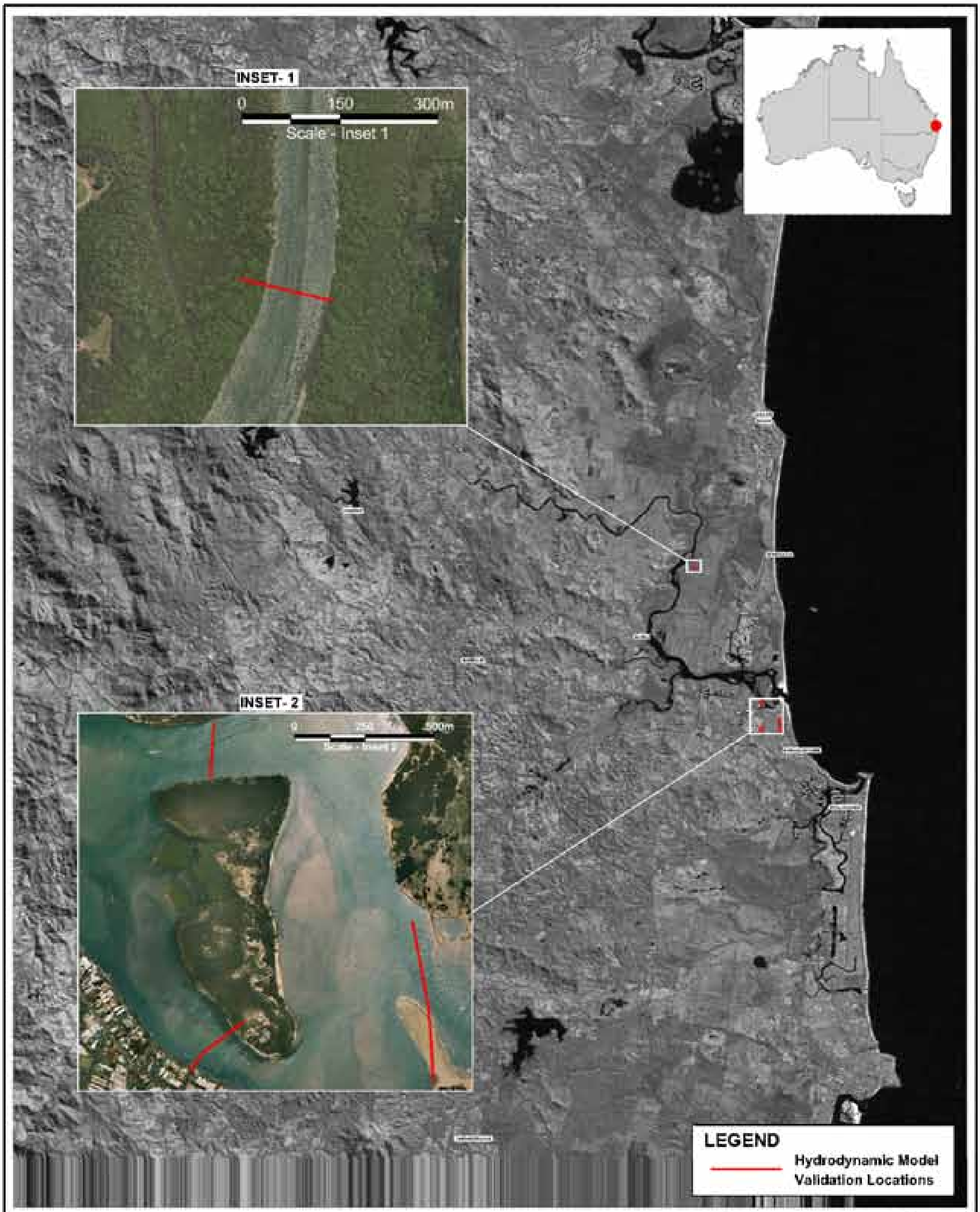
The hydrodynamic model was validated against water level and vessel mounted ADCP flow measurements collected in October 2012 expressly for the AEP. Water level measurements were collected at two locations, near the entrance and near the Marcoola Drain. Flow measurements were collected at four locations, three near the entrance of the Maroochy and one near the Marcoola Drain. Figure 3-4 shows the location of the hydrodynamic data collection sites.

