The Halloran Trust

Estuarine Processes Modelling Report: Proposed Mixed Use Subdivision, West Culburra, NSW

ENVIRONMENTAL

WATER

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PROJECT MANAGEMENT

P1203365JR04V02
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All enquiries regarding this project are to be directed to the Project Manager.

Executive Summary

Overview

Martens & Associates Pty Ltd (MA) have prepared this estuarine processes modelling report to support an Overview Report for a mixed use subdivision at Lot 61 DP 755971, and parts of Lots 5, 6 and 7 DP 1065111, Culburra Road, West Culburra, NSW (MP 09_0088).

Estuarine hydrodynamics and contaminant fate and transport conditions have been assessed using a Tuflow Advection Dispersion (AD) model for the Crookhaven River and Curleys Bay, NSW. This modelling has been undertaken to extend the water quality impact assessment undertaken for the site using the MUSIC water quality modelling system as documented in the project Water Cycle Management Report (WCMR, Martens, 2016a). Stormwater flow and pollutant concentration outputs from the project WCMR MUSIC model were used as inputs to the Tuflow AD model.

Methodology

A comprehensive monitoring regime was undertaken to collect water level, flow and salinity data in the Crookhaven River for the purposes of model calibration. A Tuflow AD model was setup and calibrated. The resultant model replicates estuarine hydrodynamics and advection / dispersion processes; is very well calibrated; and is adequate for the purposes of development impact assessment.

To evaluate development impacts and model sensitivity the following model suite of eight 'development assessment models' and twenty-four 'sensitivity models' was run:

- Models were run for four meteorological scenarios to assess the development's water quality impacts for average, dry and wet years as well as extreme local wet months.
- The 'development assessment' model compared pre and post development scenarios. All eight of these models used calibrated dispersion coefficients and outputs from MUSIC which considered vegetation uptake of infiltrated pollutants as part of the treatment train.
- 'Sensitivity models' assessed upper and lower bound dispersion coefficients and MUSIC outputs excluding vegetation uptake of infiltrated pollutants. The purpose of these models was to confirm the sensitivity of assessment model findings to a range of input parameters.

The model scope and modelling approach, inputs and parameters have been developed in close consultation with NSW Department of Planning and Environment (DoPE) and their peer reviewer (BMT WBM). Extensive consultation has ensured these matters were agreed prior to the impact assessment modelling being completed.

Results

The findings of the impact assessment were:

1. 'Sensitivity model' runs confirmed the adequacy of the selected 'development assessment models' as well as confirming acceptable modelling uncertainty.

2. Model outputs and development impacts were analysed using a variety of methods. These included: assessment of maximum pollutant concentrations and minimum salinity conditions and the development's impacts on both; and statistical analysis of water quality data at selected observation points through the estuary.

3. Analysis of assessment model results concluded that the changes in the estuary water quality are characterised as very minor. The maximum change to mean and median pollutant concentrations is 1%, and the maximum change to infrequent (90^{th} to 99^{th} percentile) concentrations is 5%. These represent negligible impacts, especially in the context of the large degree of natural concentration fluctuation which occurs under existing conditions. The large degree of natural variation is typical of an estuarine environment.

4. The comprehensive impact assessment has demonstrated that the proposed development will not cause any significant negative impacts on estuarine water quality.

5. The modelling completed supports the conclusion that stormwater treatment structures as detailed in the WCMR successfully ameliorate potential impacts of the proposed development on estuary water quality. Therefore, no further recommendations for water quality management are required other than those already detailed in the WCMR, Estuarine Management Study (EMS) and Water Quality Monitoring Plan (WQMP).

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1 Introduction

1.1 Overview

Martens & Associates Pty Ltd (MA) have prepared this estuarine processes modelling report to support a project Concept Approval for a mixed use subdivision at Lot 61 DP 755971, and parts of Lots 5, 6 and 7 DP 1065111, Culburra Road, West Culburra, NSW (MP 09_0088). The principle purpose of this assessment and report is to assess the potential estuarine water quality impacts of the proposed development.

Estuarine hydrodynamics and contaminant fate and transport conditions have been assessed for the Crookhaven River and Curleys Bay, located west of the existing Culburra village and south east of Nowra, NSW. Refer to Attachment A PS01-AZ00 for local area overview.

Modelling has been undertaken for a variety of scenarios to assess impacts of the proposed development on estuarine characteristics (assessment models) and to confirm the models suitability for the purposes of this assessment (sensitivity models).

This report is the outcome of extensive consultation and has been prepared to address concerns provided by the NSW Department of Planning and Environment (DoPE) and their peer reviewer, BMT WBM, in preparation of the project overview report.

Completed modelling assesses the transport of salt, nutrients (nitrogen and phosphorous) and sediment within the estuary. Modelling has been completed for both pre and post development scenarios to allow for an assessment of development impacts. Variability of impacts for a range of climate conditions including an average, dry and wet year and a local wet month have been included to ensure a comprehensive assessment of potential development consequences.

1.2 Project Scope

Project scope and objectives are:

1. Prepare a hydrologic and water quality model (MUSIC) for the site and wider Crookhaven River catchments to determine stormwater flows and pollutant loads to Crookhaven River for a range of meteorological scenarios.

2. Collect and assess hydrodynamic and water quality data for estuarine model calibration.

3. Prepare an estuarine processes model (1D/2D SMS Tuflow) for the Crookhaven River and calibrate model hydrodynamics and pollutant characteristics.

4. Define scenarios for development impact and sensitivity analyses and execute the calibrated estuarine processes model for each scenario.

5. Assess and document impacts of the proposed development and sensitivity to various scenarios.

1.3 Proposed Development

A plan of the proposed development is provided in Attachment B. The proposed development includes the following land uses:

1. Residential.
2. Commercial.
3. Industrial.
4. Tourist facilities.
5. Open space.

1.4 Concurrent Studies and Consultation

The following concurrent studies are relevant to this report:

- Martens and Associates (November 2016a), *Water Cycle Management Report – Mixed Use Subdivision; West Culburra, NSW* (P1203365JR01V07), hereafter referred to as the WCMR. Stormwater quantity and quality modelling (MUSIC) undertaken as part of the WCMR has been adapted for this assessment.

- Martens and Associates (November 2016b), *Estuarine Management Study: Proposed Mixed Use Subdivision – West Culburra, NSW* (P1203365JR02V04), hereafter referred to as the EMS.

- Martens and Associates (November 2016c), *Water Quality Monitoring Plan – Mixed Use Subdivision, West Culburra, NSW* (P1203365JR03V04), hereafter referred to as the WQMP.

BMT WBM reviewed previous versions of the WCMR and the EMS on 23 October 2014 and 7 November 2014 respectively, and raised a number of concerns. Since this time, multiple additional reports, consultative documents and emails have been exchanged between MA and

DoPE/BMT WBM, and models have been modified to address DoPE/BMT WBM comments.

This report includes the relevant details and outcomes from MA and DoPE/BMT WBM consultation in order to minimise confusion and to centralise all relevant estuarine processes modelling details.

2 Site and Study Area Description

2.1 Site Location and Existing Landuse

The site is located on the northern side of Culburra Road, West Culburra, within the Shoalhaven City Council local government area (LGA). The proposed development consists of the following lots:

- Lot 61 DP 755971
- Part Lot 5 DP 1065111
- Part Lot 6 DP 1065111
- Part Lot 7 DP 1065111

The proposed development covers an area of approximately 93 ha and consists of undeveloped vegetated land and some agricultural areas in Lot 5 DP 1065111 and Lot 61 DP 755971 (Attachment A PS01-AZ00).

2.2 Study Area Description

The estuarine study area consists of Curleys Bay and the Crookhaven River from Greenwell Point / Orient Point to the tidal limit, shown in Attachment A PS01-AZ00.

The majority of the proposed development site is located within the Crookhaven River catchment and discharges to the Crookhaven River (catchment plan provided in Attachment A PS01-AZ01). A small area of the development site also discharges to Wollumboola Lake, this is outside the scope of this assessment but has been considered as part of the WCMR.

The Crookhaven River catchment is approximately 7,000 ha (Attachment A PS01-AZ01) and consists of predominately forested, swamp and agricultural catchments, with some urban and rural residential areas. The majority of the agricultural catchments are characterised by large areas of very low gradient land which have been significantly modified and consist of multiple farm dams and rerouted drainage channels. A large proportion of the catchment ('US2', refer Attachment A PS01-AZ01) flows to a flood gate below Culburra Road bridge and is injected to the estuary at this location.

Townships within the Crookhaven River catchment include Culburra, Orient Point, Greenwell Point, and the south eastern portion of Nowra.

There are two wastewater treatment plants within the catchment (Attachment A PS01-AZ00).

Several islands are located within the estuary including Billys Island and Goodnight Island. There are also several intertidal areas, particularly in and around Curleys Bay (Attachment A PS01-AZ00).

The Shoalhaven River is located north and west of the study area and is linked to the Crookhaven River by Berrys Canal. The Crookhaven River flows to the ocean through Crookhaven Heads. Tallowa Dam is located on the Shoalhaven River approximately 70 km upstream of the confluence with Crookhaven River.

2.3 Estuarine Water Quality

Summary statistics for the available water quality monitoring data within the Shoalhaven River, Crookhaven River and Curleys Bay is summarised in Table 1, with data sources detailed in Section 11.1. Comparison to ANZECC (2000) trigger criteria for estuaries is also provided, and statistics show the system is frequently at or above ANZECC limits.

Table 1: Summary statistics for pollutants based on available Shoalhaven and Crookhaven River data and comparison to ANZECC (2000) trigger criteria.

Statistic [1]	Total Nitrogen (TN)	Total Phosphorus (TP)	Total Suspended Solids (TSS)
Number of discrete samples	423	429	112
Minimum concentration (mg/L)	0.010	0.001	3.0
Median concentration (mg/L)	0.270	0.026	25.0
Mean concentration (mg/L)	0.362	0.045	32.5
Maximum concentration (mg/L)	4.100	1.300	154.0
Estuary trigger values (mg/L) (ANZECC 2000)	0.300	0.030	NA

Notes

1. Data from multiple sources as detailed in Section 11.1.

Generally, water quality in the Shoalhaven / Crookhaven River system is affected by point (e.g. sewage treatment plant and pump station discharges, industrial waste disposal) and diffuse (e.g. urban and rural runoff, acid sulfate soils) sources of pollution (Shoalhaven River Estuary Data Compilation Study, 2005).

2.4 Tides

Table 2 summarises the tidal analysis conducted in the Shoalhaven River Data Compilation Study (2005) report for Greenwell Point, approximately 1200 m north of the site, when the entrance bar was scoured out in 1992 (as is currently the case).

Table 2: Tidal Information (mAHD) for Greenwell Point, Crookhaven River.

Mean High Water (Spring) (mAHD)	Mean High Water (mAHD)	Mean Sea Level (mAHD)	Mean Low Water (Spring) (mAHD)	Mean Low Water (mAHD)
0.483	0.386	-0.032	-0.547	-0.450

Tides at the site differ slightly from these values. The lag and attenuation / amplification of the tidal signal at the site and at other locations throughout the estuary have been monitored and modelled as part of this assessment.

2.5 Oyster Leases

NSW Food Authority has three shellfish 'harvest areas' within the study area: Goodnight Island (north of Billys Island), Curleys Bay (east of Billys Island) and Crookhaven River (south west of Billys Island). Data from NSW Food Authority (2016b) summarised in Table 3 shows that on average the harvest areas are closed for 3 – 6 months per year due to such triggers as heavy rainfall, excessive microbiological shellfish / water concentrations, sewage discharge, presence of biotoxins and low salinity concentrations.

Table 3: Summary statistics for harvest areas within the study area between 1 January 2010 and 4 October 2016 (NSW Food Authority, 2016b).

Harvest Area	Total Days	Closed Days	Closed Days (%)	Months Closed / Year
Goodnight Island	2435	649	27%	3.2
Curleys Bay	2463	1155	47%	5.6
Crookhaven River	2463	1139	46%	5.5

At the time of reporting and based on the latest NSW Food Authority harvest area status report (27 September 2016, 2016a), the Goodnight Island harvest area was open but harvest areas in the Crookhaven River and Curleys Bay had been closed for several months (since 4 June 2016 and 17 March 2016 respectively) due to 'rainfall exceeding the trigger level' and 'reported sewage discharge'.

Further oyster lease details are provided in the EMS.

2.6 Boating

As the site is undeveloped, there is very little boating activity to the site. Boating within the estuary is generally restricted to recreational fishing boats and local oyster farmers.

2.7 Wave Climate

Although the site is largely protected from ocean generated waves, wave conditions at the site may also originate from a number of other sources. These are locally generated wind waves and waves generated by boating activity.

3 Stormwater Hydrology and Pollutant Modelling Summary

The hydrologic and water quality modelling (MUSIC) undertaken as part of the WCMR has been adapted for this assessment. Updates include:

1. Modelling of additional simulation periods to provide inputs for estuarine processes calibration.

2. Addition of off-site catchments discharging to the Crookhaven River in order to produce flow and stormwater quality data for input to the estuarine processes model. Crookhaven River catchment plan is provided in Attachment A PS01-AZ01.

3. Changing the site MUSIC model to address DoPE/BMT WBM comments.

Details of site MUSIC model setup are provided in the WCMR. Details of MUSIC model changes, additions and outputs for the purposes of estuarine processes modelling are provided in Attachment C, and MUSIC model layouts are provided in Attachment A PS01-AZ02.

We note that MA and BMT WBM have not reached agreement on the use of modelling vegetation uptake as treatment for infiltrated pollutants. To move forward with this assessment, two sets of site MUSIC models have been setup and evaluated:

1. Models with vegetation uptake nodes (i.e. with infiltration) included in the site treatment train. MA believes these models best represent stormwater behaviour and water quality outcomes at the site and have used them as the project assessment model.

2. Models without vegetation uptake nodes (i.e. without infiltration) included in the site treatment train. MA believe these models are overly conservative as they route infiltrated stormwater from treatment devices directly into the estuary and completely ignore the natural processes that occur in the (minimum) 100 m wide vegetated buffer zone. These model scenarios have been run and evaluated as a sensitivity analysis to address BMT WBM's concerns.

In this report the results of models with and without vegetation uptake are evaluated. Further details are provided in Attachment C and the WCMR.

4 Estuarine Processes Modelling Summary

The estuarine processes modelling procedure is outlined below with details summarised in Table 4:

Stage 1: Select modelling system

- The Tuflow classic hydraulic model with the Advection Dispersion (AD) module was selected to model estuarine processes and to assess Crookhaven River hydraulics, flow processes and contaminant fate and transport.

Stage 2: Collect calibration data

- A comprehensive monitoring regime was undertaken to collect water level, flow and salinity data in the Crookhaven River for the purposes of model calibration.
- Data was collected via conductivity temperature depth (CTD) data loggers and Acoustic Doppler Current Profiler (ADCP) transects.
- Details of calibration data are provided in Attachment D.

Stage 3: Setup calibration model

- A Tuflow AD model was setup in accordance with best practice industry standards. Inputs are summarised in Table 4.

Stages 4 & 5: Calibration model iterations & adoption of appropriate calibration

- Model parameters were changed iteratively to achieve adequate calibration to the monitoring data.
- The resultant Tuflow AD model replicates estuarine hydrodynamics and advection / dispersion processes; is very well calibrated; and is adequate for the purposes of development impact assessment.

Stage 6: Develop scenario assessment suite

- A development scenario assessment suite was defined (Table 31) and includes 32 Tuflow models.
- Of these 32 models, 8 have been defined as 'development assessment models' and 24 used to assess the models sensitivity to input parameters and assumptions, these are described as the 'sensitivity models'.

- o Development assessment models use calibrated dispersion coefficients and outputs from water quality models with vegetation uptake / infiltration, as these outputs best represent stormwater behaviour and water quality outcomes at the site (refer Section 3). These 8 models simulate pre and post development conditions for 4 meteorological scenarios:
    - An 'average' year of rainfall.
    - A 'dry' year.
    - A 'wet' year.
    - A 'wet' month of local storm events over Culburra and the development site with no upstream inflows.
- o The sensitivity models simulate estuary conditions with upper and lower bound dispersion coefficients, and use outputs from water quality models without vegetation uptake / infiltration (refer Section 3).

Stages 7 & 8: Adapt calibration model for development models & run scenario assessment suite

- o The calibrated Tuflow AD model was adapted for development assessment and sensitivity models. Changes to inputs are summarised in Table 4.
- o All models were run and results processed.

Stages 9 & 10: Development model results and impact assessment & sensitivity model impact assessment

- o Development assessment model results and water quality impacts are analysed in Section 5.
- o Sensitivity model impacts are analysed in Section 13.
- o Model outputs and development impacts were analysed using a variety of methods including:
    - Assessment of maximum pollutant concentrations and minimum salinity conditions and the development's impacts on both.
    - Statistical analysis of water quality data at selected observation points through the estuary.

The modelling approach has been subject to extensive consultation with DoPE and their peer reviewer, Mr. Michael Barry of BMT WBM, lead developer of Tuflow Advection Dispersion (AD). All model setup, calibration and assessment methodology contained in this report have been reviewed by DoPE and BMT WBM who have confirmed them as technically acceptable.

Full details of estuarine processes modelling are provided in Attachment E (Section 12).

Table 4: Summary of estuarine processes modelling procedure.

Stage	Description	Report Section
1	**Select modelling system**	**12.1**
	Consultation with DoPE & peer reviewer BMT WBM	
	Tuflow classic with advection dispersion (AD) module	
	↓	
2	**Collect calibration data**	**12.2**
	2015 water level data (via CTD)	
	2015 flow & tidal prism data (via ADCP)	
	2015 salinity data (via CTD)	
	2004 supplementary salinity data (public data)	
	↓	
3	**Setup calibration model**	**12.3**
	Calibration simulation periods	
	Grid (LIDAR & bathymetry data)	
	Model domain	
	Roughness	
	Culburra Road flood gate and crest levels	
	Dispersion coefficients	
	Initial conditions (water level & salinity concentration)	
	Downstream boundary water level (tidal)	
	Downstream boundary salinity concentrations (synthetic relationship)	
	Upstream catchment boundary flow rates (from MUSIC)	
	Upstream catchment boundary salinity concentration	
	↓	
4	**Calibration model iterations**	**–**
	Vary parameters to achieve calibration	
	↓	

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Stage	Description	Report Section
5	**Adoption of appropriate calibration**	**12.4**
	Water level calibration	
	Flow and tidal prism calibration	
	2015 & 2004 salinity calibration	

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Stage	Description	Report Section
6	**Develop scenario assessment suite**	**12.5**
	With & without infiltration scenarios	
	Pre and post development scenarios	
	Meteorological scenarios	
	Dispersion scenarios	
	Define 8 'development assessment models' and 24 'sensitivity models'	

↓

Stage	Description	Report Section
7	**Adapt calibration model for development models**	**12.6**
	Development simulation periods	
	Downstream boundary water level (tidal) (for development period)	
	Downstream boundary salinity concentrations (synthetic relationship) (for development period)	
	Upstream catchment boundary flow rates (from MUSIC) (for development period)	
	Model additional pollutants (TN, TP & TSS)	
	Initial TN, TP & TSS concentrations	
	Downstream boundary TN, TP & TSS concentrations	
	Upstream catchment boundary TN, TP & TSS concentrations (from MUSIC)	
	Vary relevant inputs for each assessment / sensitivity model	

↓

Stage	Description	Report Section
8	**Run scenario assessment suite**	**–**
	Processes results	

↓

Stage	Description	Report Section
9	**Development model results and impact assessment**	**5**
	Average concentrations	
	Statistical analysis	
	Maximum concentrations	
	Maximum concentration impacts	

↓

Stage	Description	Report Section
10	**Sensitivity model impact assessment**	**13**
	Statistical analysis	
	Maximum concentrations	
	Maximum concentration impacts	

5 Development Model Results and Impact Assessment

5.1 Overview

Results of the development assessment models are reviewed in the following sections. This review analyses results of Tuflow model runs for each of the four meteorological scenarios by comparing pre and post development results. Assessment considers the model runs with D1 (calibrated) dispersion coefficients and with infiltration inputs, which are the 8 models displayed in **bold** in Table 31.

Assessment of model sensitivity is then completed in Section 13 by reviewing results using D2 and D3 dispersion coefficients and reviewing model runs without the vegetation buffer included as a treatment node. These sensitivity runs are provided to aid in understanding the uncertainty of the assessment models' predictions.

5.2 Analysis Methodology

The adequacy of model outputs and the results of the development impact assessment were assessed using the following methods:

Average concentration plots – Section 5.3

The model's ability to replicate 'average conditions' was assessed by comparing average modelled concentrations of each of the modelled pollutants (Attachment K PS02-EZ00 to EZ03) to the adopted initial concentrations in each zone (Attachment A PS01-AZ05) which represent typical estuary conditions (Section 12.6.4). Model outputs selected for comparison are the pre development model M01 (average rainfall, D1 dispersion coefficient, with infiltration).

Plots PS02-EZ00 to EZ03 show the average of the concentrations modelled (outputted hourly) over the 12 month simulation period.

Statistical analysis – Section 5.4

Detailed statistical analysis of pre and post development model results has been undertaken (Attachment J) using 8 key points in the estuary (Attachment A PS01-AZ06). Hourly model outputs at each location, for each of the four parameters modelled were then compared through assessment of:

1. Changes in mean and median concentrations for each parameter as a result of the development.

2. Changes in the 10th, 5th and 1st percentile concentrations for salinity, and the 90th, 95th and 99th percentile concentrations for TN, TP and TSS. Lower salinity concentrations are considered as freshening impacts are the 'adverse' outcomes being assessed.

Three observation points (Obs 2.1, Obs 2.2 and Obs 2.3) were located around Billys Island to enable a detailed understanding of advection / dispersion conditions in this general location. Statistics for the average values of these observation points are provided and assessed.

Minimum / maximum concentration plots – Section 5.5

Plots of the 'extreme' (minimum / maximum) concentration for each parameter in each model run are provided in Attachment K. Maximum concentrations are provided for TN, TP and TSS with minimum concentrations provided for salinity. Results at areas upslope of the estuary are not provided as they are not relevant to this assessment, but were required to inject stormwater to the estuary appropriately.

Plots present the minimum / maximum concentration observed in any one hour output time step over the entire length of the simulation period. These plots have been specifically required by the project peer reviewer, Martens consider them to show only an indication of the extreme, short term impact of the proposed development. Their value for assessing the development's potential impact on long term estuary health is likely to be limited.

Minimum / maximum concentration impact plots – Section 5.6

Plots of the changes to the minimum / maximum concentration as a result of the development are presented in Attachment K. They show areas of decreased concentration for salinity and increased concentration for TN, TP and TSS using the following thresholds:

a. Salinity: all changes < -100 mg/L are shown.

b. TN: all changes > 0.001 mg/L (1 µg/L) are shown.

c. TP: all changes > 0.001 mg/L (1 µg/L) are shown.

d. TSS: all changes > 0.1 mg/L (100 µg/L) are shown.

5.3 Average Concentration Plots

The following is concluded from the comparison of average modelled concentration plots (Attachment K PS02-EZ00 to EZ03) to adopted initial concentrations (Attachment A PS01-AZ05), summarised in Table 5:

1. Average concentration plots show that in an average rainfall year, a large proportion of the estuary is modelled as being above the ANZECC (2000) trigger criteria for TN and TP in estuaries (0.300 mg/L and 0.030 mg/L respectively). This result is also observed in available monitoring data (Section 2.3). The Crookhaven River is therefore considered a disturbed ecosystem with compromised health in existing conditions.

2. Where observed, differences between adopted and modelled concentrations can be attributed to low data quality as discussed in Section 12.3.4, which is due to a high degree of data variability, a small number of samples, interpolation / extrapolation of available data, and discrete sampling which may not represent typical estuary conditions.

3. Overall, modelled average concentrations are slightly underestimated compared to adopted concentrations. This is likely due to the diurnally wet and dry properties of the estuary – when model cells become dry the model reports concentrations of 0 mg/L. When the average over the entire simulation period is calculated, mean concentrations are influenced and reduced by the 0 mg/L 'dry' concentrations, which in turn reduce the zone's concentration. This is especially the case for salinity, which has the highest absolute concentration and therefore has the largest proportional reduction by the 0 mg/L 'dry' concentrations.

4. Modelled TP concentrations in the four zones furthest downstream (Zones 1-4, refer Attachment A PS01-AZ05) show the largest proportional (percentage) deviations, and are overestimated by 30% to 81% (7 to 20 µg/L) compared to adopted concentrations, which were based on median values. However, when compared to mean concentrations, the comparison shows differences of -10% to 45%. TP is more sensitive to outliers than other pollutants as it has the lowest absolute concentrations, and overall differences between modelled and adopted concentrations are ≤ 20 µg/L (or 11 µg/L considering mean concentrations), which is considered acceptable.

5. Adopted initial concentrations do not significantly affect model performance. The initial water level for all simulations is at low tide and hence the total mass of pollutants in the model is initially low. Due to significant tidal interchange the initial concentrations quickly become immaterial as they are dominated by the mass of pollutants entering Crookhaven River at Greenwell Point, as well as stormwater runoff from upstream boundaries.

6. As discussed in Section 12.4.4, the calibrated model shows processes including advection / dispersion, mixing and pollutant fate and transport are well represented by the model.

7. The differences between adopted initial and modelled average concentrations are acceptable and show the model is capable of reproducing estuarine background conditions satisfactorily.

Table 5: Comparison of adopted initial and modelled average concentrations by zone.

		Zone [1]						
Statistic	**Pollutant**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Adopted Concentration (g/L or mg/L) [2]	Salinity (g/L)	28.1	28.4	26.5	24.9	19.0	16.0	0.1
	TN (mg/L)	0.300	0.350	0.390	0.430	0.600	0.700	0.900
	TP (mg/L)	0.022	0.019	0.026	0.029	0.060	0.090	0.120
	TSS (mg/L)	25.0	26.0	26.0	27.0	28.0	30.0	30.0
Modelled Average Concentration (g/L or mg/L) [3]	Salinity (g/L)	20.3	19.7	20.8	18.2	15.6	19.1	0.1
	TN (mg/L)	0.267	0.306	0.315	0.370	0.405	0.572	0.761
	TP (mg/L)	0.029	0.034	0.037	0.049	0.060	0.085	0.106
	TSS (mg/L)	22.6	26.1	24.6	24.9	24.2	32.6	30.5
Difference (g/L or mg/L)	Salinity (g/L)	-7.8	-8.7	-5.7	-6.7	-3.4	3.1	0.0
	TN (mg/L)	-0.033	-0.044	-0.075	-0.060	-0.195	-0.128	-0.139
	TP (mg/L)	0.007	0.015	0.012	0.020	0.000	-0.005	-0.014
	TSS (mg/L)	-2.4	0.1	-1.4	-2.1	-3.8	2.6	0.5
Difference (%)	Salinity (%)	-28%	-30%	-21%	-27%	-18%	20%	-30%
	TN (%)	-11%	-12%	-19%	-14%	-32%	-18%	-15%
	TP (%)	30%	81%	45%	69%	0%	-5%	-12%
	TSS (%)	-10%	0%	-5%	-8%	-14%	9%	2%

Notes

1. Zones defined in Attachment A PS01-AZ05.
2. Based on discrete concentration data from sources detailed in Section 11.1.
3. Based on average concentration data from model [M01] as shown in Attachment K PS02-EZ00 to EZ03.

5.4 Statistical Analysis

Table 6 summarises which statistical data table (Attachment J) refers to which Tuflow impact assessment model scenario (development scenario assessment suite in Table 31). We note:

1. Pre development models:

   a. In an average year the estuary is frequently at or above ANZECC (2000) trigger criteria for TN and TP in estuaries (0.300 mg/L and 0.030 mg/L respectively). Concentrations are at or slightly below ANZECC limits in a dry year, and exceed ANZECC limits in a wet year and wet month. This further demonstrates that the Crookhaven River has compromised health in existing conditions.

b. Differences in mean and median concentrations at each location show the spatial distribution of pollutants, which is also shown in the average concentration plots (Attachment K PS02-EZ00 to EZ03).

c. Obs1 is the closest observation point to the main channel of the Crookhaven River and generally experiences the lowest salinity / highest TN, TP and TSS concentrations and highest degree of concentration change for scenarios with catchment wide inflows, due to the significant mass of pollutants from upstream flushing past this point. Conversely, Obs3 in Curleys Bay is the most sheltered observation point and generally experiences the highest salinity / lowest TN, TP and TSS concentrations and lowest degree of concentration change of all observation points for these scenarios.

d. Obs5 is the closest observation point to the existing Culburra village and generally experiences the lowest salinity and highest TN, TP and TSS concentrations and highest degree of concentration change for scenarios with only local catchment inflows. Obs1 is the furthest from discharge locations in these scenarios and generally experiences the highest salinity and lowest TN, TP and TSS concentrations.

e. During infrequent storm events the Crookhaven River experiences significant freshening, with 1st percentile salinity concentrations falling below 2,500 mg/L in an average year and falling as low as 1,000 mg/L in a wet year in impact assessment models.

f. During infrequent storm events the Crookhaven River experiences significant deterioration in water quality, with 99th percentile concentrations showing:

    i. Up to 0.70 mg/L for TN in an average year and over 1.00 mg/L in a local wet month.

    ii. Up to 0.135 mg/L for TP in an average year.

    iii. Over 40 mg/L for TSS in an average year and over 60 mg/L in a local wet month.

g. 90th to 99th percentile concentrations show that the Crookhaven River and Curleys Bay receive a large mass of pollutants, however mean and median concentrations are nearer to ANZECC trigger criteria. This demonstrates the system's ability to quickly recover from stormwater runoff pollution which is attributed to the high degree of tidal flushing within the system.

2. Post development models:

    a. Results show that changes to salinity, TN, TP and TSS concentrations at all points for all scenarios are negligible. This is because of:

        i. The effectiveness of the proposed treatment measures in reducing the concentrations of stormwater pollutants from the development site.

        ii. The reduced peak stormwater runoff flow rates due to discharge control measures incorporated into the proposed treatment train.

    b. The vast majority of changes to pollutant concentrations at all points for all impact assessment models for all considered statistics are insignificant (0% change).

    c. Many scenarios improve estuary concentrations due to the effectiveness of the proposed treatment measures and the reduction of stormwater discharge. For different points across all impact assessment scenarios and for all considered statistics:

        i. Salinity concentrations are increased by up to 10%.

        ii. TN concentrations are decreased by up to -5%.

        iii. TP concentrations are decreased by up to -7%.

        iv. TSS concentrations are decreased by up to -4%.

    d. At all locations and for all impact assessment scenarios, mean and median concentrations increase by a maximum of 1%, which indicates the proposed development does not affect long term estuarine concentrations.

    e. At all locations and for all considered statistics in all impact assessment scenarios, the maximum decrease in salinity concentration (freshening) is -5%, and the maximum increase in TN, TP or TSS concentrations is 3%. These represent negligible impacts.

f. The magnitudes of changes to estuarine concentrations due to the proposed development are insignificant compared to the large degree of natural concentration fluctuation.

g. In summary, we do not expect there will be any material impacts on estuary health due to the proposed development as concentration changes are negligible.

Table 6: Reference to Attachment J Tables containing output statistics for each Tuflow model scenario.

		Meteorological Scenario											
		Average Year 1967			Dry Year 1968			Wet Year 1969			Local Wet Month 20 Oct – 20 Nov 1969		
Infiltration Scenario	Development Scenarios	Dispersion Sensitivity Scenario											
		D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
With Infiltration	Pre Dev	**Table 32** [1]	Table 33	Table 34	**Table 35** [1]	–	–	**Table 36** [1]	–	–	**Table 37** [1]	Table 38	Table 39
	Post Dev	**Table 40** [1]	Table 41	Table 42	**Table 43** [1]	–	–	**Table 44** [1]	–	–	**Table 45** [1]	Table 46	Table 47
Without Infiltration	Pre Dev	Table 48	Table 49	Table 50	Table 51	–	–	Table 52	–	–	Table 53	Table 54	Table 55
	Post Dev	Table 56	Table 57	Table 58	Table 59	–	–	Table 60	–	–	Table 61	Table 62	Table 63

Notes

1. Impact assessment models are displayed in **bold** and results are assessed in Section 5.4. The remainder of the models are considered sensitivity runs and are assessed in Section 13.3.

5.5 Minimum / Maximum Concentration Plots

Modelled minimum salinity and maximum TN, TP and TSS concentration plots are provided in Attachment K. From a review of these we note:

1. A greater mass of pollutants is directed to the Crookhaven River from agricultural and residential areas than forested areas, as expected.

2. For all scenarios with upstream inflows, areas upstream of the site consistently have the lowest salinity / highest TN, TP and TSS concentrations due to proximity to large agricultural and residential catchments with large pollutant loads, and less tidal exchange compared to downstream areas.

3. Pollutant concentrations and plume extents from the existing Culburra village are much more intense and larger than those from the site, including in post development conditions. This is especially evident in the local wet month scenario plots. As we understand it, estuary health has not been significantly adversely affected by the presence of Culburra village. We therefore expect that the existing estuary will not be significantly affected by the proposed development, considering pollutant loads are negligible compared to those of the existing Culburra village.

4. Further to the results of the average concentration plots, maximum concentration plots show that in existing conditions the estuary is well above the ANZECC (2000) trigger criteria for TN and TP in estuaries (0.300 mg/L and 0.030 mg/L respectively). This further demonstrates that the Crookhaven River is considered a disturbed ecosystem in existing conditions.

5. Minimum salinity concentration plots show multiple cells and cell borders with concentrations of 0 mg/L in foreshore, mangrove, sand bank and oyster lease areas. These locations are diurnally wet and dry, and when dry have a modelled concentration of 0 mg/L which appears on the minimum concentration plots. Minimum concentrations for these cells should be ignored, and instead concentrations at adjacent cells should be considered the actual minimum concentrations in these locations.

6. As expected, Crookhaven River has lower minimum salinity / higher maximum TN, TP and TSS concentrations in average year scenarios compared to dry year scenarios, and worse absolute conditions for wet year scenarios.

7. Comparison between pre and post development scenarios shows minor changes to concentrations at off-site boundary conditions. All model hydraulic and advection / dispersion inputs and settings at off-site locations are identical between pre and post development scenarios. Further, these areas are upstream of the peak spring high tide water level and cannot possibly be affected by changes at site boundary conditions. We therefore conclude that these changes reflect the resolution of the Tuflow model, and are attributed to model calculation methodology. Minor changes at these locations are expected in the impact plots (Section 5.6) however are not associated with development site impacts.

8. Localised areas of changed concentration can be seen at site outlets between pre and post development scenarios. The magnitude of these changes is discussed in the following section.

5.6 Minimum / Maximum Concentration Impact Plots

Modelled minimum salinity impact and maximum TN, TP and TSS concentration impact plots are provided in Attachment K. We note:

1. The impact plots show areas of decreased salinity / increased TN, TP and TSS concentrations (thresholds in Section 5.2). Whilst this assessment focuses on evaluating the magnitude of detrimental impacts, it should be noted that there are also significant areas of no change, as well as areas of benefit. Developed conditions impact assessment scenarios have large areas of improved estuary concentrations at site outlets due to the effectiveness of the proposed treatment measures and the reduction of stormwater discharge rates.

2. As discussed in the previous section, areas of 'impact' at off-site boundary conditions are present and in some scenarios have large plumes. These 'impact' plumes are disconnected from site impact plumes, and originate from boundary condition changes upstream of the peak spring high tide level, and hence are not associated with the proposed development. The magnitude and extents of these 'impact' plumes demonstrates the resolution of model calculation methodology, which in many cases is comparable to site impact plumes.

3. The vast majority of negative site impact plumes are limited to foreshore areas immediately adjacent to site outlets, and quickly dissipate to background concentrations.

4. Local wet month scenarios generally have larger impact plumes than other meteorological scenarios due to increased sensitivity. Scenarios with upstream inflows reduce salinity / increase TN, TP and TSS concentrations in the receiving environment, and hence concentration changes due to site and Culburra inflows are not as influential. Without upstream inflows, there are larger concentration gradients due to larger differences between site / Culburra inflows compared to background concentrations, and hence there is increased sensitivity to minor changes. This is especially the case for salinity, which has the largest difference between background concentrations (28,100 mg/L) and inflow concentrations (100 mg/L, approximately 300 times different), and hence salinity has the largest concentration gradient and increased sensitivity to minor changes.

5. Further, as discussed in Section 12.5.3, local wet month scenarios are considered very conservative (the wettest month over the modelling period confined to the site / Culburra coupled with completely dry upstream conditions) and have been run as a

sensitivity analysis to determine absolute worst case development impacts.

6. As discussed in the previous section, the minimum salinity concentration plots show multiple cells with concentrations of 0 mg/L in diurnally wet and dry cells which should be ignored, and concentrations in adjacent cells should be considered as the actual minimum concentrations at these locations. This leads to changes at individual grid cells which appear as salinity 'impacts' throughout the model domain. These single cell 'impacts' should also be ignored as they are not associated with changes due to the proposed development.

7. Plume extents are shown based on the thresholds in Section 5.2. These thresholds are very conservative considering the resolution of the model. We expect concentration changes at these thresholds to be negligible.

8. The magnitude of localised changes to minimum / maximum concentrations is insignificant considering the absolute pollutant concentrations and large range of pollutant concentrations the estuary experiences, over the course of a year and even over a single tidal cycle.

9. We note that impact plots show differences in maximum concentrations for a single model output timestep (1 hour). We expect that estuary health will not be affected by minor concentration changes for one hour out of a year; rather, long-term sustained concentration changes will have a negative impact to estuary health. Changed discharge regimes due to the proposed development may slightly increase the absolute maximum concentration over a single hour, but as per the statistical analysis (Section 5.4), developed scenarios have no change to mean / median concentrations, and no material long-term sustained changes in 90th, 95th and 99th percentile conditions.

5.7 Summary

We note the following key findings of the impact assessment:

1. A review of the models' ability to replicate background estuarine concentrations has provided further evidence that the model is well calibrated.

2. Detailed statistical analysis demonstrates that:

a. Changes to estuarine concentrations due to the proposed development are negligible, even in infrequent storm events.

b. The magnitude of changes to estuarine concentrations due to the proposed development are insignificant compared to the large degree of natural concentration fluctuation which occurs under existing conditions.

3. Review of minimum / maximum concentration plots has demonstrated that:

    a. The masses of pollutants from the proposed development are minor compared to those from the existing Culburra village, and we therefore expect that, just as the existing residential development has not significantly affected estuarine health, neither will the proposed development.

4. Review of minimum / maximum concentration impact plots has demonstrated that:

    a. The vast majority of site impact plumes have small spatial extents which are limited to foreshore areas immediately adjacent to site outlets.

    b. Changed discharge regimes due to the proposed development may slightly increase the absolute maximum concentration at a specific location for one hour in a year, however as per the statistical analysis, developed scenarios have no material long-term sustained changes in 90^{th}, 95^{th} and 99^{th} percentile conditions.

5. The Crookhaven River is frequently above ANZECC (2000) trigger criteria and is therefore considered a disturbed ecosystem with compromised health in existing conditions.

6. There are many instances of positive changes to estuarine concentrations which are consequences of the effectiveness of proposed treatment measures and the controlled discharge of stormwater.

7. On the basis of these findings, we do not expect there will be any material detrimental impacts on estuarine health due to the proposed development.

6 Summary & Recommendations

This study details the design, development and calibration of a robust estuarine processes model of the Crookhaven River and Curleys Bay estuary. This model is then used to assess the potential impacts of a proposed mixed use subdivision at West Culburra on the water quality of the estuary. This modelling has been undertaken to extend the water quality impact assessment undertaken for the site using the MUSIC water quality modelling system as documented in the project Water Cycle Management Report (Martens, 2016a).

With regards to the model establishment, calibration and impact assessment we note and conclude:

1. The model scope and modelling approach, inputs and parameters have been developed in close consultation with DoPE and their peer reviewer, BMT WBM. Extensive consultation has ensured these matters were agreed prior to the impact assessment modelling being completed.

2. The model is well calibrated as measured against a number of hydrodynamic and pollutant datasets. Calibration is considered adequate for the purposes of development impact assessment.

3. Modelling of a range of meteorological conditions has been undertaken to assess the development's water quality impacts for average, dry and wet years as well as extreme local wet months.

4. Model sensitivity to a range of inputs has been assessed using a comprehensive development scenario assessment model suite to assess uncertainty in model predictions. This process confirmed the adequacy of the selected assessment models as well as confirming an acceptable level of modelling uncertainty.

5. Model outputs and development impacts have been analysed using a variety of methods. These include assessment of maximum pollutant concentrations and minimum salinity conditions and the development's impacts on both. Assessment has also included statistical analysis of water quality data at selected observation points through the estuary.

6. Analysis of results concluded that, for the development assessment models, the changes in the estuary water quality are characterised as very minor (Section 5.4). The largest change to mean and median pollutant concentrations is 1%, and the largest change to infrequent (90th to 99th percentile) concentrations is 5%. These represent negligible impacts, especially in the context of

the large degree of natural concentration fluctuation which occurs under existing conditions. The comprehensive impact assessment has demonstrated that the proposed development will not cause negative impacts of material significance to estuarine water quality.

7. The modelling completed supports the conclusion that stormwater treatment structures as detailed in the WCMR successfully ameliorate potential impacts of the proposed development on estuary water quality. Therefore, no further recommendations for water quality management are required other than those already detailed in the WCMR, EMS and WQMP.

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8 Attachment A: Estuary and Model Plans

PROJECT: PROPOSED MIXED USE SUBDIVISION

PLANSET: ESTUARY AND MODEL PLANS

CLIENT: REALTY REALIZATIONS PTY LTD

DRAWING LIST - V01		
DWG NO.	REV	DWG TITLE
GENERAL		
PS01-A000	A	COVERSHEET
ESTUARY AND MODEL PLANS		
PS01-AZ00	A	LOCAL AREA OVERVIEW
PS01-AZ01	A	CATCHMENT PLAN
PS01-AZ02	A	MUSIC MODEL LAYOUTS
PS01-AZ03	A	MONITORING AND CALIBRATION LOCATIONS
PS01-AZ04	A	TUFLOW MODEL EXTENTS & BOUNDARY CONDITIONS
PS01-AZ05	A	ADOPTED INITIAL CONCENTRATIONS
PS01-AZ06	A	OBSERVATION POINTS

LOCALITY PLAN
NOT TO SCALE

LGA: SHOALHAVEN CITY COUNCIL

WEST CULBURRA, NSW

MAJOR PROJECT APPLICATION

REV	DESCRIPTION	DATE	DRAWN	DESIGNED	CHECKED	APPRVD
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WEST CULBURRA, NSW

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DRAWING TITLE: COVERSHEET

PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
P1203365	PS01	R01	PS01-A000	A

DRAWING ID: P1203365-PS01-R01-A000

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A1 / A3 LANDSCAPE (A1LC__v02.0.01)

NOTES:
1- BACKGROUND AERIAL FROM NEARMAP (29 MAY 2016).

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SCALE: 0 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20 1.35 1.50 KILOMETRES
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DRAWING TITLE: LOCAL AREA OVERVIEW

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P1203365	PS01	R01	PS01-AZ00	A

DRAWING ID: P1203365-PS01-R01-AZ00

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A1 / A3 LANDSCAPE (A1LC_v02.0.01)

NOTES:
1- BACKGROUND AERIAL FROM NEARMAP (29 MAY 2016).
2- CATCHMENT BOUNDARIES BASED ON LPI (2001) 1:25 000 TOPOGRAPHIC MAPS.
3- SITE CATCHMENT BOUNDARY IS INDICATIVE ONLY. REFER TO MARTENS WATER CYCLE MANAGEMENT REPORT FOR DETAILED PRE AND POST DEVELOPMENT SITE CATCHMENTS.

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PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
P1203365	PS01	R01	PS01-AZ01	A

DRAWING ID: P1203365-PS01-R01-AZ01

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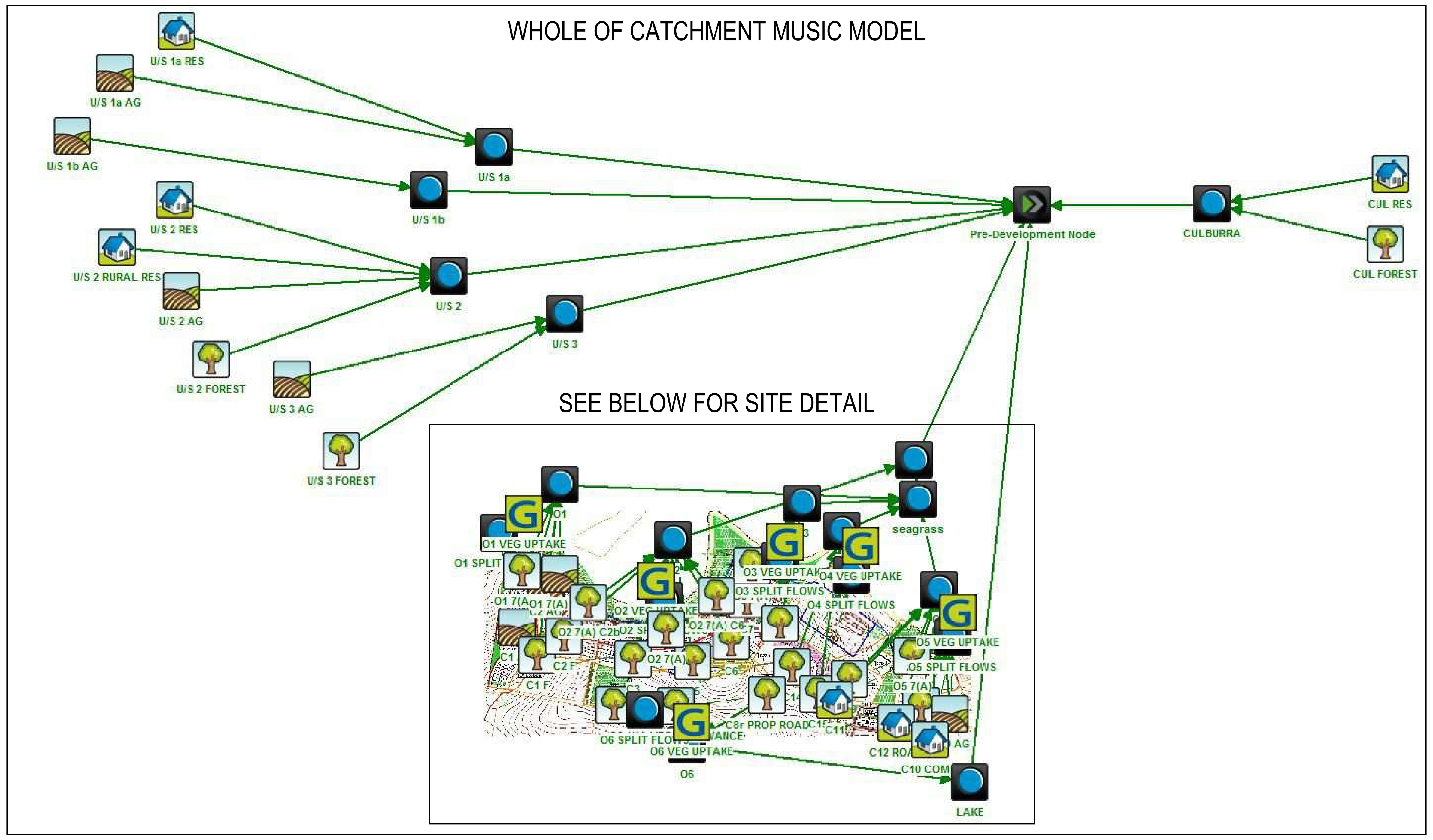

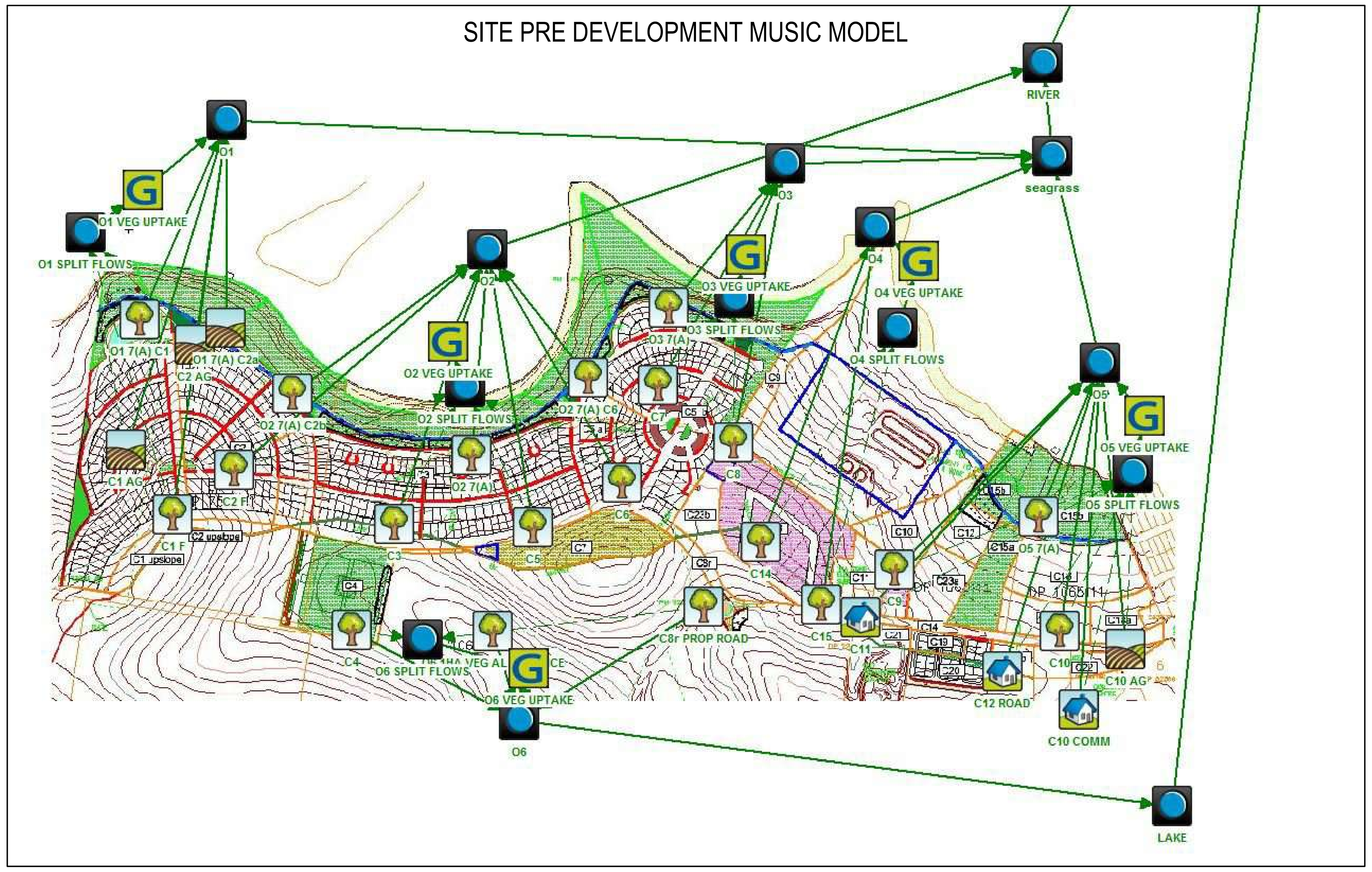

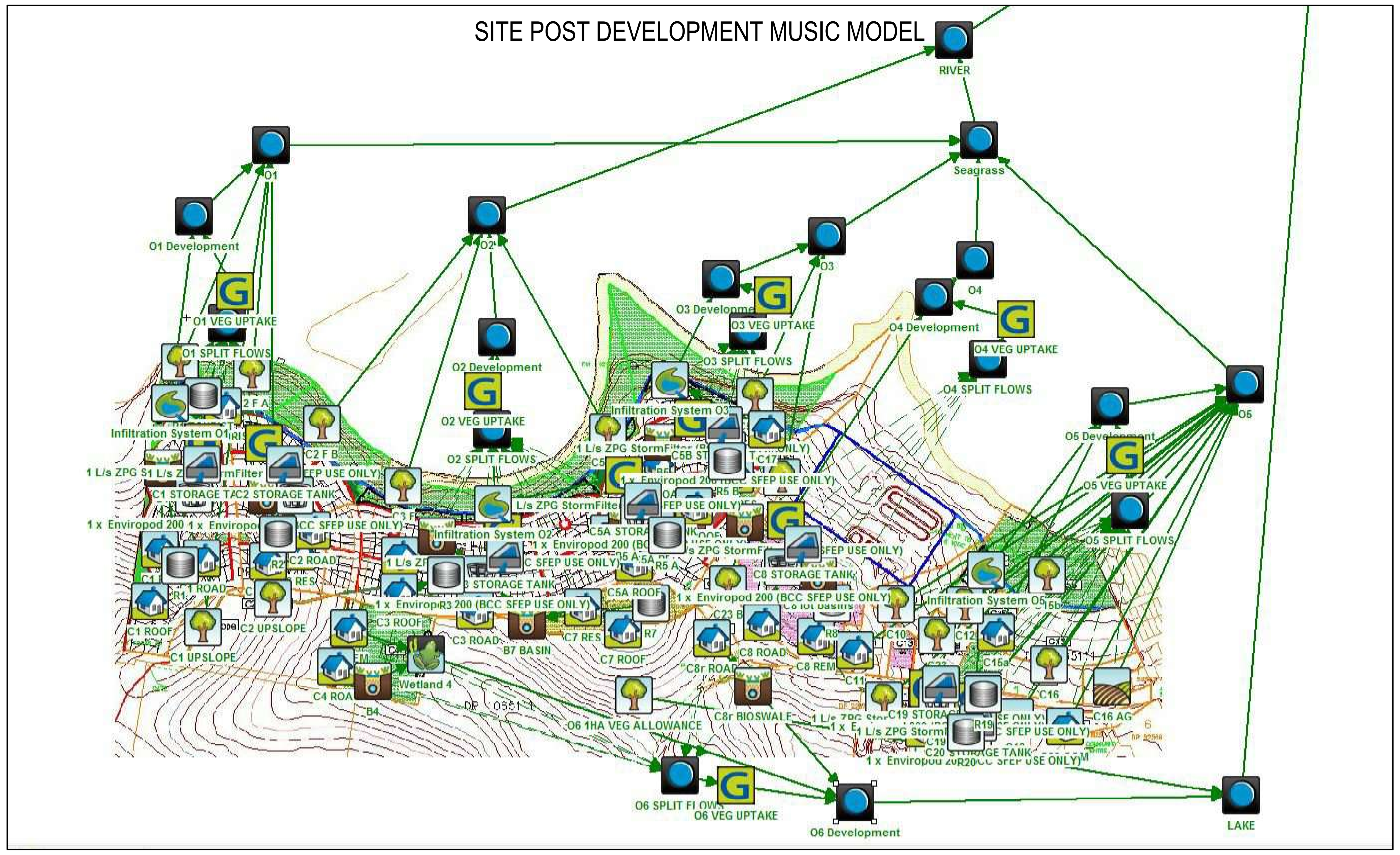

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DRAWING TITLE
MUSIC MODEL LAYOUTS

PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
P1203365	PS01	R01	PS01-AZ02	A

DRAWING ID: P1203365-PS01-R01-AZ02

A1 / A3 LANDSCAPE (A1LC_v02.0.01)

NOTES:

1- BACKGROUND AERIAL FROM NEARMAP (29 MAY 2016).

2- SHELLFISH QUALITY ASSURANCE PROGRAM (SQAP) POINTS FROM NSW FOOD AUTHORITY OYSTER INFORMATION PORTAL.

3- TRANSECT COORDINATES FROM HASKONING AUSTRALIA (2015).

4 - CTD POINTS FROM ALLEN PRICE & SCARRATTS SURVEY DATA (2015).

KEY

NSW FOOD AUTHORITY SHELLFISH QUALITY ASSURANCE PROGRAM (SQAP) SALINITY DATA POINTS (2004)	SQAP 13
MANLY HYDRAULICS LABORATORY (MHL) WATER LEVEL MONITOR	MHL GP
HASKONING AUSTRALIA (2015) ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) TRANSECT	GP TRANSECT
MARTENS & ASSOCIATES (2015) CONDUCTIVITY TEMPERATURE DEPTH (CTD) MONITOR	CTD 1

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DRAWING TITLE: MONITORING AND CALIBRATION LOCATIONS

PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
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NOTES:
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2- BOUNDARY CONDITIONS AS PER CATCHMENT PLAN (PS01-AZ01).

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CLIENT: REALTY REALIZATIONS PTY LTD

PROJECT NAME/PLANSET TITLE: PROPOSED MIXED USE SUBDIVISION
ESTUARY AND MODEL PLANS
WEST CULBURRA, NSW

martens & Associates Pty Ltd
Consulting Engineers
Environment
Water
Geotechnical
Civil
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DRAWING TITLE: TUFLOW MODEL EXTENTS & BOUNDARY CONDITIONS

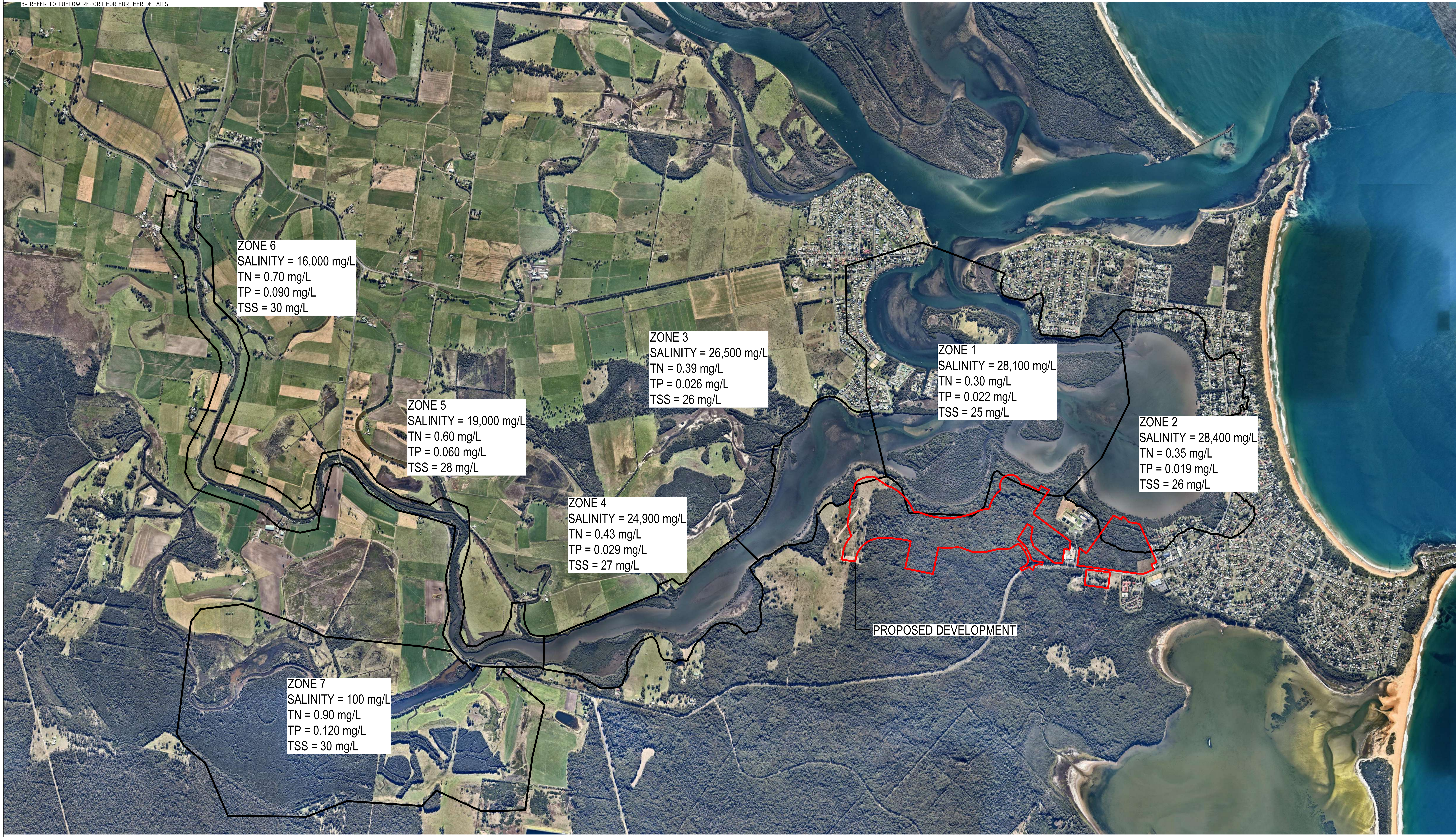
PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
P1203365	PS01	R01	PS01-AZ04	A

DRAWING ID: P1203365-PS01-R01-AZ04

A1 / A3 LANDSCAPE (A1LC_v02.0.01)

PRINTED: ---- - USER: RKOLAHDOOZHA

NOTES:
1- BACKGROUND AERIAL FROM NEARMAP (29 MAY 2016).
2- TN = TOTAL NITROGEN, TP = TOTAL PHOSPHORUS, TSS = TOTAL SUSPENDED SOLIDS.
3- REFER TO TUFLOW REPORT FOR FURTHER DETAILS.



MAJOR PROJECT APPLICATION

REV	DESCRIPTION	DATE	DRAWN	DESIGNED	CHECKED	APPRVD
A	ORIGINAL ISSUE	15/09/2016	RK	DD	AN	

SCALE: 0 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20 1.35 1.50 KILOMETRES
A1 (A3) 1:15,000 (1:30,000)

GRID	DATUM	PROJECT MANAGER
MGA	N/A	AN

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DRAWING TITLE: ADOPTED INITIAL CONCENTRATIONS

PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
P1203365	PS01	R01	PS01-AZ05	A

DRAWING ID: P1203365-PS01-R01-AZ05

PRINTED: ---- - USER: RKOLAHDOOZHA
A1 / A3 LANDSCAPE (A1LC_v02.0.01)

NOTES:
1- BACKGROUND AERIAL FROM NEARMAP (29 MAY 2016).

MAJOR PROJECT APPLICATION

REV	DESCRIPTION	DATE	DRAWN	DESIGNED	CHECKED	APPRVD
A	ORIGINAL ISSUE	15/09/2016	RK	DD	AN	

SCALE: 0 0.15 0.30 0.45 0.60 0.75 0.90 1.05 1.20 1.35 1.50 KILOMETRES
A1 (A3) 1:15,000 (1:30,000)

GRID: MGA
DATUM: N/A
PROJECT MANAGER: AN

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ESTUARY AND MODEL PLANS
WEST CULBURRA, NSW

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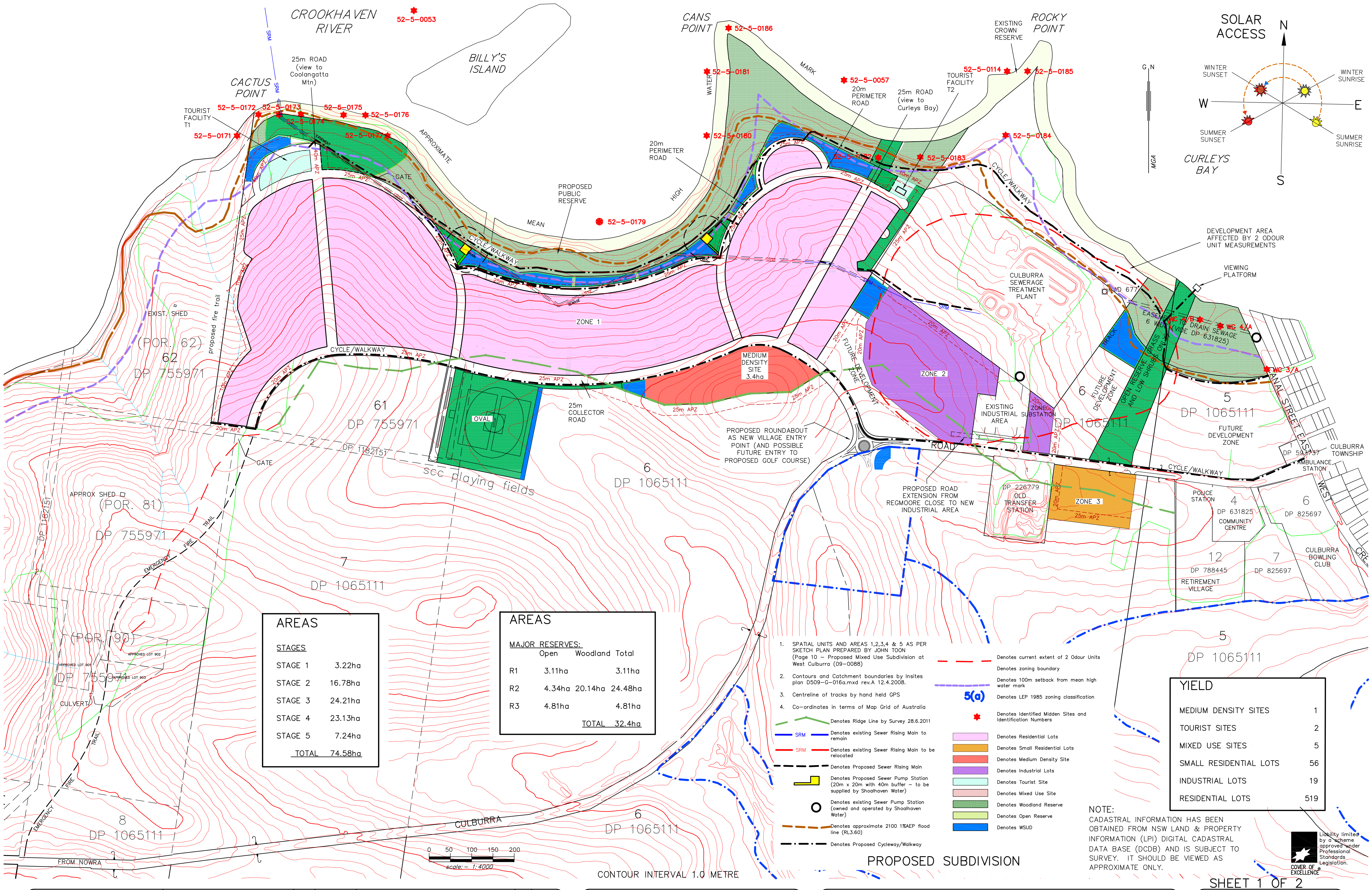
DRAWING TITLE: OBSERVATION POINTS

PROJECT NO.	PLANSET NO.	RELEASE NO.	DRAWING NO.	REVISION
P1203365	PS01	R01	PS01-AZ06	A

DRAWING ID: P1203365-PS01-R01-AZ06

PRINTED: ---- - USER: RKOLAHDOOZHA
A1 / A3 LANDSCAPE (A1LC__v02.0.01)

9 Attachment B: Proposed Site Layout



AREAS

STAGES	
STAGE 1	3.22ha
STAGE 2	16.78ha
STAGE 3	24.21ha
STAGE 4	23.13ha
STAGE 5	7.24ha
TOTAL	74.58ha

AREAS

MAJOR RESERVES:

	Open	Woodland	Total
R1	3.11ha		3.11ha
R2	4.34ha	20.14ha	24.48ha
R3	4.81ha		4.81ha
		TOTAL	32.4ha

1. SPATIAL UNITS AND AREAS 1,2,3,4 & 5 AS PER SKETCH PLAN PREPARED BY JOHN TOON (Page 10 – Proposed Mixed Use Subdivision at West Culburra (09-0088)
2. Contours and Catchment boundaries by Insites plan D509-G-016a.mxd rev.A 12.4.2008.
3. Centreline of tracks by hand held GPS
4. Co-ordinates in terms of Map Grid of Australia

- Denotes Ridge Line by Survey 28.6.2011
- SRM — Denotes existing Sewer Rising Main to remain
- SRM — Denotes existing Sewer Rising Main to be relocated
- Denotes Proposed Sewer Rising Main
- Denotes Proposed Sewer Pump Station (20m x 20m with 40m buffer – to be supplied by Shoalhaven Water)
- Denotes existing Sewer Pump Station (owned and operated by Shoalhaven Water)
- Denotes approximate 2100 1%AEP flood line (RL3.60)
- Denotes Proposed Cycleway/Walkway
- Denotes current extent of 2 Odour Units
- Denotes zoning boundary
- Denotes 100m setback from mean high water mark
- 5(a) Denotes LEP 1985 zoning classification
- Denotes Identified Midden Sites and Identification Numbers
- Denotes Residential Lots
- Denotes Small Residential Lots
- Denotes Medium Density Site
- Denotes Industrial Lots
- Denotes Tourist Site
- Denotes Mixed Use Site
- Denotes Woodland Reserve
- Denotes Open Reserve
- Denotes WSUD

YIELD

MEDIUM DENSITY SITES	1
TOURIST SITES	2
MIXED USE SITES	5
SMALL RESIDENTIAL LOTS	56
INDUSTRIAL LOTS	19
RESIDENTIAL LOTS	519

NOTE:
CADASTRAL INFORMATION HAS BEEN OBTAINED FROM NSW LAND & PROPERTY INFORMATION (LPI) DIGITAL CADASTRAL DATA BASE (DCDB) AND IS SUBJECT TO SURVEY. IT SHOULD BE VIEWED AS APPROXIMATE ONLY.

PROPOSED SUBDIVISION

RATIO:	DATUM:	SURVEY	AERIAL PHOTOGRAPHY		REVISION	BY	DATE
1 : 4000 at A1 1 : 8000 at A3	ORIGIN:	DESIGN	JT/MP	01	ROAD DETAIL ADDED SOUTH OF CULBURRA RD	MJP	08.10.2013
		DRAWN	CEG/DS	02	ROAD DETAIL AMENDED SOUTH OF CULBURRA RD	MJP	04.11.2013
		CHECK'D	MJP	03	ROUNDABOUT LOCATION AMENDED	MJP	15.07.2014
				04	HATCHING OF SUBDIVISION AREA ADDED, ROAD AMENDED TO SUIT ROUNDABOUT. SHEET 2 ADDED TO DRAWING SET	MJP	06.08.2014
	DATE OF PLAN: 27 SEPT. 2013			05	APZ LINES ADDED	MJP	13.08.2014

allen, price & associates
land and development consultants
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consultants@allenprice.com.au www.allenprice.com.au

SKETCH PLAN SHOWING SITE CONSTRAINTS & PROPOSED SUBDIVISION OVER PART OF DP 1065111, LOT 2 DP 1182151 AND PORTIONS 61, 81 & 90 DP 755971 AT WEST CULBURRA FOR REALTY REALIZATIONS

REF. No. 25405-37
SHEET 1 OF 2 SHEETS
REVISION 05

M:\Projects\20000\25000s\25405\Drawings\drawings For Client\25405-37 Proposed Subdivision For Martens 20140819 Release 2004.dwg

10 Attachment C: Stormwater Hydrology and Pollutant Modelling Details

10.1 Overview

MUSIC modelling undertaken as part of the WCMR has been used to develop catchment inflow boundary conditions for the estuary assessment. Full details of the site MUSIC model setup are provided in the WCMR. The following sections provide details of model changes, additions and outputs for the purposes of estuarine processes modelling.

The Model for Urban Stormwater Improvement Conceptualisation (*MUSIC*, Version 6.1) developed by the CRC for Catchment Hydrology was used to evaluate flows and pollutant loads from the site and the wider Crookhaven River catchments. Modelling has been undertaken in accordance with *Draft NSW MUSIC Modelling Guidelines* (2010).

10.2 MUSIC Model Changes and Additions

Updates to the WCMR MUSIC model for estuarine processes modelling included:

1. Additional simulation periods for estuarine processes calibration:

    a. Pluviograph data from 1964 – 1970 available from eWater for Nowra RAN (Station ID 068076) was used for development scenario assessment in the WCMR MUSIC model as agreed with BMT WBM.

    b. Nowra RAN pluviograph data only extended to 1997, and hence alternate climate files were required to model the 2004 and 2015 calibration periods.

    c. For the 2004 calibration period (1 January 2004 to 1 January 2005), pluviograph data was sourced from eWater at Jervis Bay (Point Perpendicular AWS) (Station ID 068151) in accordance with the NSW MUSIC guidelines. Average monthly areal potential evapotranspiration (PET) was sourced from BOM (2001), *Climatic Atlas of Australia – Evapotranspiration*. Use of data at this location is appropriate as the site is equidistant to both Jervis Bay and Nowra RAN stations. This same data was used in the previous EMS (August 2014).

    d. For the 2015 calibration period (1 January 2015 to 17 July 2015), pluviograph data and daily evapotranspiration (ET) data were sourced from BOM at Nowra RAN (Station ID 068072) in accordance with the NSW MUSIC guidelines. Daily ET was converted to daily PET using monthly Class-A evaporation pan coefficients for Nowra RAN from McMahon et al. (2013), *Supplementary Material to paper 'Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: A pragmatic synthesis'*.

2. Addition of off-site catchments discharging to Crookhaven River:

   a. Catchment delineation was developed using LPI (2001) 1:25 000 topographic maps. Refer to Attachment A PS01-AZ01 for Crookhaven River catchment plan and Table 7 for off-site catchment summary.

   b. Catchment land uses consistent with the NSW MUSIC guidelines Event Mean Concentration (EMC) categories were assigned based on recent aerials obtained from LPI (2014) SIX Maps Viewer.

   c. Catchment land use impervious areas were assigned based on:

      i. Representative aerials obtained from LPI (2014) SIX Maps Viewer for each urban and rural residential land use in each off-site catchment.

      ii. Adopted 5% and 0% impervious areas for agricultural and forested land uses respectively based on typical values for similar catchments.

   d. Rainfall-runoff parameters are consistent with those adopted for source nodes in the WCMR based on the NSW MUSIC guidelines. The only deviations to these parameters were for the three largest catchments, 'US1a', 'US1b' and 'US2'.

      i. Each of these catchments is dominated by agricultural, forest and/or swamp areas. They are characterised by large areas of very low gradient agricultural land which have been significantly modified and consist of multiple farm dams and rerouted drainage channels.

      ii. These catchments have very large depression storage volumes, resulting in increased long term infiltration and therefore an increased ratio of baseflow to stormflow.

iii. Changes to MUSIC rainfall-runoff parameters were made to account for these characteristics, and included increasing the depth of root zone (and associated soil storage and field capacities) by 25% to 0.625 m in accordance with soil profiles viewed on eSpade (2015), and changing the daily baseflow rate to 5%.

iv. Total outflow volume from each catchment is unaffected by this change, but flows are delivered over an extended period to replicate expected prolonged delivery of baseflow.

v. These changes were necessary to achieve adequate calibration as detailed in Section 12.4.

e. EMCs for source nodes are consistent with NSW MUSIC guidelines (2010) and are summarised in the WCMR.

3. Changing the site MUSIC model to address DoPE/BMT WBM comments:

a. All changes recommended in BMT WBM's correspondence of 23 October 2014 have been incorporated in the site MUSIC model as detailed in the WCMR.

b. The only outstanding point of disagreement between MA and BMT WBM (DoPE's peer reviewer) is the modelling of vegetation uptake as treatment for infiltrated pollutants.

c. MA believe the (minimum) 100 m wide vegetated buffer zone between the proposed development and foreshore area will treat subsurface flows, and vegetation uptake rates have been adopted for modelling based on supporting literature. BMT WBM does not agree with this view.

d. As agreement on the use of this parameter could not be reached, two sets of site MUSIC models have been setup and evaluated:

i. Models <u>with</u> vegetation uptake nodes (i.e. <u>with</u> infiltration) included in the site treatment train. MA believe these models best represent stormwater behaviour and water quality outcomes at the site and have used them as the project assessment model.

ii. Models without vegetation uptake nodes (i.e. without infiltration) included in the site treatment train. MA believe these models are overly conservative as they route infiltrated stormwater from treatment devices directly into the estuary and completely ignore the natural processes that occur in the (minimum) 100 m wide vegetated buffer zone. These model scenarios have been run and evaluated as a sensitivity analysis to address BMT WBM's concerns.

e. In this report the results of models with and without vegetation uptake are evaluated. Importantly, MA believe the assessment with vegetation uptake is the appropriate scenario for assessment of the development's potential impacts. The assessment without vegetation uptake has been included but is considered by MA to be a worst case sensitivity analysis, is unrepresentative and overly conservative.

No other changes to modelling details provided in the WCMR were made. MUSIC model layouts are provided in Attachment A PS01-AZ02.

Table 7: Off-site Crookhaven River catchments used in MUSIC modelling.

Catchment	Land Use / EMC Category [1]	Area (ha) [2]	Impervious Area (%) [3]
Culburra	Urban	177.3	33%
	Forest	44.1	0%
	Total	221.4	27% [4]
US1a	Urban	62.7	31%
	Agricultural	708.7	5%
	Total	771.4	7% [4]
US1b	Agricultural	886.6	5%
US2	Urban	186.4	35%
	Agricultural	1517.5	5%
	Rural Residential	311.5	6%
	Forest	2618.1	0%
	Total	4633.5	3% [4]
US3	Forest	147.9	0%
	Agricultural	122.9	5%
	Total	270.8	2% [4]
Total Off-site Crookhaven River Catchment		**6783.7**	**5%** [4]

Notes

1. Adopted based on LPI (2014) SIX Maps Viewer aerials and NSW MUSIC guidelines (EMC) categories.
2. Delineated based on LPI (2001) 1:25 000 topographic maps. Refer to Attachment A PS01-AZ01 for catchment plan.
3. Adopted based on representative aerials obtained from LPI (2014) SIX Maps Viewer for urban and rural residential land uses for each catchment, and assumed 5% and 0% impervious area for agricultural and forested land uses respectively based on typical values for similar catchments.
4. Weighted average impervious areas.

10.3 MUSIC Results

MUSIC results are summarised in:

- o Table 8, Table 9 and Table 10 over the assessment period (1964 to 1970). Results are summarised for flows and pollutant loads as follows:
  - Table 8 – off-site catchments which remain unchanged in pre and post development models.
  - Table 9 – site receivers in pre and post development models with vegetation uptake included in the treatment train.

- Table 10 – site receivers in pre and post development models <u>without</u> vegetation uptake included in the treatment train.

- Table 11 over the calibration periods (2004 and 2015). Only flow results are provided from each off-site catchment and to each site receiver. Load results are not presented as only hydrodynamics and salinity concentrations (which are not evaluated by MUSIC) were required for estuarine processes calibration.

We note the following:

1. Flows and pollutant loads to Crookhaven River from off-site catchments including the existing Culburra village (Table 8) are significantly greater than those from the developed site (Table 9 and Table 10).

2. Table 9 and Table 10 show flow volumes and peak flow rates to receiving environments are identical with and without vegetation uptake as no lag is applied to the vegetation uptake node and flows are not modelled stochastically by MUSIC. Receiving environments receive changed flow volumes due to changed impervious areas and flow regime on the development site, however peak flow rates are reduced due to controlled discharge from site water quality structures.

3. Table 9 shows NorBE <u>is achieved</u> for all pollutants at all receiving environments for models <u>with</u> vegetation uptake. As discussed at Section 10.2, MA believe these results incorporating vegetation uptake are the best representation of actual stormwater quality conditions at the site.

4. Table 10 shows NorBE <u>is not achieved</u> for all pollutants at all receiving environments for models <u>without</u> vegetation uptake. As discussed at Section 10.2, MA believe these models without vegetation uptake are overly conservative as they route infiltrated stormwater from treatment devices directly into the estuary and completely ignore the natural processes that occur in the vegetated buffer zone.

5. Table 11 shows flow volumes and peak flow rates are generally higher in 2015 than 2004. This is because:

   a. 2004 annual rainfall was 994 mm/year at Jervis Bay (Point Perpendicular AWS), below the annual mean rainfall.

b. 2015 rainfall over the calibration period (198 days between 1 January 2015 and 17 July 2015) was 719 mm. Extrapolating this rainfall to 365 days (as MUSIC does with flow volumes) gives an annual rainfall of 1325 mm/year, above the annual mean rainfall.

c. Rainfall depths and modelled flow rates over the 2015 calibration period are therefore expected to be greater than those for the 2004 calibration period.

Table 8: MUSIC results – assessment period (1964 to 1970) – off-site catchments.

Scenario	Location	Flow (ML/yr)	Peak Flow (m3/s)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)
Off-site – Unchanged	Culburra	813	52.0	97900	185	1420
	US1a	1840	180.0	146000	575	3470
	US1b	2000	207.0	143000	616	3800
	US2	9780	1050.0	429000	1490	10900
	US3	643	63.7	29200	116	777

Table 9: MUSIC results – assessment period (1964 to 1970) – site receivers with vegetation uptake.

Scenario	Location	Flow (ML/yr)	Peak Flow (m^3/s)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)
Site – Pre Development	Crookhaven River	296	28.6	12319	26.5	180.2
	Lake Wollumboola	19	2.0	214	0.5	5.2
	Billys Island inlet (SEPP 14 Wetlands)	104	10.8	1180	2.7	31.5
	Seagrass and Oyster Leases	192	17.8	11139	23.8	148.7
	Curleys Bay	92	7.4	8890	16.1	94.5
Site – Post Development	Crookhaven River	381	20.9	10067	22.3	162.2
	Lake Wollumboola	16	1.0	125	0.5	4.5
	Billys Island inlet (SEPP 14 Wetlands)	105	6.2	510	2.5	26.6
	Seagrass and Oyster Leases	276	14.6	9557	19.8	135.6
	Curleys Bay	88	6.2	8660	15.2	89.1
Change (%)	Crookhaven River	28%	-27%	-18%	-16%	-10%
	Lake Wollumboola	-15%	-49%	-42%	-1%	-15%
	Billys Island inlet (SEPP 14 Wetlands)	1%	-42%	-57%	-9%	-16%
	Seagrass and Oyster Leases	43%	-18%	-14%	-17%	-9%
	Curleys Bay	-4%	-16%	-3%	-6%	-6%
Complies with NorBE (Y/N)	Crookhaven River	–	–	Y	Y	Y
	Lake Wollumboola	–	–	Y	Y	Y
	Billys Island inlet (SEPP 14 Wetlands)	–	–	Y	Y	Y
	Seagrass and Oyster Leases	–	–	Y	Y	Y
	Curleys Bay	–	–	Y	Y	Y

Table 10: MUSIC results – assessment period (1964 to 1970) – site receivers without vegetation uptake.

Scenario	Location	Flow (ML/yr)	Peak Flow (m^3/s)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)
Site – Pre Development	Crookhaven River	296	28.6	13639	33.0	250.7
	Lake Wollumboola	19	2.0	287	0.9	9.4
	Billys Island inlet (SEPP 14 Wetlands)	104	10.8	1550	4.6	50.3
	Seagrass and Oyster Leases	192	17.8	12089	28.4	200.4
	Curleys Bay	92	7.4	9180	17.9	114.0
Site – Post Development	Crookhaven River	381	20.9	12433	42.8	345.7
	Lake Wollumboola	16	1.0	318	2.0	18.6
	Billys Island inlet (SEPP 14 Wetlands)	105	6.2	1270	9.2	88.9
	Seagrass and Oyster Leases	276	14.6	11163	33.6	256.8
	Curleys Bay	88	6.2	9140	17.7	115.0
Change (%)	Crookhaven River	28%	-27%	-9%	30%	38%
	Lake Wollumboola	-15%	-49%	11%	135%	97%
	Billys Island inlet (SEPP 14 Wetlands)	1%	-42%	-18%	98%	77%
	Seagrass and Oyster Leases	43%	-18%	-8%	19%	28%
	Curleys Bay	-4%	-16%	0%	-1%	1%
Complies with NorBE (Y/N)	Crookhaven River	–	–	Y	N	N
	Lake Wollumboola	–	–	N	N	N
	Billys Island inlet (SEPP 14 Wetlands)	–	–	Y	N	N
	Seagrass and Oyster Leases	–	–	Y	N	N
	Curleys Bay	–	–	Y	Y	N

Table 11: MUSIC results – calibration periods (2004 and 2015) – all off-site catchments and site receivers.

		2004		2015	
Scenario	Location	Flow (ML/yr)	Peak Flow (m3/s)	Flow (ML/yr)	Peak Flow (m3/s)
Off-site – Unchanged	Culburra	641	22.5	1540	11.0
	US1a	1090	21.1	3900	34.5
	US1b	1140	17.0	4340	39.6
	US2	5340	58.6	21500	201.0
	US3	400	15.0	1440	12.7
Site – Pre Development	Crookhaven River	187	6.8	657	5.7
	Lake Wollumboola	12	0.5	44	0.4
	Billys Island inlet (SEPP 14 Wetlands)	62	2.5	238	2.2
	Seagrass and Oyster Leases	125	4.2	419	3.5
	Curleys Bay	66	1.8	189	1.5

10.4 Data for Estuarine Processes Modelling

Time series flow and concentration data from each catchment have been exported from MUSIC for use in the estuarine processes model. We note that summary results in Section 10.3 may be slightly different from these time series results as they have been stochastically generated as required by BMT WBM.

Four of the five off-site catchments summarised in Table 7 were split into smaller sub-catchments to ensure inflows are distributed at multiple locations along the foreshore in the estuarine processes model. This represents a more realistic inflow distribution rather than all catchment flow being concentrated into a small area in the model. The only off-site catchment which was not split was 'US2' which flows to the flood gate below Culburra Road bridge and is injected to the Crookhaven River at only this location, and hence splitting the catchment further would not be representative of catchment inflow behaviour.

Refer to Attachment A PS01-AZ01 for Crookhaven River catchment plan and Table 12 for summary of off-site sub-catchment areas. Flows to the estuarine processes model were apportioned based on the ratio of the sub-catchment area to the total catchment area. Concentrations from MUSIC were held constant across sub-catchments.

The site catchment 'O2' was also split to deliver flow to both sides of Billys Island. Catchment boundaries for 'O2' change in pre and post development conditions as detailed in the WCMR, however for consistency in estuarine processes modelling constant splits were assigned. These are based on sub-catchment boundaries in pre and post development conditions which direct flow to the west (sub-catchment 'O2a', 47% of 'O2' adopted) and east of Billys Island (sub-catchment 'O2b', 53% of 'O2' adopted). No other site MUSIC catchments were split in the estuarine processes model due to their smaller size and because their discharge locations did not require further discretisation.

A total of 20 inflow locations were developed for the estuarine processes model – 14 off-site sub-catchments (as per Table 12) and 6 site sub-catchments (including the split 'O2' catchment).

Table 12: Off-site Crookhaven River sub-catchments used in estuarine processes modelling.

MUSIC Catchment [1]		Estuarine Processes Sub-Catchment			
Name	**Total Area (ha)**	**#**	**Name**	**Area (ha) [2]**	**(% of MUSIC Catchment) [3]**
Culburra	221.4	1	Culburra 1	92.0	42%
		2	Culburra 2	35.5	16%
		3	Culburra 3	67.8	31%
		4	Culburra 4	26.1	12%
US1a	771.4	5	US1a1	411.0	53%
		6	US1a2	293.5	38%
		7	US1a3	46.0	6%
		8	US1a4	20.9	3%
US1b	886.6	9	US1b1	709.9	80%
		10	US1b2	176.7	20%
US2	4633.5	11	US2	4633.5	100%
US3	270.8	12	US3a	106.1	39%
		13	US3b	112.4	42%
		14	US3c	52.3	19%

Notes

1. From Table 7.
2. Delineated based on LPI (2001) 1:25 000 topographic maps. Refer to Attachment A PS01-AZ01 for catchment plan.
3. Flows to the estuarine processes model apportioned based on ratio of sub-catchment area to total catchment area.

11 Attachment D: Calibration Data Details

11.1 Available Calibration Data

The following data have been made available by other parties and were used for estuary model setup and calibration:

- Manly Hydraulics Laboratory (MHL 2015) have provided continuous water level monitoring data at Greenwell Point from 1988 to 2015. Refer Attachment A PS01-AZ03 for monitoring location.

- Water NSW (2015) (previously Sydney Catchment Authority) have provided daily Tallowa Dam storage level and storage volume data from 1976 (year of construction completion) to 2015. Tallowa Dam is located on Shoalhaven River approximately 70 km upstream of the confluence with Crookhaven River.

- The Shoalhaven City Council (2015) *Aqua Data* website has discrete sample data for pollutants at multiple locations throughout Crookhaven River and Shoalhaven River from 1990 to 2015. Sampled pollutants include salinity, total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS).

- The Oyster Information Portal (2014) has discrete salinity sample data at multiple NSW Food Authority Shellfish Quality Assurance Program (SQAP) monitoring points in the Crookhaven River. Three SQAP points with frequent data over 2004 were selected for estuary model calibration, as shown in Attachment A PS01- AZ03. We note that:

    - The observed data at each location was interpolated from the available graphs, and it is therefore possible that discrepancies in the observed data may exist.

    - We expect that these discrepancies are in the order of ± 7 days and ± 1 g/L.

- Dr. Ana Rubio (previously worked with the Australian Oyster Industry) provided discrete sample data for pollutants at two locations in Crookhaven River from 2004 to 2006. Sampled pollutants include salinity, TP, TN and TSS.

- Mr. Robert Thorne (local Greenwell Point resident) provided approximately daily salinity sample data in Shaws Creek from 1995 to 2015. This data has also been used by University of New South Wales Water Research Laboratory (UNSW WRL) in their nearby study *Environmental Flow Modelling of Salinity Structure in the Shoalhaven Estuary* (2006). Data post 2006 is private, but has been presented to the peer reviewer on 9 November 2015.

These data sources supplement and allow evaluation of project specific data collected as part of the monitoring regime undertaken by MA, as detailed in the following sections.

Summary statistics for all available TN, TP and TSS discrete sample data are summarised in Table 1. Comparison to ANZECC (2000) trigger criteria for estuaries is also provided, and statistics show the estuary is frequently at or above ANZECC limits.

11.2 2015 Monitoring Regime

11.2.1 Overview

Details of the monitoring regime used to inform estuary model calibration were discussed between MA and BMT WBM and all elements were agreed between December 2014 and July 2015.

The two calibration data suites required included flow data collected via acoustic Doppler current profiler (ADCP) monitoring, and water level and salinity concentration data collected via conductivity temperature depth (CTD) monitoring. Agreed monitoring regimes for each of these data suites are summarised in the following sections.

11.2.2 Acoustic Doppler Current Profiler (ADCP) Monitoring

The agreed ADCP monitoring regime consisted of:

- Two boat mounted ADCP transects located between Greenwell Point / Orient Point and adjacent to Billys Island to capture flow variations within the intertidal area between the two transects. Transect locations are provided in Attachment A PS01- AZ03.
- Monitoring over a full 13 hour tidal cycle during neap and spring tides with flow measurements taken approximately every hour over each transect. Flow measurements taken at each transect are offset by approximately 30 minutes due to boat speed restrictions between the two locations.
- Duplicate measurements in opposing directions across transects conducted approximately every 4 hours.
- Allowance for certain transects being unable to be measured during low tides due to safety issues introduced by shallow water depths.

11.2.3 Conductivity Temperature Depth (CTD) Monitoring

The agreed CTD monitoring regime consisted of:

- Four CTDs as shown in Attachment A PS01- AZ03 to capture tidal variations in water level and fluctuations in salinity concentration. The agreed locations are:

    1. Location 1 – Culburra Road Bridge

    2. Location 2 – Billys Island

    3. Location 3 – Curleys Bay

    4. Location 4 – Goodnight Island

- One month of continuous measurements at each location to monitor spring and neap tide conditions as well as capture 2 – 3 rainfall / inflow events, and allowance for a longer monitoring duration should sufficient rainfall / storm flushing events not be experienced over this month.

- Salinity dip readings taken at each location at the time of data collection to check accuracy of CTD measurements.

11.3 2015 ADCP Data Analysis

ADCP monitoring was undertaken by Haskoning Australia over the neap tide on 11 May 2015 and the spring tide on 18 – 19 May 2015. The ADCP report (Attachment H) shows both transect locations and the adopted end bank coordinates. Transect locations are also shown in Attachment A PS01- AZ03.

The downstream transect at the mouth of the Crookhaven River (named 'GP' after Greenwell Point) was able to be monitored over the full 13 hour tidal cycle, however the same was not possible for the upstream transect (named 'US') due to shallow water depths, as expected. When the US transect was unable to be monitored hourly, half hourly transects were taken at the GP transect. A total of 68 transects were completed for the two locations over the neap and spring tides, as well as 17 duplicate transects which generally confirmed similar flow rates.

Full details of ADCP monitoring setup and configuration, quality assurance and quality control processes, measured discharge curves, tidal prisms and transect velocity profiles are provided in the ADCP report (Attachment H).

11.4 2015 CTD Data Analysis

11.4.1 Operational Aspects

CTD monitoring was undertaken by MA over a period of 10.5 weeks between 17 April 2015 and 1 July 2015. Device locations are given in Attachment A PS01- AZ03.

Each CTD was installed within a 50 mm slotted PVC well screen and secured to a star picket driven into the river bed and located within oyster leases. A barometer was also installed for the first month at Location 3 at the top of the screen then moved for the second month to a location at Greenwell Point to allow compensation of collected data with air pressure to convert to water depth. Each device was surveyed by Allen Price & Scarratts (2015) to allow depth measurements to be converted to the Australian height datum (mAHD). The devices were synced to record simultaneously at 15 minute intervals. Data was collected on three dates – first on 21 May 2015, then on 29 May 2015, and finally on 1 July 2015.

The make and type of each device as well as the range and typical accuracy of pressure and conductivity measurements are summarised in Table 13. All devices are Schlumberger Water Services (SWS) 'Divers' except for the two 30 m CTDs by Van Essen Instruments (VEI). Device locations for each monitoring period are provided in Table 14 showing which devices were used at what times to address data quality control matters (discussed in Section 11.4.2).

Table 13: Parameters for each device used for CTD monitoring.

	Measurement Range [1]		Typical Accuracy [1]	
Device Name/Type	**Pressure (mH_2O)**	**Conductivity (mS/cm)**	**Pressure**	**Conductivity**
SWS 10 m Mini-Diver	0 – 10	NA	± 5 mmH_2O	NA
SWS 20 m Mini-Diver	0 – 20	NA	± 10 mmH_2O	NA
SWS 10 m CTD	0 – 10	0 – 120	± 5 mmH_2O	± 1.0%
SWS 50 m CTD	0 – 50	0 – 120	± 25 mmH_2O	± 1.0%
VEI 30 m CTD	0 – 30	0 – 80	± 0.1% [2]	± 1.0%

Notes

1. Device parameters are from product manuals:
    a. Schlumberger Water Services (2014), *Diver Manual*.
    b. Van Essen Instruments (2004), *Diver by Van Essen Instruments*.
2. The VEI product manual only provides pressure accuracy as a percentage which applies for the full measurement range over the operating temperature.

Table 14: Devices used at each location for each monitoring period.

	Device Used for Monitoring Period (Start – Finish Date)		
Location	**17 April – 21 May 2015**	**21 – 29 May 2015**	**29 May – 1 July 2015**
1 – Culburra Rd Bridge	SWS 10 m CTD	(same device)	(same device)
2 – Billys Island	SWS 50 m CTD	(same device)	(same device)
3 – Curleys Bay	VEI 30 m CTD	SWS 10 m Mini-Diver	SWS 10 m CTD
4 – Goodnight Island	VEI 30 m CTD	SWS 20 m Mini-Diver	SWS 10 m CTD
Barometer [1]	SWS 20 m Mini-Diver	(same device)	SWS 10 m Mini-Diver

Notes

1. The barometer was relocated from Location 3 to an oyster farmer's shed on 29 May 2015 as discussed in Section 11.4.2.

Conductivity dip readings were taken with a field water quality meter hired from Thermo Fisher Scientific Australia at each location during installation and on each data collection date. In each case three readings were taken to obtain an average conductivity for the location. This data was compared to CTD measurements to serve as a check and to correct for drift. Each CTD and screen was cleaned when data was collected to minimise biofouling.

11.4.2 Quality Control

CTD measurements were checked in the field when collecting data and during data processing. Several quality control issues arose and were dealt with as follows:

- Conductivity sensors on the VEI 30 m CTDs at Location 3 and Location 4 were found to have failed on 21 May 2015. Conductivity readings from the installation date to this time were unreliable and have been excluded from further analysis. Replacement SWS 10 m CTDs were installed at these two locations on 29 May 2015. From 21 May – 29 May 2015 regular SWS Mini-Divers (i.e. measuring temperature and depth only) were used to continue monitoring of water levels before CTDs could be reinstalled on 29 May 2015.

- The CTD at Location 4 was found to be buried in silt within the slotted screen on 1 July 2015. During installation the bottom of the screen was located at the river bed, however upon retrieval the bottom of the screen was buried in 31 cm of silt, and 19 cm of silt had infiltrated the screen. This is likely due to the large rainfall and associated flood events experienced over the monitoring period. The CTD was buried and the conductivity sensor covered in slurry. When compared to dip readings the CTD readings were found to be unrepresentative of the water conductivity, instead showing a much lower salinity within the silt. Location 4 CTD conductivity readings have therefore been excluded from analysis.

- The CTD at Location 3 was found to have several negative 'spikes' in the salinity data. 'Spikes' had a magnitude of up to 16 g/L and an average duration of 15 – 30 minutes (1 or 2 readings) per 'spike'. These observations are not aligned with periods of high rainfall and have no physical explanation. These observed measurements are not representative of water salinity but rather are device recording errors. These 'spikes' have been removed to enable better representation of expected concentrations and allow comparison with modelled concentrations.

- The barometer at Location 3 was found to become wet for a short duration during several high tides prior to collection on 21 May 2015. Pressure readings clearly displayed when the barometer was not measuring atmospheric pressure. This data was ignored and atmospheric pressure readings taken on either side of high tide inundation were linearly interpolated. The barometer was replaced and a new barometer secured within a shed at Greenwell Point on 29 May 2015 to avoid further wetting.

- Salinity logger data at Location 2 was inconsistent with observed data over the monitoring period at multiple locations, as well as data recorded at a nearby location on different dates. This data has therefore been excluded from further analysis. Details follow:

  - The Location 2 logger was intended to record Billys Island salinity, and was located west of the island (as shown in Attachment A PS01- AZ03) in oyster leases to protect the device from passing boats.

  - During the monitoring period a large rainfall event in mid-late April 2015 caused salinity concentrations in the Crookhaven River to decrease significantly. This decrease occurred upstream and downstream of Billys Island:

    - Location 1 salinity data (Attachment G Figure 26) shows concentrations upstream of Billys Island decline by 15 g/L over 5 days.

    - Shaws Creek salinity data (private data presented to the peer reviewer) shows concentrations downstream of Billys Island decline by 30 g/L over 5 days, and salinity is < 10 g/L for almost 2 weeks following this rainfall event.

  - Similarly in mid-late June 2015 a storm event caused salinity concentrations at Location 1 and Location 3 (Attachment G Figure 3) and at Shaws Creek (private data) to decrease simultaneously in response to freshwater runoff.

- We expect Location 2 salinity should also be significantly impacted by these storm events considering monitored concentrations upstream and downstream of Billys Island are significantly reduced. However, monitored Location 2 salinity showed a steadily declining concentration over the 10.5 week monitoring period, with no response to, or recovery from, catchment rainfall events.

- Data from the Shoalhaven City Council *Aqua Data* website (2015) has discrete salinity sample data adjacent to Billys Island in the main Crookhaven River channel (Location E-454). This data shows salinity concentrations vary significantly, and fall as low as 5 g/L following large rainfall events. We conclude that salinity concentrations at Billys Island in the Crookhaven River should respond to catchment rainfall / inflow events, as would be expected.

- Cumulative local rainfall prior to low salinity concentrations at Aqua Data site E-454 was lower than cumulative rainfall over the mid-late April 2015 storm event. We therefore expect Billys Island concentrations should also be < 5 g/L after the mid-late April 2015 storm event; however no response to catchment inflow was monitored.

- Based on this evidence we conclude that Location 2 monitoring data does not represent salinity conditions at Billys Island or the wider Crookhaven River, but rather represents specific localised conditions west of Billys Island at a certain depth. This is due to a combination of the following:

  - Stratification: the CTD was installed close to the river bed at -0.5 mAHD (to capture water level data at very low tides) and possibly monitored a denser saltwater wedge whilst a freshwater wedge on top went unmonitored.

  - Location: If the Location 2 CTD was monitoring the same point as Aqua Data site E-454 within the main Crookhaven River channel, we would expect responses similar to those observed at other locations over the 2015 monitoring period. However the CTD was positioned in the shallows approximately 225 m from the main channel and adjacent to diurnally wet / dry areas behind Billys Island. Based on this information and the observed Location 2 concentrations, the CTD may have been located within a 'dead spot' which did not experience expected Crookhaven River tidal exchange.

- We conclude that Location 2 salinity does not represent Billys Island salinity and we have therefore excluded this data from further analysis.

o Dip readings and CTD readings for conductivity were found to vary on collection dates. To better understand this variability testing of known concentration samples was undertaken. Conductivity calibration efforts are summarised in Section 11.4.3.

o Minor offsets in pressure measurements were found when comparing replacement divers with failed conductivity sensor CTDs, and hence all devices were tested. Three devices, including the two VEI 30 m CTDs with failed conductivity sensors, were found to require minor pressure corrections. Depth calibration efforts are summarised in Section 11.4.3.