Figure 3-5 shows comparison of modelled to observed water levels at the two locations, and Figure 3-6 shows comparison of modelled to observed flows at the four locations. The root mean square error (RMSE) of the two water level sites is less than ±0.1m. Table 3-3 presents performance statistics of the hydraulic model, suggest and overall satisfactory validation with the normalised error of flows at the entrance (including north and south channels) at 10% or less. This suggests that the overall flushing volume at the entrance of the estuary is simulated well within the model.

Table 3-3 Hydraulic (Flow) Model Performance: RMSE and NRMSE

Location	RMSE (m3/s)	NRMSE (%)
Entrance	62.6	7%
North	17.2	3%
South	28.8	10%
Upstream	2.8	23%

APPENDIX B6:A



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Hydrodynamic Model Validation Locations

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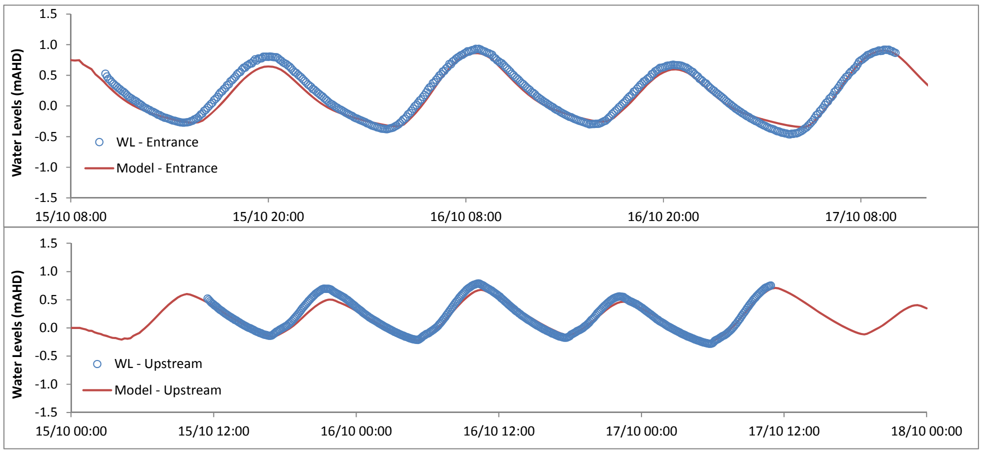

Figure 3-5 Model Validation Water Levels - October 2012; From the Top - Entrance, Upstream