11.4.3 Device Calibration

Two conductivity calibration samples were prepared for each CTD; one sample of demineralised water (conductivity ≈ 0.0 mS/cm) and one conductivity reference sample (80 mS/cm at 25°C) provided by Aqualab Scientific. The water quality meter and all CTDs (excluding those with failed conductivity sensors) were tested on 29 May 2015 and 1 July 2015.

All devices had similarly low conductivity readings when testing the demineralised water samples. The differences in conductivity readings only became apparent when compared to the 80 mS/cm reference sample. Summaries of measurements and differences to the 80 mS/cm reference sample are provided in:

o Table 15 for the Location 1 CTD prior to cleaning on 29 May 2015 in order to estimate calibration factors up to this date.

o Table 16 for the water quality meter and all CTDs after cleaning on 29 May 2015 in order to estimate calibration factors from this date.

o Table 17 for the water quality meter and all CTDs before cleaning on 1 July 2015 in order to estimate calibration factors up to this date.

Based on these calibration tests conductivity calibration factors for each device and for each monitoring period were adopted as summarised in Table 18 and have been used to scale up or down the measured conductivity data.

Table 15: Conductivity calibration summary 1 – undertaken on 29 May 2015 before CTD cleaning and compared to 80 mS/cm specific conductivity reference sample at 25°C.

Device	Measured Conductivity (mS/cm)	Measured Temperature (°C)	Specific Conductivity (mS/cm) [2]	Difference [3] (mS/cm)	Difference [3] (%)	Calibration Factor (%) [4]
Location 1 CTD [1]	64.132	16.43	76.68	-3.32	-4.1%	104.3%

Notes

1. Location 1 CTD was tested in the field before cleaning on 29 May 2015.
2. (Specific conductivity at reference temperature) = 100 x (Conductivity at sample temperature) / (100 + (Temperature coefficient) x ((Sample temperature) – (Reference temperature)))

   Where:

   Temperature coefficient = 1.91 %/°C and

   Reference temperature = 25°C.
3. Difference between device and 80 mS/cm reference sample specific conductivity at 25°C.
4. (Calibration factor) = (Reference sample specific conductivity)/(Device specific conductivity)

   Where:

   Reference sample specific conductivity = 80 mS/cm.

Table 16: Conductivity calibration summary 2 – undertaken on 29 May 2015 after CTD cleaning and compared to 80 mS/cm specific conductivity reference sample at 25°C.

Device	Measured Conductivity (mS/cm)	Measured Temperature (°C)	Specific Conductivity (mS/cm) [4]	Difference [5] (mS/cm)	Difference [5] (%)	Calibration Factor (%) [6]
Water quality meter [1]	77.9	22.2	82.30	2.30	2.9%	97.2%
Location 1 CTD [2]	63.352	17.0	74.78	-5.22	-6.5%	107.0%
Location 3 CTD [3]	74.368	22.2	78.57	-1.43	-1.8%	101.8%
Location 4 CTD [3]	76.344	22.4	80.33	0.33	0.4%	99.6%

Notes

1. The water quality meter was tested prior to field deployment on 29 May 2015.
2. Location 1 CTD was tested in the field after cleaning on 29 May 2015.
3. Location 3 and Location 4 CTDs refer to the replacement SWS 10 m CTDs installed on 29 May 2015 (see Table 14 for further information). These CTDs were tested prior to field deployment.
4. Formula as per Table 15 Note 2.
5. Formula as per Table 15 Note 3.
6. Formula as per Table 15 Note 4.

Table 17: Conductivity calibration summary 3 – undertaken on 1 July 2015 before CTD cleaning and compared to 80 mS/cm specific conductivity reference sample at 25°C.

Device	Measured Conductivity (mS/cm)	Measured Temperature (°C)	Specific Conductivity (mS/cm) [3]	Difference [4] (mS/cm)	Difference [4] (%)	Calibration Factor (%) [5]
Water quality meter [1]	77.8	21.8	82.86	2.86	3.6%	96.5%
Location 1 CTD [2]	69.868	18.83	79.20	-0.80	-1.0%	101.0%
Location 3 CTD [2]	62.724	13.45	80.48	0.48	0.6%	99.4%
Location 4 CTD [2]	71.716	19.04	80.93	0.93	1.2%	98.9%

Notes

1. The water quality meter was tested prior to field deployment on 1 July 2015.
2. All CTDs were tested after collection and before cleaning on 1 July 2015.
3. Formula as per Table 15 Note 2.
4. Formula as per Table 15 Note 3.
5. Formula as per Table 15 Note 4.

Table 18: Adopted calibration factor summary for each device and monitoring period.

	Calibration Factor Adopted for Monitoring Period (Start – Finish Date)		
Device	**17 April – 21 May 2015 [1]**	**21 – 29 May 2015 [1]**	**29 May – 1 July 2015 [2]**
Water quality meter [3]	96.9%	97.2%	96.5%
Location 1 CTD	104.3%	104.3%	104.0%
Location 3 CTD	– [4]	– [4]	100.6%
Location 4 CTD	– [4]	– [4]	99.2%

Notes

1. Adopted CTD calibration factors are as measured on 29 May 2015 before cleaning (Table 15).
2. All adopted CTD calibration factors are the average of calibration factors measured on 29 May 2015 after cleaning (Table 16) and 1 July 2015 before cleaning (Table 17).
3. The water quality meter was cleaned and calibrated by Thermo Fisher between each collection date. For this reason, the calibration factors on 29 May 2015 and 1 July 2015 are adopted for these dates, and the adopted calibration factor prior to these dates is the average of the two calibration factors assuming the calibration factor would be within this range.
4. Conductivity data unavailable for these monitoring periods for these locations as discussed in Section 11.4.2.

Further testing on all devices was undertaken to compare pressure readings. Three tests were conducted – one for atmospheric pressure, one for shallow water, and one for deeper water.

Three devices were found to be fairly consistently over or under reporting pressure. Fixed adjustments were adopted and introduced for these devices as shown in Table 19. Devices were checked in the field to determine the effects of any local environmental factors, however the adopted adjustments remained acceptable. These adjustments have been used to correct previously measured data in order to increase the accuracy of depth measurements. These three devices were replaced in the field and were not used for later measurements after inconsistencies were identified.

Table 19: CTD depth calibration summary.

Previous Device Use	Monitoring Period (Start – Finish Date)	Adopted Adjustment (m)
Location 3 CTD (VEI 30 m CTD)	17 April – 21 May 2015	-0.310
Location 4 CTD (VEI 30 m CTD)	17 April – 21 May 2015	+0.050
Location 3 Barometer (SWS 20 m Mini-Diver)	17 April – 29 May 2015	+0.055

11.4.4 Data Analysis

Water level observations at each of the four monitoring locations are given in Attachment G Figure 1and a detailed extract plot of the data is given in Attachment G Figure 2. The adopted adjustments have been used for the three devices requiring depth corrections as shown in Table 19. Tidal signal data at Greenwell Point (MHL 2015) is also shown for comparison (refer Attachment A PS01-AZ03 for location).

Table 20 summarises tidal data at each location for a typical tidal cycle. Compared to tidal observations at Greenwell Point (from MHL), tides are amplified at Culburra Road Bridge and Curleys Bay, and attenuated at Billys Island and Goodnight Island. There is a smaller tidal range and longer lag between high / low tides with increased distance from the Crookhaven River mouth at Greenwell Point. There is a longer lag / slower response time to low tides, and a shorter lag / faster response time to high tides.

Table 20: Tidal data summary for a typical tidal cycle.

Location	Order of Tidal Ranges (m) [1]	Change in Water Level [2]	Lag to High Tide (hr) [3]	Lag to Low Tide (hr) [3]
1 – Culburra Rd Bridge	1.08	Amplified	1.00	2.00
2 – Billys Island	1.09	Attenuated	0.75	1.50
3 – Curleys Bay	1.12	Amplified	0.50	1.25
4 – Goodnight Island	1.18	Attenuated	0.25	0.50
Greenwell Point (MHL) [4]	1.21	NA	NA	NA

Notes

1. High tide water level minus low tide water level for a typical tide. Although the tidal range varies for each individual tide, this parameter describes the order of tidal range changes between monitoring locations.
2. When compared to Greenwell Point peak water levels. Amplification means the high tide water level is higher than that at Greenwell Point; attenuation means the high tide water level is lower than that at Greenwell Point.
3. Lag time from the Greenwell Point high / low tide. Note the monitoring interval is 0.25 hours.
4. Data provided by Manly Hydraulics Laboratory (MHL 2015).

Salinity observations at all locations with valid data are given in Attachment G Figure 3, with monitoring data for individual locations provided in Attachment G Figure 4 and Figure 5. In generating this data we note:

- Calibration factors for each device as shown in Table 18 have been applied to the observed data.
- Estuary water samples at each of the 4 CTD locations were laboratory tested by Envirolab Services (2015) for electrical conductivity (EC) and total dissolved solids (TDS). Results were used to determine salinity conversion factors at each monitoring location in order to convert measured conductivity to salinity concentrations. Data and conversion factors are summarised in Table 21.
- Daily rainfall at Callala Treatment Plant (BOM station 68245) is shown overlaying the salinity data for the monitoring period.
    - Culburra Treatment Works (BOM station 68083) is closer to the study area however rainfall data up to the end of monitoring was not available at the time of data analysis.
    - Over the monitoring period 408 mm rainfall fell at Callala Treatment Plant.
    - A major rainfall event occurred in mid to late-April, when 185 mm of rain fell over 4 days, including a maximum daily rainfall of 72 mm on 23 April 2015.
    - A second major rainfall event occurred in mid-June 2015, when 83 mm of rain fell over 4 days, including 48 mm on June 19 2015.
    - Review of other nearby BOM stations showed similar rainfall depths were experienced over the catchment draining to the Crookhaven River and Shoalhaven River.
- Data provided by Water NSW (2015) for Tallowa Dam (discharging to Shoalhaven River) showed 1.36 m and 25,804 ML of weir flow on 22 April 2015. Following this storm event Tallowa Dam continued to spill until 8 June 2015, and then started spilling once again during the mid-June 2015 rainfall event. These large volumes of fresh water entering the Shoalhaven River also had a significant impact on salinity within the Crookhaven River.

Table 21: Lab test data summary to derive salinity conversion factors (Envirolab Services 2015).

Location	Electrical Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Salinity Conversion Factor [1]
1 – Culburra Rd Bridge	14,000	9,800	0.700
2 – Billys Island	34,000	27,000	0.794
3 – Curleys Bay	36,000	28,000	0.778
4 – Goodnight Island	40,000	32,000	0.800

Notes

1. Salinity Conversion Factor = Total Dissolved Solids (mg/L) / Electrical Conductivity (µS/cm).

Salinity concentration observations show the following:

- Location 1 Culburra Road Bridge – Attachment G Figure 4

  - During the monitoring period salinity concentrations range between 2.2 g/L minimum and 29.8 g/L maximum with an average salinity of 18.3 g/L and a median salinity of 17.9 g/L.
  - The salinity amplitude on the diurnal tide is approximately 0.5 – 5.0 g/L.
  - Salinity concentration observations at Culburra Road Bridge are always lower than those at Billys Island, Curleys Bay and Goodnight Island, as expected being further upstream and experiencing less tidal flushing.
  - Concentrations decline slowly from the start of monitoring to 23 April 2015, after which they decline sharply in response to 72 mm of rainfall on 23 April 2015.
  - The twin troughs in salinity observed on 23 April 2015 correspond to low tides, and the peak between these troughs corresponds to the high tide. This is likely due to freshwater inflow from the nearby Culburra Road flood gate opening during low tide, then closing during high tide and experiencing tidal flushing, before opening again during low tide and injecting additional freshwater.
  - Salinity concentrations rise fairly steadily until mid-June 2015, when the second major rainfall event causes additional freshening.
  - Salinity concentrations decline until late June 2015 after which they plateau. Salinity concentrations do not recover to initially observed values.

- The freshening event on 17 May 2015 occurs on the spring low tide. The observed freshening is likely the result of release of freshwater from the flood gate and discharge into a small volume (due to low tide) of estuarine water. The result is a significant depression in salinity not directly as a result of rainfall immediately prior. We do not expect this event will be able to be replicated by the estuarine processes model.

o <u>Location 2 Billys Island</u>

- Although continuous monitoring observations are unavailable due to unrepresentativeness of the CTD (as discussed at Section 11.4.2), discrete samples from dip readings are shown in Attachment G Figure 3.

- Dip readings at Billys Island are always higher than those at Culburra Road Bridge and always lower than those at Goodnight Island, as expected due to intermediate distance between the ocean and upstream areas. Dip readings at Billys Island are generally similar to those at Curleys Bay.

- Salinity concentrations follow the same overall downward trend as the other three monitoring points due to the significant rainfall events.

o <u>Location 3 Curleys Bay</u> – Attachment G Figure 5

- During the monitoring period salinity concentrations range between 20.3 g/L minimum and 34.1 g/L maximum with an average salinity of 28.8 g/L and a median salinity of 29.6 g/L.

- The salinity amplitude on the diurnal tide is approximately 1.0 – 5.0 g/L.

- Negative 'spikes' have been removed from the data as discussed at Section 11.4.2.

- As with Billys Island, salinity concentration observations in Curleys Bay are always higher than those at Culburra Road Bridge and always lower than those at Goodnight Island, as expected due to intermediate distance between the ocean and upstream areas.

- Salinity concentrations rise from 29 May 2015 to mid-June 2015 and are likely recovering from freshening caused by the rainfall event in late May 2015.

- The second major rainfall event in mid-June 2015 causes concentrations to decrease, and by late June 2015 observed concentrations are recovering back to ocean concentrations.

o Location 4 Goodnight Island

- Although continuous monitoring observations are unavailable due to siltation of the CTD (as discussed at Section 11.4.2), discrete samples from dip readings are shown in Attachment G Figure 3.

- Dip readings at Goodnight Island are always higher than those of upstream locations as expected due to proximity to the ocean.

- Salinity concentrations follow the same overall downward trend as the other three monitoring points due to the significant rainfall events.

In general, freshening events occur during and after periods of high rainfall, with tidal flushing then increasing salinity concentrations. Water quality meter dip readings generally confirm measured CTD salinity concentrations, which have been adjusted by the calibration factors summarised in Table 18. We note that we did not perform calibration checks on the water quality meter used on 17 April and 21 May 2015 prior to readings being taken, and hence the calibration factor applied to these readings may be incorrect. This may be the reason for differences in CTD and dip reader observations on these dates. We believe, however, that the dip readings confirm field CTDs have recorded salinity data sufficiently accurately for the purposes of this exercise.

11.4.5 Uncertainty

Uncertainty in CTD measurements is due to:

o Instrument accuracy limitations as provided in Table 13.

o Possible minor movement of riverbed and equipment which would affect surveyed water levels.

o Possible minor differences in barometer pressure readings introduced by assumed linear interpolation over high tide inundation periods.

- o Possible minor differences in actual pressure and conductivity calibration factors and salinity conversion factors to those adopted.

The combination of these factors is expected to introduce a minor error to the data. The range of uncertainty for water level observations is of the order of ± 2.5%, and the range of uncertainty for salinity concentration observations is of the order of ± 5.0%. We consider however that the observed trends, shapes of curves, orders of measurements, ranges of measurements and agreement with dip readings enable a reliable representation of the water level and salinity concentration conditions at the site.

11.5 Summary

The 2015 ADCP and CTD datasets as a whole are considered to be adequate. Together with the supplementary data (Section 11.1), we believe this combined data suite provides a detailed snapshot of estuarine salinity, flow and water level conditions within the Crookhaven River. We believe the data is sufficiently accurate for the purposes of estuary characterisation and model hydrodynamic and advection dispersion calibration.

The information presented in this section has been sent to the peer reviewer who confirmed it is as being suitable for the purposes of model calibration (email 28 July 2015).

12 Attachment E: Estuarine Processes Modelling Details

12.1 Overview

12.1.1 Model Approach

The adopted modelling approach for the estuarine processes assessment is:

1. Develop hydrodynamic and concentration calibration dataset – refer Section 12.2.

2. Develop hydrodynamic and solute transport model – refer Section 12.3.

3. Calibrate hydrodynamic and solute transport model – refer Section 12.4.

4. Define development scenario assessment suite – refer Section 12.5.

5. Adapt calibrated model for the development scenario assessment suite – refer Section 12.6.

6. Assess development scenario impacts – refer Section 5.

This modelling approach has been subject to extensive consultation with DoPE and their peer reviewer, Mr. Michael Barry of BMT WBM, lead developer of Tuflow Advection Dispersion (AD). All model setup, calibration and assessment methodology contained in this report (steps 1 to 5 above) have been reviewed by DoPE and BMT WBM who have confirmed them as technically acceptable.

12.1.2 Model Suite

The Tuflow classic hydraulic model together with the Advection Dispersion (AD) module (version received 22 September 2015 from BMT WBM) and the SMS graphical user interface package (SMS 11.2.10, May 11 2015) were used to model estuarine processes and to assess Crookhaven River hydraulics, flow processes and contaminant fate and transport.

DoPE / BMT WBM have confirmed the adopted model suite is acceptable for the purposes of this assessment (18 December 2014 and 10 April 2015).

12.2 Calibration Data Summary

A comprehensive monitoring regime was undertaken between April 2015 and July 2015 and comprised:

1. Water level data at 5 locations throughout Crookhaven River.

2. Acoustic Doppler Current Profiler (ADCP) transect flow data at 2 locations across Crookhaven River.

3. Salinity concentration data at 4 locations throughout Crookhaven River.

This monitoring regime represents the primary data suite used for estuarine processes model calibration, and is referred to as the '2015 calibration period' throughout this report.

A secondary dataset based on discrete salinity concentration samples at 3 NSW Food Authority Shellfish Quality Assurance Program (SQAP) monitoring points has also been used for calibration and is referred to as the '2004 calibration period'.

Locations of each of the monitoring points and transects for 2015 and 2004 calibration periods are provided in Attachment A PS01-AZ03. Full details of the monitoring regime, data analysis and supplementary data are provided in Attachment D.

12.3 Calibration Model Setup

12.3.1 Overview

The Tuflow AD model was constructed to represent approximately 14 km of the Crookhaven River from the confluence with Berrys Canal to the tidal limit, including the Curleys Bay estuary.

The same model setup was used to simulate the two different time periods for the purposes of calibration. The '2015 calibration period' was run to calibrate water levels, flows and salinity concentrations. The '2004 calibration period' was run to check calibration of salinity concentrations. The only differences between these models are the boundary condition inputs, all other model elements and inputs are unchanged.

12.3.2 Simulation Setup

The following simulation setup was adopted:

1. Simulation period:

    a. The '2015 calibration period' was run for six months from 1 January 2015 to 3 July 2015. This provided sufficient time for the model to 'warm up' and distribute salinity throughout the estuary prior to CTD monitoring data which commenced 17 April 2015.

    b. The '2004 calibration period' was run for 12 months from 1 January 2004 to 1 January 2005. This provided sufficient time for the model to 'warm up' and distribute salinity throughout the estuary prior to the available SQAP data set commencing 1 April 2004.

2. A computational timestep of 12.5 seconds was adopted based on minimising model run times and ensuring model stability (i.e. half the adopted grid cell size of 25m x 25m as detailed in Section 12.3.3).

    a. Use of this timestep involves over 2.5 million computational steps at each model grid cell over the course of a simulated year.

    b. This timestep has been selected in part to ensure that stormwater volumes injected into estuary cells adjacent to the site do not exceed the ambient volume over any given timestep. This prevents mass conservation issues within the model.

    c. The adopted grid cell size is 25m x 25m as detailed in Section 12.3.3. The ambient volume of a cell at the boundary of the estuary (into which upslope stormwater inflows discharge) with a depth of 40 mm (approximate minimum depth for these areas) is 25 m^3 (25m x 25m x 0.04m), which when divided by the 12.5 second timestep is 2 m^3/s.

    d. The maximum flow rate from any site boundary condition for any scenario considered by this assessment is < 1 m^3/s, which is distributed over several cells as discussed in Section 12.3.3.

e. Stormwater injection, < 1 m^3/s over several cells, does not exceed the ambient cell volume (minimum 2 m^3/s), preventing mass conservation issues.

3. Model results are output every 15 minutes for consistency with the 2015 calibration data monitoring interval (refer Section 11.4.1).

12.3.3 Hydraulic Setup

The following model construction was used to achieve adequate hydrodynamic calibration:

1. 25m x 25m topographic / bathymetric grid derived from a 3D surface based on:

    a. Topography data sourced from LIDAR (LPI, 2010).

    b. Bathymetric data (NSW OEH, 2012) – refer Attachment I.

        i. We note the bathymetry data terminates west of Pyree Lane and does not extend to the tidal limit at Greenwell Point Road, as shown in Attachment I.

        ii. A constant bed slope based on the available bathymetric data was used to extend the model past the bathymetric data extent to the tidal limit.

    c. A range of grid cell sizes were trialled to test the adequacy of calibration. Grids coarser than 25m x 25m provided marginally poorer overall calibration, whilst finer grids had comparable calibration (but significantly longer model run times). The 25m x 25m was selected to optimise simulation run times whilst maintaining comparable calibration.

    d. The 25m x 25m grid has a sufficiently fine resolution to represent key bathymetric features and hydraulic constrictions, this is demonstrated by its achievement of adequate hydrodynamic calibration (Section 12.4.2 and 12.4.3).

    e. At a resolution of 25m x 25m the model domain has up to14,000 wet cells for the simulated scenarios.

2. Establishment of model extents to provide an adequately large model domain (Attachment A PS01-AZ04):

    a. The downstream model extent was placed across the Crookhaven River between Greenwell Point and Orient Point to coincide with the Manly Hydraulics Laboratory

(MHL) Greenwell Point tidal monitoring gauge (Attachment A PS01-AZ03).

i. This boundary is 1.8 km downstream of the proposed development site as the crow flies, or approximately 2.5 km following the main channel centre line of the Crookhaven River.

ii. We consider this boundary is located sufficiently far away from the proposed development site to ensure it does not incorrectly influence model predictions in the area of interest.

b. The upstream model extent was placed at the tidal limit as shown in Attachment I (NSW OEH, 2012).

c. An area upstream (south) of the Culburra Road flood gate was included to model stormwater storage and flood gate discharge.

d. The remainder of the model extents included upstream inflow locations and all areas inundated by the peak spring high tide.

3. Establishment of model boundary conditions (Attachment A PS01-AZ04):

a. Boundary conditions are located at the edges of the active model domain and are required to define how the model interacts with the environment outside of the study area.

b. Downstream boundary at Greenwell Point based on tidal water level data provided by MHL (2015) over the simulation period. Water levels from 2015 and 2004 were used for the 2015 and 2004 calibration models respectively.

c. Upstream flow boundaries based on hydrological and site sub-catchments as shown in Attachment A PS01-AZ01 and consistent with stormwater hydrology and pollutant (MUSIC) modelling (Attachment C).

i. Flow rates are driven by 2015 and 2004 pluviograph and evapotranspiration data for the 2015 and 2004 calibration periods respectively (Attachment C, Section 10.2).

ii. MUSIC model results with and without vegetation uptake have the same flow results as flow rates are not affected by the vegetation uptake node (Attachment C, Section 10.3).

iii. A total of 20 flow boundaries (14 off-site sub-catchments and 6 site sub-catchments) were used in foreshore areas to account for all upstream flow arriving at the Crookhaven River (Attachment C, Section 10.4).

iv. Site boundaries distribute flow over several cells to represent sheet flow from forested areas in existing conditions, and to ensure consistency with proposed water quality control systems which discharge stormwater over long (> 100 m) weirs to distribute flows across the foreshore, as discussed in the WCMR.

v. All stormwater inflow boundaries are located upslope of the water's edge as shown in Attachment A PS01-AZ04. These cells ensure shallow stormwater insertion (overland flow only) to the model and prevent artificial dilution of pollutants.

vi. All upstream flow boundaries are modelled using 'SA' polygons.

vii. We have researched gauge data within Crookhaven River to compare with input hydrographs but conclude data is unavailable.

4. Joining Crookhaven River invert levels with z-line modifications based on the bathymetric data to ensure key bathymetric features were included in modelling by ensuring grid cells were at documented invert levels.

5. Assigning Manning's roughness coefficients based on SIX Maps Viewer (2015) and Nearmap (2015) aerials as shown in Table 22. We note that materials include foreshore areas where catchment runoff enters Crookhaven River.

6. Incorporation of the Culburra Road flood gate as a 1D element within the 2D domain. This included:

   a. Assigning size and invert levels based on survey data provided by Allen Price & Scarratts (2015).

   b. Adoption of a blockage of 90% considering the physical blockage by the flood gate and at-site debris potential, and based on the range of blockages given by the procedure in Australian Rainfall & Runoff (AR&R 2013) *Project 11 – Blockage of Hydraulic Structures Stage 2 Report*.

c. Assigning a Mannings roughness coefficient of 0.013 (concrete).

d. Modelling connections to the 2D domain as 'SX' type inflows to ensure they are recognised by Tuflow AD.

7. Specification of Culburra Road crest levels based on survey data provided by Allen Price & Scarratts (2015) to ensure road overtopping from land south of the flood gate is appropriately modelled (although overtopping did not occur for any scenario modelled).

8. Initial water level of -0.6 mAHD to simulate the Crookhaven River at a spring low tide.

Table 22: Mannings roughness used in Tuflow modelling.

Catchment Material	Manning's Roughness Applied
Crops	0.070
Forest	0.120
Grassland	0.035
Mangrove	0.120
Urban	0.020
Watercourse	0.04 when depth ≤ 0.1 m
	0.03 when depth > 0.1 m

12.3.4 Advection / Dispersion Setup

The following model construction was used to achieve adequate salinity advection dispersion calibration:

1. Longitudinal and transverse dispersion coefficients of 2,500 m^2/s and 250 m^2/s respectively. A proprietary version of Tuflow AD (received 22 September 2015 from BMT WBM) was used to enable modelling of dispersion coefficients in excess of 500 m^2/s, which was required to achieve calibration. Details of dispersion coefficient calibration are provided in Section 12.4.4.

2. Minimum dispersion coefficient of 0 m^2/s for the entire model domain, as this parameter was found to introduce model instabilities.

3. Exclusion of decay and settlement parameters.

4. Initial concentrations based on approximate average data in the estuary as shown in Attachment A PS01-AZ05.

    a. Adopted initial concentrations for each zone based on discrete concentration data from sources detailed in Section 11.1.

    b. Where data is not available in a specific zone the initial concentration has been estimated based on interpolation / extrapolation.

    c. We note the available data is not of high quality:

        i. There is a high degree of concentration variability;

        ii. Some locations have a small amount of available samples; and

        iii. Data is based on discrete sampling which may be undertaken specifically after storm events to check water quality trigger values, and hence data may not represent typical estuary conditions.

    d. Notwithstanding this, the data represents the best available pollutant concentration information in the Crookhaven River, and spatial variation reflects the expected trend of increasing concentration with increasing distance upstream.

5. Stormflow salinity concentration of 100 mg/L assigned to each inflow boundary as per discussions with BMT WBM (June 18 2014).

6. Varying downstream salinity boundary condition at Greenwell Point specified to simulate Shoalhaven River freshening, as described in the following section.

12.3.5 Downstream Salinity Boundary Condition Setup

The downstream salinity boundary condition was established as follows:

1. Approximately daily salinity concentration data at Shaws Creek provided by Mr. Robert Thorne (2015, refer Section 11.1) was compared to antecedent rainfall at three Bureau of Meteorology (BOM) rainfall stations across the Shoalhaven River catchment for 1997 and 1998.

2. Tallowa Dam storage and spilling data provided by Water NSW (2015) (previously Sydney Catchment Authority) was considered and used as a filter for upstream catchment antecedent rainfall.

3. A relationship between catchment antecedent rainfall, Tallowa Dam freshwater contributions and Greenwell Point salinity was derived based on this data.

4. Different relationship trend types were trialled including linear, exponential / logarithmic and power relationships.

5. 12 day antecedent rainfall was adopted based on iterative regression analysis and 'goodness of fit' to the salinity data.

The relationship for Greenwell Point (GP) salinity developed from iterative regression analysis is:

If Tallowa Dam is not spilling (storage level ≤ +50 mm),

$$\text{GP Salinity} = e^{[(R1)/3 - b]/c]}$$

If Tallowa Dam is spilling (storage level > +50 mm),

$$\text{GP Salinity} = e^{[(R1 + R2*S/M + R3*S/M)/3 - b]/c]}$$

Where:

GP Salinity =	Greenwell Point salinity concentration (g/L)
b =	coefficient determined through iterative regression analysis to maximise goodness of fit (158.0)
c =	coefficient determined through iterative regression analysis to maximise goodness of fit (-44.4)
R1 =	12 day antecedent rainfall downstream of Tallowa Dam at Nowra Treatment Works / Nowra Boat Shed (BOM Station 68048 / 68213) based on data availability (mm)
R2 =	12 day antecedent rainfall upstream of Tallowa Dam at Braidwood (Wallace Street) (BOM Station 69010) (mm)
R3 =	12 day antecedent rainfall upstream of Tallowa Dam at Nerriga (Tolwong) (BOM Station 68085) (mm)
S =	Tallowa Dam storage level (m) (depth of water over Tallowa spillway)
M =	Maximum Tallowa Dam storage level (m)

This relationship provides appropriate prediction of salinity concentrations at Greenwell Point compared to Shaws Creek 1997 – 1998 salinity monitoring data as presented in Attachment G Figure 6.

The developed relationship was then used to estimate Greenwell Point salinity over the 2015 and 2004 calibration periods based on the available rainfall and Tallowa Dam storage data. The estimated salinity applied at the Greenwell Point tidal boundary over the simulation periods are presented in Attachment G Figure 6 and Figure 7 for the 2014 and 2004 calibration periods respectively.

Private Shaws Creek salinity data over these periods provided by Mr. Robert Thorne ('Thorne' data) had acceptable agreement to the developed relationship. The comparison to 2015 salinity concentrations has been presented to the peer reviewer on 9 November 2015.

12.4 Calibration Results

12.4.1 Overview

Table 23 summarises parameters iteratively modified and optimised during calibration. Various combinations of the parameters within the given ranges were used, and over 100 total simulations were run iteratively to achieve the adopted 'best case' calibration. The combination of parameters summarised in Section 12.3 and in the adopted values in Table 23 provide the best hydrodynamic and advection dispersion calibration to the monitoring data, as discussed in the following sections.

Table 23: Parameters optimised and adopted during calibration.

Parameter	Calibration Range / Option	Adopted Values
Grid cell size	17.5m x 17.5m to 50m x 50m	25m x 25m [1]
Grid rotation	Horizontal / rotated	Horizontal [2]
Crookhaven River invert specification	Manually specified / grid specified	Manually specified [3]
Flood gate	Exclusion / inclusion	Inclusion [4]
Model extents	Bathymetry extent / tidal limit / upstream of flood gate	Tidal limit and upstream of flood gate [5]
Boundary condition type	SA polygons / QT lines	SA polygons [6]
Flood gate blockage	0% – 90%	90% [7]
Mannings roughness coefficients	0.04 ≤ 0.1 m, 0.01 > 0.1m to 0.06 constant depth	0.04 ≤ 0.1 m, 0.03 > 0.1m [8]
Longitudinal/transverse dispersion coefficients	100/10 m^2/s to 10,000/1,000 m^2/s	2,500/250 m^2/s [9]
Factored inflow hydrographs	12.5% to 100% of MUSIC output	50% of MUSIC output [10]
Stormflow salinity concentration	100 – 5,000 mg/L	100 mg/L [11]
Greenwell Point salinity boundary condition	Constant / synthetic	Synthetic [12] (see Section 12.3.5)
Initial salinity	Constant / spatially varying Assumed / based on data	Spatially varying and based on data [13]
Minimum dispersion	Exclusion / inclusion: 0 – 100 m^2/s, constant / spatially varying	Exclusion [14]

Notes

1. Overall calibration for 17.5m x 17.5m grid is comparable to the 25m x 25m grid, while coarser grids provide marginally poorer overall calibration. 25m x 25m grid adopted over 17.5m x 17.5m grid to minimise simulation run times whilst maintaining comparable calibration.
2. Horizontal grid adopted as the Crookhaven River is sinuous without a principal flow direction, and there were no appreciable differences to overall calibration using a rotated grid.
3. Manual z-line specification ensured grid cells were at Crookhaven River inverts and provided best tidal exchange calibration.
4. Inclusion of flood gate enabled modelling of intermittent freshwater inflow and provided best salinity calibration at Location 1 Culburra Road bridge.
5. Modelling to the tidal limit and the area upstream of the flood gate enabled best tidal exchange calibration and best simulation of flood gate operation.
6. SA polygon boundary condition type increased model stability and had no material difference to overall calibration.
7. 90% flood gate blockage provided best salinity calibration at Location 1 Culburra Road bridge.
8. Adopted Mannings roughness coefficients provided best tidal exchange and water level calibration.
9. Adopted dispersion coefficients provided best overall salinity calibration, as discussed further in Section 12.4.4.
10. Adopted 50% factored MUSIC hydrographs provided best overall salinity calibration, as discussed further in Section 12.4.4.
11. Changing the stormflow salinity concentration had no appreciable differences to salinity calibration.
12. Use of synthetic Greenwell Point salinity boundary condition enabled modelling of salinity dynamics. Various iterations of the synthetic salinity boundary were modelled before adoption of the relationship in Section 12.3.5 which provided the best overall salinity calibration.
13. Spatially varying initial salinity concentrations based on the total available estuary dataset (refer Attachment D Section 11.1) provided best overall salinity calibration.

14. Exclusion of minimum dispersion coefficient provided best overall salinity calibration and avoided model instabilities, which were introduced when minimum dispersion > 0 m^2/s.

12.4.2 2015 Water Level Calibration

Tuflow modelled water levels compared to CTD measured water levels over the 10.5 week monitoring period at each of the five monitoring locations (including the Manly Hydraulics gauge) are summarised in Attachment G Figure 9 to Figure 23. Figures show calibration data for the entire monitoring period and are 'zoomed in' over neap and spring tides. Summary of correlation between observed and modelled temporal water levels at each location are summarised in Table 24.

Correlation between observed and modelled temporal water levels shows excellent calibration ($R^2 > 0.95$) at all locations. Modelled water levels have consistent amplitude and phase with measured water levels at all locations. Monitored water level attenuations / amplifications and lags to peaks / troughs to the downstream boundary are similarly well replicated by the model. Minor phase differences occur at times however we consider these will not materially affect the outcomes of this assessment.

Table 24: Water level correlation between observed and modelled water levels at each location.

Location	Correlation Coefficient (R^2)
1. Culburra Road bridge (CTD data)	0.979
2. Billys Island (CTD data)	0.967
3. Curleys Bay (CTD data)	0.966
4. Goodnight Island (CTD data)	0.989
Greenwell Point (Manly Hydraulics data)	1.000

12.4.3 2015 Flow Calibration

Tuflow modelled flows compared to ADCP measured flows during neap and spring tides at Greenwell Point (GP) and upstream adjacent to Billys Island (US) are summarised in Attachment G Figure 24 and tidal exchange calibration is summarised in Table 25.

Results show excellent calibration at both locations for both monitored tides. The full range of tidal inflows and outflows are reproduced at Greenwell Point for both spring and neap flood and ebb tides, and modelled tidal volumes closely match estimated volumes. The modelled tidal prism at the US transect are overpredicted. We note that the ADCP report (Haskoning 2015, Attachment H) advises care be taken in interpretation of US tidal prisms due to extrapolation of the measured data and estimation of US bank flows which were inaccessible (due to water depth) during monitoring. Following from this, we conclude the estimated US ADCP tidal exchanges were underpredicted, and the modelled tidal exchanges are considered appropriately calibrated. All results show very good correlation between the timing of tide peaks and troughs.

Table 25: Tidal exchange calibration results for neap and spring ebb and flood tides at both ADCP monitored locations.

	Estimated Flow ($m^3 \times 10^6$) [1]		Modelled Flow ($m^3 \times 10^6$) [2]		Difference ($m^3 \times 10^6$)		Difference (%)	
	Location		Location		Location		Location	
Tide	**GP**	**US**	**GP**	**US**	**GP**	**US**	**GP**	**US**
Neap – Flood	3.212	1.366	3.064	1.169	-0.148	-0.197	-5%	-14%
Neap – Ebb	2.360	0.587	2.462	0.983	0.102	0.396	4%	67%
Spring – Flood	5.033	1.788	4.880	1.817	-0.153	0.029	-3%	2%
Spring – Ebb	5.225	1.269	4.883	1.854	-0.342	0.585	-7%	46%

Notes

1. Estimated tidal exchange from the ADCP report (Haskoning 2015, Attachment H Table 8).
2. Tuflow modelled tidal exchange.

12.4.4 2015 and 2004 Advection / Dispersion Calibration

Measured 2015 salinity concentrations over the 10.5 week monitoring period (Attachment G Figure 3) are compared to 2015 modelled salinity concentrations in Attachment G Figure 25 and at each individual CTD location in Attachment G Figure 26 to Figure 29. 2004 modelled salinity concentrations are provided in Attachment G Figure 30 and are compared to 2004 data at each individual SQAP location in Attachment G Figure 31 to Figure 33. Results show salinity concentrations are generally well predicted by the model.

We note the following regarding parameter optimisation undertaken to achieve adequate salinity calibration:

- Factored hydrographs
    - We expect catchments will have a large amount of storage due to catchment characteristics discussed in Section 10.2, which include multiple swamps and large areas of very low gradient agricultural land which have been significantly modified and consist of multiple farm dams and rerouted drainage channels.
    - MUSIC output suggests 40 – 55% of catchment rainfall is converted to runoff for various catchments, however due to significant catchment storage this is likely lower in reality.
    - Use of the full MUSIC hydrographs in the model resulted in freshening of the Crookhaven River beyond observed

freshening, which is likely due to MUSIC's overprediction of runoff.

- Calibration process involved factoring of hydrographs at 12.5%, 25% and 50% of MUSIC output to test sensitivity.
- Through various iterations, best calibration was achieved with a factor of 50% of MUSIC hydrographs. This suggests 20 – 28% of catchment rainfall is converted to runoff, which is considered to be a more reasonable rate than the full MUSIC output.

o Dispersion

- Typical dispersion values in longitudinal estuaries are 100 – 1,000 m^2/s (Fischer et al. 1979 and Schnoor 1996 as reported in US EPA 2013).
- Utilising dispersion values within this range resulted in modelled salinity gradients and diurnal salinity amplitudes in excess of those observed during monitoring. This may be due to three dimensional mixing processes occurring in the estuary which are not incorporated in the Tuflow classic (2D) calculations.
- Dispersion coefficients were increased above typical values (1,000/100 m^2/s) to better account for 3D effects and achieve better salinity calibration. A proprietary version of Tuflow AD (received 22 September 2015 from BMT WBM) was used to enable modelling of higher dispersion coefficients.
- Higher longitudinal / transverse dispersion coefficients of up to 10,000/1,000 m^2/s and minimum dispersion coefficients of up to 100 m^2/s were trialled.
- Best overall calibration was achieved with longitudinal/transverse dispersion coefficients of 2,500/250 m^2/s and no minimum dispersion (to avoid model instabilities when minimum dispersion > 0 m^2/s). These values gave the best balance of salinity gradient calibration of all simulation iterations at all locations.
- 3D processes effects have been adequately parameterised in the 2D Tuflow classic model through the use of these atypically high dispersion coefficients, as demonstrated by the calibration discussed in the following sections.

- Summary of monitored and modelled salinity amplitudes on the diurnal tide at each calibration point is provided in Table 26. With the exception of Culburra Road bridge (which is affected by nearby inflow boundary conditions, as detailed in following sections), all points are well calibrated to monitored diurnal salinity amplitudes.

- Modelled diurnal salinity amplitudes generally increase with further distance upstream, as expected due to increased interaction with freshwater and increased salinity gradient.

Table 26: Comparison of monitored and modelled salinity amplitudes on diurnal tide at all locations.

Location [1]	Approximate Salinity Amplitude on Diurnal Tide (g/L)	
	Monitored – Attachment G Figure 3	Modelled – Attachment G Figure 25 & Figure 30
1. Culburra Road bridge	0.5 – 5.0	0.5 – 10.0 [2]
2. Billys Island	NA [3]	0.5 – 7.5
3. Curleys Bay	1.0 – 5.0	0.5 – 5.0
4. Goodnight Island	NA [3]	0.5 – 5.0
SQAP 1 [4]	Likely 0.5 – 5.0 [5]	0.5 – 5.0
SQAP 2 [4]	Likely 1.0 – 5.0 [6]	0.5 – 2.0
SQAP 13 [4]	NA	0.0 – 2.5

Notes

1. Refer to Attachment A PS01-AZ03 for calibration locations.
2. Salinity amplitude is overpredicted at Culburra Road bridge due to proximity to inflow boundary conditions, as discussed in further detail in the following sections.
3. Salinity logger data has been excluded from this analysis as discussed in Section 11.4.2.
4. SQAP data is based on discrete sampling and hence diurnal salinity amplitude data is unavailable, however has been estimated for points near 2015 CTD monitoring locations.
5. SQAP 1 is 1.7 km from the Culburra Road bridge CTD and likely has a similar diurnal salinity amplitude.
6. SQAP 2 is 500 m from the Curleys Bay CTD and likely has a similar diurnal salinity amplitude.

The following description of results is provided:

- <u>Overall results at all locations</u> – Attachment G Figure 25 and Figure 30

  - Larger storm events occurred during the 2015 calibration period than during the 2004 calibration period. During the 2015 calibration period Tallowa Dam was at or over capacity 93% of the time, whereas during the 2004 calibration period Tallowa Dam did not overtop (based on data from Water NSW 2015). Crookhaven River therefore experienced increased stormwater freshening during 2015 compared to 2004 due to larger local rainfall events and greater upstream freshwater contributions, as reflected by model results.

- Modelled salinity concentrations at downstream locations (i.e. closest to the ocean boundary) are sensitive to the synthetic salinity boundary condition at Greenwell Point. Sensitivity and response timing decreases with further distance upstream.

- The model replicates short-term mixing processes as reflected by the generally well calibrated diurnal salinity amplitude (Table 26), and also replicates broad scale long-term salinity trends as reflected by the generally well calibrated recovery timing and pattern of responses at all locations.

o <u>Location 1 Culburra Road bridge</u> – Attachment G Figure 26

- 68% of the total off-site catchment draining to the Crookhaven River is detained by the flood gate beneath Culburra Road Bridge, which releases freshwater during major inflows and then incrementally on daily low tides for a long period after stormflows cease. This is evident in the Location 1 CTD salinity data, which shows salt concentrations continue to decline for up to a week after rainfall as periodic inflow to the estuary continues through the flood gate.

- The modelled flood gate simulates this intermittent outflow and provides a similar decline in salinity over a number of days after large rainfall events, as per observed conditions.

- Modelled freshening is not as rapid as monitored freshening but resultant concentrations prior to recovery are similar.

- Modelled salinity concentration has matching recovery timing and pattern to observed concentrations, although salinity levels are slightly overpredicted after the mid-late June 2015 rainfall event.

- Diurnal salinity amplitude:

  - The modelled amplitude of diurnal salinity variation at Location 1 is overestimated as a consequence of proximity to inflow boundary conditions.

  - Location 1 is immediately adjacent to the flood gate through which sub-catchment 'US2' discharges, and also close to sub-catchment 'US1b2', both of which are significant model freshwater contributors.

- These catchments have an increased ratio of baseflow to stormflow to account for catchment characteristics (as discussed in Section 10.2), and hence post-storm events they release freshwater slowly over long time periods. Intermittent flow from the flood gate also contributes to this effect. This freshwater mixes with the saltier estuarine water over a long time period, which leads to the greater salinity amplitudes modelled in this area after storm events.

- Observations of several points in the upstream area confirmed that areas closer to boundary conditions experienced larger than monitored diurnal salinity amplitudes. Conversely, areas further from boundary conditions experienced expected diurnal salinity amplitudes.

- For comparison, SQAP 1 (Attachment G Figure 31) is 1.7 km downstream of Location 1 and is not adjacent to any major catchment inflow locations, and hence the modelled diurnal salinity amplitude at this point is smaller than that at Location 1. As per Table 26, SQAP 1 modelled diurnal salinity amplitude matches expected conditions.

- A video of modelled salinity concentrations in this area has been sent to the peer reviewer who agreed with this explanation (email 12 February 2016).

- We therefore conclude that the overestimated salinity amplitude at Location 1 is a modelling artefact which occurs due to proximity to large inflow boundary conditions.

- This modelling artefact is spatially restricted to this area, as shown by the diminished effects at SQAP 1 (Attachment G Figure 31) and in the video presented to the peer reviewer.

- In summary, despite the modelling artefact influencing localised diurnal salinity amplitudes, modelled Location 1 salinity has good agreement with monitored freshening and recovery patterns and absolute concentrations.

- Location 2 Billys Island – Attachment G Figure 27

  - Modelled salinities correspond well with discrete sampling points.

  - Salinities after the large storm event (23 April 2015) remain close to freshwater concentrations for up to a week, which matches monitored concentrations upstream at Culburra Road bridge (Attachment G Figure 26) and downstream at Shaws Creek ('Thorne' data).

- Location 3 Curleys Bay – Attachment G Figure 28

  - Modelled salinities very closely follow observed patterns, rates of response to freshwater inflow events, and recovery to seawater concentrations.

  - Modelled salinity gradient and amplitude of diurnal salinity variation match observed trends.

- Location 4 Goodnight Island – Attachment G Figure 29

  - Modelled salinities correspond well to discrete sampling points.

  - Salinities after the large storm event (23 April 2015) remain close to freshwater concentrations for up to a week, which is supported by downstream data at Shaws Creek ('Thorne' data).

  - Location 4 salinity is controlled predominately by the adopted Greenwell Point boundary condition relationship.

- SQAP Data – Attachment G Figure 31 to Figure 33

  - As discussed in in Section 11.1, the observed data at each SQAP location was interpolated from available graphs, and it is possible that discrepancies in the observed data exist. We expect that these discrepancies are in the order of ± 7 days and ± 1 g/L.

  - 2004 modelling results correspond well with discrete monitoring data. Modelled salinity concentration has matching recovery timing and pattern to observed concentrations, and corresponds well with observed data after freshening events.

- Considering the uncertainty associated with the SQAP data, the majority of observed data points overlap or are very close to modelled salinity concentrations.

- Modelled results show good calibration to expected salinity gradient and amplitude of diurnal salinity variation at all SQAP locations, based on the observed amplitudes of the 2015 monitored data (Table 26). Model results show that at locations away from boundary conditions, salinity amplitude is well calibrated to expected amplitudes.

12.4.5 Summary

We conclude that:

- o Calibration of 2015 water levels and flows indicates estuarine hydrodynamics are very well represented by the model.

- o Calibration of 2015 and 2004 salinity indicates estuarine advection / dispersion, mixing and pollutant fate and transport are also very well represented by the model.

    - Matters which arose during model calibration, including data reliability, modelling instabilities and modelling artefacts, have been investigated and discussed in detail. Explanations have been provided to demonstrate that these matters have been adequately addressed, and do not materially affect the outcomes of model predictions.

    - Modelled salinities very closely follow observed patterns, rates of response to freshwater inflow events, and recovery to seawater concentrations, and have good agreement with monitored diurnal salinity amplitudes.

- o Overall the model is very well calibrated and is adequate for the purposes of development impact assessment.

12.5 Development Scenario Assessment Suite

12.5.1 Overview

The following scenarios have been used in combination to build a development scenario assessment suite, and are described in the following sections:

1. Scenarios with and without vegetation uptake / infiltration included (Section 3).

2. Pre development and post development scenarios (Section 12.5.2).

3. Various meteorological scenarios (Section 12.5.3).

4. Various dispersion sensitivity scenarios (Section 12.5.4).

12.5.2 Development Scenarios

The only differences between pre development and post development scenarios are the 6 site boundary conditions for flows and pollutant loads, data for which was generated using the MUSIC model.

The pre development site is mostly forested land with some areas of agricultural, commercial and industrial land, as well as road areas. No treatment is applied to the pre development site except for the vegetation uptake treatment nodes in the 'with infiltration' scenario to ensure consistency with the post development model.

The post development site is mostly residential and forested land, with some areas of agricultural, commercial and industrial land, as well as road areas. Proposed treatment trains include a combination of rainwater tanks, bioretention swales, Stormwater360 'Stormfilter / Enviropod' treatment devices, on-site detention systems, bioretention basins, wetlands, and infiltration systems. 'With infiltration' scenarios include vegetation uptake treatment nodes, whilst 'without infiltration' scenarios bypass these nodes.

Summary of outputs from site pre and post development models for with / without infiltration scenarios are provided in Section 10.3. Full details of MUSIC model changes between pre and post development scenarios are provided in the WCMR.

12.5.3 Meteorological Scenarios

Four meteorological scenarios have been modelled to account for varying rainfall conditions:

1. An 'average' year of rainfall.

2. A 'dry' year.

3. A 'wet' year.

4. A 'wet' month of local storm events over Culburra and the development site with no upstream inflows.

Site MUSIC modelling used rainfall data from Nowra RAN from 1964 – 1970 as detailed in the WCMR and as agreed with the peer reviewer. Table

27 summarises rainfall statistics at Nowra RAN from 1964 – 2013 in order to define 'wet', 'dry' and 'typical' yearly rainfall depths. Based on Table 27 and using the same modelled period adopted by MUSIC, proposed rainfall adopted for 'average', 'dry' and 'wet' years is summarised in Table 28.

Table 27: Rainfall statistics at Nowra RAN (1964 – 2013).

Rainfall Statistic [1]	Rainfall Depth (mm/yr)
Minimum	464
Median	890
Mean	968
Maximum	1888

Notes

1. Excludes years with invalid/missing data.

Table 28: Proposed rainfall inputs for 'average', 'dry' and 'wet' year meteorological scenarios.

Meteorological Scenario	Adopted Year	Nowra RAN Rainfall Depth (mm/yr)
Average year	1967	879
Dry year	1968	464
Wet year	1969	1468

With regard to the years adopted for each meteorological scenario, we note:

1. Average year – 1967 is closest to mean/median yearly rainfall over the modelled MUSIC period. The adopted typical rainfall represents a slightly dry year, which is a conservative approach to reduce the 'swamping' effect identified in the initial EMS peer review (7 November 2014).

2. Dry year – 1968 is the driest year on record (1964 – 2013) and hence represents a conservative modelling approach to eliminate the 'swamping' effect.

3. Wet year – 1969 is the 93rd percentile wettest year on record and is considered appropriate for adoption as a 'wet' year.

Time series flows and pollutant concentrations data for each of these years were exported from the MUSIC model for use in the estuarine processes model, as described in Section 10.4.

The 'wet' month of local storm events was defined as follows:

1. Rainfall data used in MUSIC modelling was assessed to identify a 'wet' month. The month from 20 October – 20 November 1969 had 418 mm rainfall (43% of mean annual rain) and 4 days of > 50 mm

rainfall. This period represents the wettest month (31 days with the highest cumulative rainfall depth) over the MUSIC modelling period.