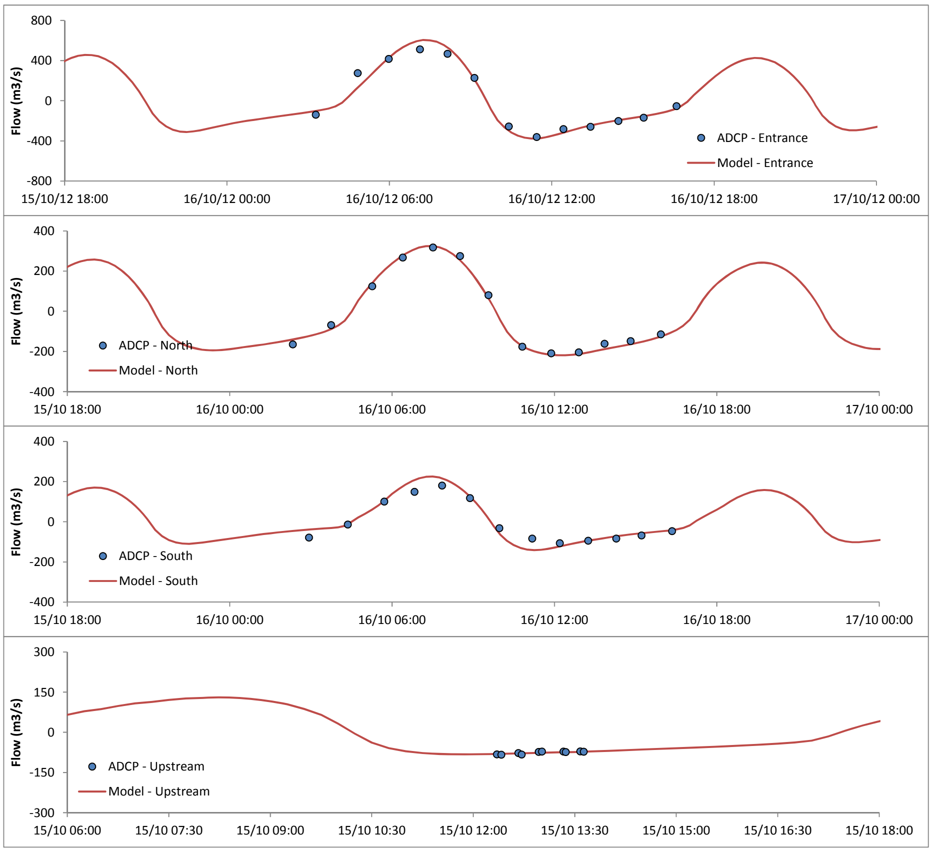

Figure 3-6 Hydrodynamic (Flow) Model Validation with ADCP Data - October 2012; From the Top - Entrance, North Channel, South Channel, and Upstream

3.2.2 Advection-Dispersion

Visual comparison of modelled and observed salt recovery values were used as the primary means of AD validation. For the AD calibration and validation two 1-year periods were selected to represent wet and dry conditions. The 01/07/2008 to 30/06/2009 period was chosen as the calibration period to represent recovery in wet conditions. The 01/07/2009 to 30/06/2010 was selected as the validation period to represent dry conditions. During the last half of 2009, there was an extended (6-month) period with little to no rainfall. Figure 3-7 shows salinity recovery plots at two EHMP locations for wet year (2008-2009), one in the lower estuary (E01501) and one at the Marcoola Drain (E01505). Figure 3-8 shows the same plots for 2009-2010.

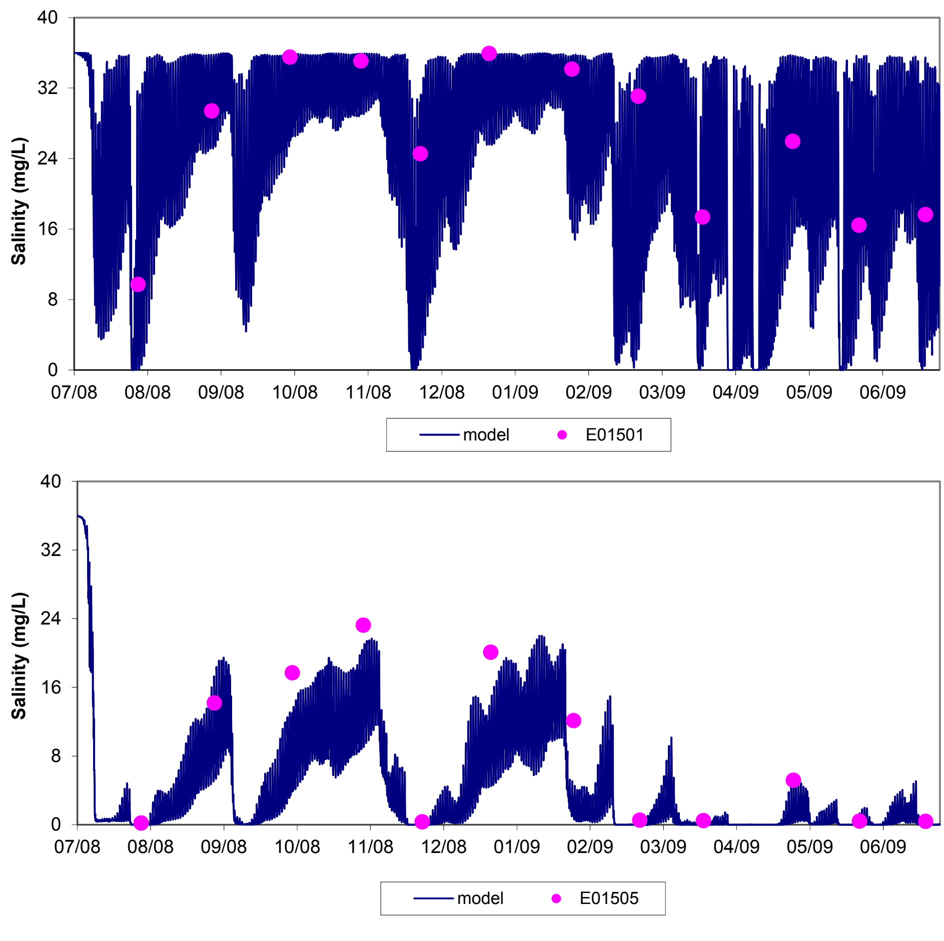

Figure 3-7 Salt Recovery Calibration Plots – 2008-09; Top – Lower Maroochy River (E01501); Bottom – Maroochy River at Marcoola Drain (E01505)

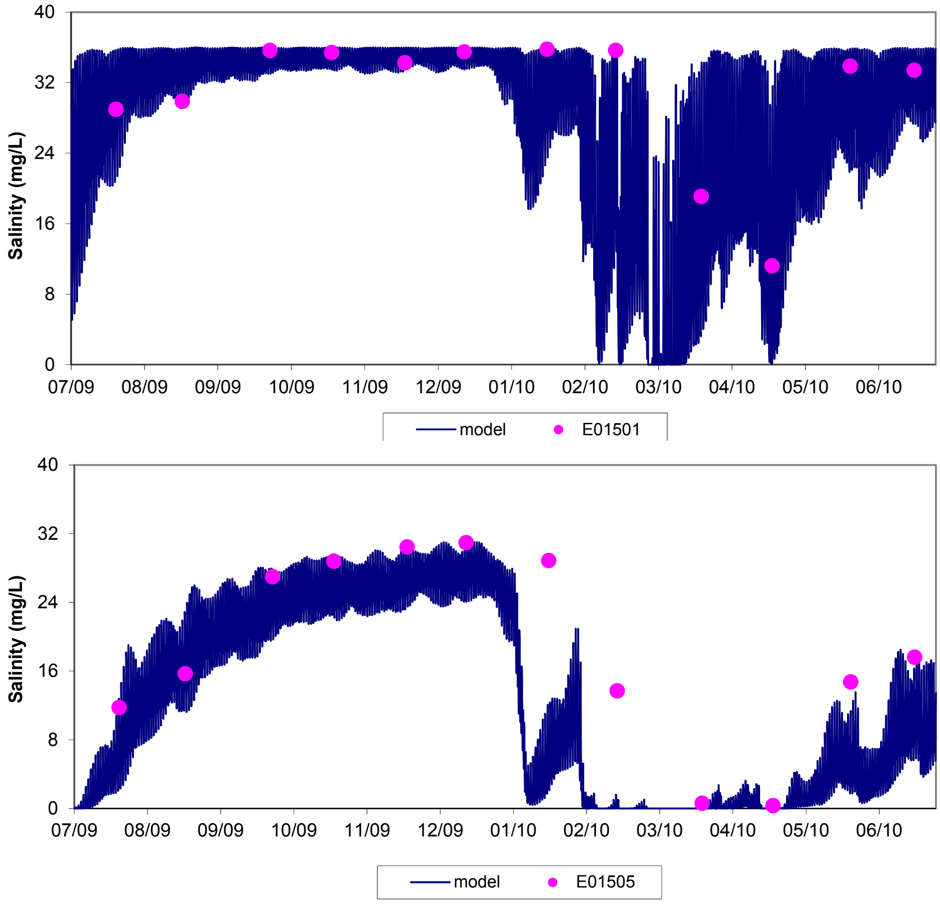

Figure 3-8 Salt Recovery Validation Plots – 2009-10; Top – Lower Maroochy River (E01501); Bottom – Maroochy River at Marcoola Drain (E01505)

3.2.3 Sediment Model

Similar to the AD calibration, the sediment module was validated against two year-long periods – wet (2008-2009) and dry (2009-2010). Figure 3-9 shows the turbidity levels for the wet year, and Figure 3-10 shows the turbidity level plots for the dry year. It should be noted that the model simulates sediments in the water column, while the WQOs are expressed in terms of turbidity. To derive turbidity from the sediment concentrations in the model, TSS was multiplied by 1.5 based on monitoring of previous dredge activities in the SCR (BMT WBM 2011).