2. The estuarine processes model was run over this period with only the Culburra and site sub-catchments discharging, and with no other upstream sub-catchment inflows.

3. We note that this scenario is very conservative, as it is unrealistic to have such a wet month (the wettest month over the modelling period) with such large storm events isolated to only the site and Culburra.

4. A more realistic scenario may be to have an average month of local storms over the site and Culburra with no upstream inflow, or the wettest local month with average inflows. Nonetheless, this scenario has been run as a sensitivity analysis at the peer reviewer's request to determine absolute worst case development impacts.

12.5.4 Dispersion Sensitivity Scenarios

The peer reviewer has requested that sensitivity analysis be undertaken for dispersion coefficients to ensure that upper bound and lower bound scenarios are evaluated. Modelled dispersion scenarios are summarised in Table 29 and are summarised as follows:

- Dispersion scenario D1 uses the calibrated dispersion parameters (Section 12.3.4). D1 coefficients have been used for modelling of each meteorological scenario.

- Dispersion scenarios D2 and D3 represent lower and upper bound dispersion coefficients respectively, and represent a wide range of dispersion coefficients.

- D2 and D3 coefficients have been modelled in conjunction with two meteorological scenarios: the 'average' year of rainfall (1967) and the 'wet' month of local rainfall (20 October – 20 November 1969).

- These scenarios enable assessment of model sensitivity to dispersion coefficients.

Table 29: Dispersion sensitivity scenario definition.

Scenario ID	Longitudinal Dispersion (m^2/s)	Transverse Dispersion (m^2/s)	Minimum Dispersion (m^2/s) [1]
D1	2,500	250	0
D2	1,000	100	0
D3	10,000	1,000	0

Notes

1. Exclusion of the minimum dispersion coefficient was necessary to avoid model instabilities, which were introduced when minimum dispersion > 0 m^2/s.

D2 and D3 dispersion coefficients were used to rerun the 2015 calibration model in order to place the lower and upper bound coefficients in context and to evaluate their influence on model predictions. Table 30 summarises the Attachment G Figures which corresponded to each monitoring location and each dispersion scenario. Based on comparison of these results we note:

- D2 dispersion scenario sensitivity analysis:
  - Modelled salinities at Culburra Road bridge poorly match: observed concentration patterns; rates of response to freshwater inflow events; and rate of recovery to dry weather concentrations.
  - Modelled salinities at Culburra Road bridge are overpredicted for the first third of the monitoring period and underpredicted for the remainder of the monitoring period.
  - Modelled salinity gradient and amplitude of diurnal salinity variation at all locations is overpredicted and does not match observed trends.
  - Apart from diurnal salinity amplitudes, modelled salinity concentrations at Billys Island, Curleys Bay and Goodnight Island generally have comparable calibration to D1 dispersion scenario results.
- D3 dispersion scenario sensitivity analysis:
  - Modelled salinities at Culburra Road bridge respond well to the freshening event in mid to late-April 2015, however resultant modelled salinities are underpredicted.
  - Modelled salinities at Culburra Road bridge recover after the freshening event in mid to late-April 2015 more quickly than observed salinities, and are then overpredicted for the remainder of the monitoring period.

- Modelled salinities at Culburra Road bridge generally match observed responses, but do not replicate observed concentrations.

- Modelled salinity gradient and amplitude of diurnal salinity variation at all locations is underpredicted and does not match observed trends.

    - D3 modelled Culburra Road bridge diurnal salinity amplitude is closer to observed trends, however as discussed in Section 12.4.4 the model overpredicts the amplitude because of proximity to large inflow boundary conditions, which we believe is acceptable.

    - Whilst the D3 coefficients give a better match for the Culburra Road bridge diurnal salinity amplitude, amplitudes at downstream locations are underpredicted, as can be seen at Curleys Bay (Attachment G Figure 40).

    - As discussed in Section 12.4.4, the D1 dispersion coefficients gave the best balance of salinity gradient calibration of all simulation iterations across all locations.

- Modelled salinity concentrations at Billys Island, Curleys Bay and Goodnight Island do not match observed salinities as well as with D1 dispersion coefficients.

- Modelled salinities at all locations are controlled predominately by the adopted Greenwell Point boundary condition relationship, and are not sensitive enough to observed inflows.

o Based on these observations, the model with D1 dispersion coefficients provides best overall calibration. D2 and D3 scenarios do not replicate overall estuary advection / dispersion conditions to the same degree of confidence. The completed sensitivity analysis concludes the appropriateness of D1 dispersion coefficients for impact assessment purposes.

Table 30: Summary of model outputs (Attachment G) for comparison of calibrated (D1) dispersion scenario model and lower bound / upper bound (D2 / D3) dispersion scenario models.

	Dispersion Scenario		
Location	**D1 (Calibrated)**	**D2 (Lower Bound)**	**D3 (Upper Bound)**
1. Culburra Road bridge	Figure 26	Figure 34	Figure 38
2. Billys Island	Figure 27	Figure 35	Figure 39
3. Curleys Bay	Figure 28	Figure 36	Figure 40
4. Goodnight Island	Figure 29	Figure 37	Figure 41

12.5.5 Summary

The combination of infiltration, development, meteorological and dispersion sensitivity scenarios is summarised in Table 31, and includes 32 Tuflow models. Of these 32 models, 8 have been defined as 'development assessment models' and 24 defined as 'sensitivity models' as follows:

- Development assessment models (8 models)
  - Models use the D1 dispersion coefficients, these coefficients delivered the best calibration results and therefore best represent estuarine conditions (refer Section 12.5.4).
  - Models use MUSIC outputs with vegetation uptake / infiltration included in the treatment train as these outputs best represent stormwater behaviour and water quality outcomes at the site (refer Section 3).
  - Models compare pre and post development simulations for the four meteorological scenarios.
  - Development assessment models are displayed in bold in Table 31.
- Sensitivity models (24 models)
  - Models use the lower bound (D2) and upper bound (D3) dispersion coefficients, these resulted in poorer calibration than the development assessment model coefficients (D1, refer Section 12.5.4)).
  - Models assess the impact of MUSIC outputs without vegetation uptake / infiltration included in the treatment train. These are considered unrepresentative of site

stormwater behaviour and natural soil processes resulting in overly conservative model outcomes (refer Section 3).

- Sensitivity models also compare pre and post development simulations for the four meteorological scenarios.

- Sensitivity models are all models not displayed in bold in Table 31.

The peer reviewer has been consulted to define scenarios and determine the development scenario assessment suite and has accepted the assessment suite adopted for this assessment (email 10 February 2016).

Table 31: Development scenario assessment suite and Tuflow model naming.

		Meteorological Scenario [3]											
		Average Year 1967			Dry Year 1968			Wet Year 1969			Local Wet Month 20 Oct – 20 Nov 1969		
Infiltration Scenario [1]	Development Scenarios [2]	Dispersion Sensitivity Scenario [4]											
		D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
With Infiltration	Pre Dev	**M01** [5]	M02	M03	**M04** [5]	–	–	**M05** [5]	–	–	**M06** [5]	M07	M08
	Post Dev	**M09** [5]	M10	M11	**M12** [5]	–	–	**M13** [5]	–	–	**M14** [5]	M15	M16
Without Infiltration	Pre Dev	M17	M18	M19	M20	–	–	M21	–	–	M22	M23	M24
	Post Dev	M25	M26	M27	M28	–	–	M29	–	–	M30	M31	M32

Notes

1. Infiltration scenarios defined in Section 2.
2. Development scenarios defined in Section 12.5.2.
3. Meteorological scenarios defined in Section 12.5.3.
4. Dispersion sensitivity scenarios defined in Section 12.5.4.
5. Development assessment models are displayed in **bold.** The remainder of the models are sensitivity models.

12.6 Development Scenario Model Setup

12.6.1 Overview

The calibrated model setup discussed in Section 12.3 has been adapted for the 32 development scenarios defined in Table 31. Changes to the calibrated model are discussed in the following sections.

12.6.2 Simulation Setup

The following simulation setup changes were made:

1. Simulation period:

a. All models for each of the three yearly meteorological scenarios (average year 1967, dry year 1968 and wet year 1969) were run for the full year, from 1 January to 1 January the following year.

b. All models for the local wet month meteorological scenario (20 October – 20 November 1969) were run for the full 31 days.

2. Model results are output every hour.

No other changes from the calibrated model simulation setup were made.

12.6.3 Hydraulic Setup

The only changes to model hydraulic setup were to boundary condition inputs. No other changes from the calibrated model hydraulic setup were made.

The following changes to model boundary conditions were made:

1. Greenwell Point downstream boundary condition

    a. As tidal water level data at Greenwell Point was not available from MHL prior to 1988, data from 1 January 2004 to 1 January 2007 was adopted for meteorological scenarios from 1 January 1967 to 1 January 1970.

    b. This period was adopted as it represented three years of quality controlled water level data and had the least amount of missing data (less than 2 hours missing data total, which was interpolated).

2. Upstream flow boundaries

    a. Flow rates modelled by MUSIC are calculated from 1967 – 1970 pluviograph and evapotranspiration data as detailed in Attachment C Section 10.2.

    b. MUSIC model results with and without infiltration have the same flow results as detailed in Attachment C Section 10.3.

    c. Only site sub-catchment flow rates change between pre and post development models, whilst off-site sub-catchment flow rates are constant.

    d. For the local wet month meteorological scenarios, only site sub-catchments and Culburra sub-catchments are used, and no other upstream off-site sub-catchment delivers flow to the model.

No other changes from the calibrated model boundary conditions setup were made.

12.6.4 Advection / Dispersion Setup

The following advection / dispersion setup changes were made:

1. Longitudinal and transverse dispersion coefficients are varied for D2 and D3 dispersion sensitivity scenarios as per the coefficients summarised in Table 29.

2. Addition of three pollutant constituents: total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS):

    a. Downstream boundary at Greenwell Point is based on available median pollutant concentrations in Shoalhaven and Crookhaven River, as summarised in Table 1.

        i. Median concentrations have been adopted as they are more 'statistically robust' than mean concentrations, which are influenced by outliers.

        ii. The peer reviewer has accepted use of median concentrations for these pollutants.

    b. Concentration time series (pollutographs) modelled by MUSIC are calculated from 1967 – 1970 pluviograph and evapotranspiration data, as well as NSW MUSIC modelling guidelines (2010) event mean concentrations (EMCs), as detailed in Attachment C Section 10.2.

    c. Pollutographs for each of the three additional constituents and for each of the 20 upstream inflow boundaries were assigned based on the MUSIC output for each of the meteorological scenarios.

    d. Only site sub-catchment pollutographs change between pre and post development and with / without infiltration MUSIC / Tuflow scenarios, off-site sub-catchment pollutographs remain unchanged.

    e. For the local wet month meteorological scenarios, only site sub-catchments and Culburra sub-catchments are used, and no other upstream off-site sub-catchment deliver pollutants to the model.

f. Like salinity, the additional pollutants are soluble, the model advection / dispersion calibration remains valid.

3. As per the calibration model, initial concentrations are assigned based on approximate mean / median data in the estuary as shown in Attachment A PS01-AZ05. A comparison between adopted initial concentrations and Tuflow model outputs is provided in Section 5.3 to ensure the model is able to approximately reproduce these spatially varying average concentrations.

4. The varying downstream salinity boundary condition at Greenwell Point was slightly modified, as described in Section 12.6.5.

   a. For local wet month scenarios the salinity boundary at Greenwell Point was assumed to be constant (i.e. no upstream freshening). A constant salinity of 28,100 mg/L was adopted based on approximate mean / median data at this location (Zone 1 as shown in Attachment A PS01-AZ05).

No other changes from the calibrated model advection / dispersion setup were made.

12.6.5 Downstream Salinity Boundary Condition Setup

The MUSIC modelling assessment period is 1964 – 1970 as detailed in the WCMR and as agreed with the peer reviewer. The estuarine processes development scenario assessment period is constrained to the MUSIC assessment period and must assess estuarine water quality conditions within this period. The years 1967 – 1970 have been selected for assessment as agreed with the peer reviewer (Section 12.5.3).

The calibrated downstream salinity boundary condition (Section 12.3.5) used the Tallowa Dam storage level to scale and filter upstream catchment antecedent rainfall. However, Tallowa Dam was constructed in 1976 after the development scenario assessment period (1967 – 1970), and hence the Tallowa Dam storage level cannot be used for development scenario assessment. The synthetic relationship was therefore modified to exclude Tallowa Dam parameters, and instead adopted average antecedent rainfall of the three rainfall stations across the catchment. The synthetic relationship is the same as that developed in Section 12.3.5 but without the storage level filter and without the parameters ‘S’ and ‘M’ which were used to scale upstream rainfall.

The estimated salinity applied at the Greenwell Point tidal boundary over the development scenario periods are presented in Attachment G

Figure 7 for the 1967 assessment period and Attachment G Figure 8 for the 1968 and 1969 assessment periods.

12.6.6 Summary

The relevant changes outlined in these previous sections were applied to the calibrated model to produce the 32 development scenario models as per the assessment suite summarised in Table 31. The results of the 32 models are assessed in the following sections.

13 Attachment F: Model Sensitivity Assessment

13.1 Overview

The impact assessment models are reviewed in Section 5. Results of the sensitivity models are reviewed in the following sections. Assessment considers the models using D2 and D3 dispersion coefficients and scenarios without vegetation uptake / infiltration, which are the 24 models which are not displayed in bold in Table 31. Sensitivity runs are provided to aid in understanding the uncertainty of the assessment model's predictions.

13.2 Analysis Methodology

Results from the sensitivity models were assessed using the same methods described in Section 5.2. The only changes were:

1. Average modelled concentrations were not reassessed as sensitivity models are not representative of average estuary conditions.

2. Attachment K presents minimum / maximum concentration and concentration impact plots for all models with infiltration. Attachment L presents equivalent results for all models without infiltration.

3. Minimum / maximum concentration impact plots:

    a. Results of dispersion sensitivity analysis are co-plotted with the impact assessment results – this is done to enable visual comparison of all three dispersion scenarios.

    b. For these plots the background image is the D1 (assessment model) dispersion scenario maximum concentration impact. The extents of the D2 and D3 dispersion sensitivity scenario maximum concentration impacts are shown overlain.

    c. Co-plotted results are given in Attachment K PS02 and Attachment L PS03 in drawings Z115, Z175, Z315, Z375, Z515, Z575, Z715 and Z775.

13.3 Statistical Analysis

Table 6 summarises which statistical data table (Attachment J) refers to which Tuflow sensitivity model scenario (development scenario assessment suite in Table 31). We note the following changes from impact assessment model results:

1. Pre development models:

    a. Sensitivity models experience greater degrees of freshening and pollution than impact assessment models.

    b. During infrequent storm events the Crookhaven River experiences significant freshening, with 1st percentile salinity concentrations falling below 2,000 mg/L in an average year and falling as low as 1,000 mg/L in a wet year in sensitivity models.

    c. During infrequent storm events the Crookhaven River experiences significant deterioration in water quality, with 99th percentile concentrations showing:

        i. Up to 1.00 mg/L for TN in an average year and over 1.50 mg/L in a local wet month.

        ii. Above 0.20 mg/L for TP in an average year.

        iii. Over 50 mg/L for TSS in an average year and up to 100 mg/L in a local wet month.

2. Post development models:

    a. As with the impact assessment models, the vast majority of results show that changes to salinity, TN, TP and TSS concentrations at all points for all scenarios are negligible, again because of:

        i. The effectiveness of the proposed treatment measures in reducing the concentrations of stormwater pollutants from the development site.

        ii. The reduced peak stormwater runoff flow rates due to discharge control measures incorporated into the proposed treatment train.

    b. As with the impact assessment models, the vast majority of changes to pollutant concentrations at all points for all sensitivity models for all considered statistics are insignificant (0% change).

    c. As with the impact assessment models, many scenarios improve estuary concentrations due to the effectiveness of the proposed treatment measures and the reduction of stormwater discharge. For different points across all sensitivity models and for all considered statistics:

i. Salinity concentrations are increased by up to 22%.

ii. TN concentrations are decreased by up to -6%.

iii. TP concentrations are decreased by up to -10%.

iv. TSS concentrations are decreased by up to -8%.

d. At all locations and for all considered statistics in all sensitivity scenarios, the maximum decrease in salinity concentration is -7% (freshening), which, although greater than the development assessment models, remains a negligible impact.

e. At all locations and for all considered statistics in all sensitivity scenarios, the maximum increase in TN concentration is less than 10% except for 54 µg/L (15%) at Avg2 for the 90th percentile concentration in scenario M31, and 71 µg/L (11%) increase at Avg2 for the 99th percentile concentration in scenario M26.

f. At all locations and for all considered statistics in all sensitivity scenarios, the maximum increase in TP concentration is less than 10% except for 8 µg/L (22%) at Avg2 for the 90th percentile concentration in scenario M31, and 7 µg/L (18%) increase at Avg2 for the 95th percentile concentration in scenario M31.

g. At all locations and for all considered statistics in all sensitivity scenarios, the maximum increase in TSS concentration is 1%, which represents a negligible impact.

h. Out of the 16 total development scenarios and 4 pollutants modelled, for each of the 5 locations and 5 statistics considered, there are only 4 instances where concentrations are increased by more than 10%. These occur for TN and TP concentrations at Avg2 for two model scenarios, both of which are without infiltration and use D2 dispersion scenario coefficients.

i. We note the following regarding observations at Avg2:

i. This 'point' represents the average concentrations at three points around Billys Island (Obs2.1, Obs2.2 and Obs2.3).

ii. Of these three points, Obs2.2 is located in an area covered by OEH (2012) bathymetry data (refer Attachment I), however Obs2.1 and Obs2.3 are located in areas with only LPI (2010) LIDAR data as bathymetry is not available south and south west of Billys Island. The differences in levels at the bathymetry / LIDAR interface range from 300 – 800 mm.

iii. Over the 3 years of tidal water level data at Greenwell Point used in the development models (discussed at Section 12.6.3), Obs2.2 (in the bathymetry) is above the tidal water level 35% of the time, whereas Obs2.1 and Obs2.3 (in the LIDAR) are above the tidal water level 79% of the time.

iv. Whilst the 3D surface used is the best representation of the study area, it is likely that actual levels south and south west of Billys Island are lower than the LIDAR levels.

v. Because of the increased elevations, tidal flushing and exchange at Obs2.1 and Obs2.3 are likely being underpredicted by the model. The modelled water level at these two points is stagnant when the tidal water level recedes, and cell concentrations are also constant in stagnant water. This makes these locations more sensitive to minor concentration changes because pollutants are modelled as remaining at these locations for longer than what would occur in reality.

vi. We expect that if data for actual levels around Obs2.1 and Obs2.3 was available and used for modelling, increased tidal flushing and exchange would occur at these locations, and concentrations would be lower than currently modelled.

vii. Consequently, modelled concentrations at Avg2 are likely conservative (i.e. estimate higher pollutant concentrations in post development scenarios), and actual concentrations will likely be lower due to increased mixing.

j. The 4 instances where concentrations are increased by more than 10% are considered insignificant being unrepresentative due to the combination of:

i. Underpredicted tidal flushing and exchange at specific locations.

ii. Modelling without vegetation uptake which routes infiltrated stormwater from treatment devices directly into the estuary and completely ignores the natural processes that occur in the (minimum) 100 m wide vegetated buffer zone (as discussed in Section 3).

iii. Modelling using D2 dispersion coefficients, which is considered a sensitivity analysis due to poor advection / dispersion calibration with use of these parameters (as discussed in Section 12.5.4).

k. As with the impact assessment models, the magnitudes of changes to estuarine concentrations due to the proposed development are insignificant compared to the large degree of natural concentration fluctuation which occurs under existing conditions.

l. In summary, modelling concludes that, even considering extreme sensitivity models, there will be no material detrimental impacts on estuary water quality due to the proposed development.

13.4 Minimum / Maximum Concentration Plots

Modelled minimum salinity and maximum TN, TP and TSS concentration plots are provided in Attachment K and Attachment L for Tuflow model scenarios with and without infiltration respectively. We note the following changes from impact assessment model results:

1. Scenarios without infiltration have slightly higher concentrations at site outlets compared to equivalent scenarios with infiltration, as expected.

2. As discussed in Section 12.5.4, scenarios with higher dispersion coefficients (i.e. D3 dispersion scenarios) are more sensitive to Greenwell Point boundary conditions and are not sensitive enough to observed catchment inflows. D3 dispersion scenarios (i.e. upper bound sensitivity) have faster than observed response times and recover to background estuary concentrations more quickly, whilst D2 (i.e. lower bound sensitivity) dispersion scenarios take longer to respond and recover. It follows that D3 dispersion scenarios experience the lowest absolute concentrations due to fast recovery, and D2 dispersion scenarios experience the highest

absolute concentrations due to slow recovery, with D1 (i.e. calibrated) dispersion scenario concentrations in the middle.

13.5 Minimum / Maximum Concentration Impact Plots

Modelled minimum salinity impact and maximum TN, TP and TSS concentration impact plots are provided in Attachment K and Attachment L for Tuflow model scenarios with and without infiltration respectively. We note the following changes from impact assessment model results:

1. As with the impact assessment models, many sensitivity models show large areas of improved estuary concentrations at site outlets due to the effectiveness of the proposed treatment measures and the reduction of stormwater discharge rates, as also noted in Section 13.3.

2. The vast majority of negative site impact plumes are limited to foreshore areas immediately adjacent to site outlets. Where plumes extend further into the estuary, concentration changes are generally very minor, and quickly dissipate to background concentrations.

3. Scenarios without infiltration have slightly larger impact plumes and / or have slightly higher maximum concentrations at site outlets compared to equivalent scenarios with infiltration, as expected.

4. As discussed in the previous section, D2 dispersion scenarios have protracted recovery to estuary concentration times and D3 dispersion scenarios have overly rapid recovery. It follows that D2 dispersion scenarios generally experience the largest impacts due to increased sensitivity to minor pollutant residence time changes. Conversely, D3 dispersion scenarios experience smaller impacts, and D1 (i.e. calibrated) dispersion scenario impacts are in the middle. This is demonstrated in the co-plotted outputs (Attachment K PS02 and Attachment L PS03 in drawings Z115, Z175, Z315, Z375, Z515, Z575, Z715 and Z775).

13.6 Summary

Key findings of the sensitivity assessment are:

1. Detailed statistical analysis demonstrates that:

    a. Sensitivity models experience more extreme concentrations in existing conditions than impact assessment models.

b. Of all the output statistics presented, there are only 4 instances where concentrations are increased by more than 10% due to the proposed development. These results are considered overly conservative due to a combination of extreme factors.

c. Changes to sensitivity models' estuarine concentrations due to the proposed development are considered negligible, even in infrequent storm events.

d. As with the impact assessment models, the magnitudes of changes to estuarine concentrations due to the proposed development are insignificant compared to the large degree of natural concentration fluctuation which occurs under existing conditions.

2. Review of minimum / maximum concentration plots has demonstrated the sensitivity to upper / lower bound dispersion coefficients and exclusion of the vegetation uptake / infiltration treatment node.

3. Review of minimum / maximum concentration impact plots has demonstrated that:

   a. As with the impact assessment models, the vast majority of site impact plumes for sensitivity models are limited to foreshore areas immediately adjacent to site outlets.

   b. Where plumes extend further into the estuary, concentration changes are generally very minor, and are a reflection of the conservative thresholds adopted by this assessment.

4. Sensitivity models further demonstrate the Crookhaven River is likely to be frequently above ANZECC (2000) trigger criteria and is therefore considered a disturbed ecosystem with compromised health in existing conditions.

5. Implications of the sensitivity analysis are detailed in Section 13.7.

13.7 Uncertainty of Model Predictions

Models are constructed to represent complex natural systems in order to enable predictions and forecast system behaviour under various scenarios. All models require assumptions in order to simplify natural processes. Further, the detail and complexity of a model used to assess development impacts should reflect the scale of the development.

In the case of this assessment, we believe the model assumptions made are reasonable and have enabled adequate representation of the Crookhaven River and estuary for the purposes of this assessment. This is reflected by the quality of the model calibration as summarised in Section 12.4. Model assumptions and calibration have been approved as being acceptable for the purposes of this assessment by the peer reviewer. Further, as far as we are aware, this assessment represents the highest degree of modelling effort undertaken for a residential subdivision in NSW.

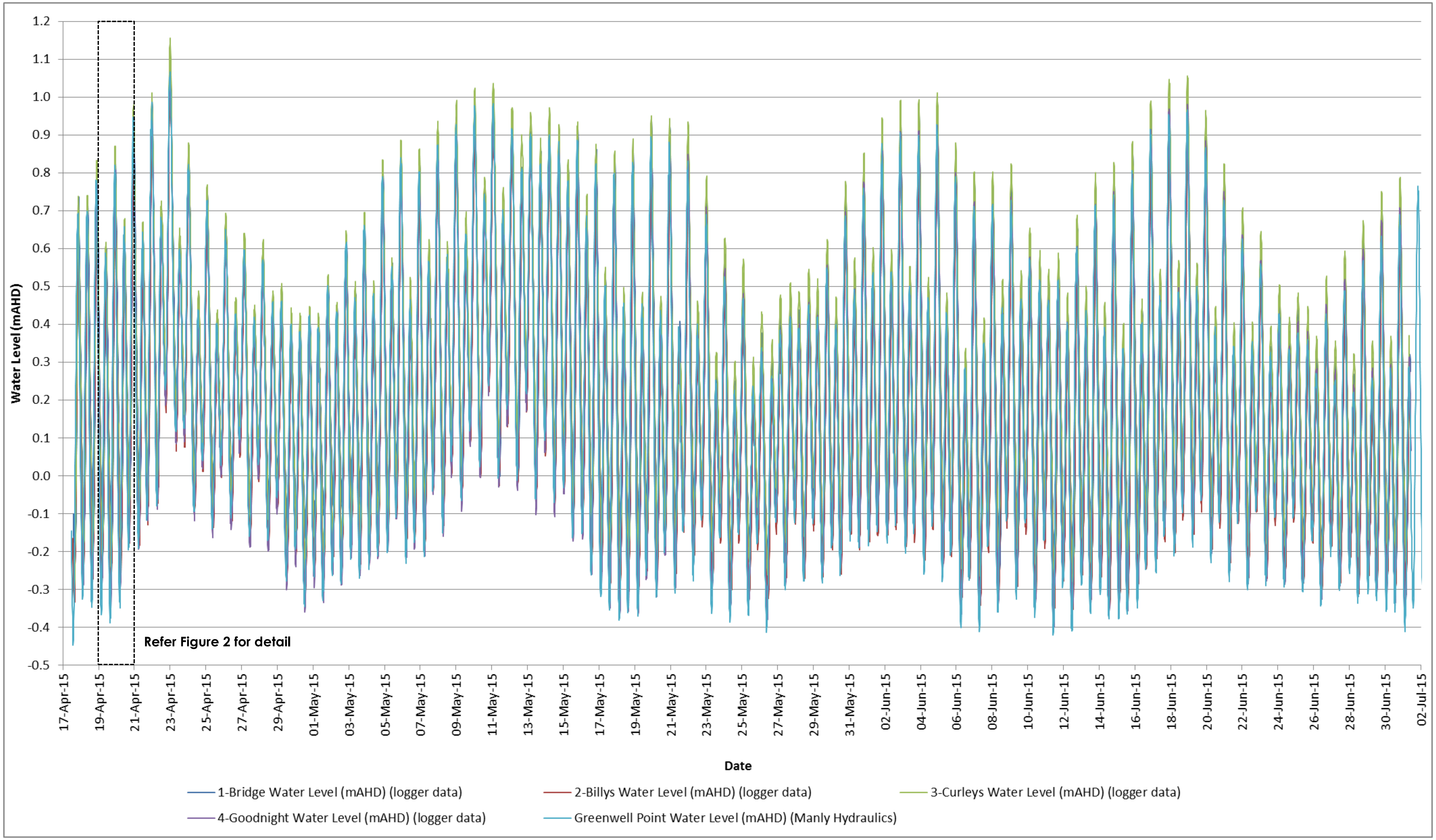
The uncertainty of model predictions has been assessed through a comprehensive scenario suite. Modelling of a number of meteorological scenarios has been included to allow assessment of the models' sensitivity to rainfall conditions throughout the assessment period. The models' sensitivity to critical transport factors (dispersion coefficients) has been completed with results co-plotted to show the significance due to this. Modelling with and without infiltration in the MUSIC water quality model has been completed to assess the sensitivity of the model to this underlying assessment assumption.

Based on the sensitivity analysis completed we conclude that development assessment models used (**bold** in Table 31) are the most appropriate means of assessing the development impacts. Outputs of sensitivity models demonstrate the adequacy of the assessment models and do not show an undue level of variance from the predictions of these models. Therefore, the completed sensitivity assessment confirms the adequacy of the selected assessment models as well as demonstrating the reliability of the prediction capacity of those models.

14 Attachment G: Monitoring Data & Calibration Figures

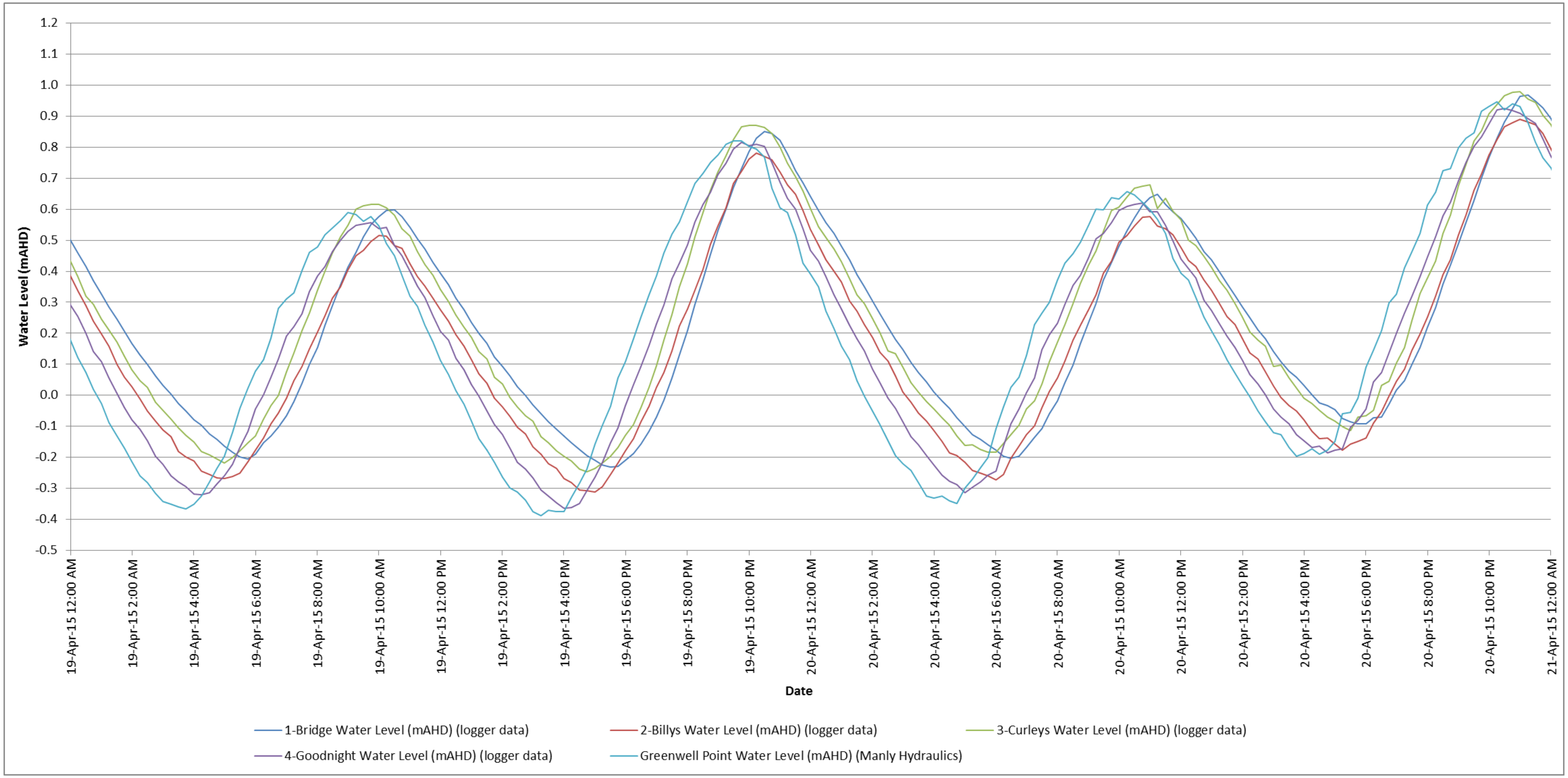
Figures

Figure 41: D3 Sensitivity Test, Location 4 – Goodnight Island, CTD Data VS Tuflow Modelling



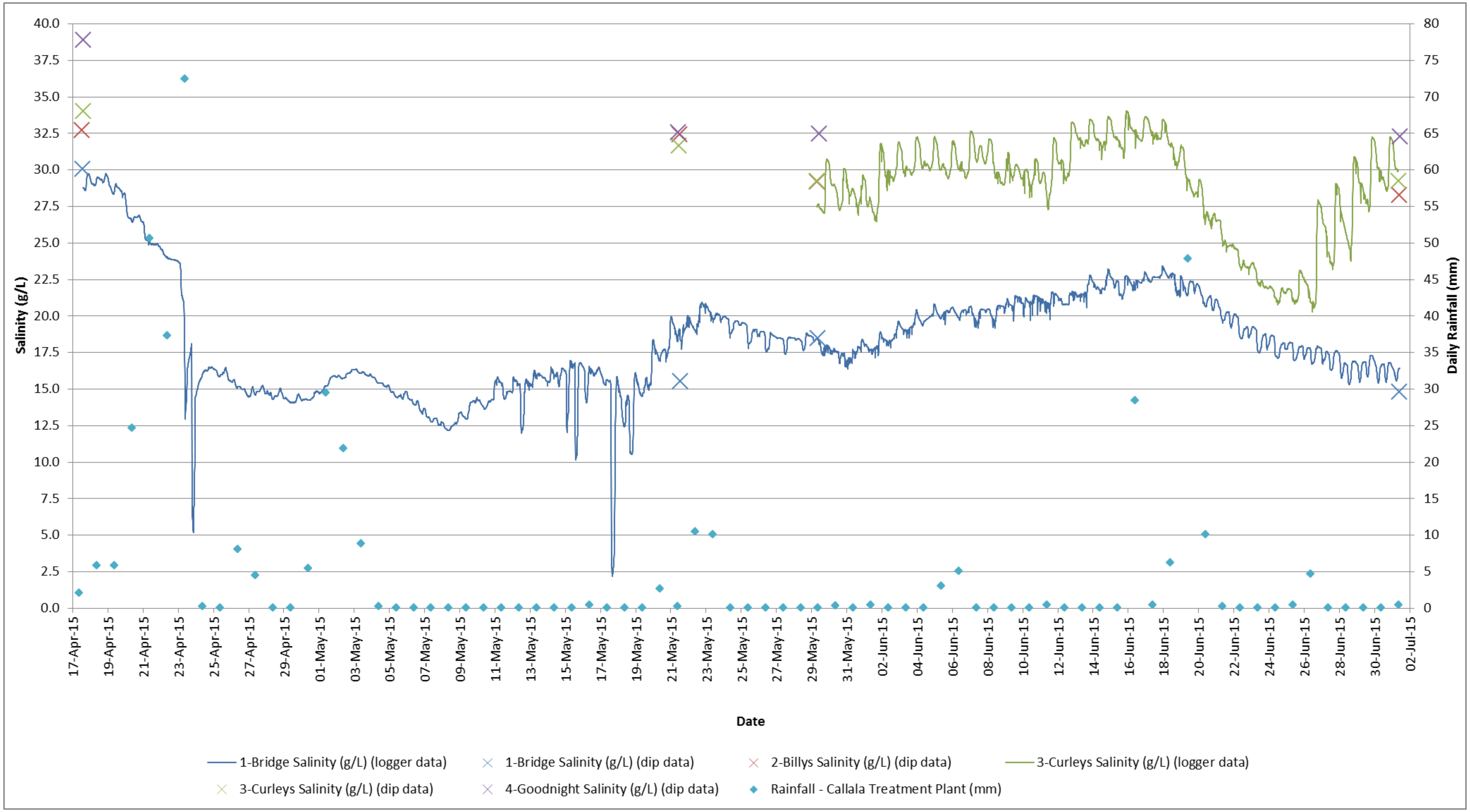
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**ALL MEASURED WATER LEVELS (mAHD) 17 APRIL – 1 JULY 2015**	Drawing No: **FIGURE 1**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



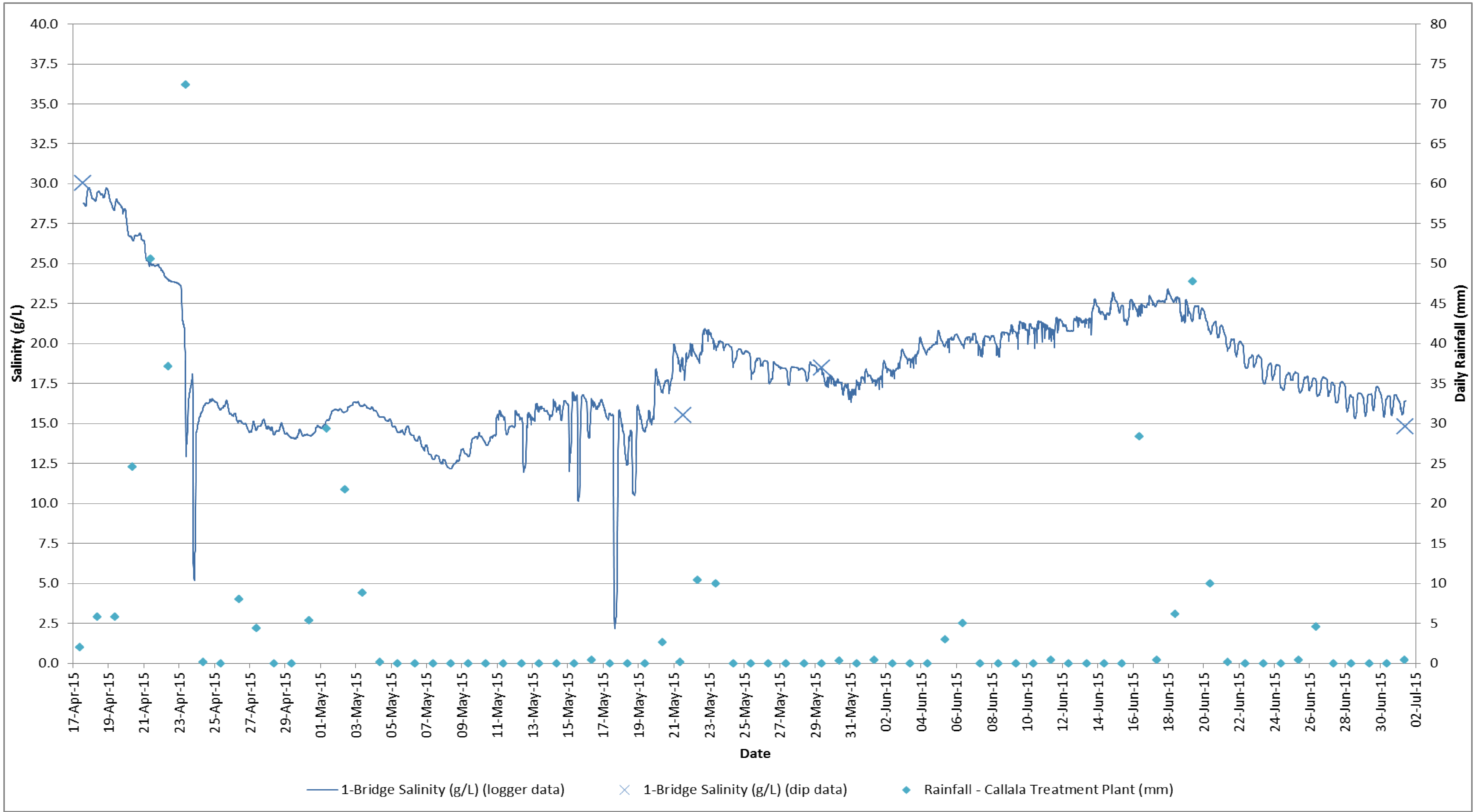
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**DETAILED MEASURED WATER LEVELS (mAHD) 19 – 21 APRIL 2015**	Drawing No: **FIGURE 2**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



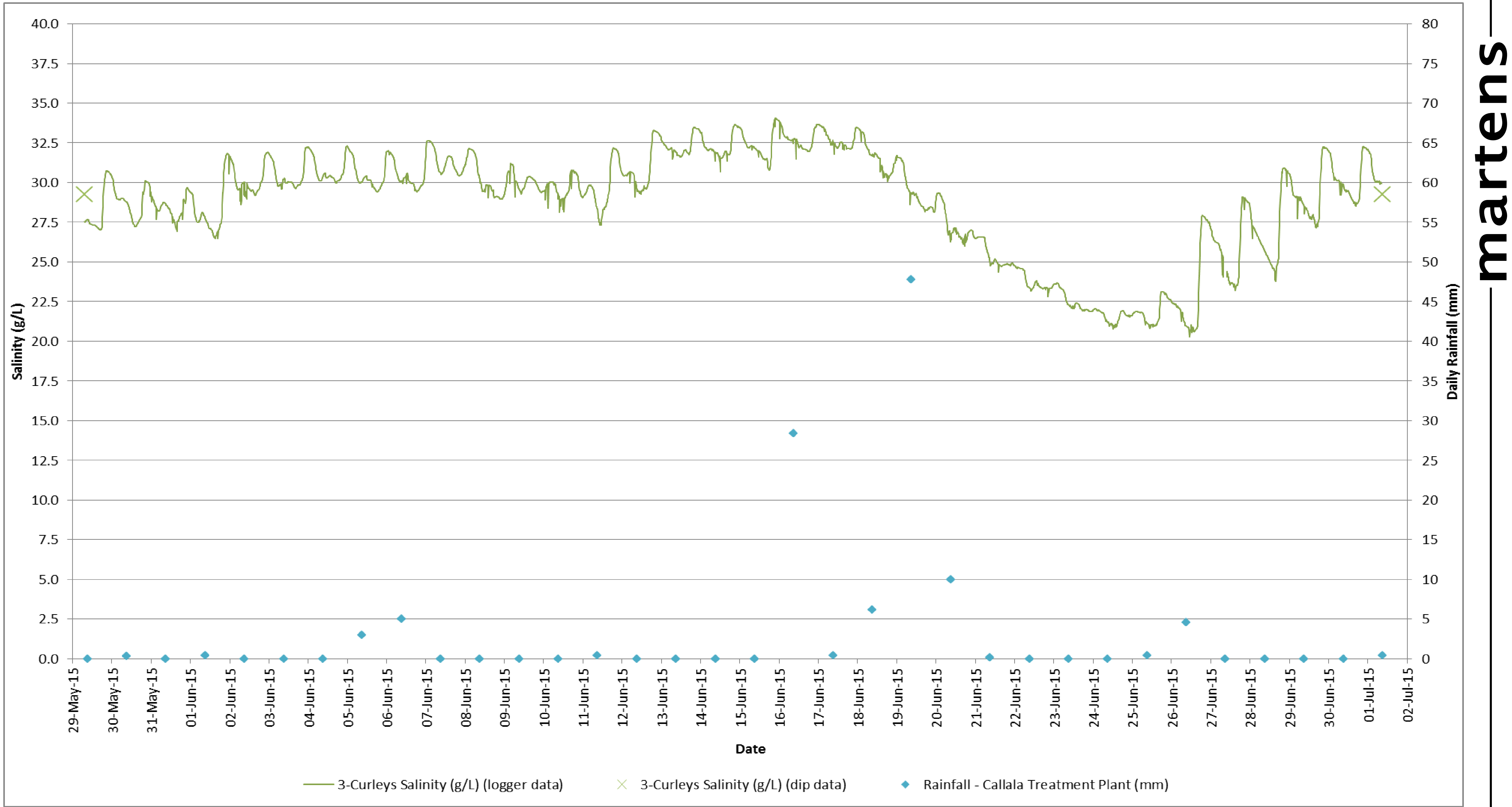
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	ALL MEASURED SALINITY CONCENTRATIONS (g/L) 17 APRIL – 1 JULY 2015	Drawing No: FIGURE 3
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

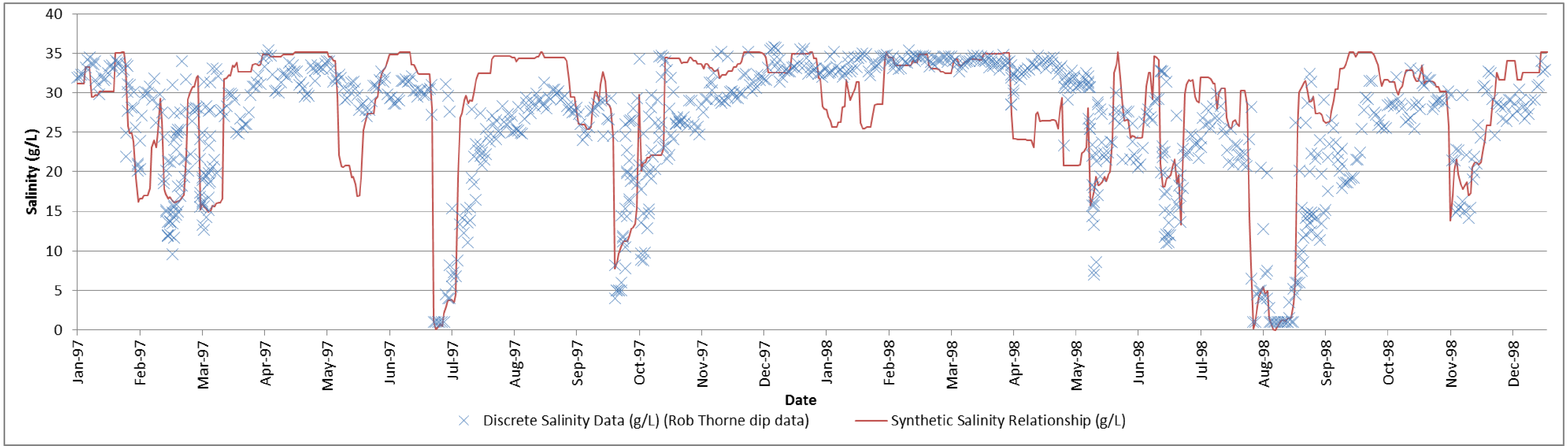


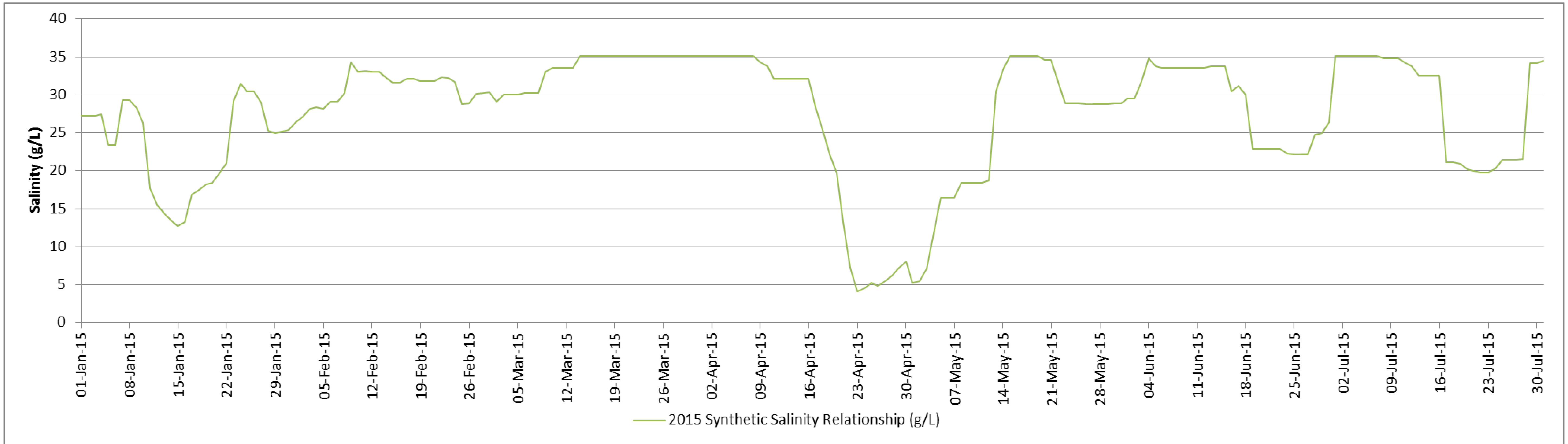
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	LOCATION 1 – CULBURRA ROAD BRIDGE MEASURED SALINITY CONCENTRATIONS (g/L) 17 APRIL – 1 JULY 2015	Drawing No: FIGURE 4
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



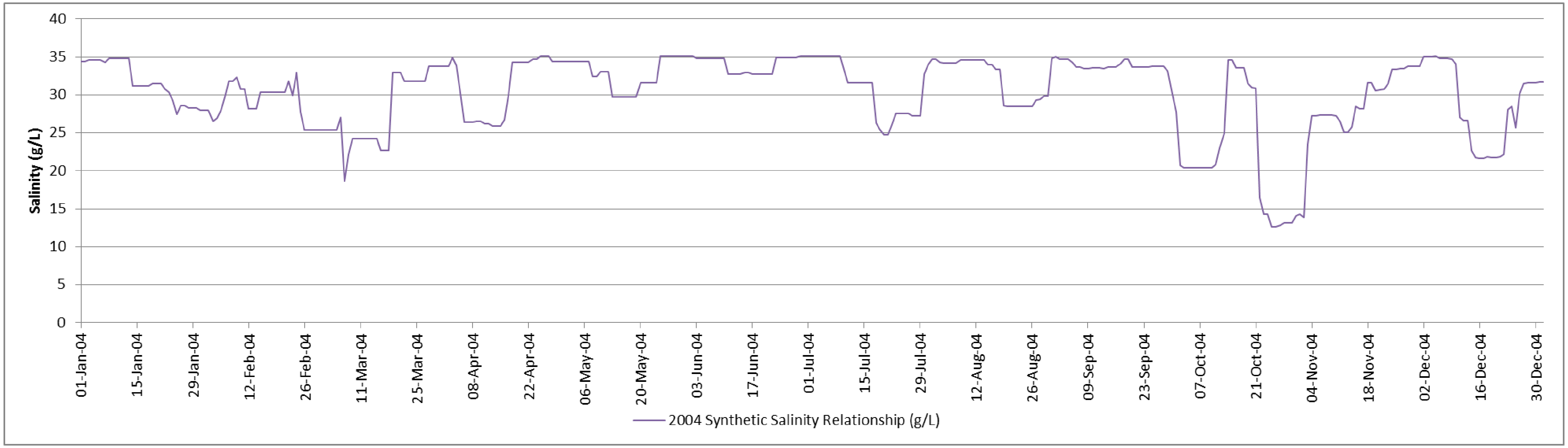
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	LOCATION 3 – CURLEYS BAY MEASURED SALINITY CONCENTRATIONS (g/L) 29 MAY – 1 JULY 2015	Drawing No: **FIGURE 5**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