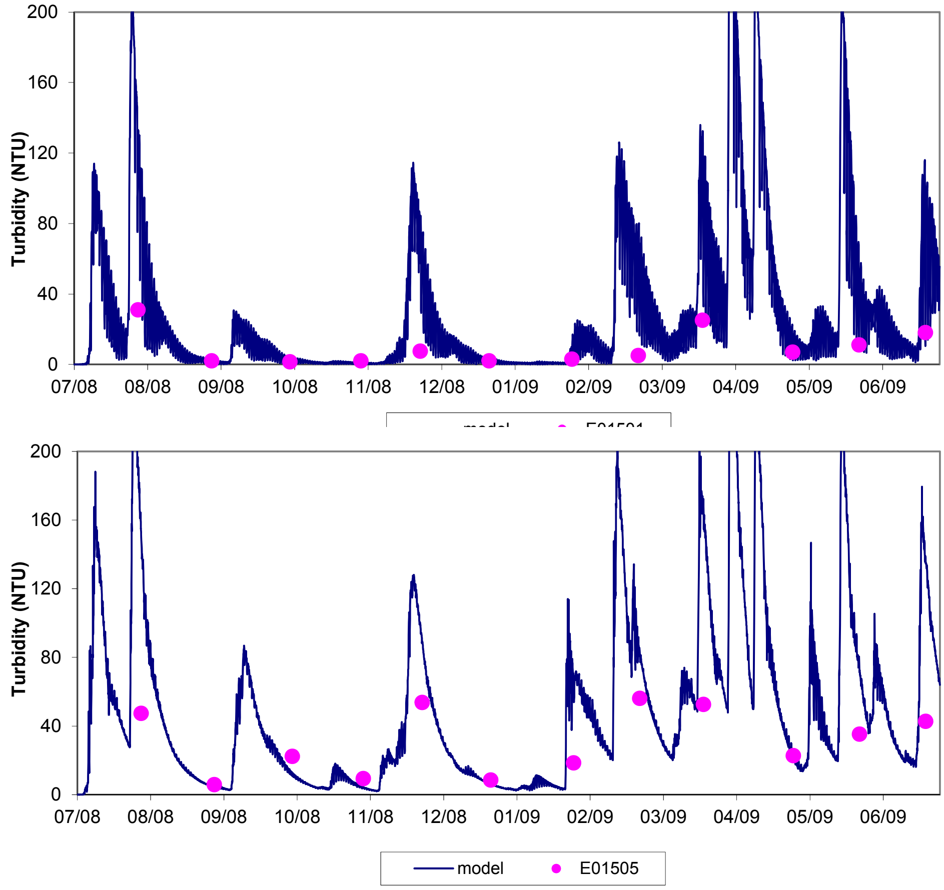

Figure 3-9 Sediment Calibration Plots – 2008-09; Top – Lower Maroochy River (E01501); Bottom – Maroochy River at Marcoola Drain (E01505)