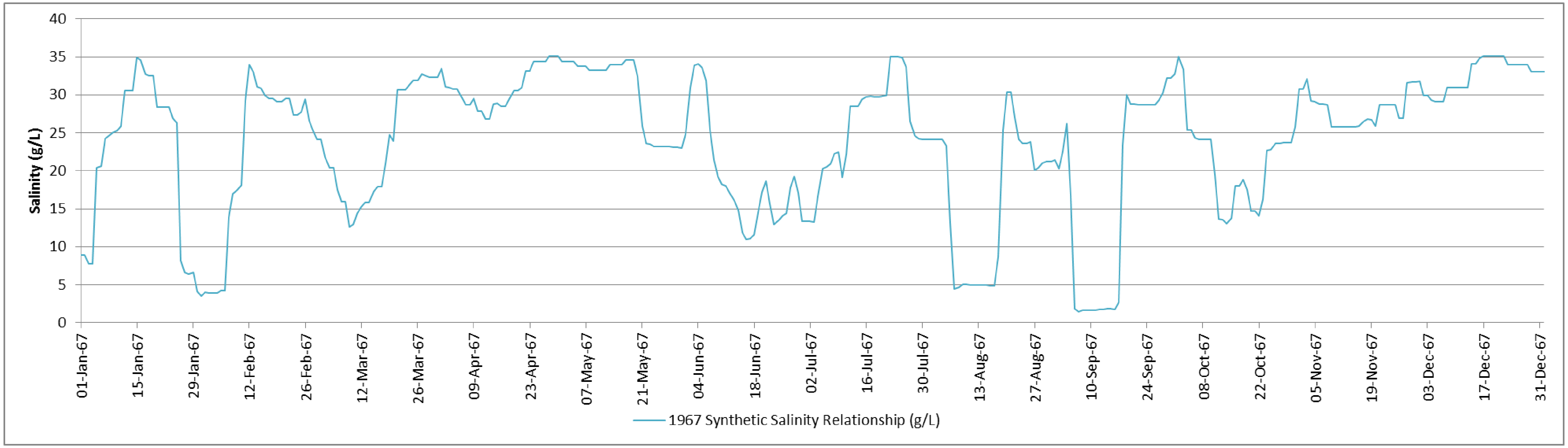




martens

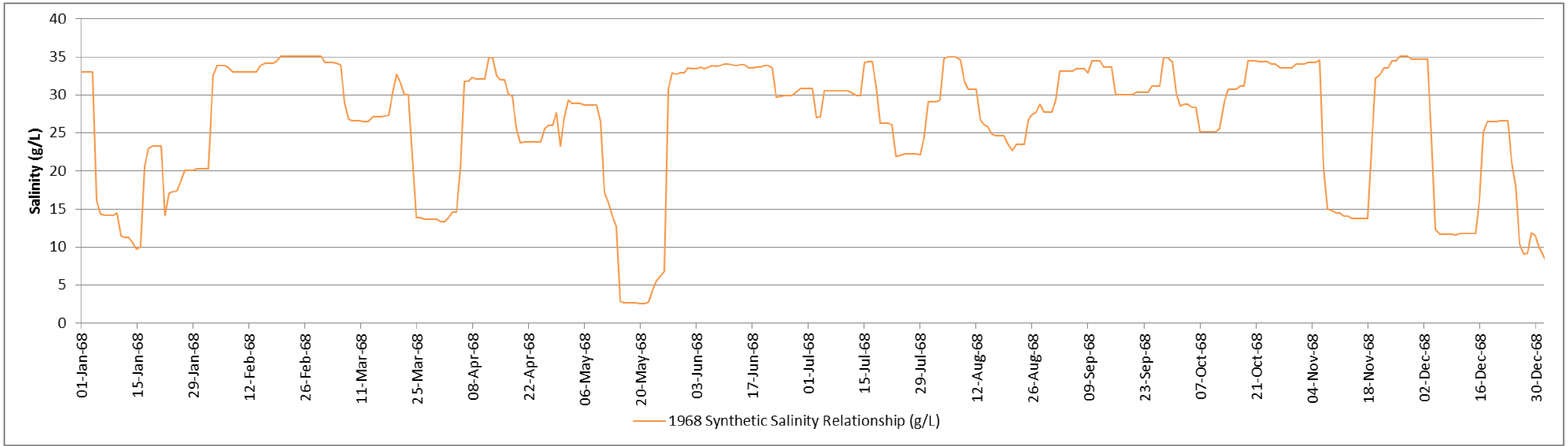
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**GREENWELL POINT SYNTHETIC SALINITY BOUNDARY CONDITION (TOP) DATA USED TO DEVELOP RELATIONSHIP (BOTTOM) 2015 RELATIONSHIP**	Drawing No: **FIGURE 6**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

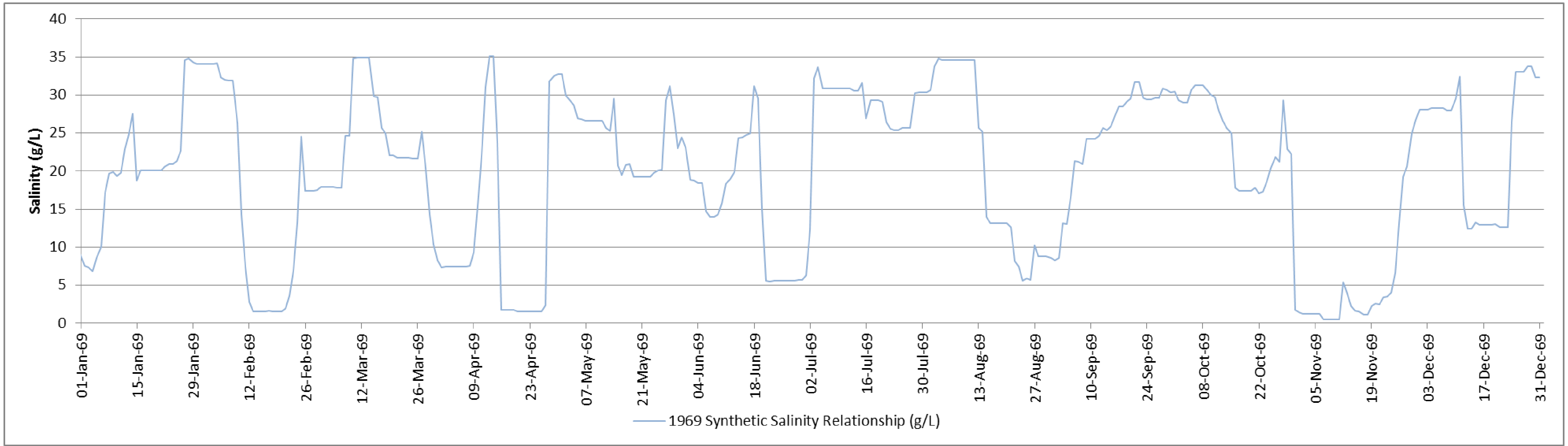




martens

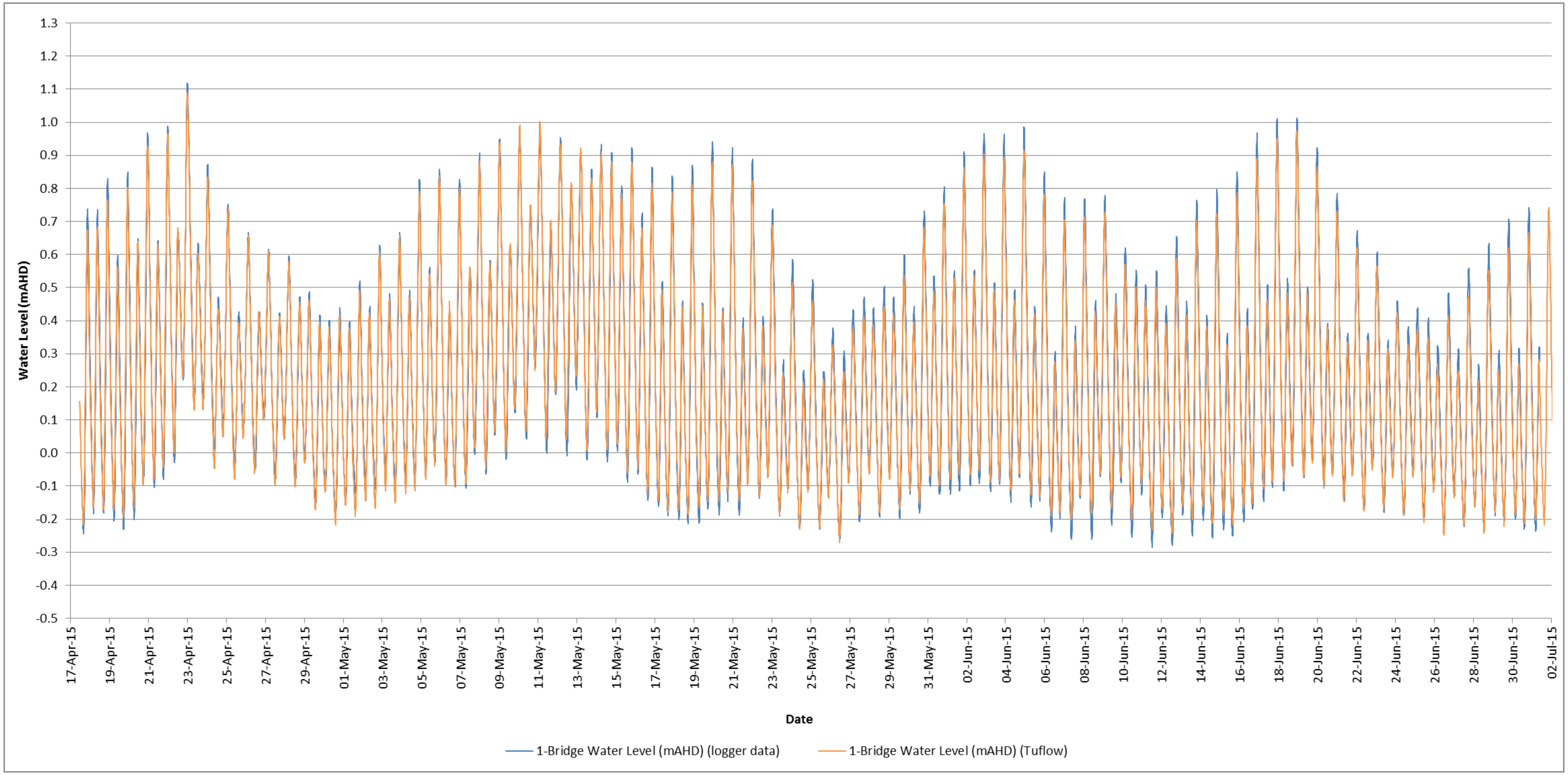
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**GREENWELL POINT SYNTHETIC SALINITY BOUNDARY CONDITION (TOP) 2004 RELATIONSHIP (BOTTOM) 1967 RELATIONSHIP**	Drawing No: **FIGURE 7**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365





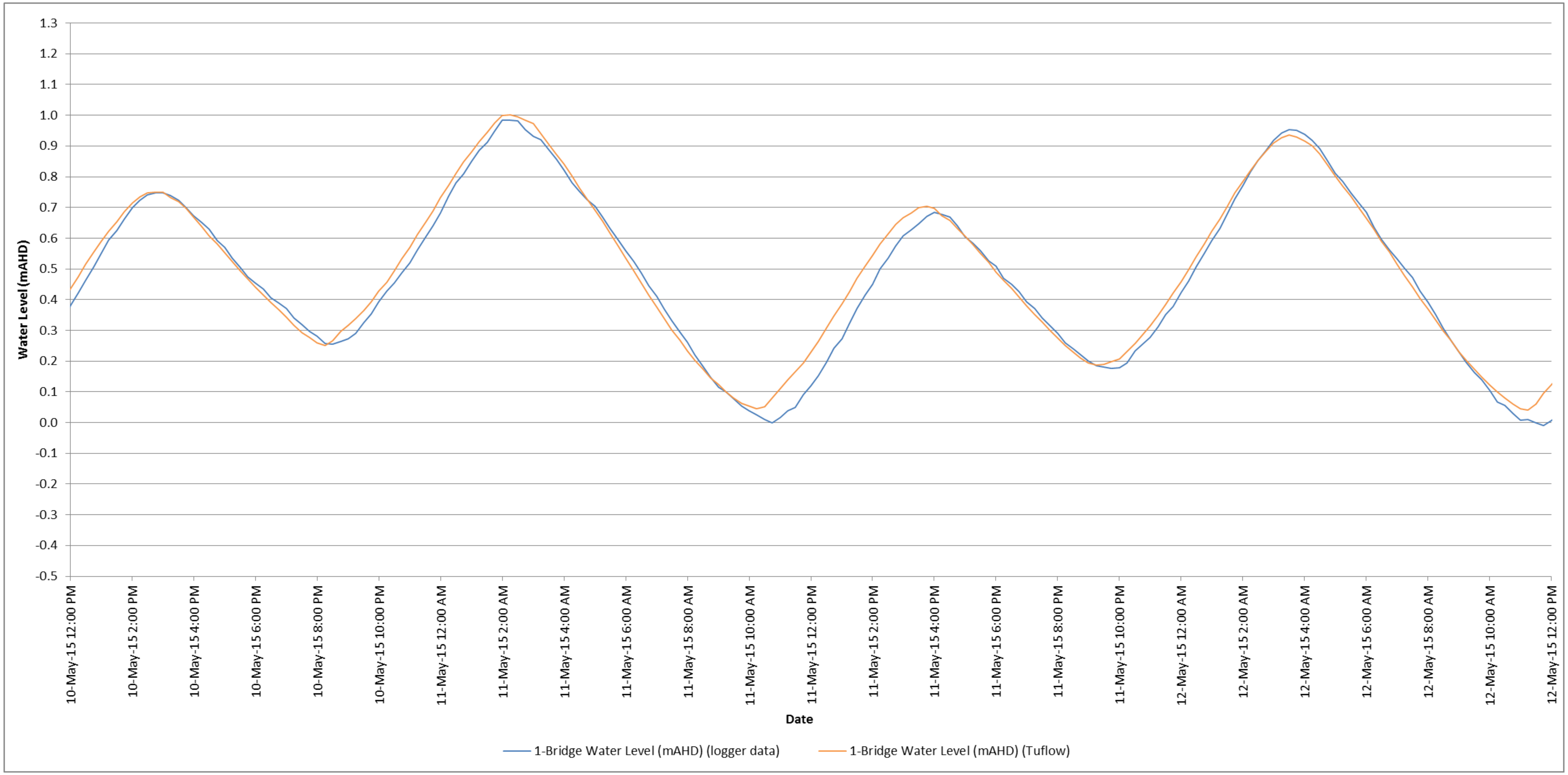
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**GREENWELL POINT SYNTHETIC SALINITY BOUNDARY CONDITION (TOP) 1968 RELATIONSHIP (BOTTOM) 1969 RELATIONSHIP**	Drawing No: **FIGURE 8**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



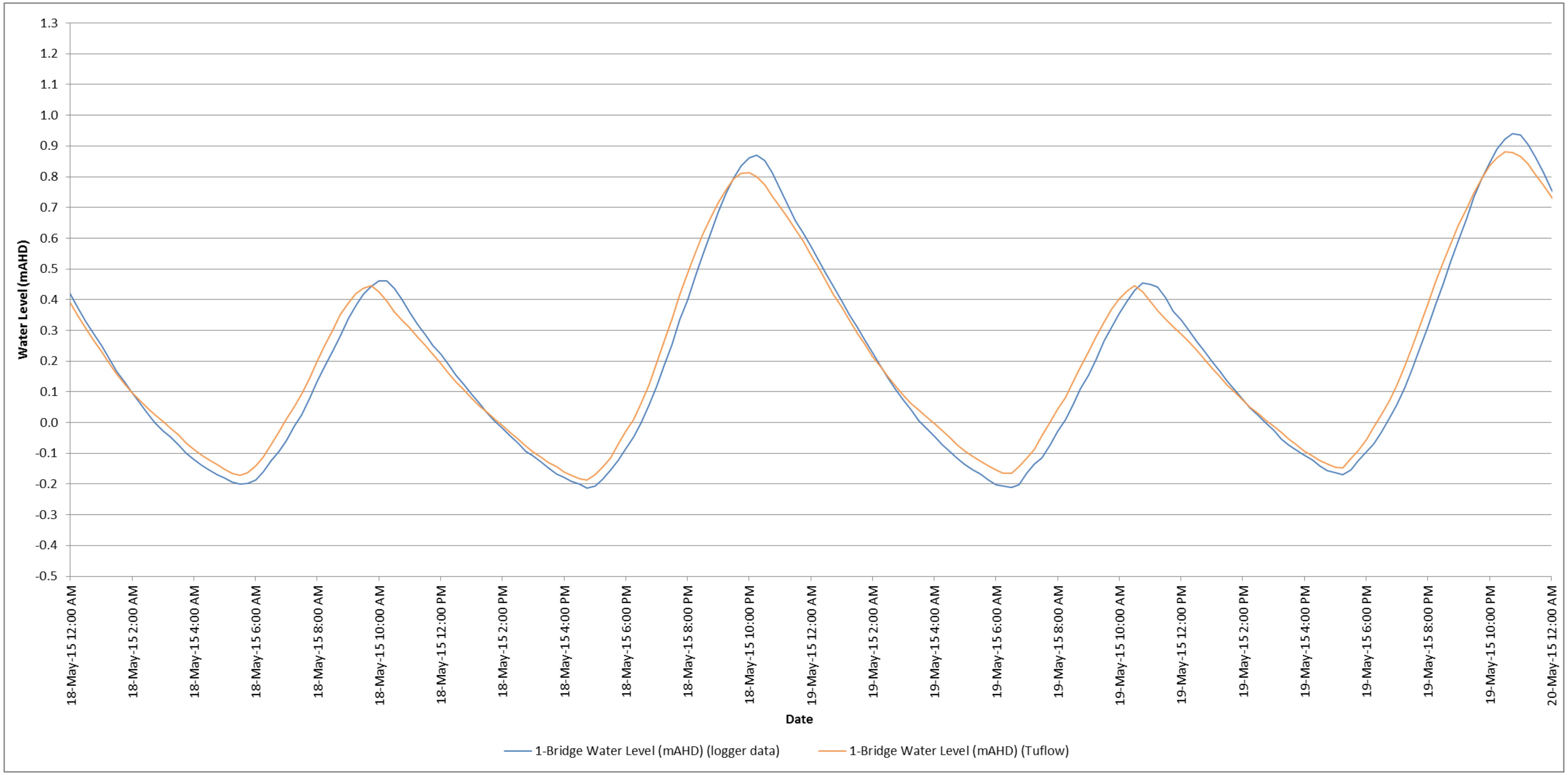
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 9**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



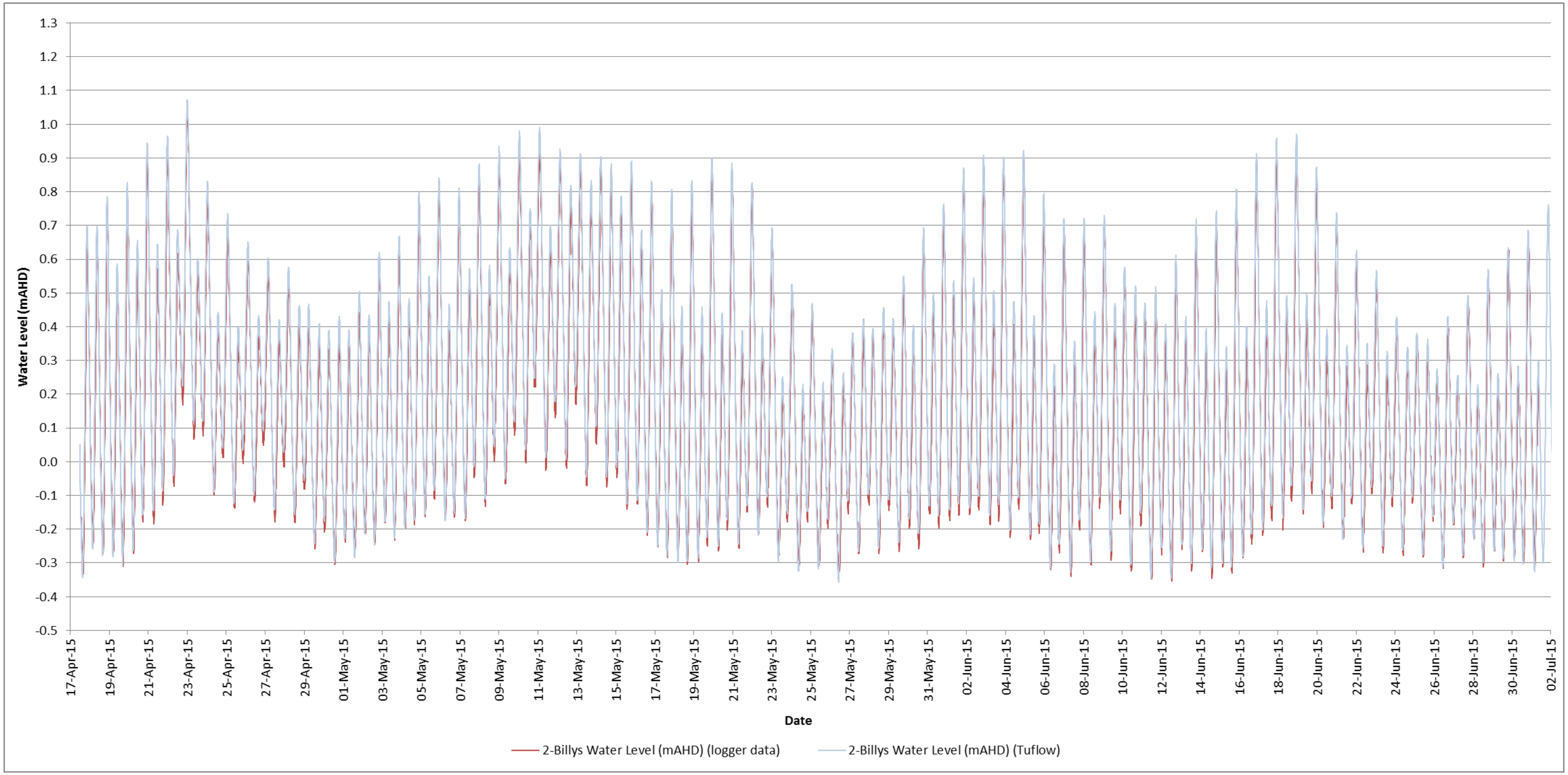
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 10**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



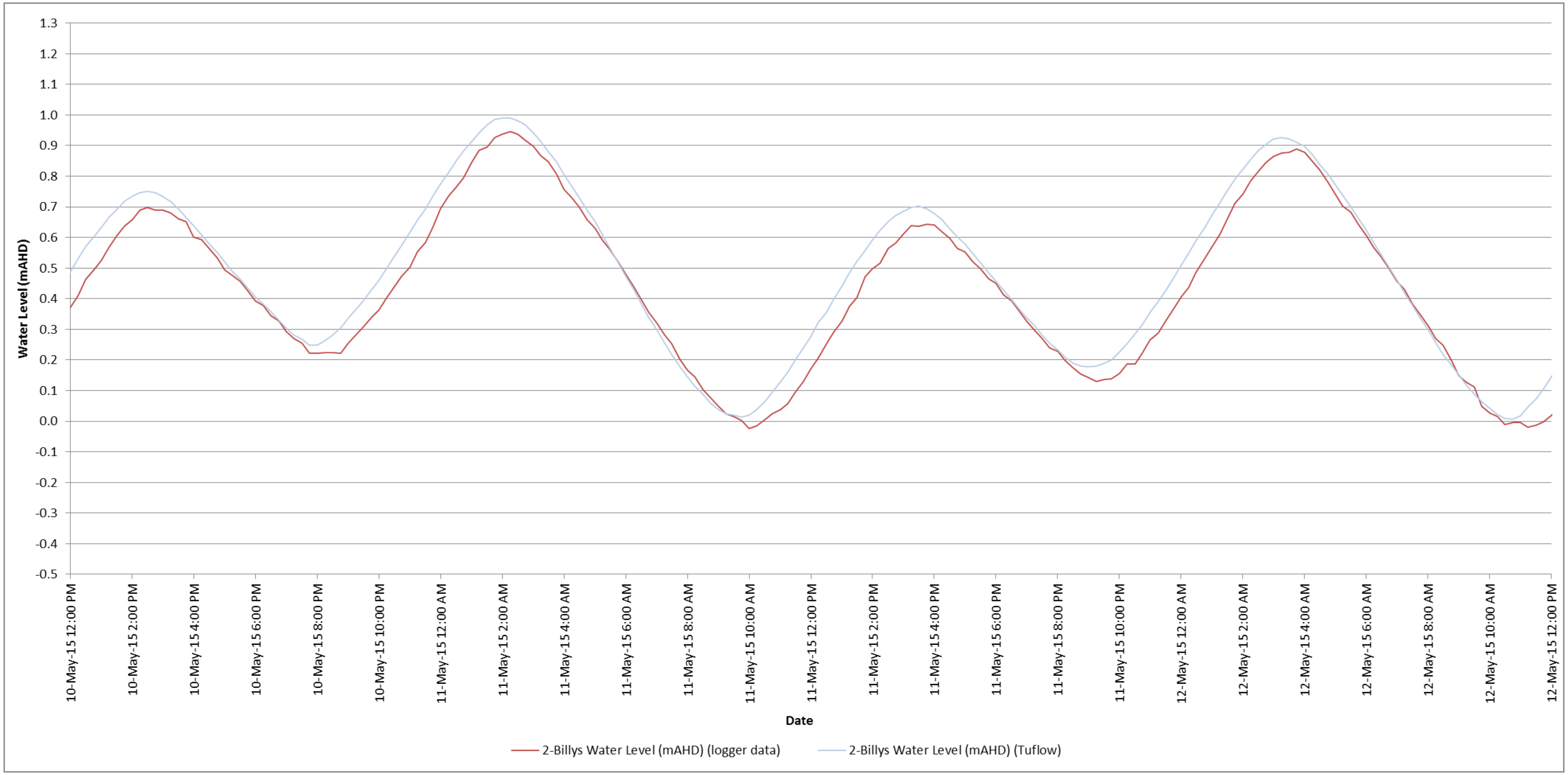
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 11
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



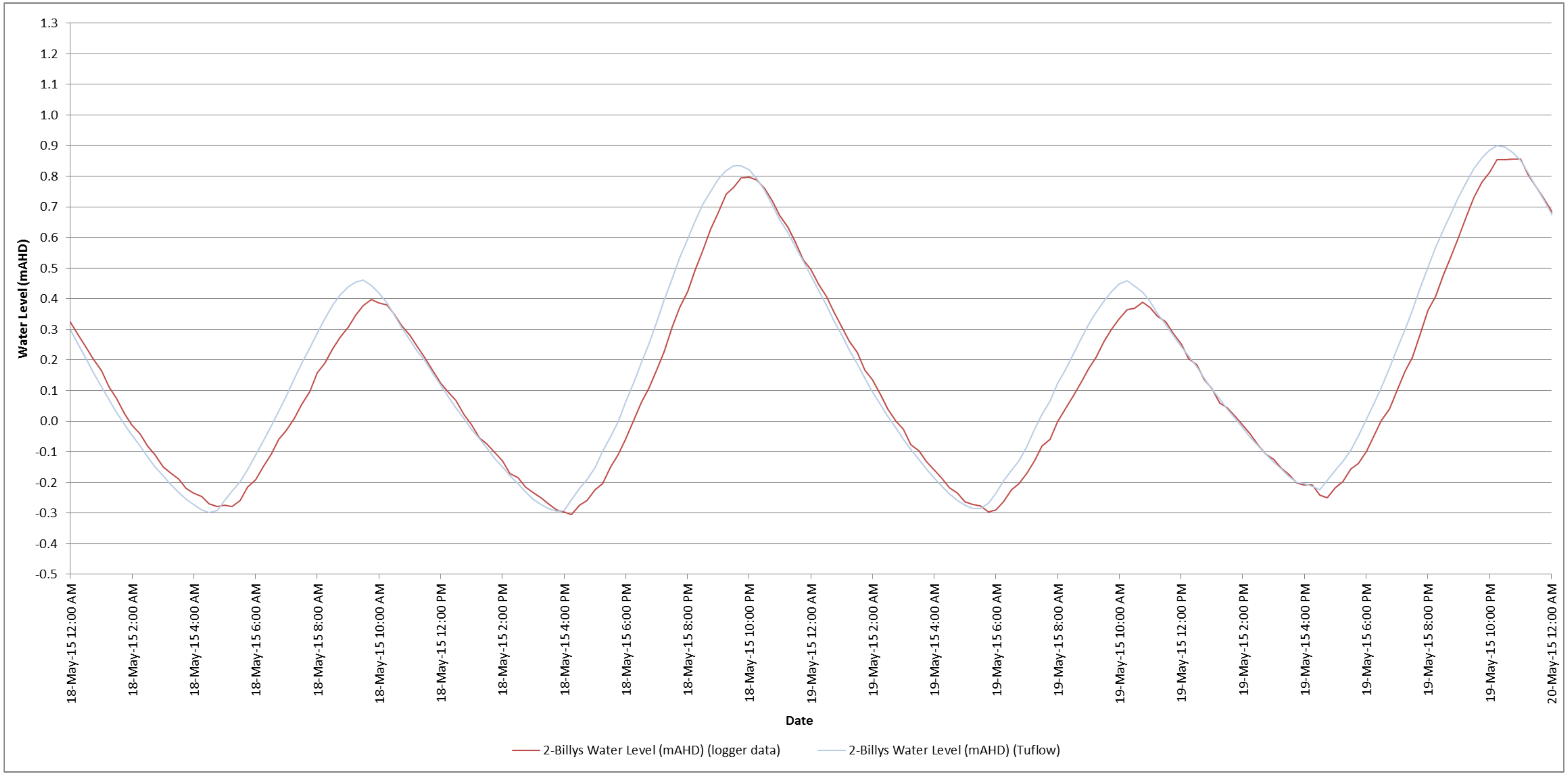
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	WATER LEVEL CALIBRATION LOCATION 2 – BILLYS ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 12
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	WATER LEVEL CALIBRATION – NEAP TIDE LOCATION 2 – BILLYS ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 13
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

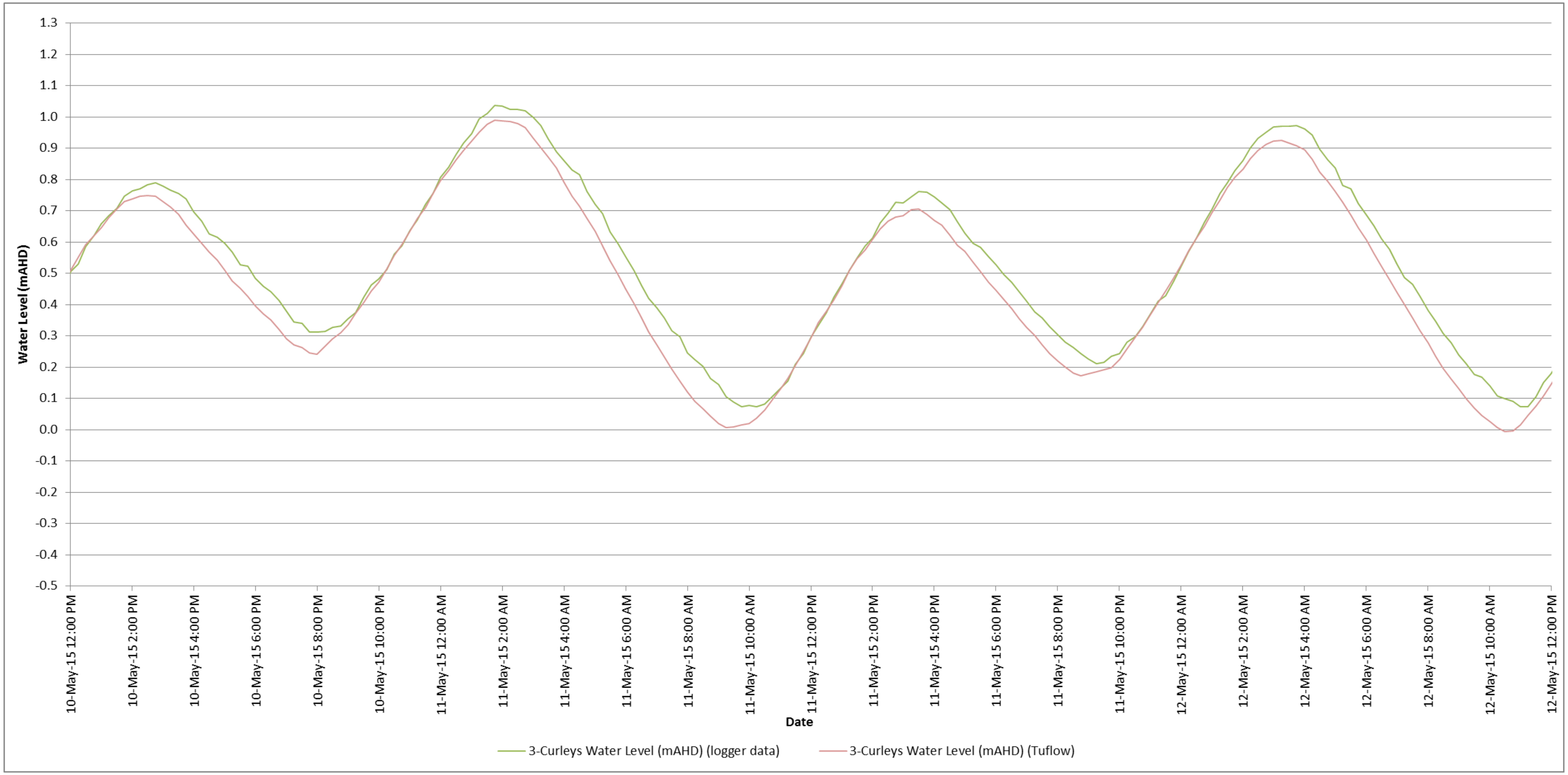


martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 2 – BILLYS ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 14
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

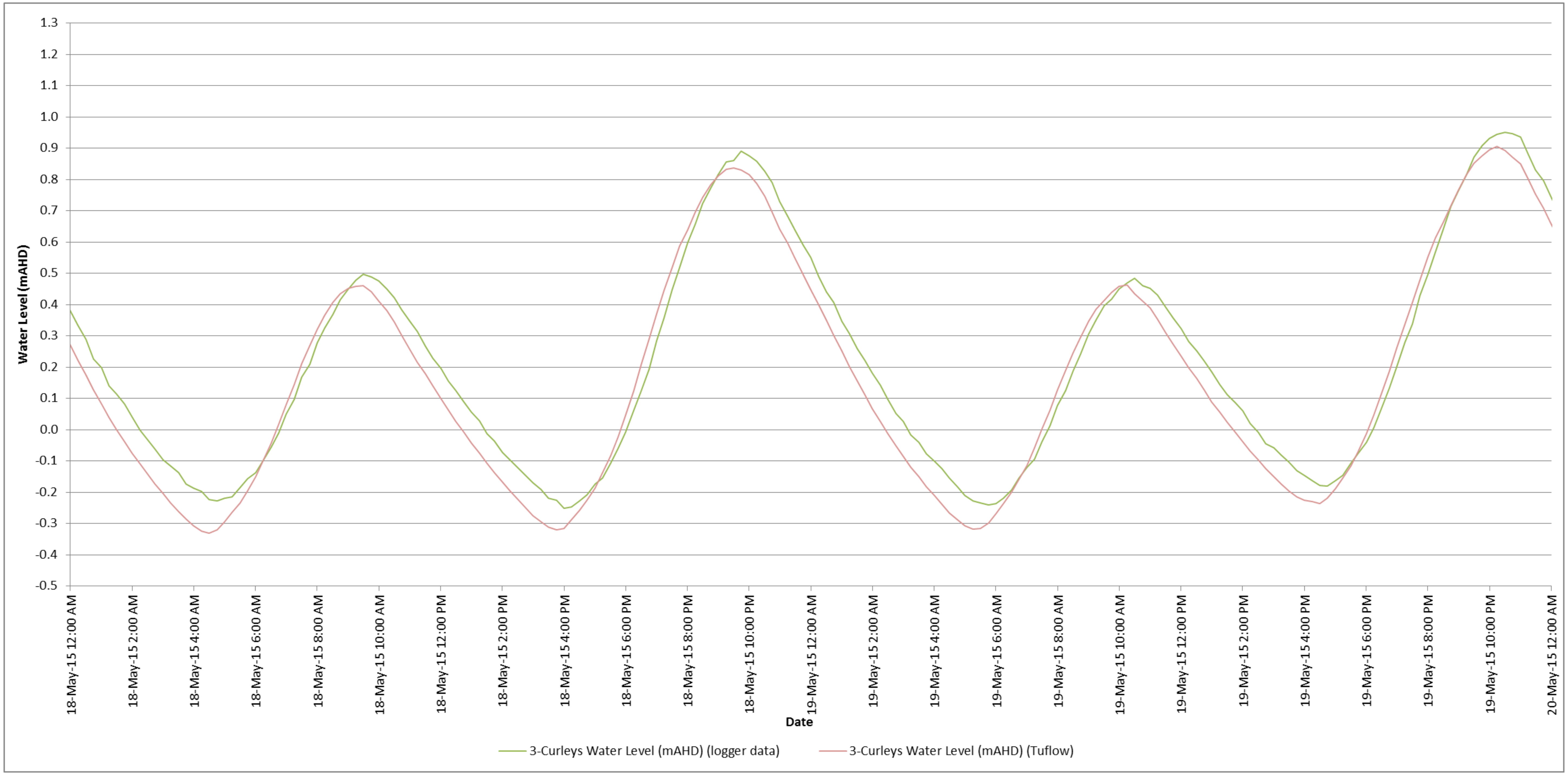
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 3 – CURLEYS BAY CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 15**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



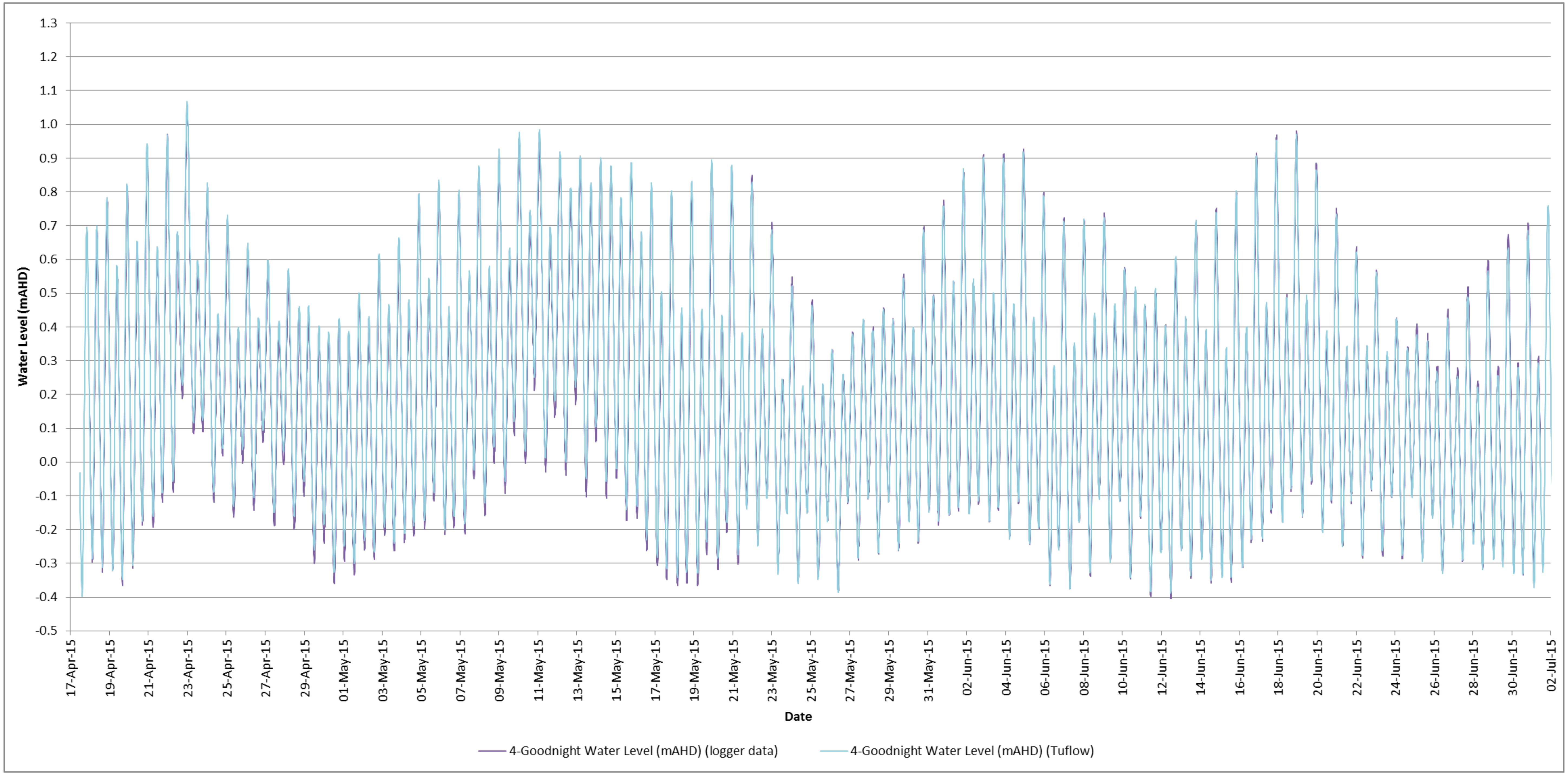
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE** **LOCATION 3 – CURLEYS BAY** **CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 16**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



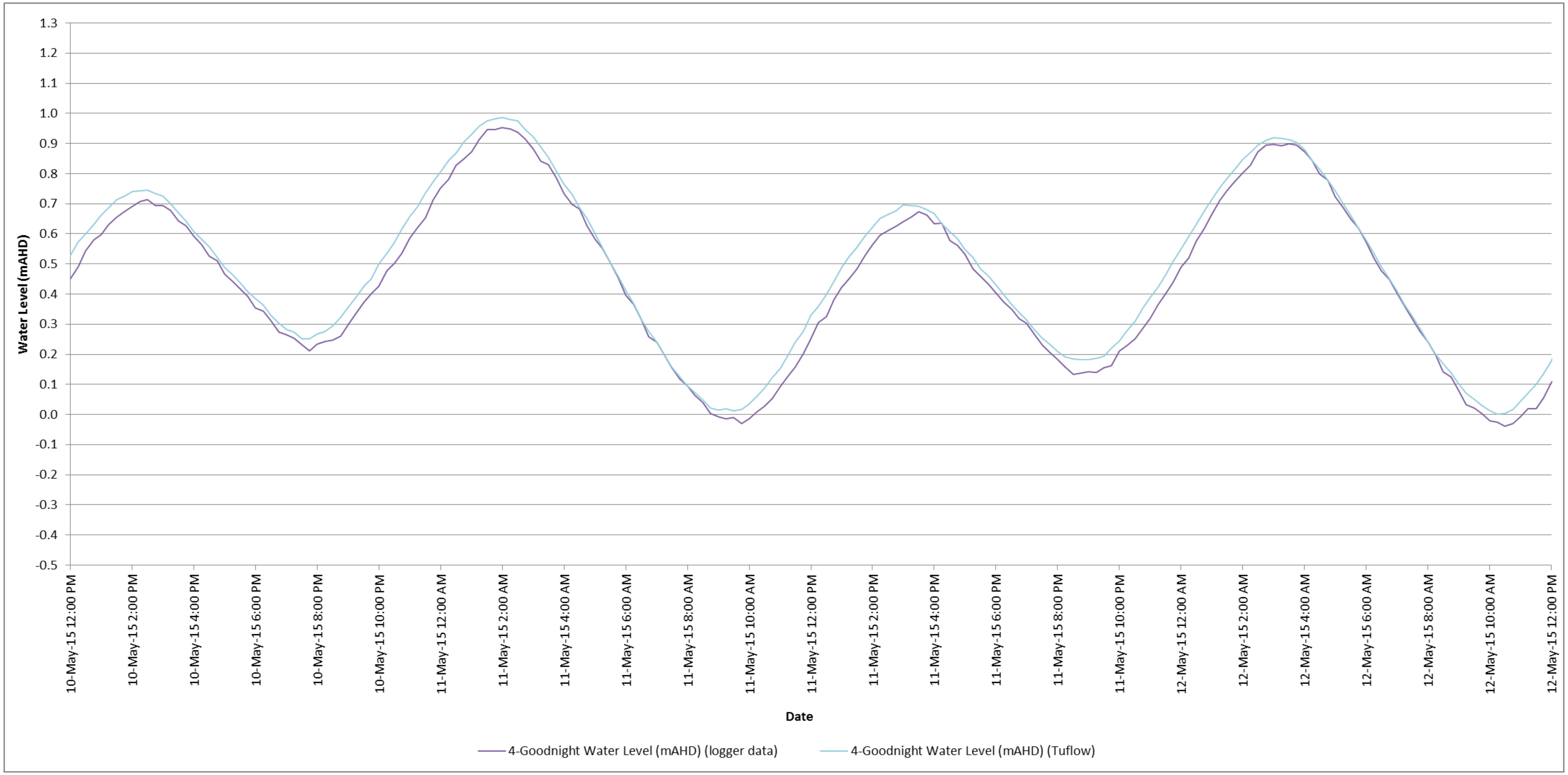
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION – SPRING TIDE** **LOCATION 3 – CURLEYS BAY** **CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 17**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



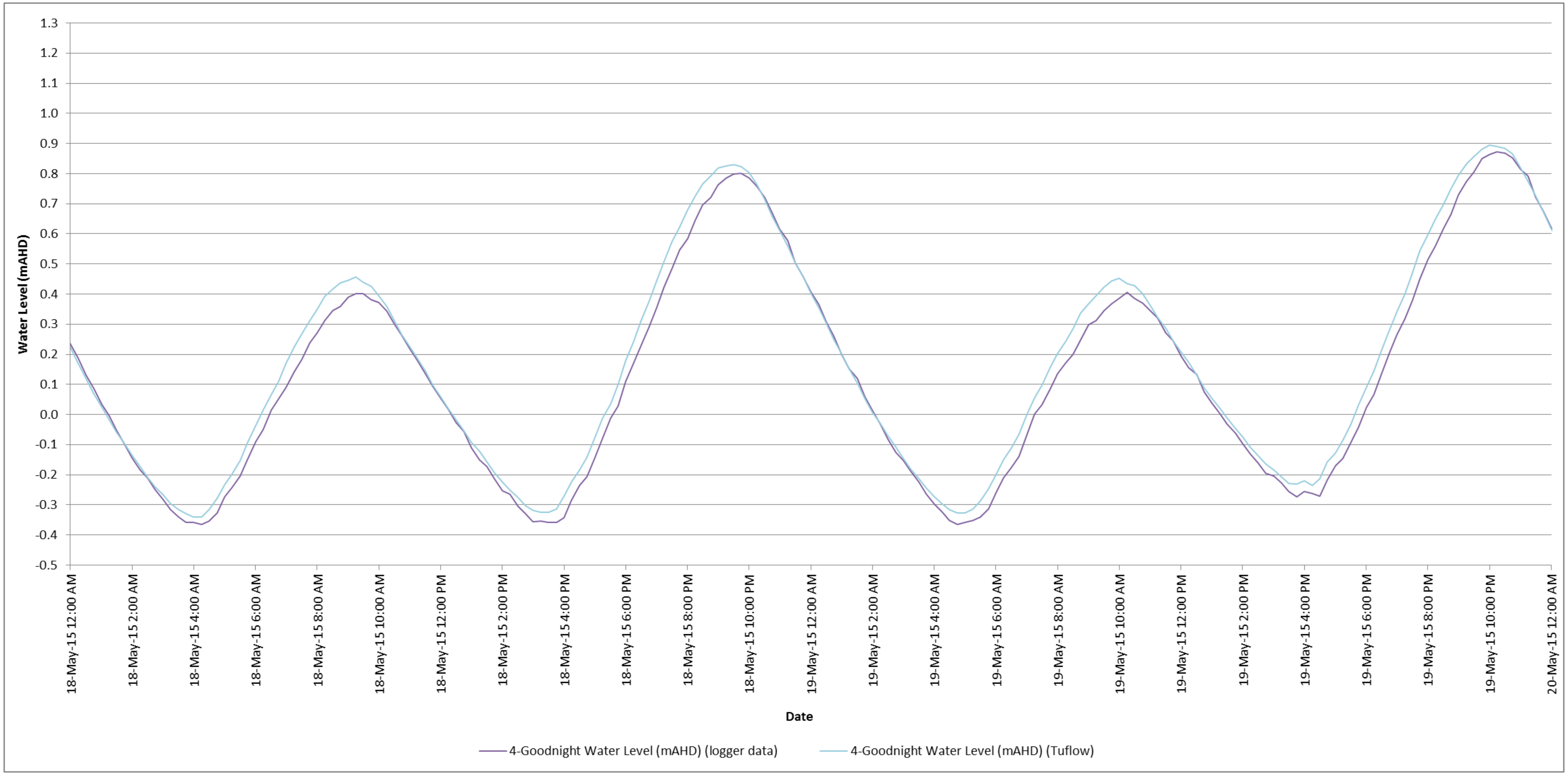
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION** **LOCATION 4 – GOODNIGHT ISLAND** **CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 18**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



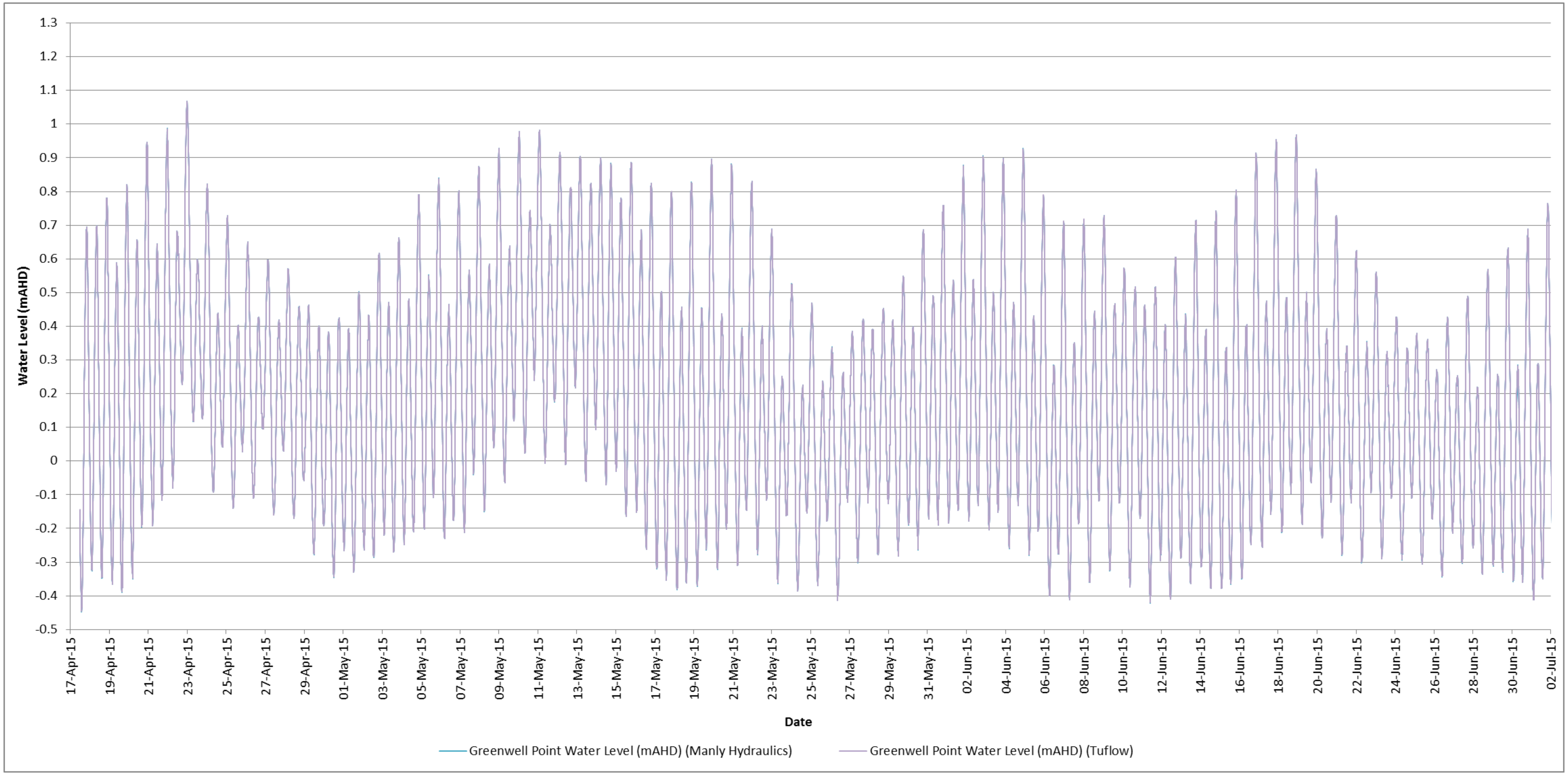
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 19**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



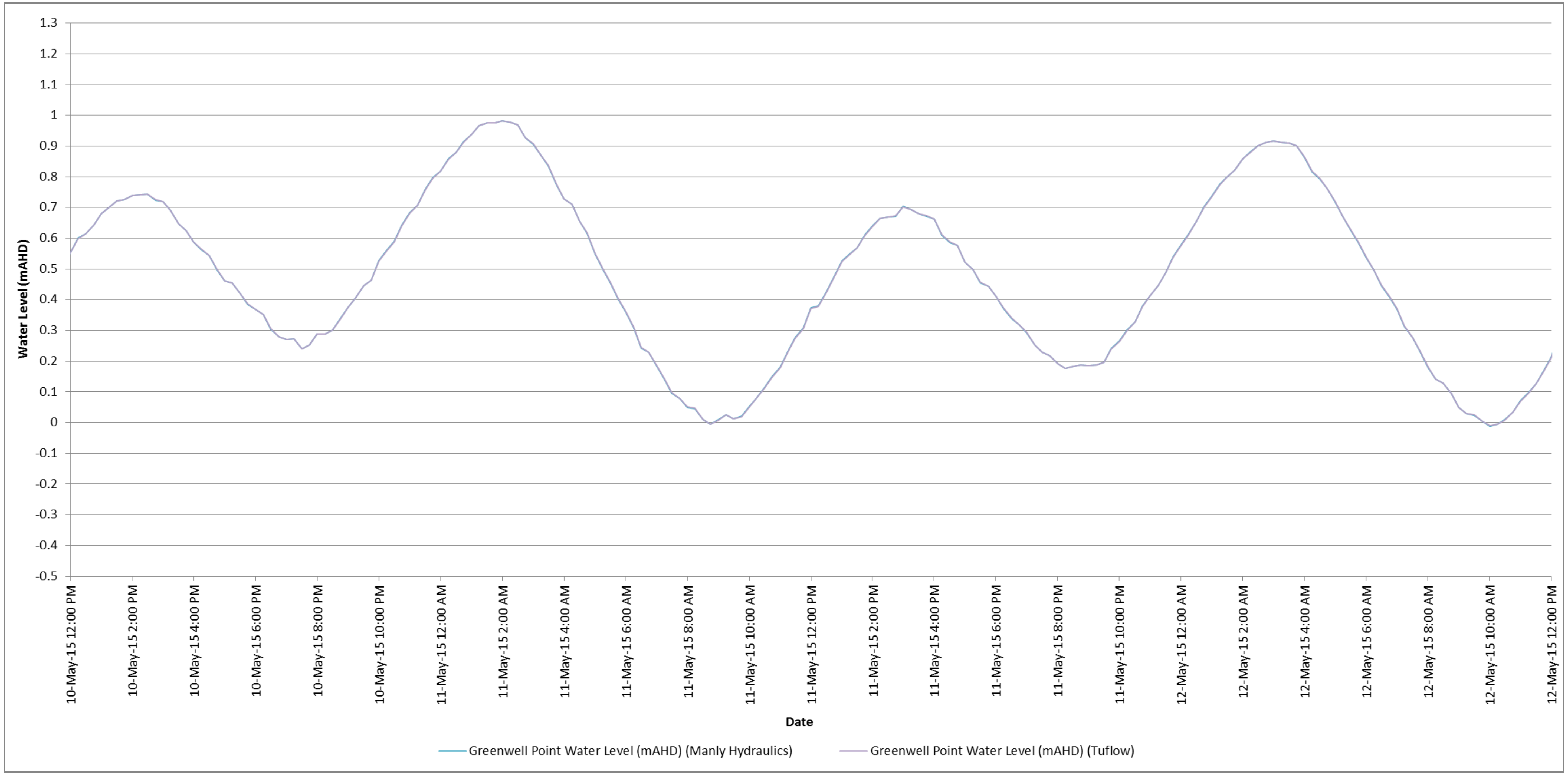
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: **FIGURE 20**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



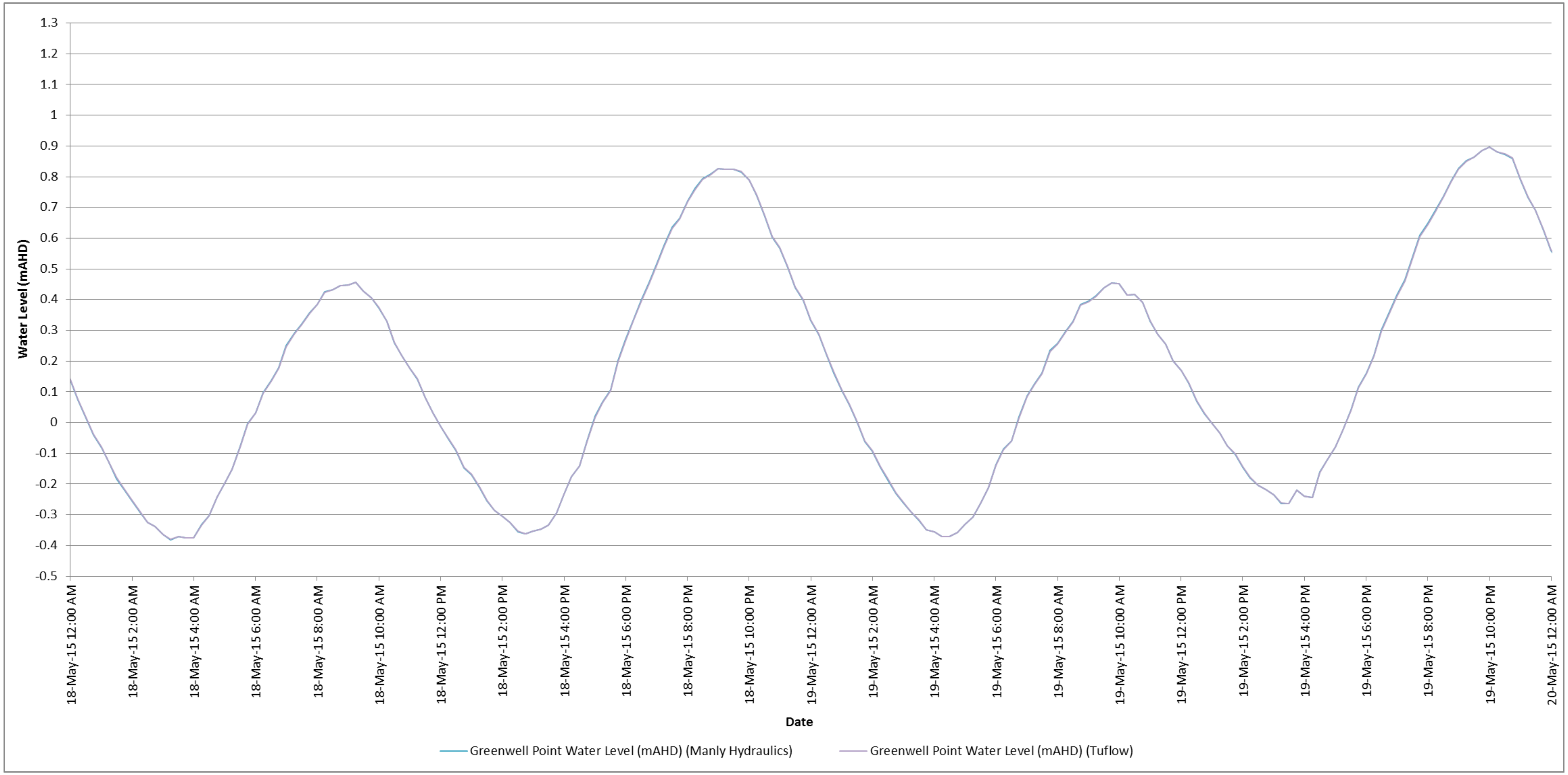
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 5 – GREENWELL POINT MHL DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 21**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



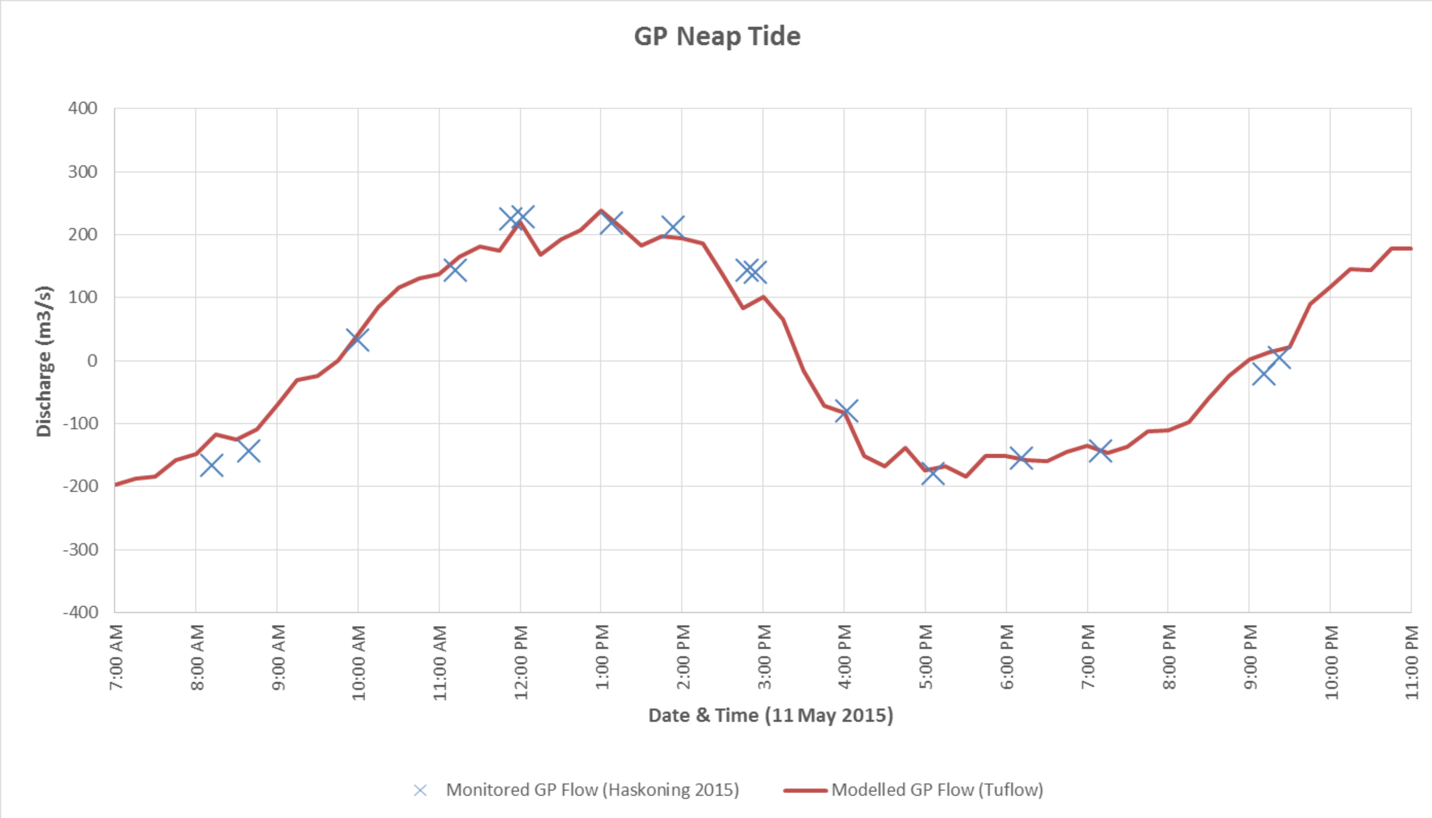
martens

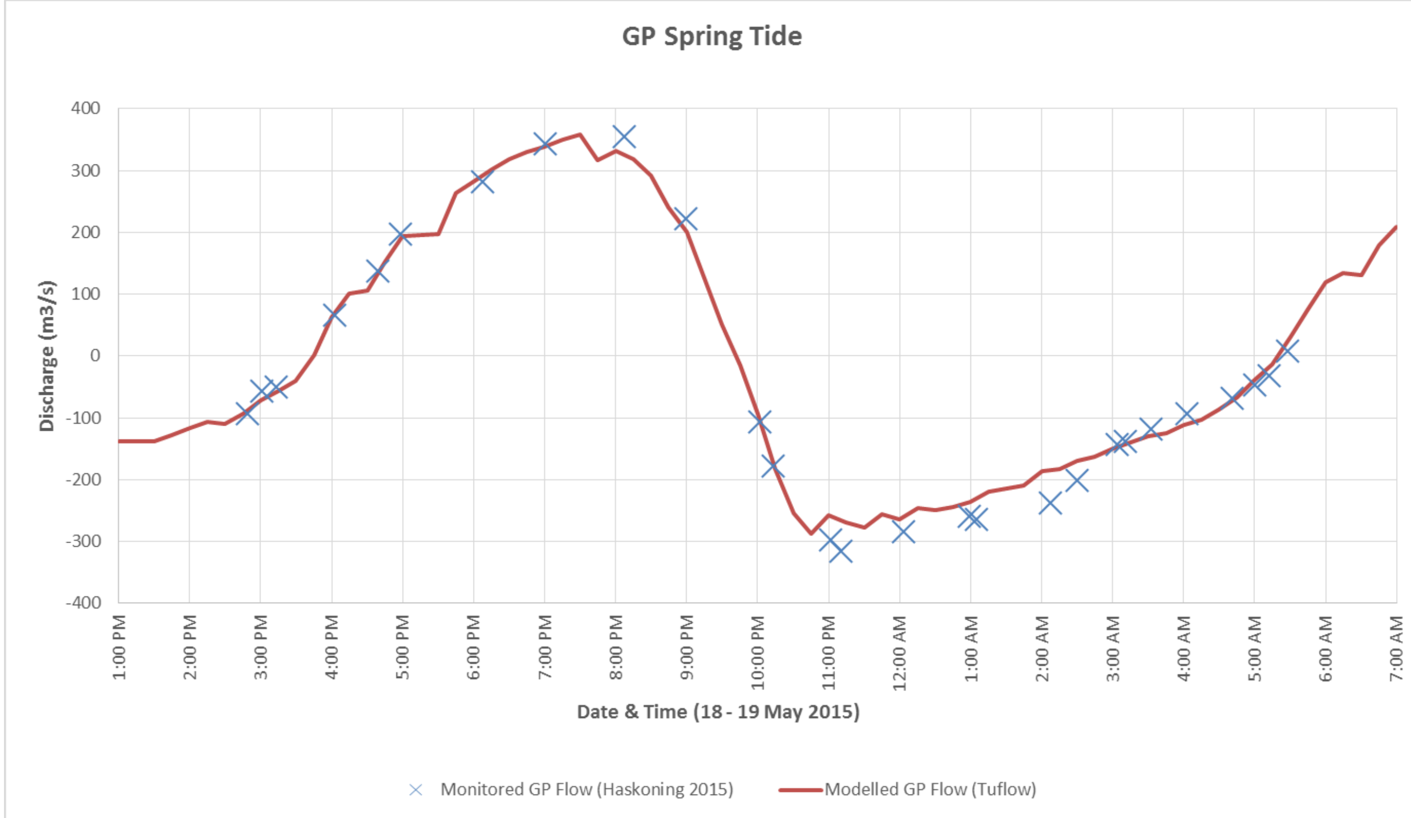
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE** **LOCATION 5 – GREENWELL POINT** **MHL DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 22**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

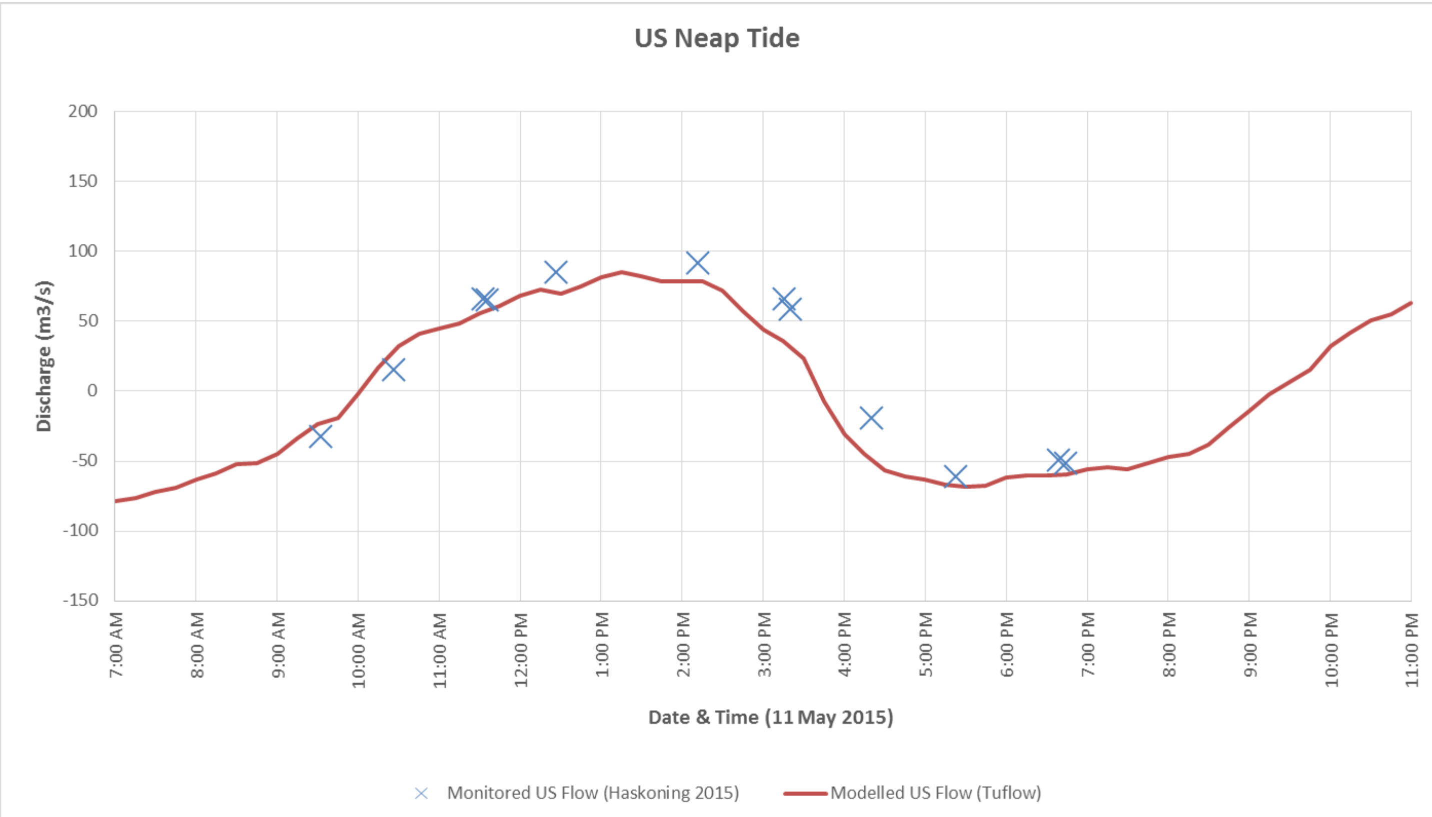


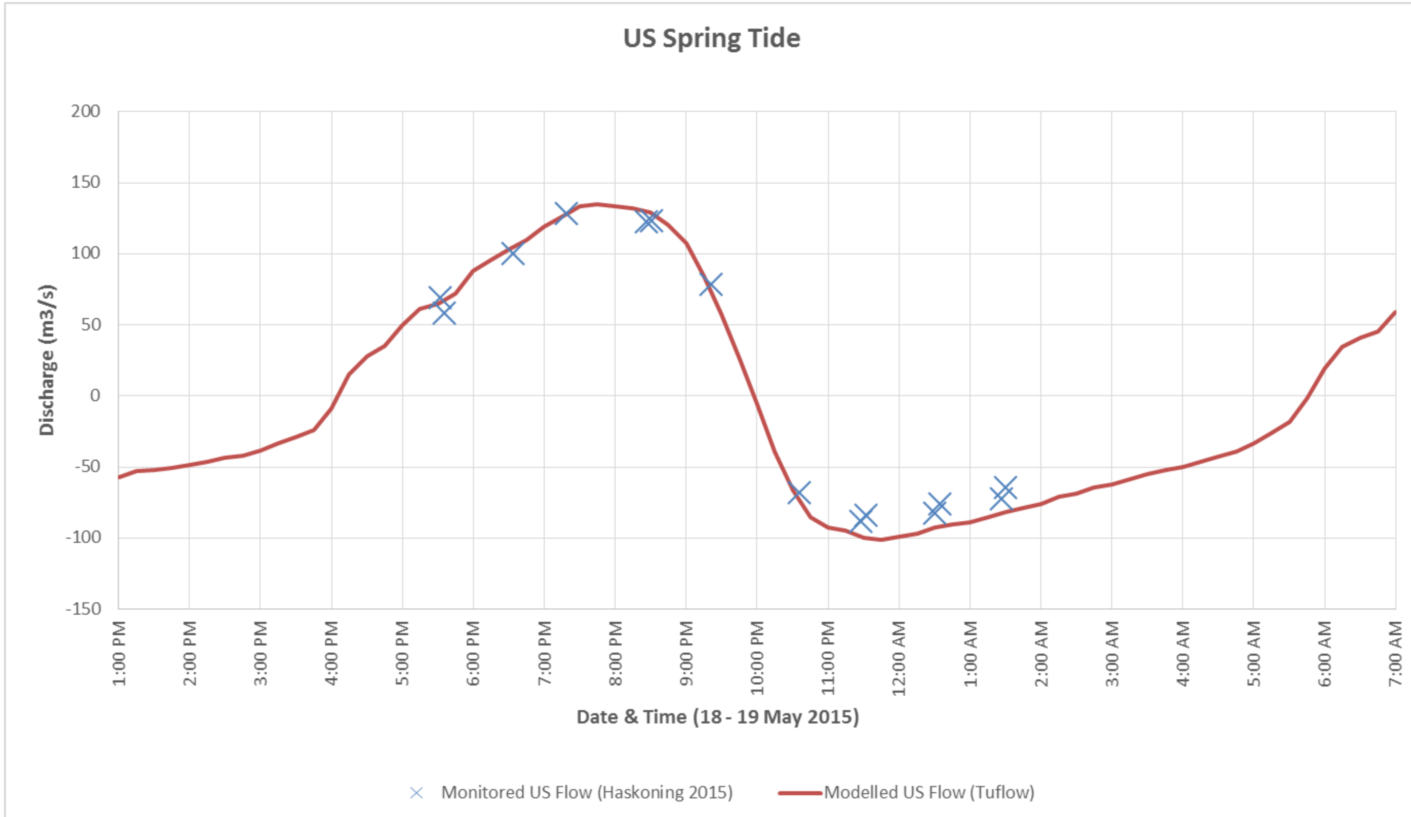
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION – SPRING TIDE** **LOCATION 5 – GREENWELL POINT** **MHL DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 23**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



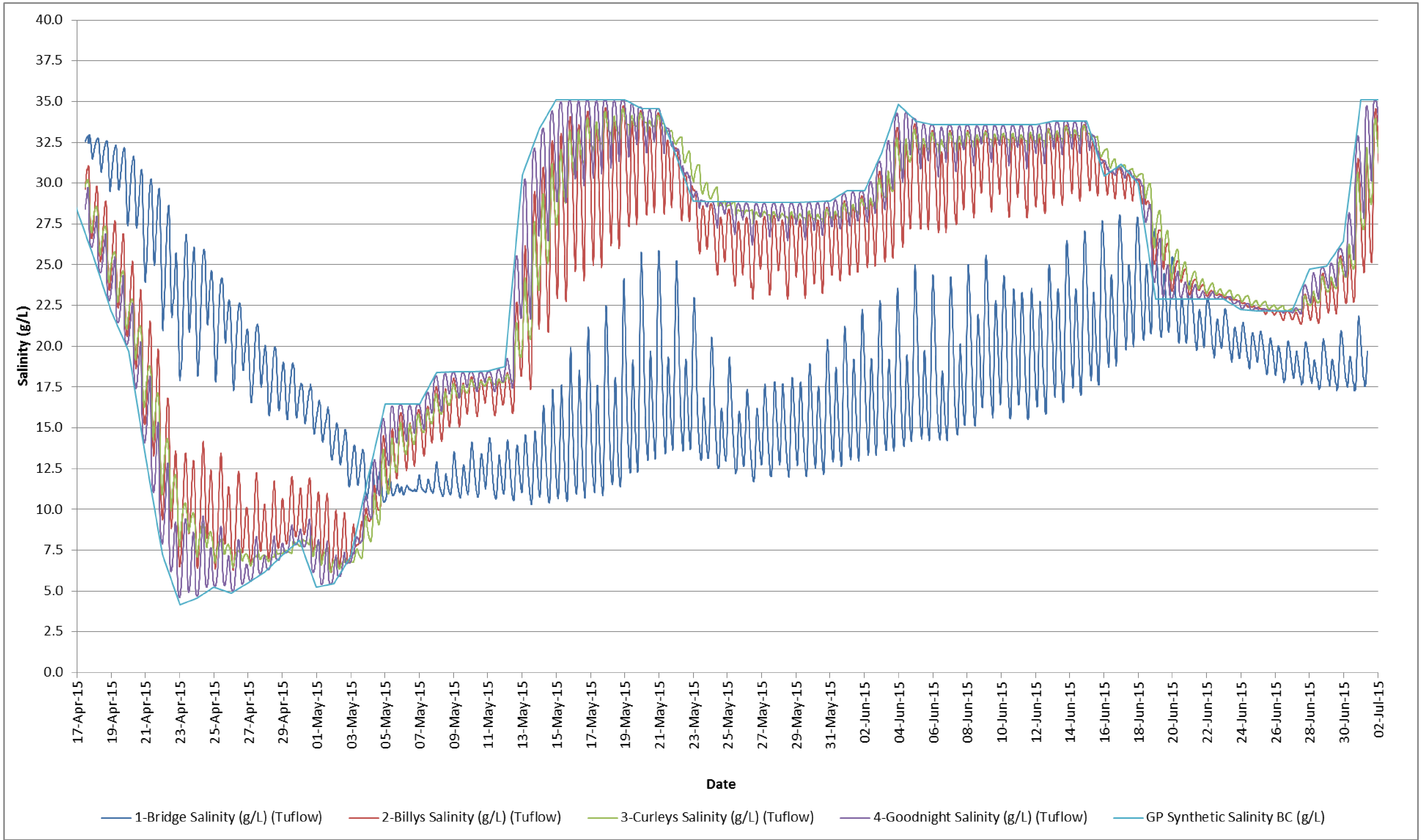






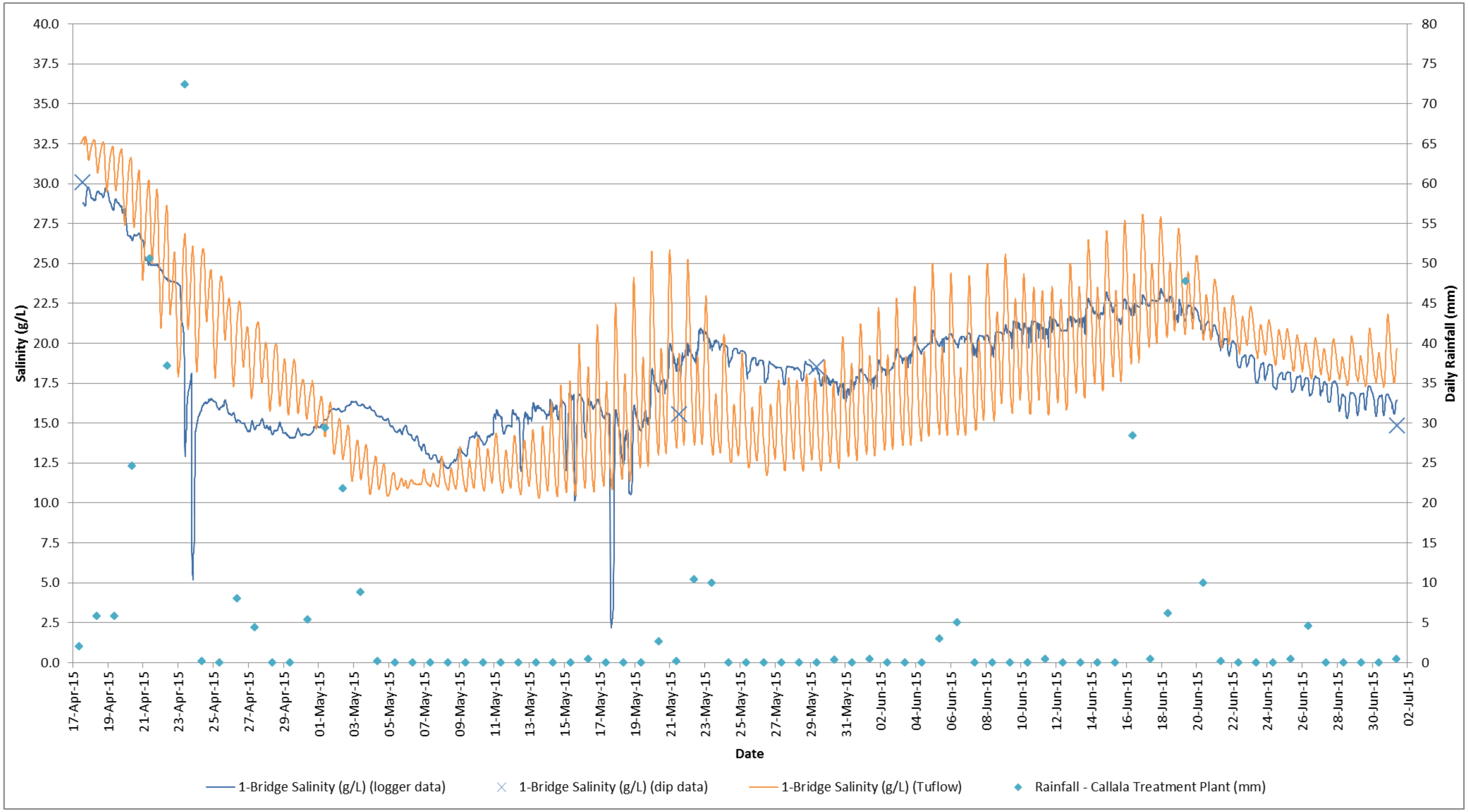
Note:
1. Positive discharge relates to water entering the estuary. Negative discharge relates to water leaving the estuary.
2. GP = transect between Greenwell Point and Orient Point, US = transect adjacent to Billys Island.
3. Full details of monitoring provided in Crookhaven ADCP Transect Study Report (Haskoning Australia 2015, Attachment F).

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**FLOW CALIBRATION ADCP DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 24**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**2015 SALINITY CALIBRATION MODELLED SALINITY CONCENTRATIONS AND GREENWELL POINT SYNTHETIC SALINITY BOUNDARY CONDITION**	Drawing No: **FIGURE 25**
Approved:	AN		
Date:	03.11.2016		Job No: P1203365
Scale:	NA		



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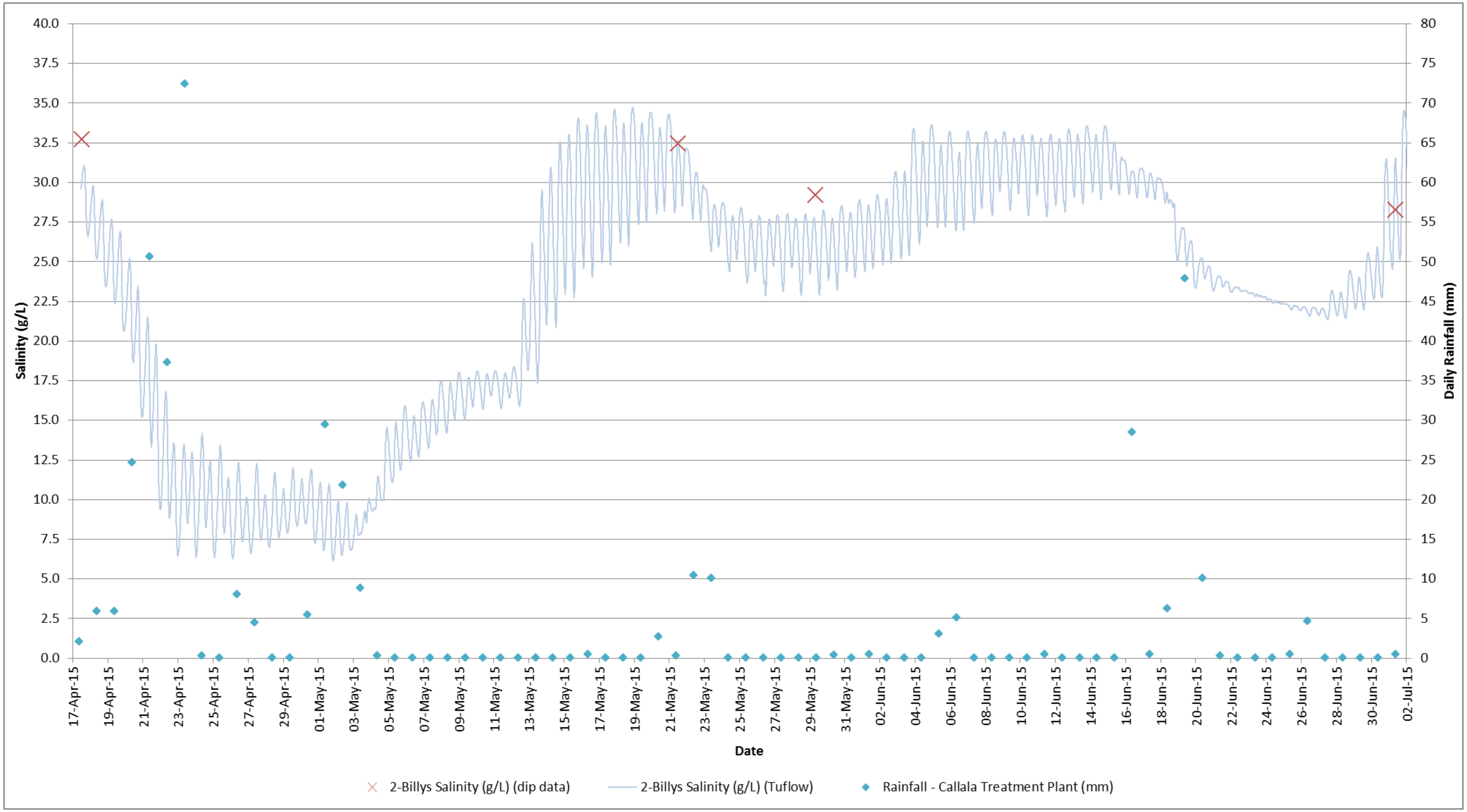
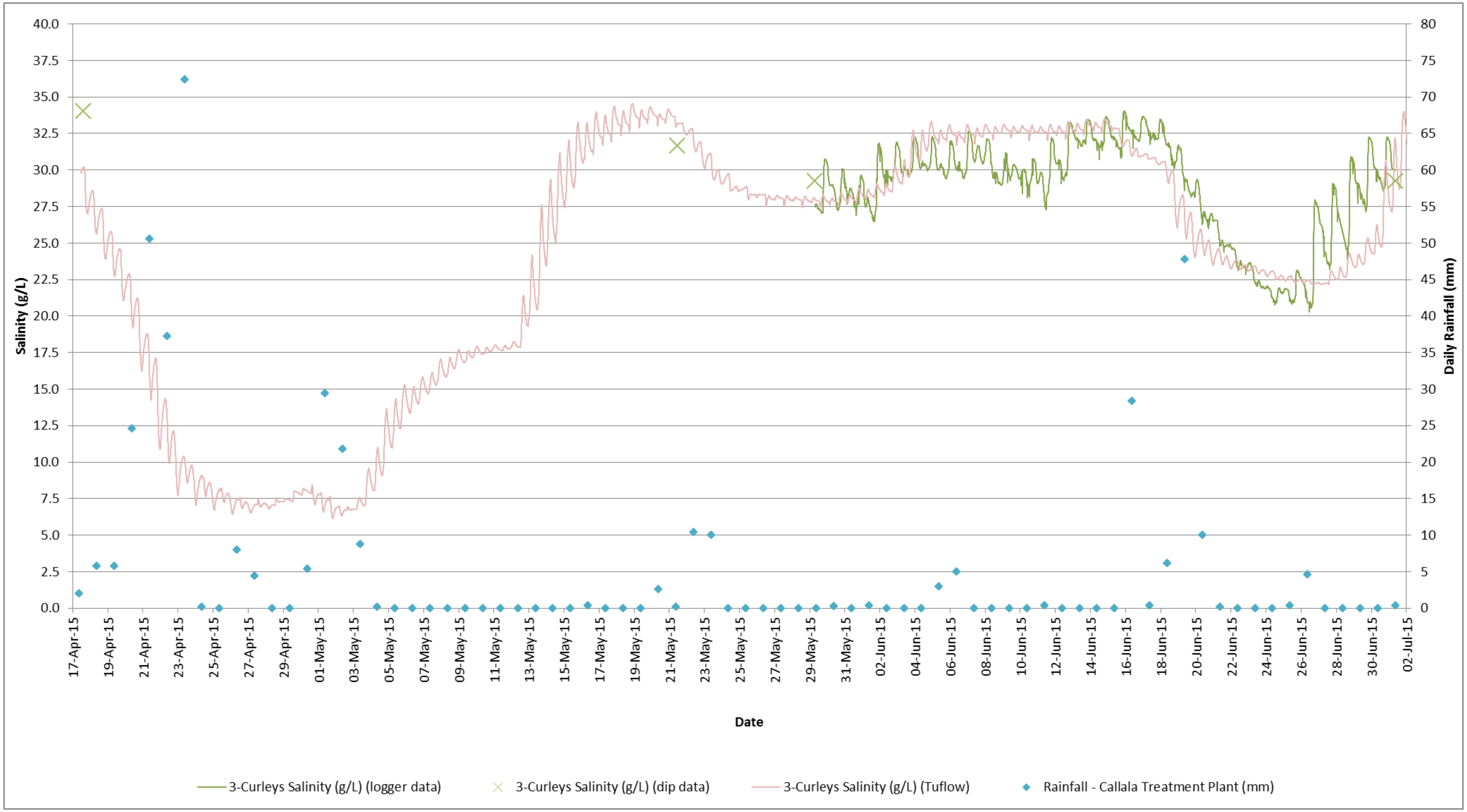
Note:
1. Modelled salinity amplitude is overpredicted due to proximity to inflow boundary conditions, as discussed in Section 3.4.4.

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**2015 SALINITY CALIBRATION LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 26**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



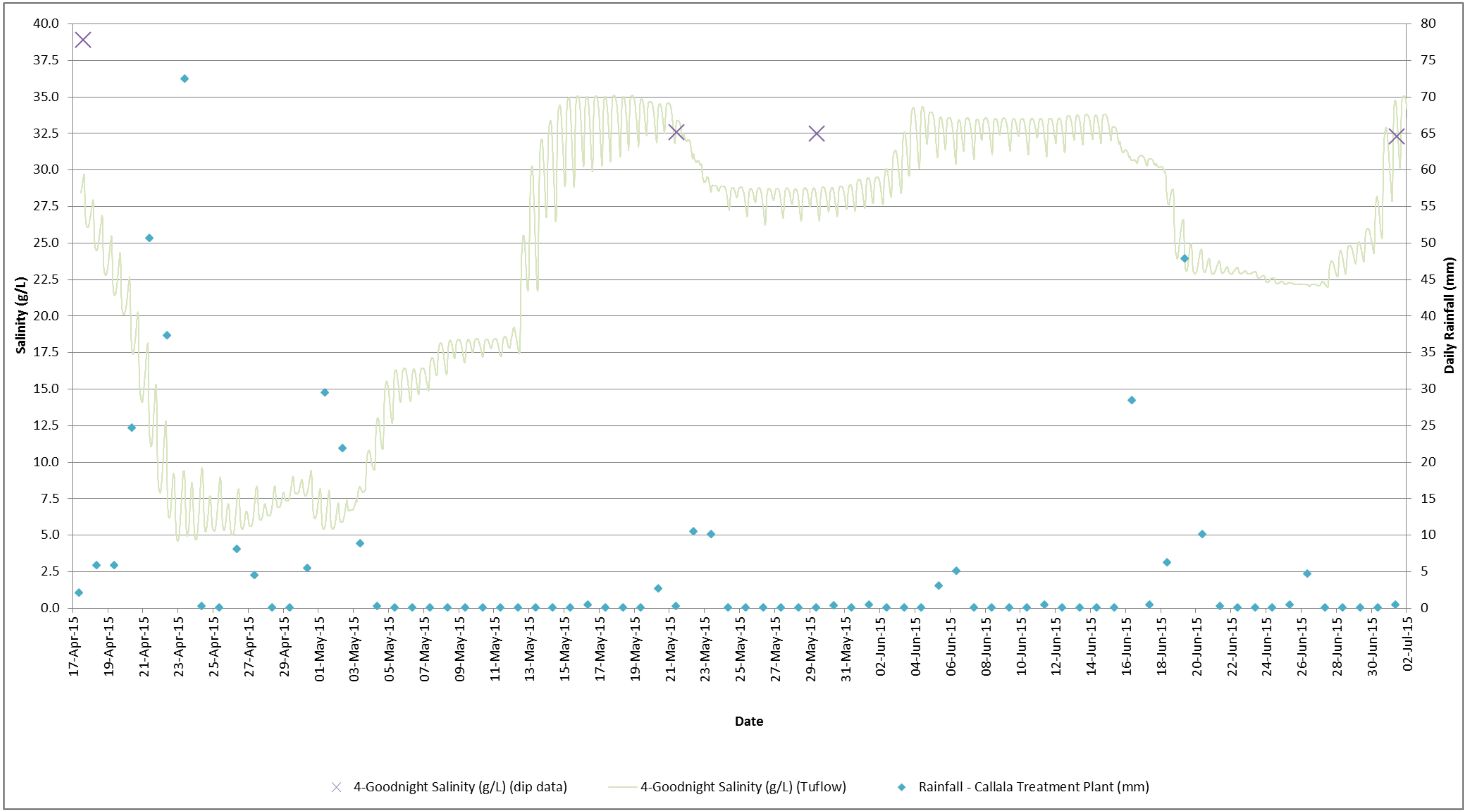
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**2015 SALINITY CALIBRATION LOCATION 2 – BILLYS ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 27**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



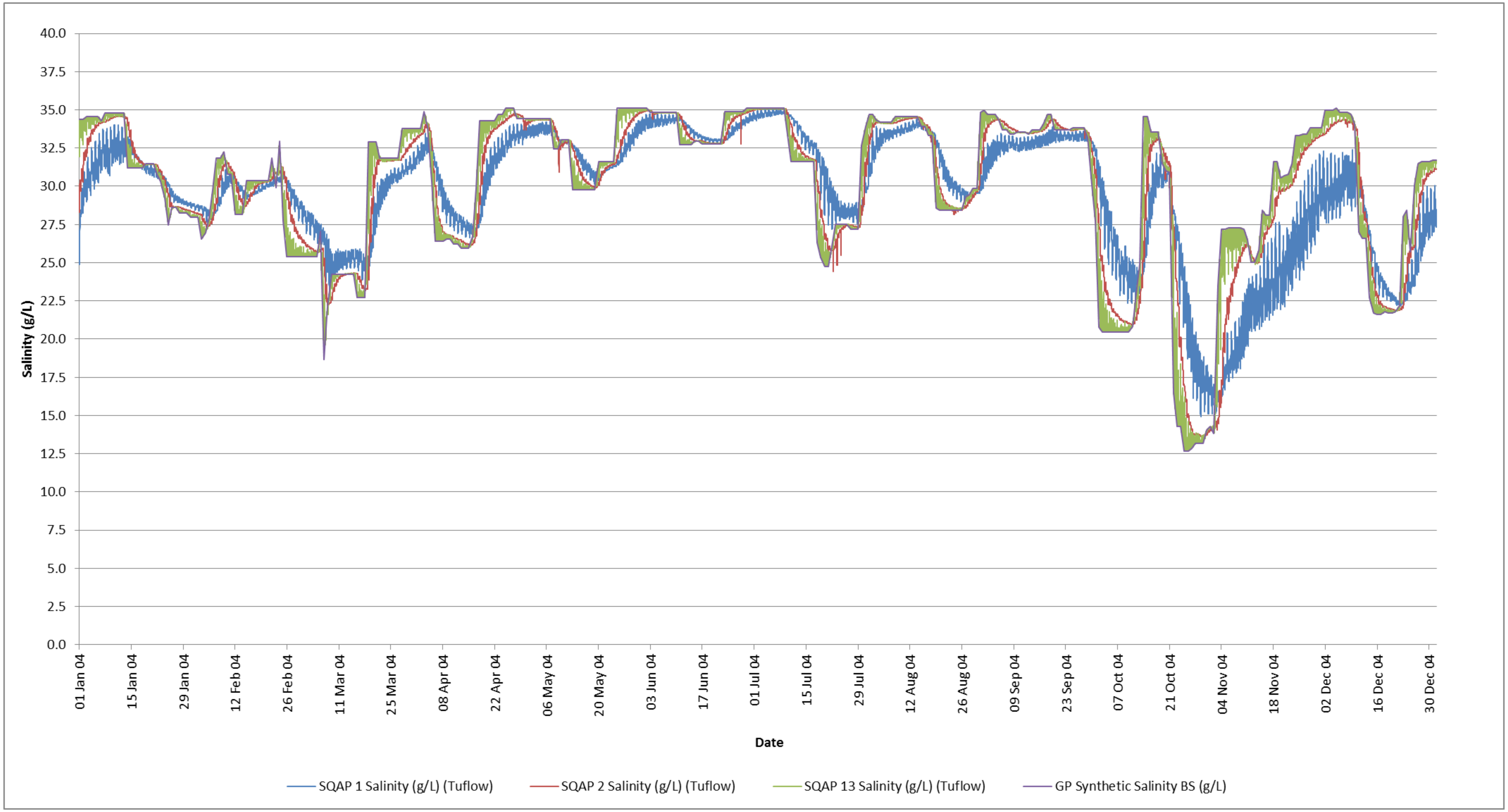
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**2015 SALINITY CALIBRATION LOCATION 3 – CURLEYS BAY CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 28**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