BMT WBM

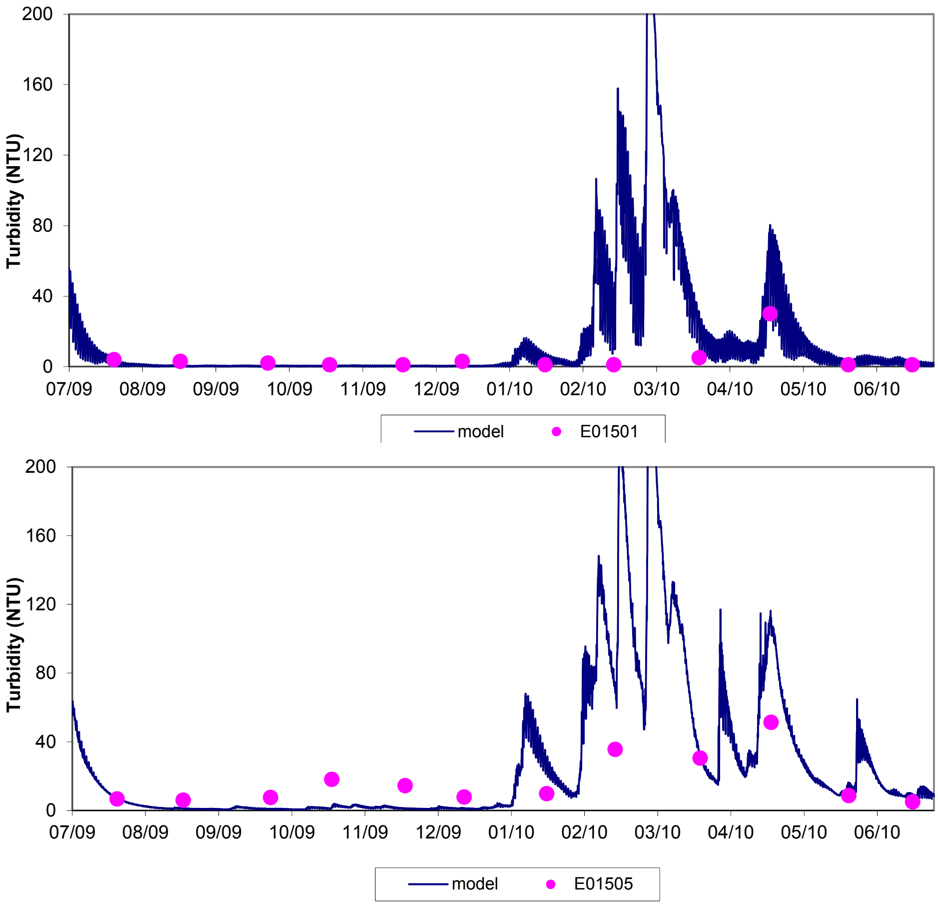

Figure 3-10 Sediment Validation Plots – 2009-10; Top – Lower Maroochy River (E01501); Bottom – Maroochy River at Marcoola Drain (E01505)

3.2.4 Discussion

The following points are made regarding the model suite development and validation processes:

- The Source model demonstrates a very good validation according to the metrics set forth in Moriasi et al (2007) for almost all of the statistical measures. The exception to this is the daily NSE value of the Petrie Creek gauge (141003C), however, the other statistics compare very well to the guidelines. Baseflow might be under-represented in certain periods and within certain regions, however, peak flow magnitudes, peak flow timing, flood recession, and responsiveness of the catchment to events are captured well within the catchment modelling;

- TUFLOW FV hydrodynamic model demonstrates a satisfactory validation with small errors in predictions amounting to no more than 100mm for water levels and 10% of the total flow range through the entrance of the Maroochy River. Difference observed by be a result of differing bathymetry as mentioned previously;

- The TUFLOW FV AD model validation is sufficient for assessment of baseline conditions and AEP impacts. The model slightly under-predicts salt recovery during some of the validation periods, and this has been attributed to high points within the bathymetry were salt recovery is blocked. Efforts were made to remove these were possible, as it is unknown the exact morphology of the Maroochy River at any given time due to highly transient bed scour and aggradation;

- The TUFLOW FV sediment transport model is also sufficient for assessment of baseline conditions and impacts assessments. TSS concentrations might be slightly low in low-flow periods and over-predicted during the wet period of 2010, however it is important to note that the EHMP data are periodic (monthly) grab samples or in-situ water quality measurements taken at a discrete point in the day, month, or season. As such the EHMP cannot capture all of the perturbations of water quality within the Maroochy at all times and locations;

- The modelling suite of Source and TUFLOW FV as developed and validated is sufficient and appropriate to use for the assessment of impacts from the AEP on hydrology and water quality within the Maroochy River.

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APPENDIX B6:A

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