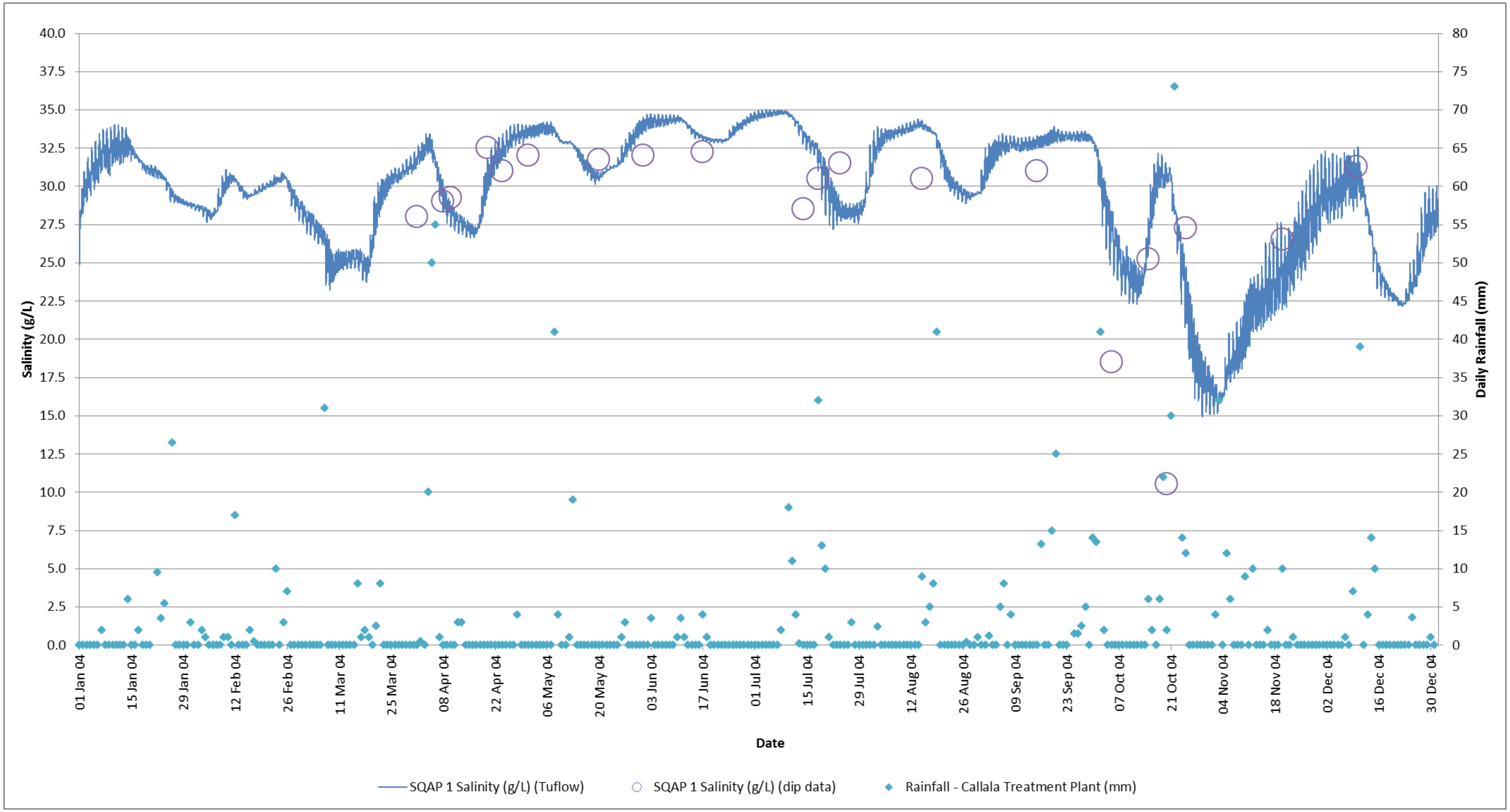
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**2015 SALINITY CALIBRATION LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 29**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



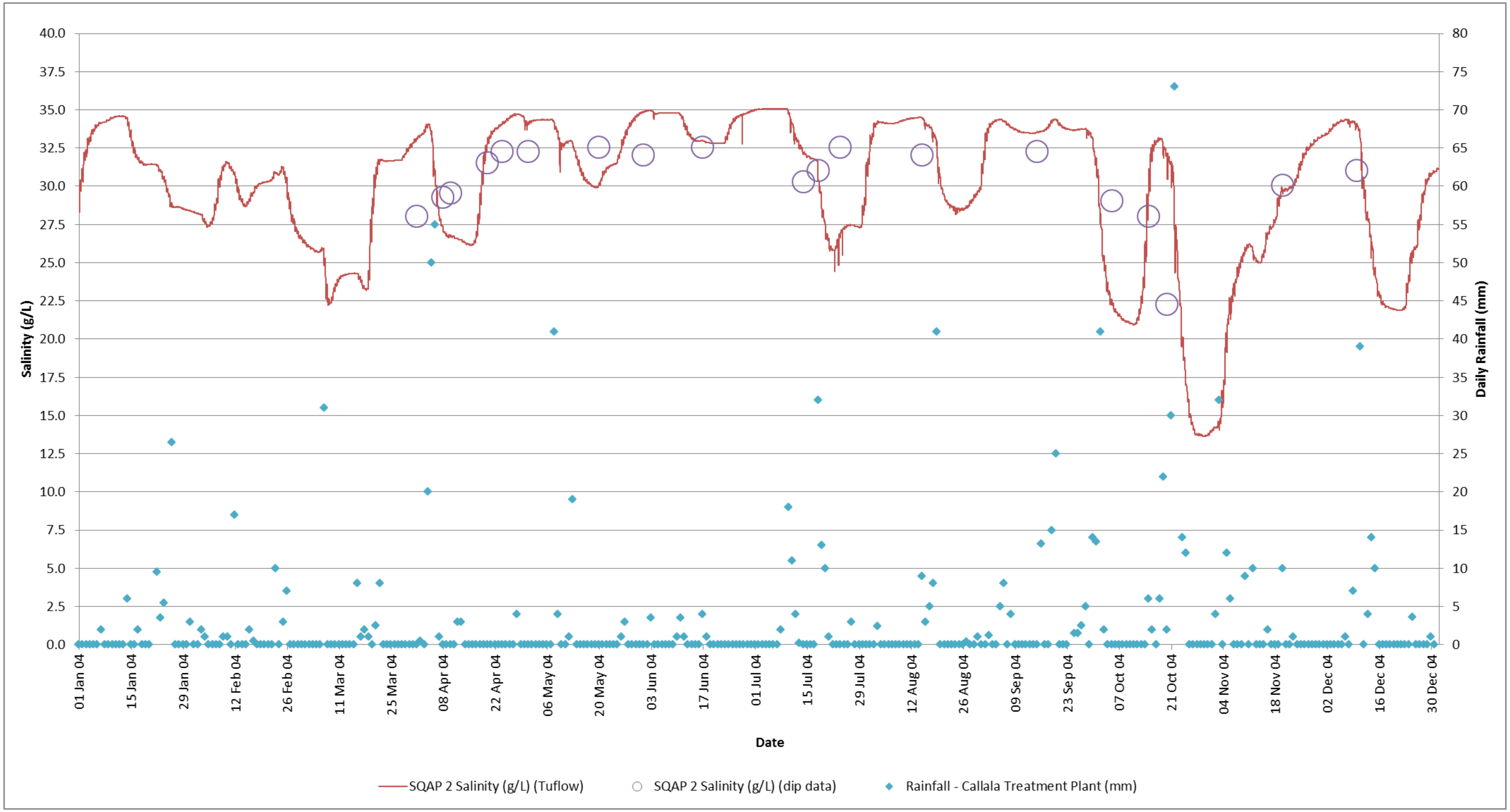
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**2004 SALINITY CALIBRATION MODELLED SALINITY CONCENTRATIONS AND GREENWELL POINT SYNTHETIC SALINITY BOUNDARY CONDITION**	Drawing No: **FIGURE 30**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



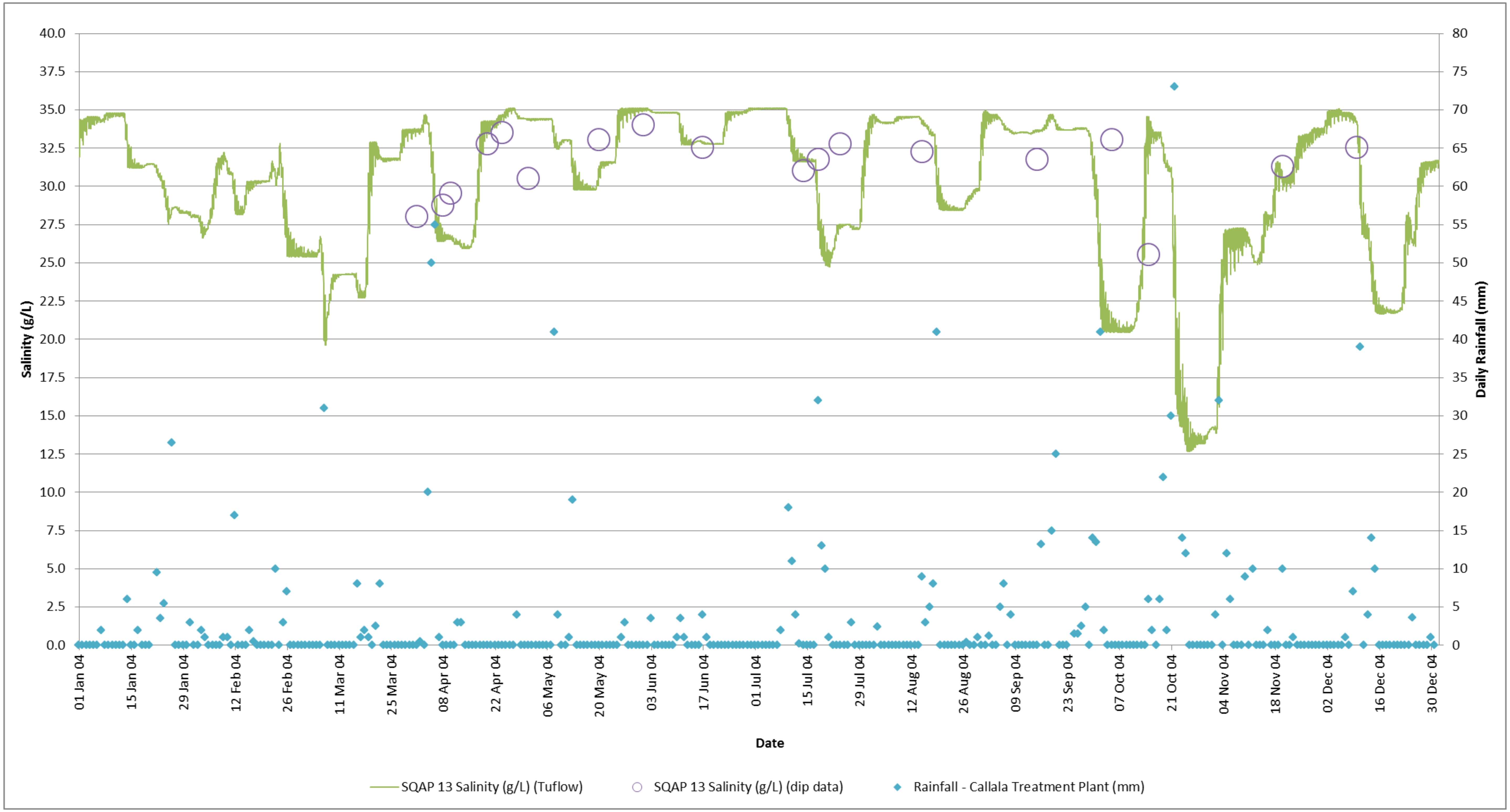
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**2004 SALINITY CALIBRATION SQAP 1 SQAP DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 31**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



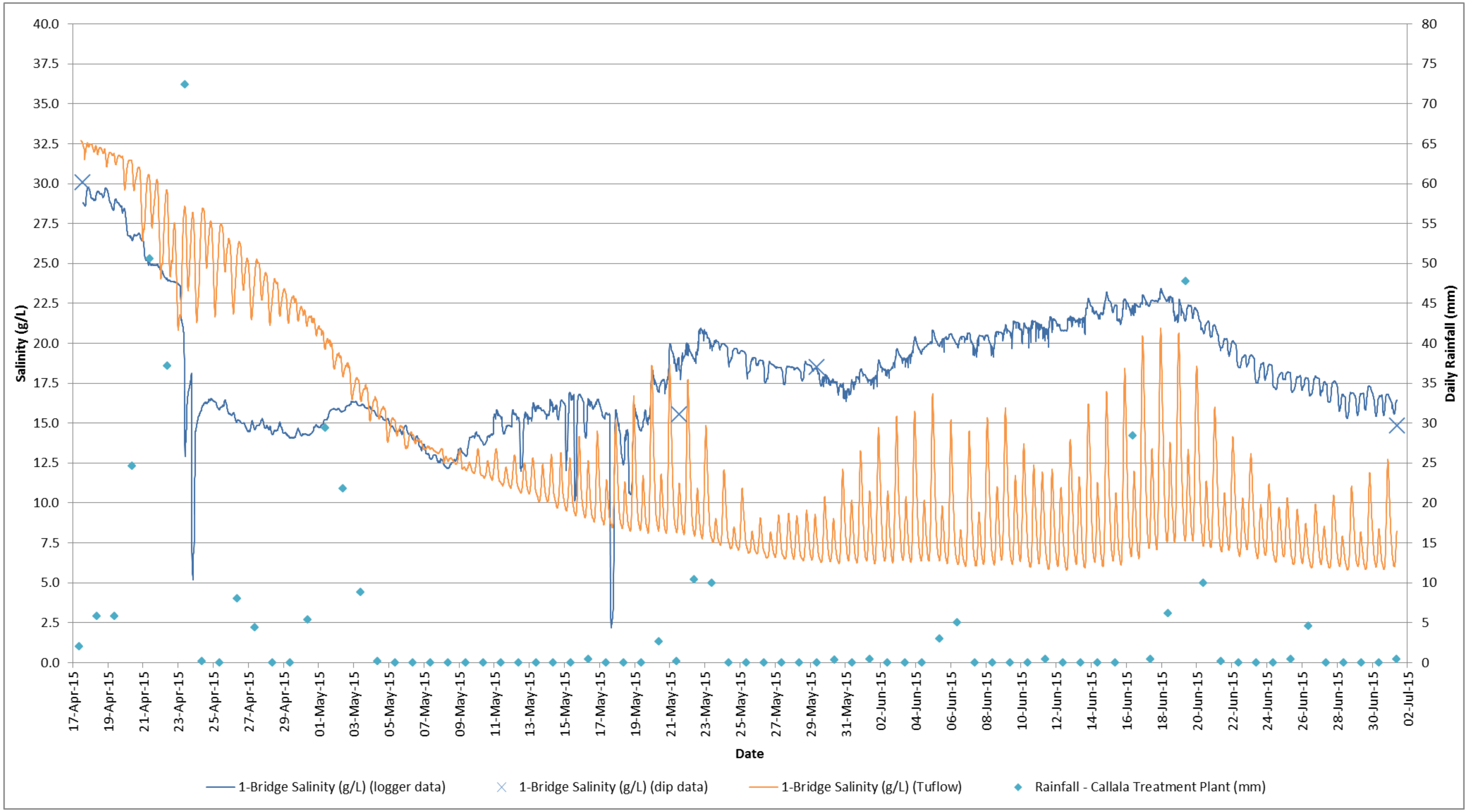
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**2004 SALINITY CALIBRATION SQAP 2 SQAP DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 32**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



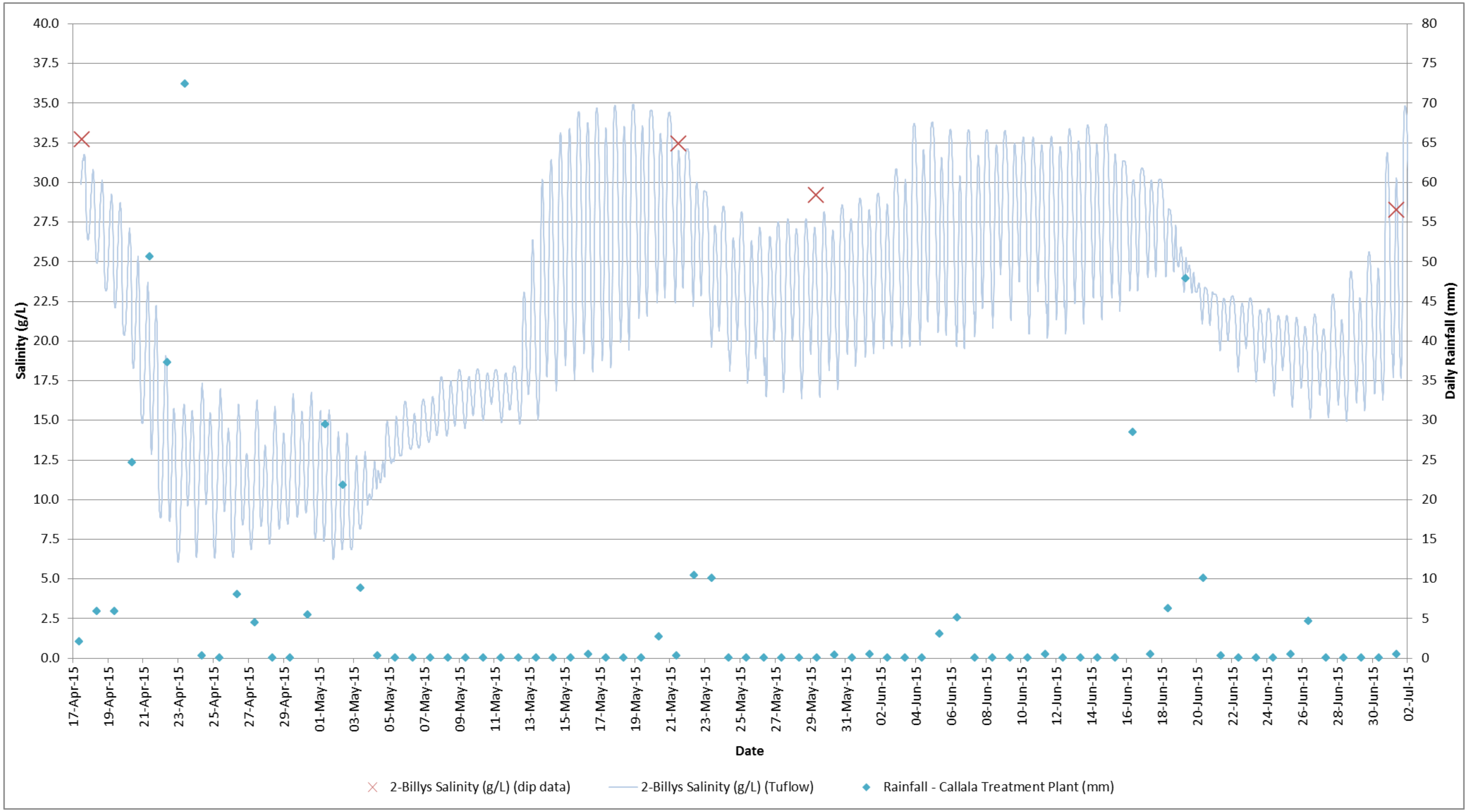
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**2004 SALINITY CALIBRATION SQAP 13 SQAP DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 33**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



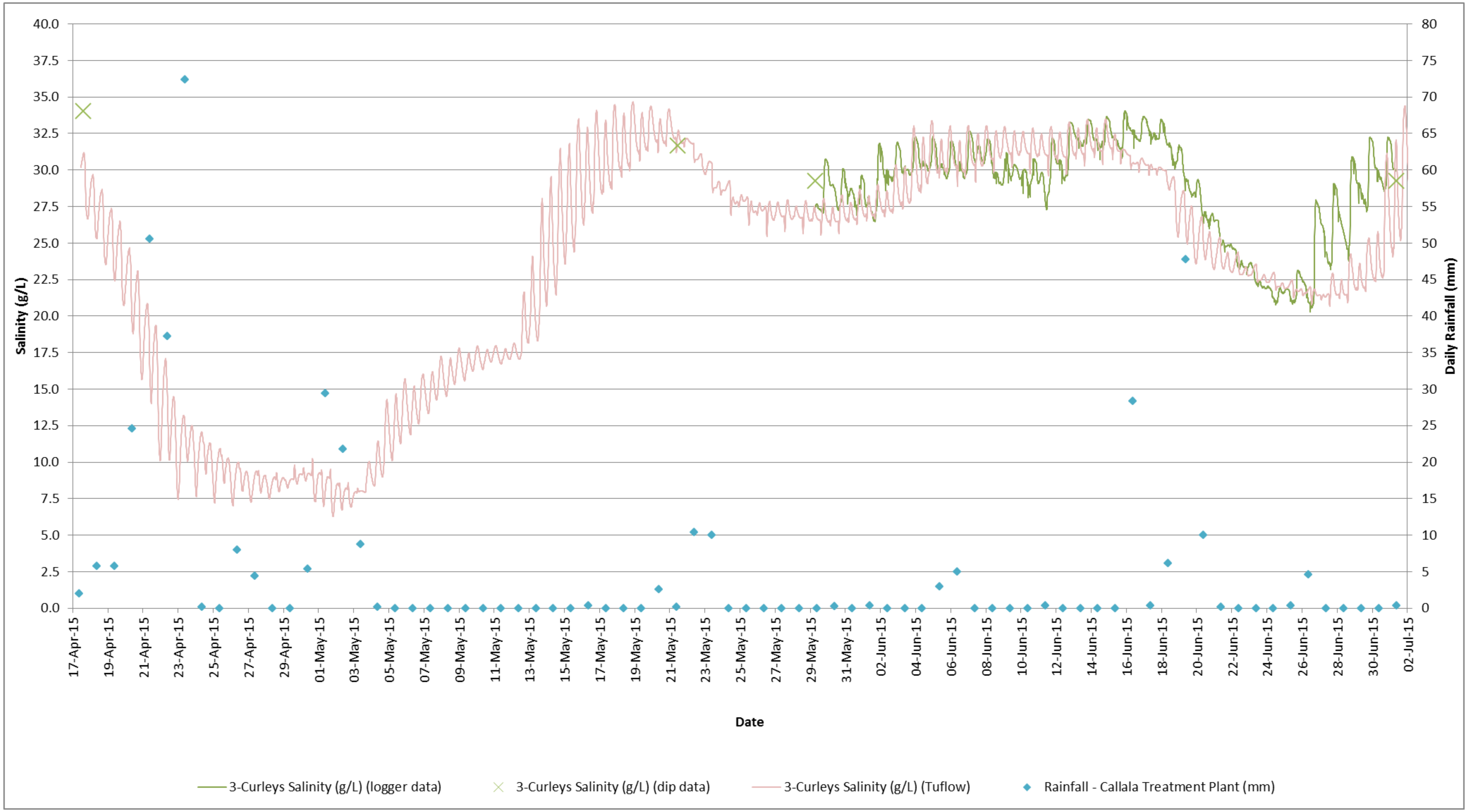
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**D2 SENSITIVITY TEST** **LOCATION 1 – CULBURRA ROAD BRIDGE** **CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 34**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



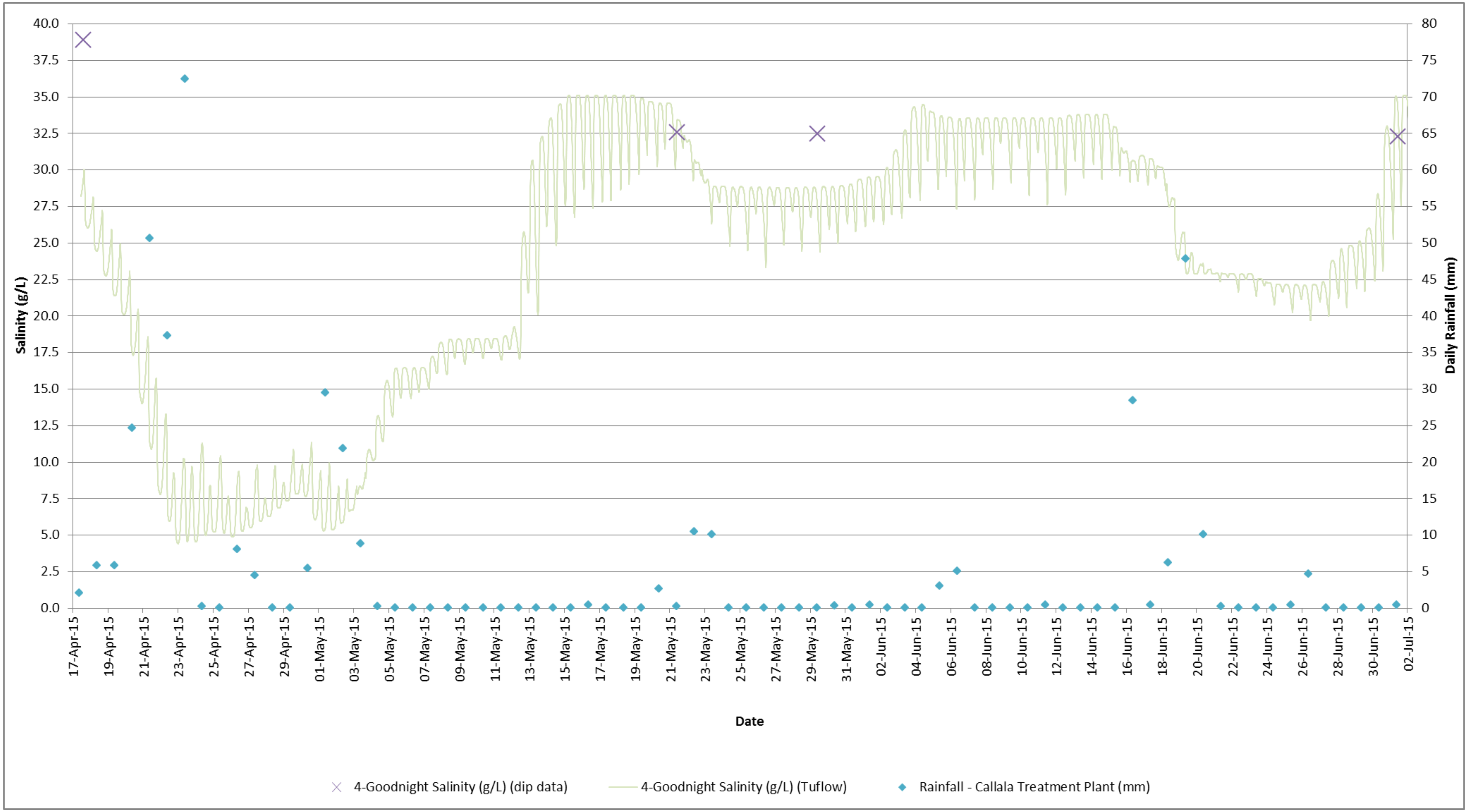
martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**D2 SENSITIVITY TEST LOCATION 2 – BILLYS ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 35**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	D2 SENSITIVITY TEST LOCATION 3 – CURLEYS BAY CTD DATA VS TUFLOW MODELLING	Drawing No: **FIGURE 36**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



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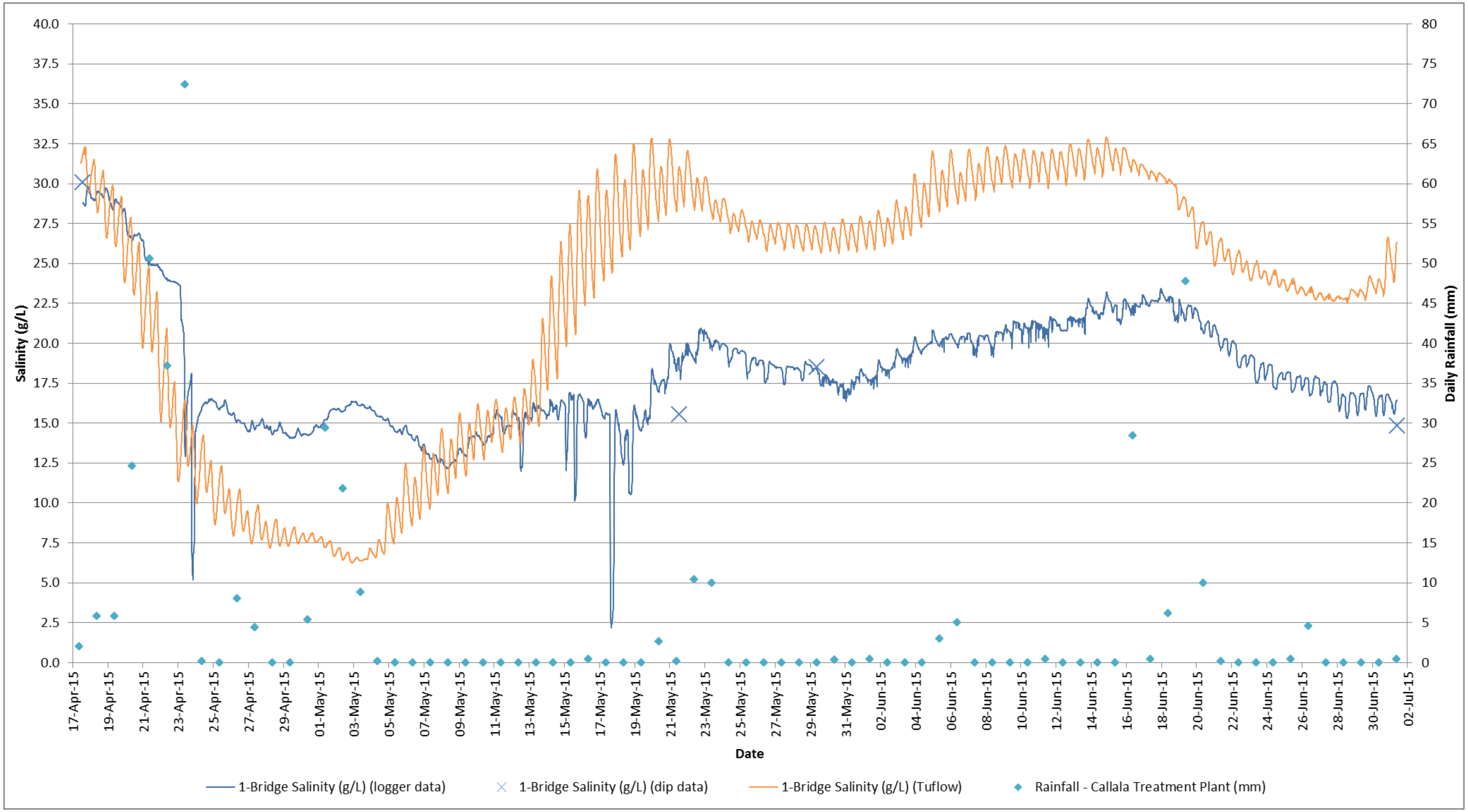
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	D2 SENSITIVITY TEST LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 37
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



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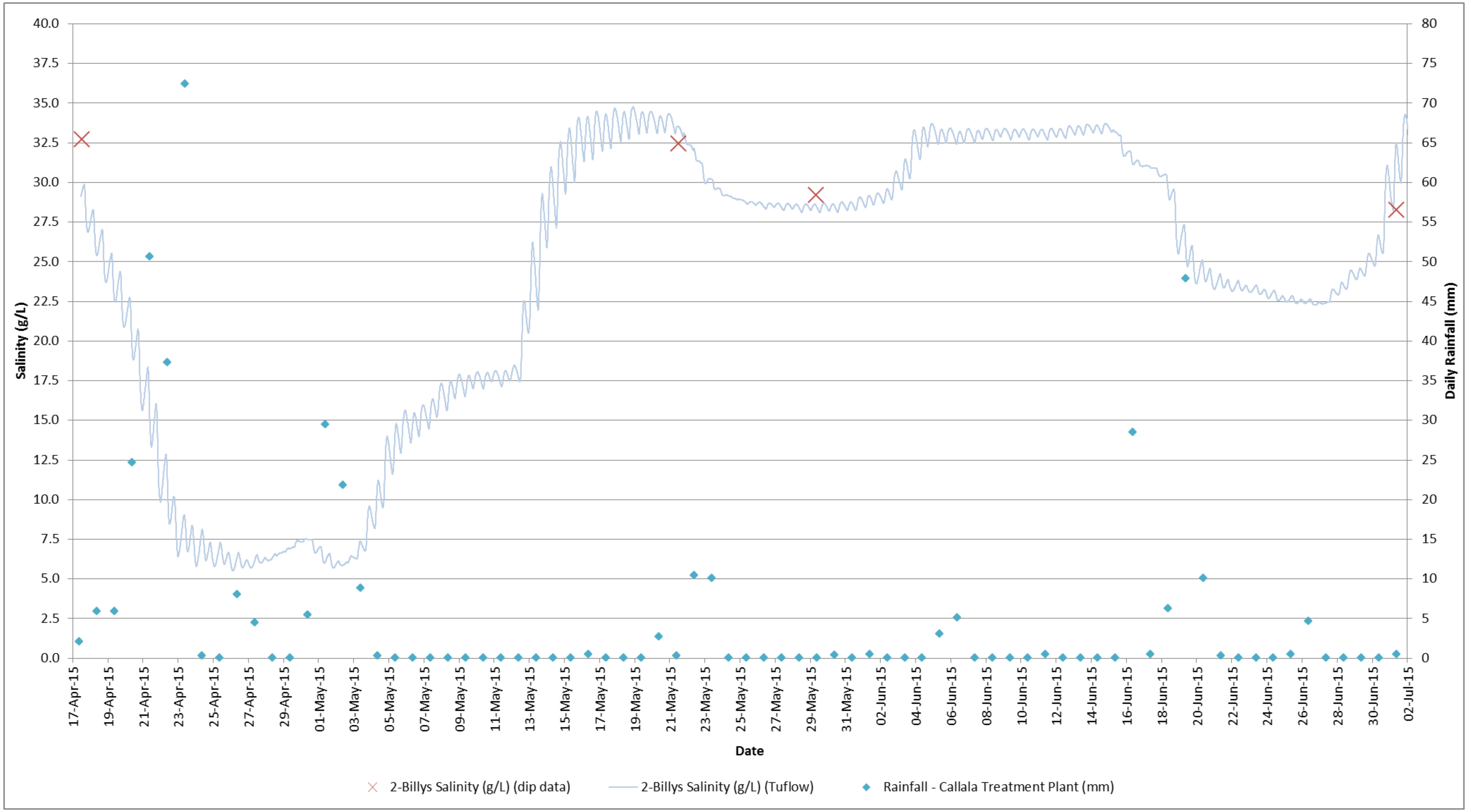
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	D3 SENSITIVITY TEST LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 38
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



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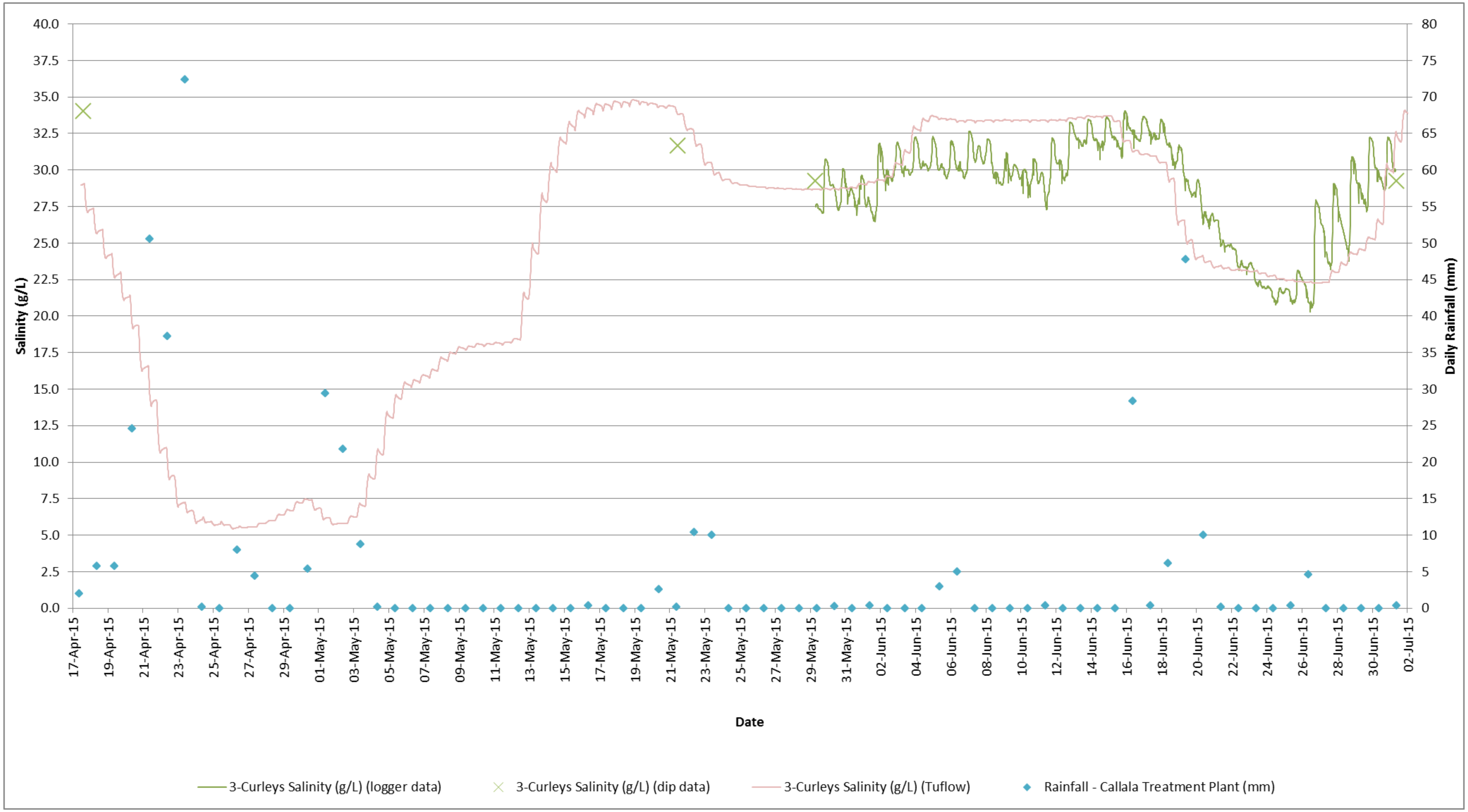
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	D3 SENSITIVITY TEST LOCATION 2 – BILLYS ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 39
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



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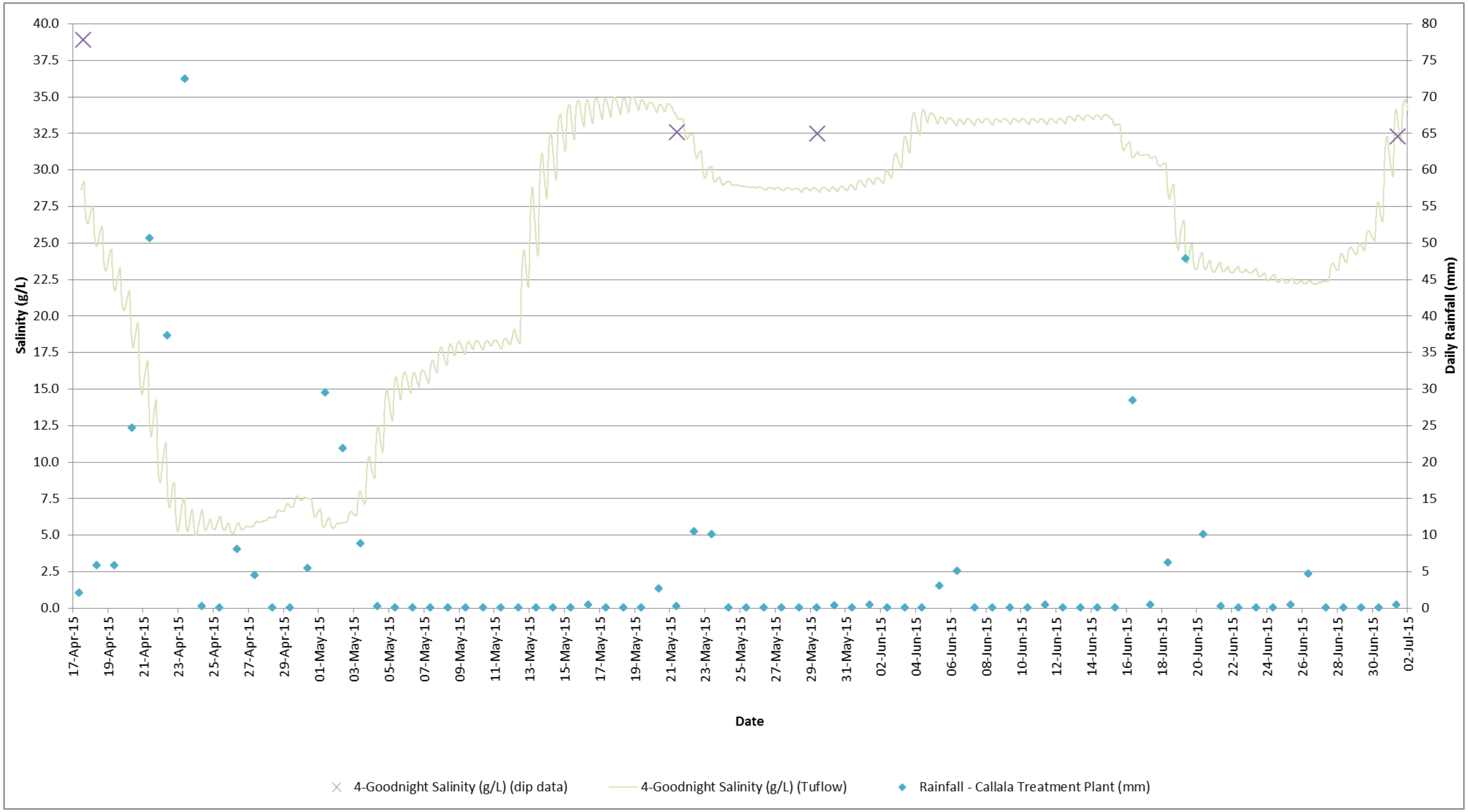
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	D3 SENSITIVITY TEST LOCATION 3 – CURLEYS BAY CTD DATA VS TUFLOW MODELLING	Drawing No: **FIGURE 40**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365



martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**D3 SENSITIVITY TEST** **LOCATION 4 – GOODNIGHT ISLAND** **CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 41**
Approved:	AN		
Date:	03.11.2016		
Scale:	NA		Job No: P1203365

15 Attachment H: Crookhaven ADCP Transect Study Report (Haskoning Australia 2015)

REPORT

Crookhaven ADCP Transect Study

Client: Martens & Associates Pty Ltd

Reference: M&WPA1091R001F03

Revision: 03/Final

Date: 2/06/2015

Royal HaskoningDHV
Enhancing Society Together

HASKONING AUSTRALIA PTY LTD.

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Document title:	Crookhaven ADCP Transect Study
Document short title:	
Reference:	M&WPA1091R001F03
Revision:	03/Final
Date:	2/06/2015
Project name:	Crookhaven ADCP Transect Study
Project number:	PA1091
Author(s):	James Donald
Drafted by:	James Donald
Checked by:	Evan Watterson
Date / initials:	EKW 18/06/15
Approved by:	Evan Watterson
Date / initials:	18/06/15

Classification
Project related

MANAGEMENT SYSTEM CERTIFICATION ISO 9001 = ISO 14001 = OHSAS 18001 DNV

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1 Project Outline

Haskoning Australia, a wholly owned subsidiary of Royal HaskoningDHV, was engaged by Martens & Associates in May 2015 to undertake metocean data collection works in the Crookhaven River, NSW. The works involved the use of a vessel mounted, downward looking Acoustic Doppler Current Profiler (ADCP) to measure current speed, current direction and depth across two predefined transects in the estuary. The following short report outlines the methodology implemented and the Quality Assurance/Quality Control (QA/QC) procedures used to process the resulting data. The report also presents the final processed data collected from the works.

1.1 Methodology & Operational Aspects

1.1.1 ADCP Background

ADCPs are a family of acoustic based instrumentation which can be used to measure water velocity and depths. Measurements are undertaken by transmitting an acoustic pulse of known frequency into the water and measuring the “Doppler shift” of returned signals from reflective particles in the water. For these works the ADCP has been mounted on the side of the vessel in a downward looking orientation. The ADCP measures the velocity of the water beneath the vessel as it navigates across predefined cross sections.

The ADCP utilises bottom tracking technology as well as an RTK GNSS system to log the displacement of the vessel as it crosses the transect. The processing software is then able to utilise this information to determine the absolute magnitude and direction of the water flowing across the channel. This information can then be coupled with measured depth data to calculate absolute discharge across the channel.

1.2 Transect Locations

The primary objective of the study was to measure the tidal discharge in the estuary at two predefined transect locations. The locations of these transects were selected by Martens & Associates and are represented in Table 1 and Table 2. For ease in identification these transects have been labelled Greenwell Point (GP) and Upstream (US) transect.

Table 1.Transect Locations

 Greenwell Point (GP) Transect	 Upstream (US) Transect

Table 2. Transect Co-ordinates

	Greenwell Point Transect	Upstream Transect
Point 1 (Left Bank)	34° 54.461'S 150° 44.142'E	34° 55.147'S 150° 44.205'E
Point 2 (Right Bank)	34° 54.551'S 150° 44.366'E	34° 55.273'S 150° 44.244'E

1.3 Transect Timings

The works were completed over two exercises, one exercise to coincide with the neap tide and the other to coincide with the spring tide. Each exercise was completed over a 13-hour period with transects beginning approximately 30 minutes before low tide and continued through the tidal cycle until just after the subsequent low tide. Table 3 details the date and time of each exercise. The tide heights and timings presented in Table 3 were obtained from the Manly Hydraulic Laboratories tide gauge at Greenwell Point.

Table 3. Exercises Timings

	First Transect	Low Tide (relative to AHD)	High Tide (relative to AHD)	Low Tide (relative to AHD)	Last Transect
Neap Exercise	11/05/2015 08:11	11/05/2015 09:00 0.001 m	11/05/2015 15:00 0.703 m	11/05/2015 20:30 0.184 m	11/05/2015 21:22
Spring Exercise	18/05/2015 14:49	18/05/2015 15:00 -0.362 m	18/05/2015 21:00 0.824 m	19/05/2015 04:15 -0.37 m	19/05/2015 05:00

1.3.1 Operational Aspects

Throughout the study a total of 68 transects were successfully completed between the first and last transects times provided in Table 3, transects were completed at each location at approximately hourly intervals. Table 4, details the number of transects and replicate transects completed at each site.

It should be noted that due to navigational issues in being able to access the upstream site, the upstream site could not be surveyed over the complete tidal cycle. The waterways linking both transect sites were extremely shallow in some places. This was especially an issue when undertaking the works at night as parts of the estuary were unmarked, unlit and uncharted. For this reason it was agreed with Martens & Associates that the field team would only conduct surveys at the upstream site when the water depth was sufficient to safely navigate to the site. At times when it was unsafe to access the upstream site, transects were undertaken at the Greenwell Point site at half hourly intervals.

Replicate transects were also undertaken at approximate intervals of 4 hours at each sites. Due to time restraints associated with travelling between both sites, there was not enough time to complete replicates for all transects.

Table 4. Transect Completed

	Number of transects at GP	Number of replicate transects at GP	Number of transects at US	Number of replicate Transects at US	Total number of transects
Neap Exercise	12	4	9	3	28
Spring Exercise	21	5	9	5	40

1.3.2 ADCP Configuration

For both exercises the ADCP was configured by an experienced metocean engineer in order to achieve the best possible data capture given the environmental conditions and the limitations of the instrument. This involved manually selecting the profiling mode, depth cell sizes, estimated water depth and ensemble resolution. The configuration of the ADCP is presented in Table 5. Note the ADCP configuration was constant for both the neap and spring tide monitoring exercises.

Table 5. ADCP Configuration

Parameter	Value
ADCP Instrument	Workhoarse Monitor 1200 KHz
Depth Cell Sizes	25 cm
Blanking Distance	25 cm
Depth of Instrument	30 cm
Water Track Mode	1
Bottom Track Mode	5
Bottom Track Pings	1
Water Track Pings	1
GPS Data	Used
Magnetic Declination	+12.7 °

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2 QA/QC & Data Processing

Haskoning Australia has developed and implements a number of QA/QC procedures in order to ensure the integrity of the data collected. The subsections below further detail the QA/ QC procedures implemented for these works.

2.1 QA/QC

2.1.1 Pre Transect Checks and Test

Before each data collection exercise a number pre transect checks and tests were completed by the field team. These tests are summarised in Table 6.

Table 6.Instrument Test

Test	Neap Exercise	Spring Exercise
Instrument Diagnostic Test	Completed (0 Fail)	Completed (0 Fail)
Compass Calibration	Completed	Completed
Instrument Clock Set	Completed	Completed
Moving Bed Test	Completed (moving bed negligible)	Completed (moving bed negligible)

2.1.2 Replicate Transects

During each transect the measured data is closely monitored by the field team. In instances where significant errors are identified the transect is repeated and the transect in question is discarded. Transects were also repeated at times where passing vessel traffic affected the safe navigation.

The field team also undertook replicate transects at a number of stages over the tidal cycle. Duplicate transects were undertaken to check the accuracy of the discharge measurements. Due to time constraints in being able to undertake transects at hourly intervals, at both sites, it was agreed with Martens & Associates that duplicate transects would be conducted at each site at approximately 4 hour intervals. The replicate transects help to quantify possible uncertainties in the data. Table 7 presents the measured discharge data from each replicate exercise. The table also presents the percentage difference and standard deviation from each replicate set.

As evident in the data presented in Table 7, 14 out of the total 17 duplicate transects undertaken resulted in a measured discharge variance of 15% or less between transects. It is important to note that throughout each exercise the tide is constantly changing and therefore altering flow in the estuary. For this reason no two transects will be exactly the same as tidal velocities are constantly varying.

It can be seen from the data in Table 7 that the larger differences between replicates occurred during times of slack tide. It is not uncommon to see notable variations between transects during times of slack tide as influences such as minor variations in boat speed and transect navigation can have more of an influence on discharge calculations when estuary current speeds are low.

With the majority of duplicate transects being in close agreement we consider the measured discharge data set to be dependable.

Table 7. Replicate Transects

Transect Number	Date / Time	Measured Discharge (m^3/s)	Percentage Difference (%)	Standard Deviation (m^3/s)
Greenwell Point Transect – Spring Tide Exercise				
CrookhavenSpring002 CrookhavenSpring004	18/05/2015 15:01 18/05/2015 15:13	-56.9 -51.6	9.3	3.7
CrookhavenSpring029 CrookhavenSpring031	18/05/2015 23:02 18/05/2015 23:10	-298 -316.8	6.3	13.3
CrookhavenSpring038 CrookhavenSpring039	19/05/2015 00:59 19/05/2015 13:05	-260.1 -264.5	1.7	3.1
CrookhavenSpring045 CrookhavenSpring046	19/05/2015 03:03 19/05/2015 03:10	-144 -138.9	3.5	3.6
CrookhavenSpring053 CrookhavenSpring054	19/05/2015 04:41 19/05/2015 05:12	-47.2 -32.3	31.6	10.5
Upstream Transect – Spring Tide Exercise				
CrookhavenSpring009 CrookhavenSpring010	18/05/2015 17:30 18/05/2015 17:35	69.1 57.8	16.4	8
CrookhavenSpring019 CrookhavenSpring020	18/05/2015 20:26 18/05/2015 20:31	122 123	0.8	0.7
CrookhavenSpring032 CrookhavenSpring033	18/05/2015 23:28 18/05/2015 23:33	-88.5 -84.1	5	3.1
CrookhavenSpring036 CrookhavenSpring037	19/05/2015 00:30 19/05/2015 00:34	-82.5 -76.3	7.5	4.4
CrookhavenSpring040 CrookhavenSpring041	19/05/2015 01:27 19/05/2015 01:30	-72.3 -64.9	10.2	5.2
Greenwell Point Transect – Neap Tide Exercise				
CrookhavenNeap2001 CrookhavenNeap2002	11/05/2015 08:11 11/05/2015 08:39	-166.3 -143.8	13.5	15.9
CrookhavenNeap1003 CrookhavenNeap1004	11/05/2015 11:53 11/05/2015 12:02	224.6 228.2	1.6	2.5

CrookhavenNeap1012 CrookhavenNeap1013	11/05/2015 14:48 11/05/2015 14:54	143.1 139.7	2.4	2.4
CrookhavenNeap1027 CrookhavenNeap1029	11/05/2015 21:11 11/05/2015 21:22	-22.6 4.8	121.2	19.4
Upstream Transect – Neap Tide Exercise				
CrookhavenNeap1001 CrookhavenNeap1002	11/05/2015 11:32 11/05/2015 11:35	65.4 65.2	.3	0.1
CrookhavenNeap1014 CrookhavenNeap1015	11/05/2015 15:15 11/05/2015 15:20	65.9 58.5	11.2	5.2
CrookhavenNeap1023 CrookhavenNeap1024	11/05/2015 18:39 11/05/2015 18:44	-49.8 -51.9	4.2	1.5

2.1.3 Data Screening & Processing

At the completion of both monitoring exercises the data was screened to ensure erroneous data points were identified and removed before the final data set was processed. The collected data was screened and ultimately processed using RDI's Win River II software.

One limitation in measuring estuary discharge through ADCP transects is the influence channel depth has on the total survey area. Portions of the transects that have water depths less than 1 m are unable to be accessed by the survey vessel and are unable to be accurately profiled by the ADCP. In order to generate discharge rates across the whole channel RDI's Win River II software has been used to provide estimations of discharge across the areas of the channel that cannot be accurately surveyed. For these unmeasured parts of the channel the power law method has been implemented in order to extrapolate and estimate discharge over these unmeasurable areas. Further explanation on the power law method can be found in RDI's Win River II manual and Chen (1991), *Unified Theory on Power Laws for Flow Resistance*.

Areas where the power law method was used in Win River II to estimate discharge include:

1. Bed Region – Side lobe energy output from the ADCP's transducers interfere with velocity measurements in the bottom 6% of the water column, meaning the ADCP cannot accurately measure current velocities close to the bed. For this reason RDI's Win River II software was used to estimates discharge over this bed region.
2. Near Surface Region – Throughout each exercise the ADCP was positioned 30 cm below the water line. The ADCP also has a blanking distance of 25 cm in front of the instrument face where it cannot accurately measure water velocities. This means that the top 0.5 m of the water column is not measured. Therefore Win River II has been used to estimate discharge over this near surface region.
3. Channel Edges – The ADCP has a minimum depth at which it can profile meaningful velocity data. Along the edges of both transects the water depth was too shallow for the ADCP to make valid measurements. Each transect was started and completed at points in the channel closest to the banks where at least two valid velocity bins could be measured (approximately 1.2 m water depth). The remaining distance to the edge of the channel was then entered into Win River II to allow the software to estimate discharge over the bank sections of the channel.

It should be noted that portions of both transects were unable to profiled due to the presence of shallow banks extending out into the channels. At the Greenwell Point transect, approximately 50% of the transect was unable to be surveyed due to the presence of a wide shallow bank on the eastern shoreline. The water depth over this eastern shoal is approximately 0.2m (relative to AHD) and approximately 180m wide. During the spring tide exercise the field team observed the bank remaining dry for approximately 1.5 hours either side of low tide with the bank being submerged during all other times. The field team also noted that during the neap tide exercise the bank remained inundated throughout the entire exercise. Figure 1 and Figure 2 present photos of the eastern bank at Greenwell Point taken by the field team during the monitoring works.

The shallow depths over this bank meant that during most stages in the tide the eastern bank section of the transect was too shallow to be accessed by the survey vessel. The shallow water depth over the bank also meant it was too shallow for the ADCP to make valid measurements. The field team observed that at times when the bank was inundated some flow over the bank did occur. It is for this reason the Win River II software was used to estimate the discharge over this shallow bank section. Further details on these bank estimations can be found in the accompanying Microsoft Excel spreadsheet with filename: '*PA1091 - Crookhaven ADCP Transect Study - Discharge Data Final.xls*'.

Figure 1. Greenwell Point (GP) Transect – Eastern bank, Spring Low Tide (18/05/2015 14:11)

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Figure 2. Greenwell Point (GP) Transect – Eastern bank, Neap High Tide (11/05/2015 14:51)

At the Upstream transect, approximately 55% of the transect was unable to be surveyed due to the presence of a wide shallow bank that runs along the southern shoreline. This southern bank is approximately 90m wide and has an average water depth of approximately 0.4m (relative to AHD). The field team noted that the shallow bank was inundated throughout both neap and spring tide exercise. Figure 3 presents a photo of the southern bank taken by the field team during the neap tide exercises.

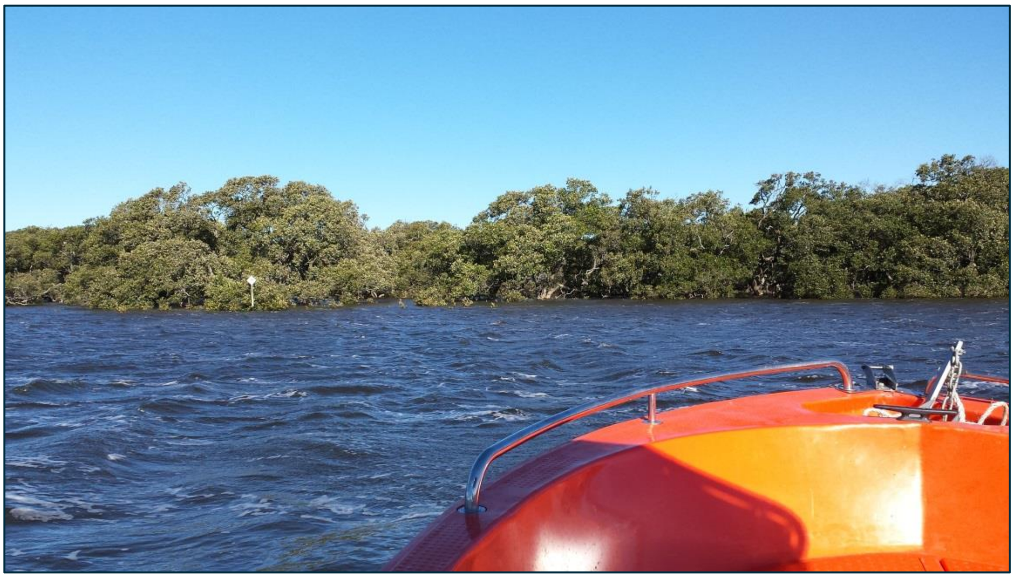

Figure 3. Upstream (US) Transect – Southern bank, Neap High Tide (11/05/2015 13:30)

The shallow water depth meant the southern bank section of the upstream transect could not be safely and accurately surveyed by the field team. The field team observed that at times when the bank was inundated some flow over the bank did occur. It is for this reason the Win River II software was used to estimate the discharge over this shallow bank section. Further details on these bank estimations can be found in the accompanying Microsoft Excel spreadsheet with filename: '*PA1091 - Crookhaven ADCP Transect Study - Discharge Data Final.xls*'.

3 Data & Results

With the majority of duplicate transects being in close agreement and given the application of the QA/QC procedures described in Section 2, we consider the measured discharge data set to be reliable. It is, however, important to note that as a result of the presence of shallow bank sections, discharge over certain portions of both transects are estimations.

3.1 Discharge Curves

Figure 4 to Figure 7 present discharge curves derived from data collected at both transect locations. A comprehensive set of discharge data obtained from each transect can be found in the accompanying Microsoft Excel spreadsheet with filename: '*PA1091 - Crookhaven ADCP Transect Study - Discharge Data Final.xls*'. Positive discharge relates to water entering the estuary while negative discharge corresponds to water leaving the estuary. The tide data presented in the figures was obtained from the Manly Hydraulic Laboratories tide gauge at Greenwell Point.

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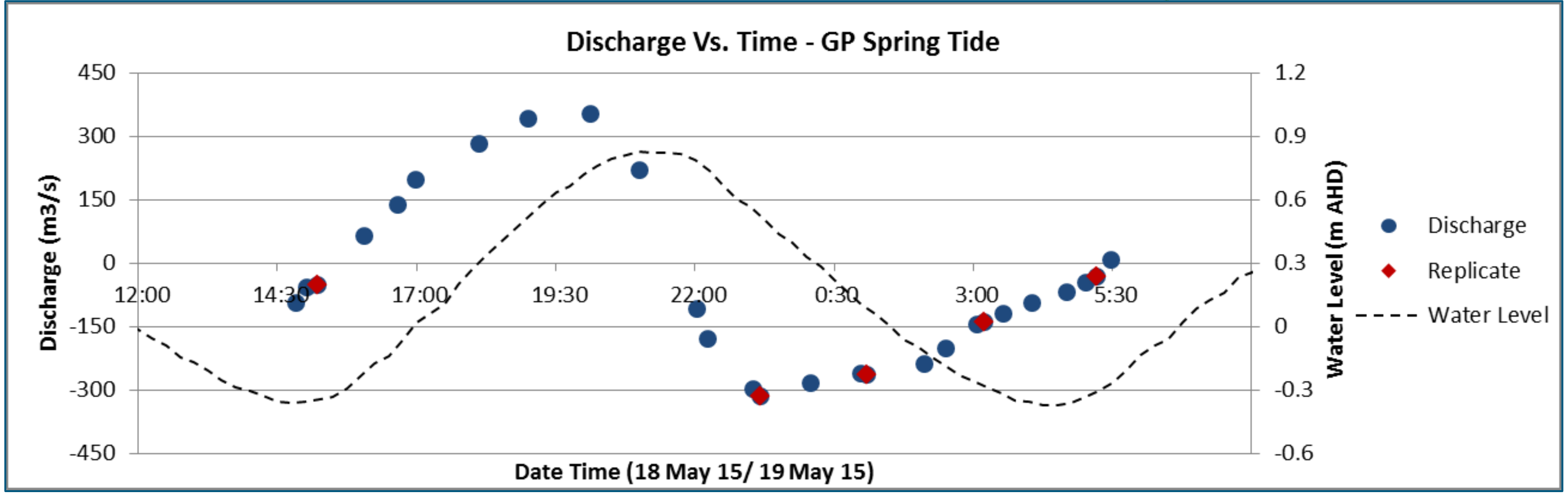

Figure 4.Discharge Vs. Time - GP Spring Tide

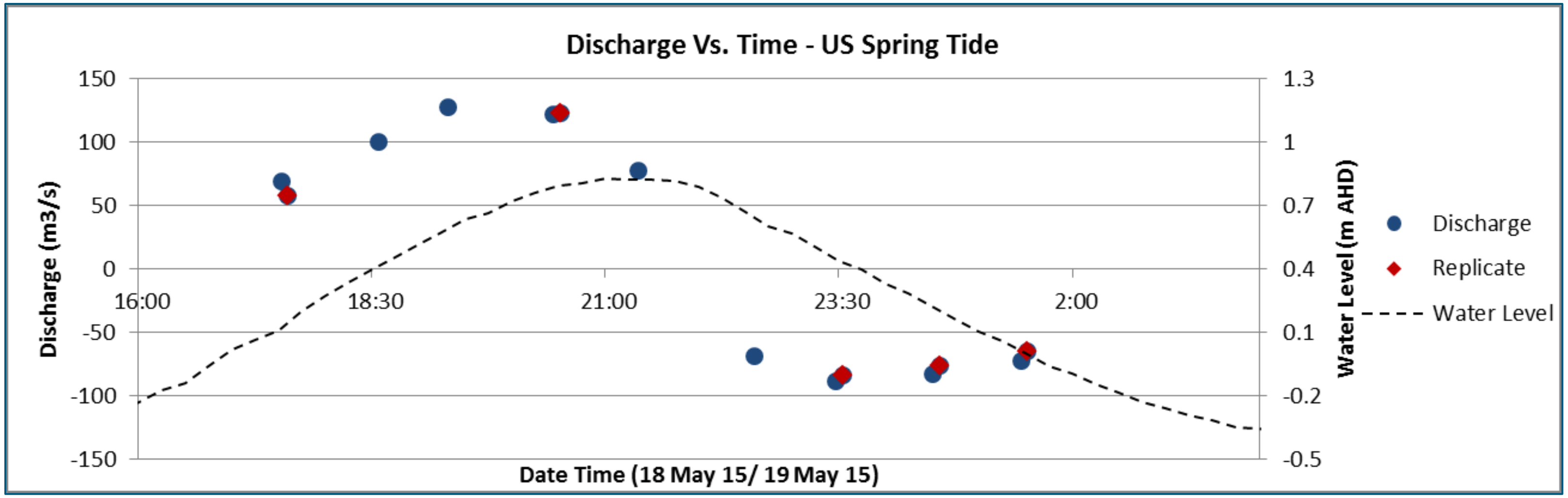

Figure 5.Discharge Vs. Time - US Spring Tide

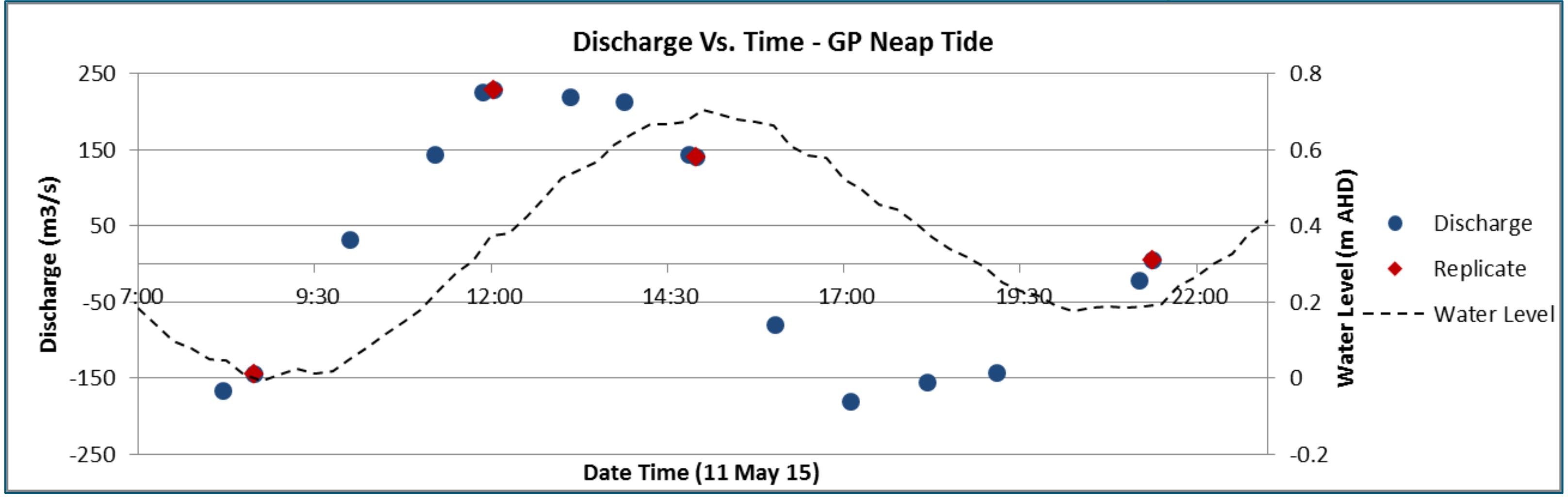

Figure 6. Discharge Vs. Time - GP Neap Tide

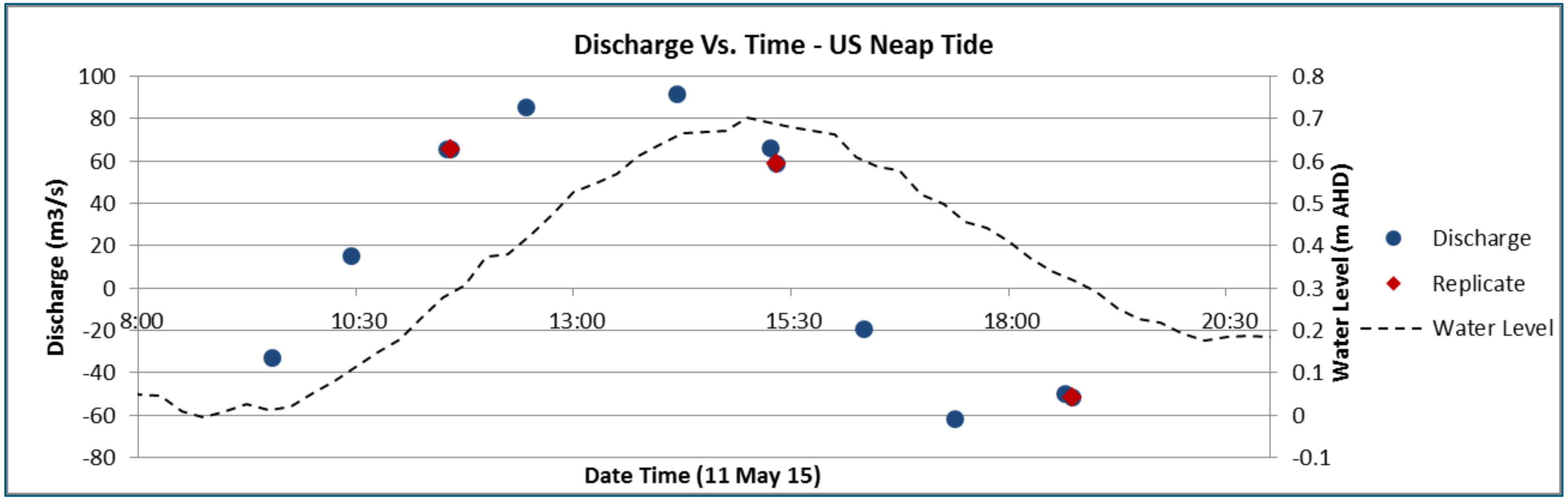

Figure 7. Discharge Vs. Time - US Neap Tide

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3.2 Tidal Prism Calculation

An estuaries tidal prism can be described as the volume of water moving past a fixed cross section during each flood or ebb tide. The tidal prism volumes for both transect sites have been calculated from the discharge data and presented in Table 8. The tidal prism volumes were computed by calculating the area beneath the discharge curves.

Care should be taken when interpreting the tidal prism volume estimations for the upstream transect site. As mentioned in section 2.1.3 depth restrictions limited the field team's ability to access the upstream site at low tide. For this reason no discharge data was measured at the upstream site during low tide when discharge volumes are near zero. Accurate tidal prism calculations require both zero crossing points on the discharge curve in order to integrate between. Times of zero discharge have therefore been estimated by fitting a cubic spline to the measured data. The spline has then been extrapolated in order to estimate times of zero discharge. The estimation of times of zero discharge means tidal prism volumes calculated for the upstream site are only best estimations.

Table 8. Tidal Prism Calculations

	Tidal Prism (m^3 x 10^6)	Tide Range (m)
Greenwell Point Spring Tide - Flood	5.033	1.18
Greenwell Point Spring Tide - Ebb	5.225	1.19
Greenwell Point Neap Tide - Flood	3.212	0.71
Greenwell Point Neap Tide - Ebb	2.360	0.53
Upstream Transect Spring Tide – Flood	1.788	1.18
Upstream Transect Spring Tide – Ebb	1.269	1.19
Upstream Transect Neap Tide – Flood	1.366	0.71
Upstream Transect Neap Tide - Ebb	0.587	0.53

3.3 Transect Velocity Profiles

Figure 8 to Figure 74 present velocity profiles for each completed transect. The vessel track is presented by the red line, while the blue sticks represent current magnitude and direction. The velocity data presented in each figure is the depth averaged velocity.

3.3.1 2D Velocity Profiles – Spring Tide Exercise – Greenwell Point

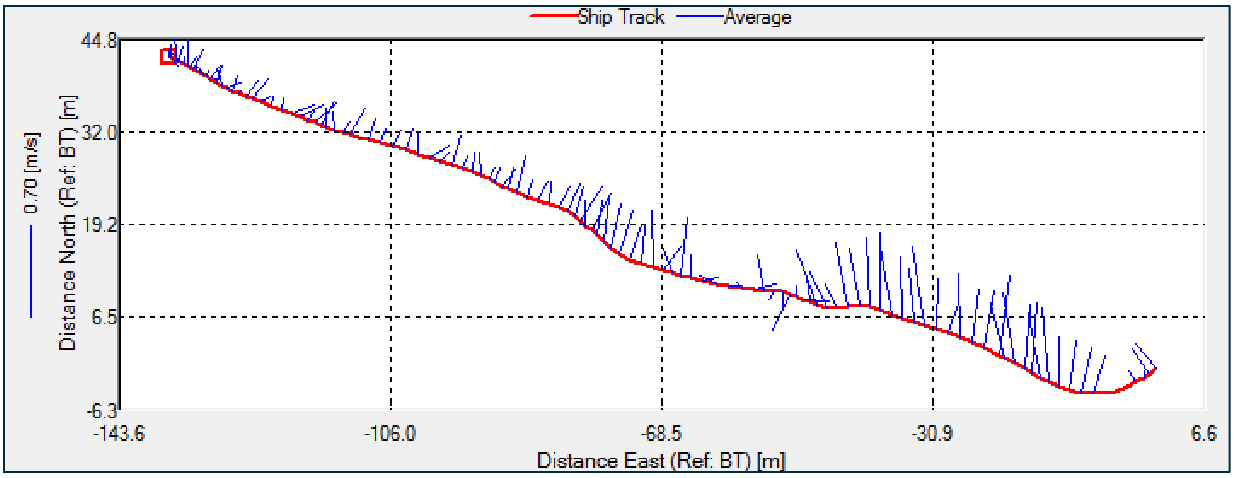


Figure 8. CrookhavenSpring001 - 18/05/2015 14:49

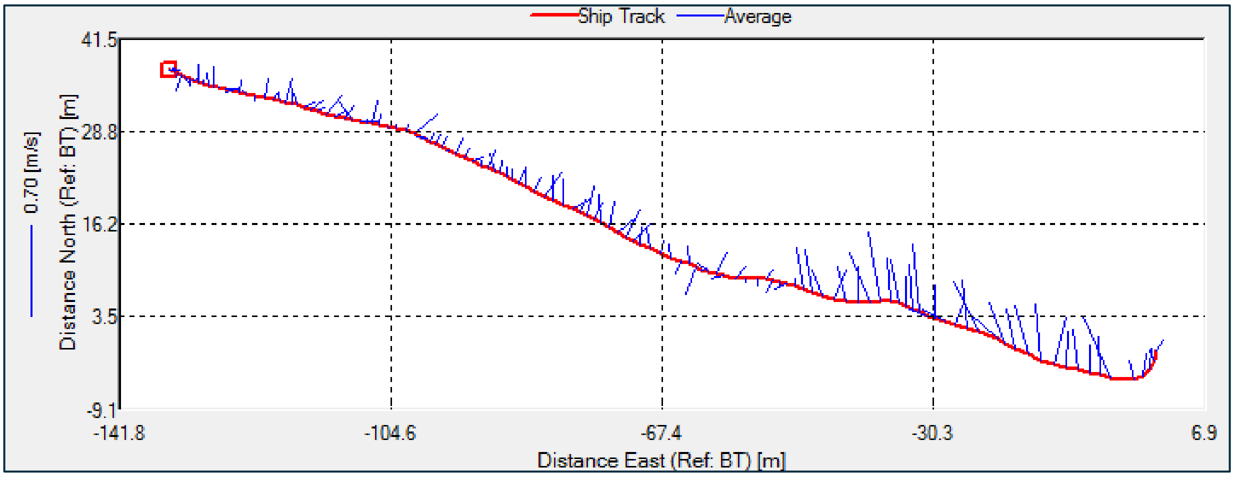


Figure 9. CrookhavenSpring002 18/05/2015 15:01

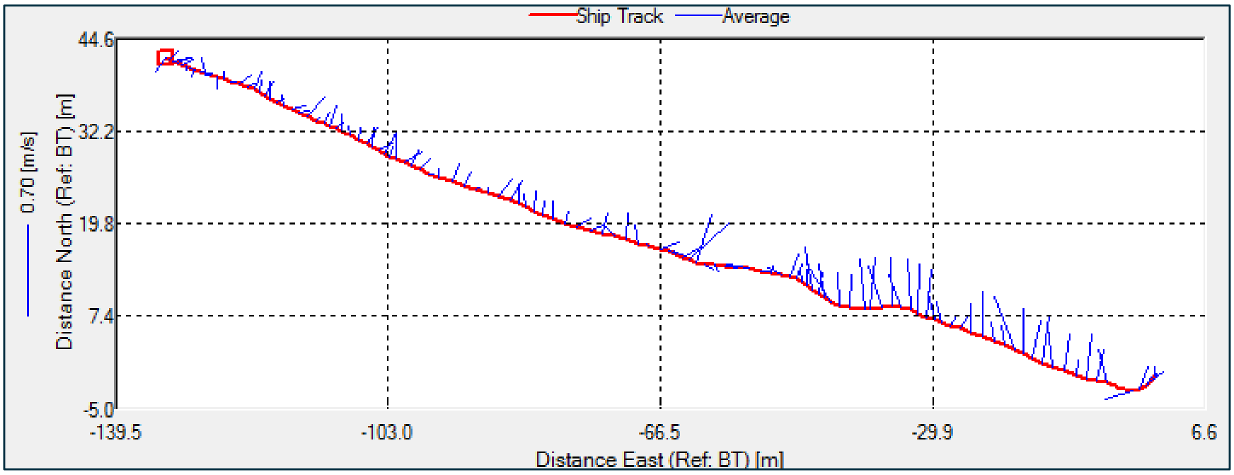


Figure 10. CrookhavenSpring004 18/05/2015 15:13

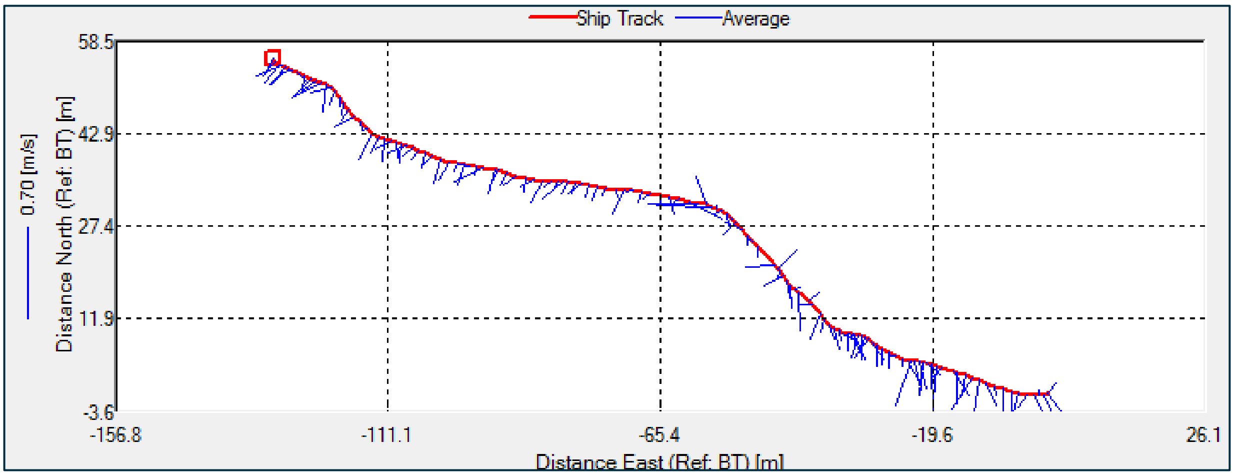


Figure 11. CrookhavenSpring006 18/05/2015 16:03

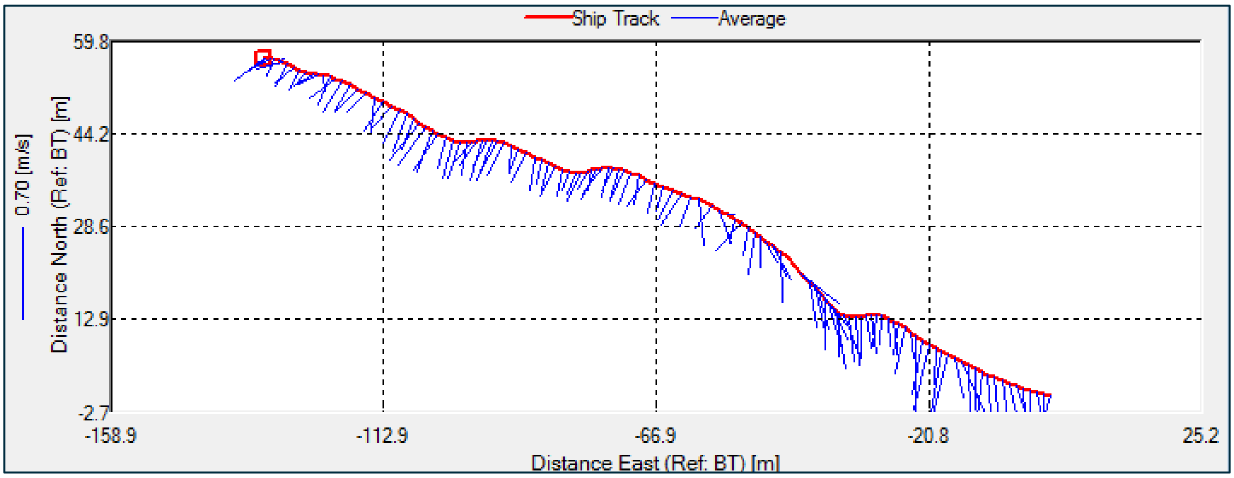


Figure 12. CrookhavenSpring007 18/05/2015 16:39

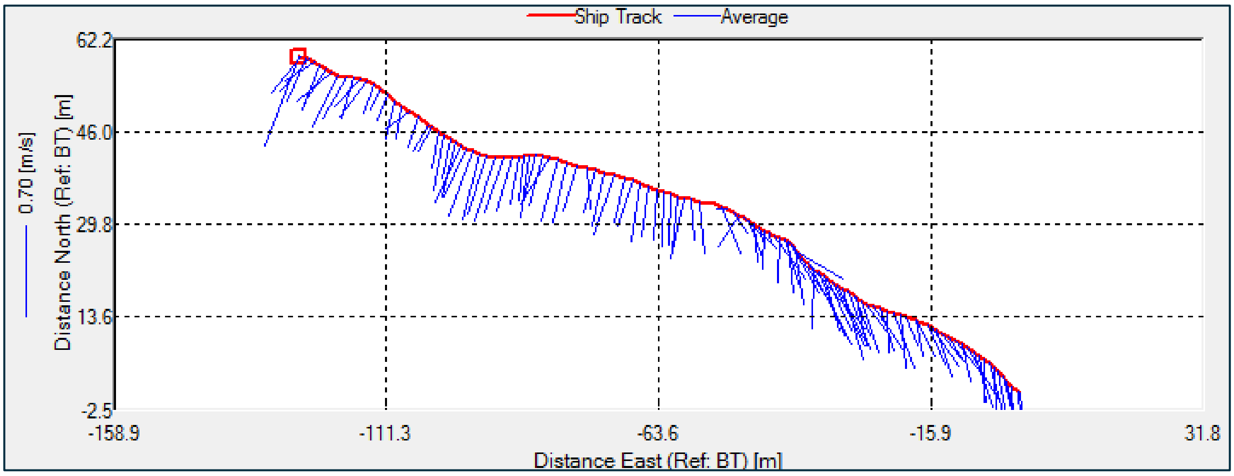


Figure 13. CrookhavenSpring008 18/05/2015 16:58

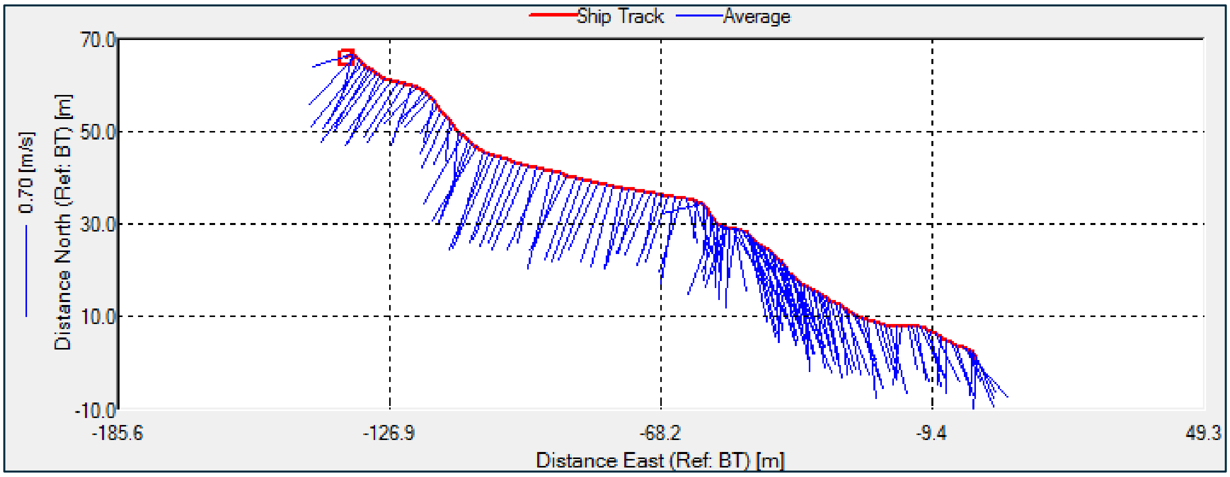


Figure 14. CrookhavenSpring011 18/05/2015 18:07

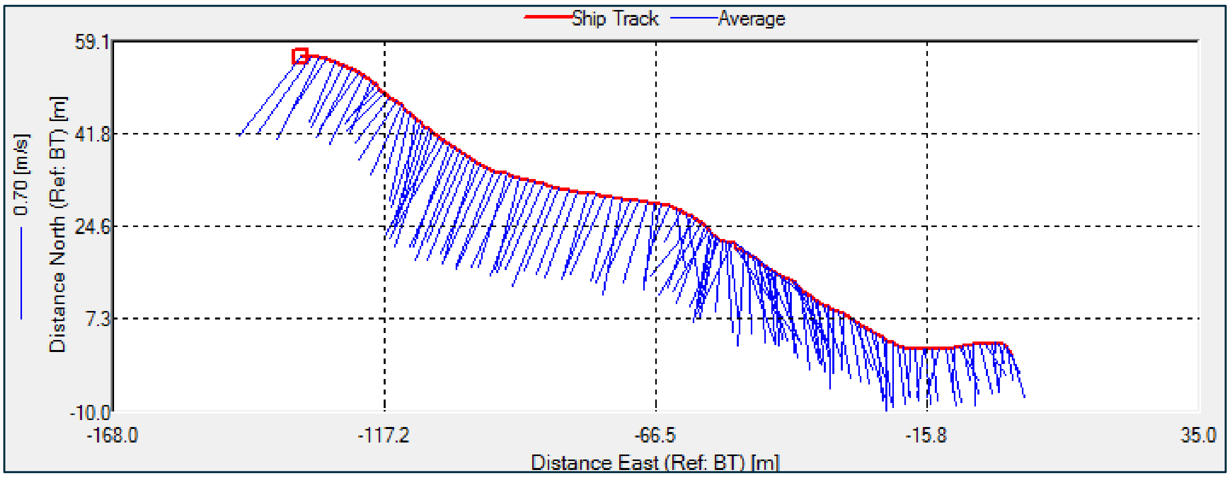


Figure 15. CrookhavenSpring015 18/05/2015 19:00

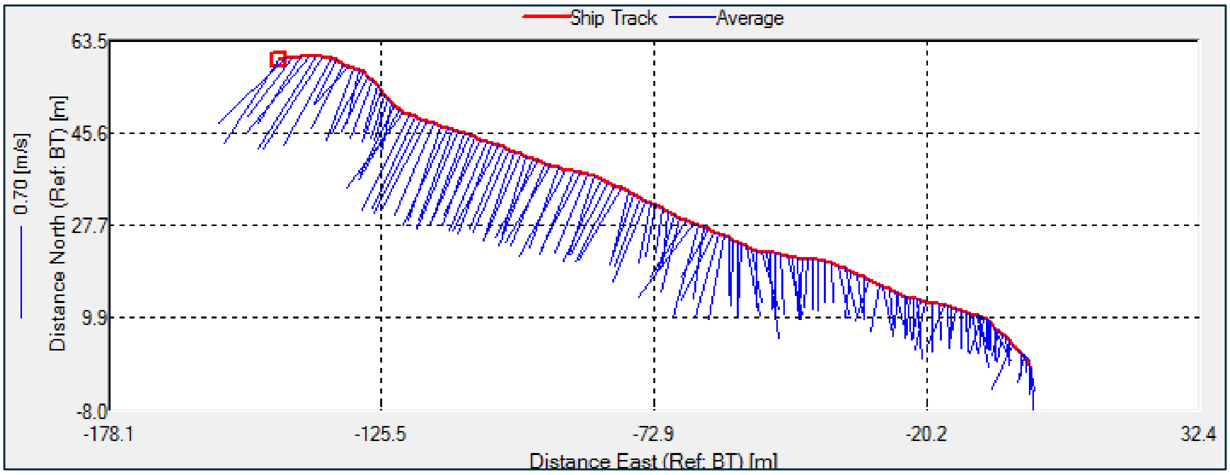


Figure 16. CrookhavenSpring018 18/05/2015 20:07

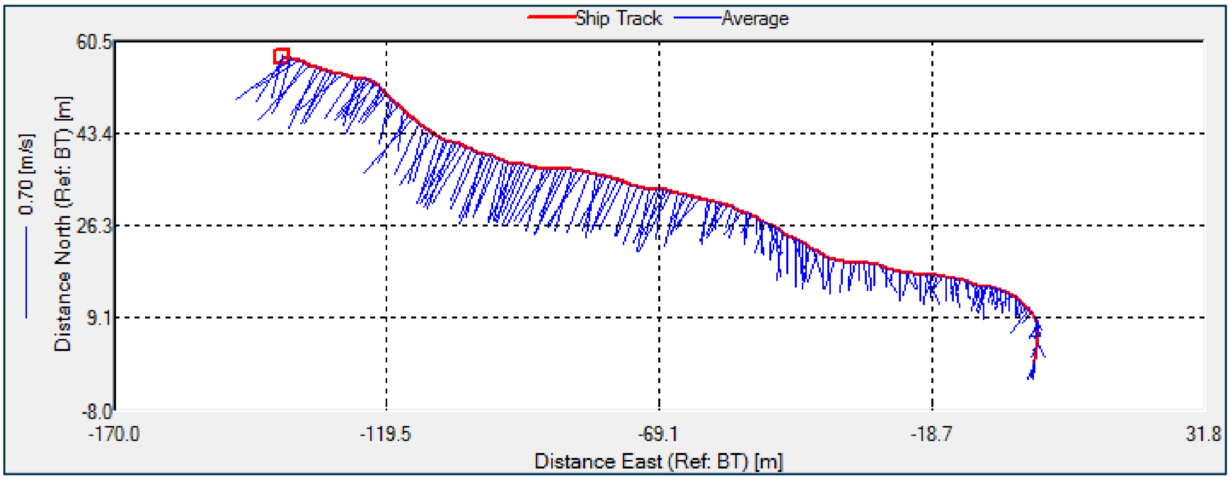


Figure 17. CrookhavenSpring021 18/05/2015 21:00

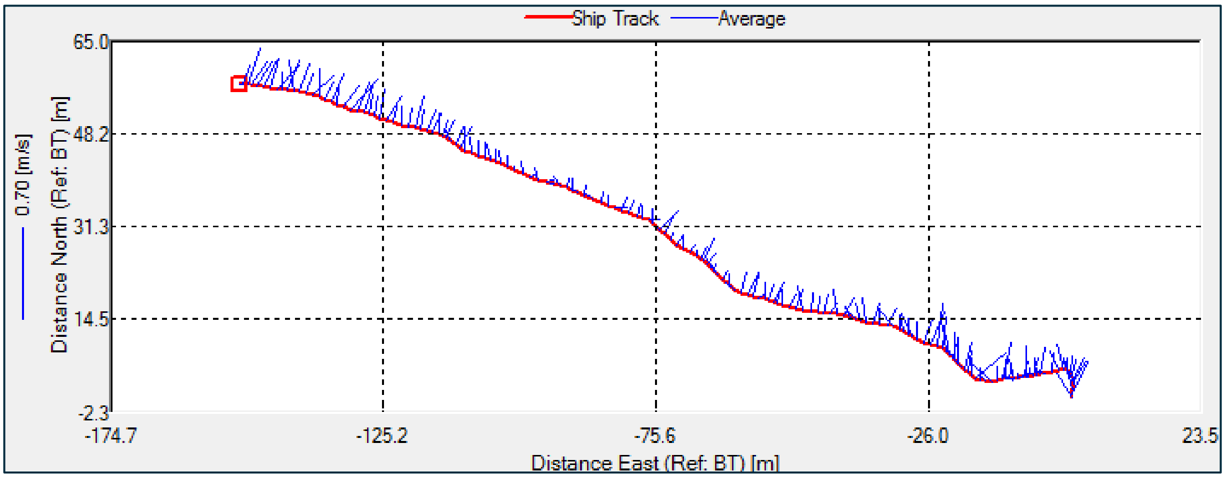


Figure 18. CrookhavenSpring023 18/05/2015 22:02

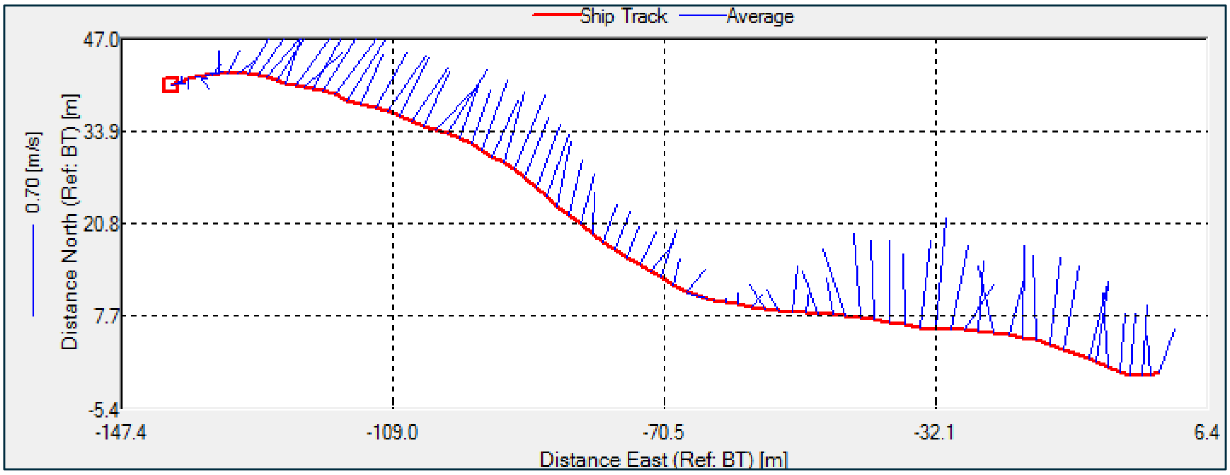


Figure 19. CrookhavenSpring025 18/05/2015 22:13

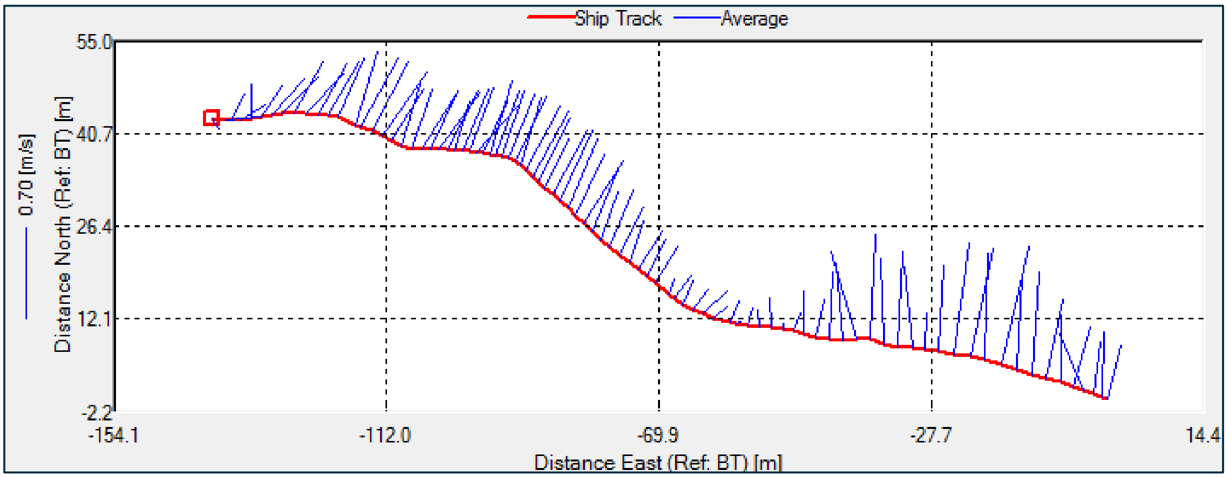


Figure 20. CrookhavenSpring029 18/05/2015 23:02

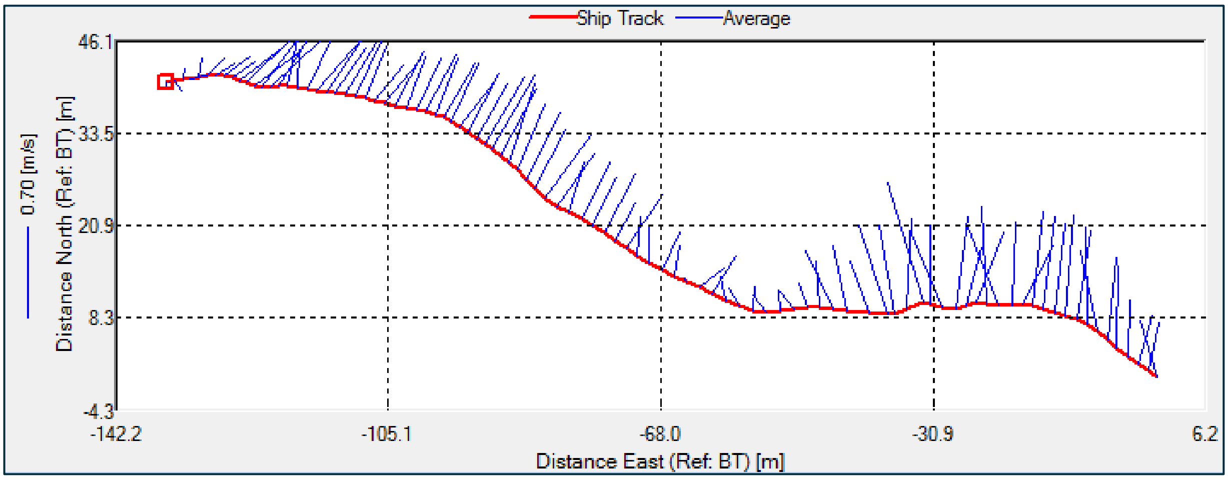


Figure 21. CrookhavenSpring031 18/05/2015 23:10

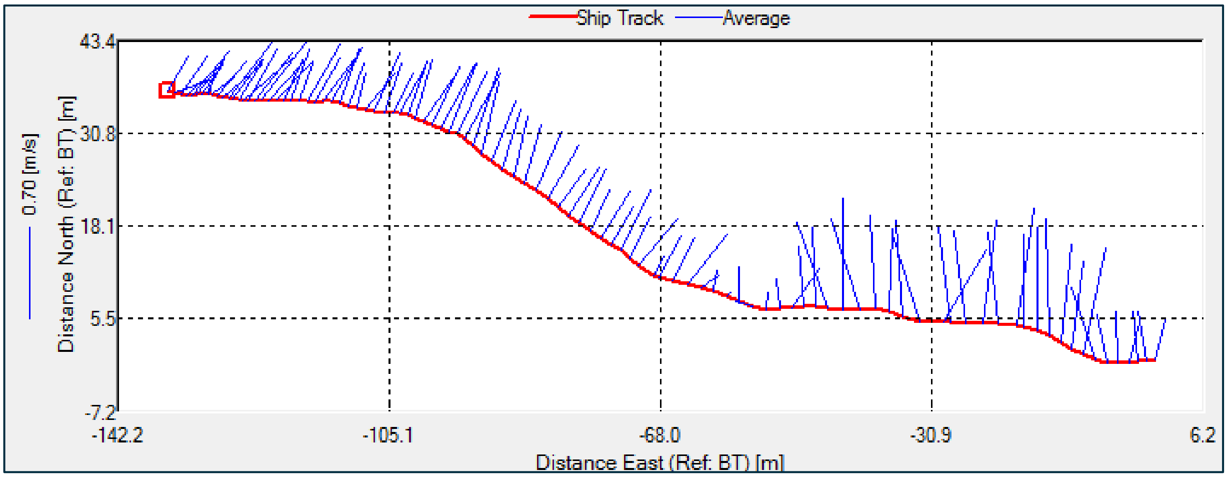


Figure 22. CrookhavenSpring034 19/05/2015 0:04

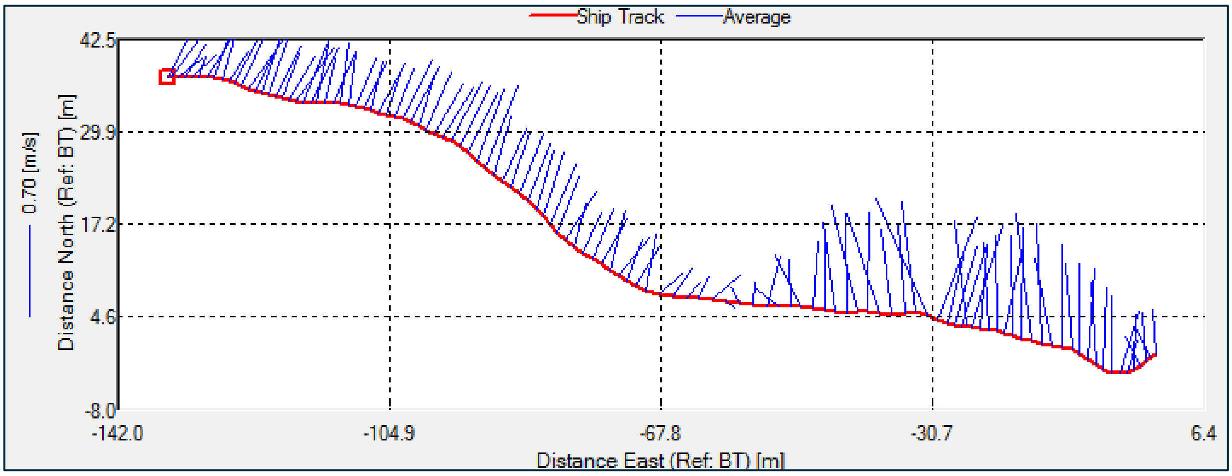


Figure 23. CrookhavenSpring038 19/05/2015 0:59

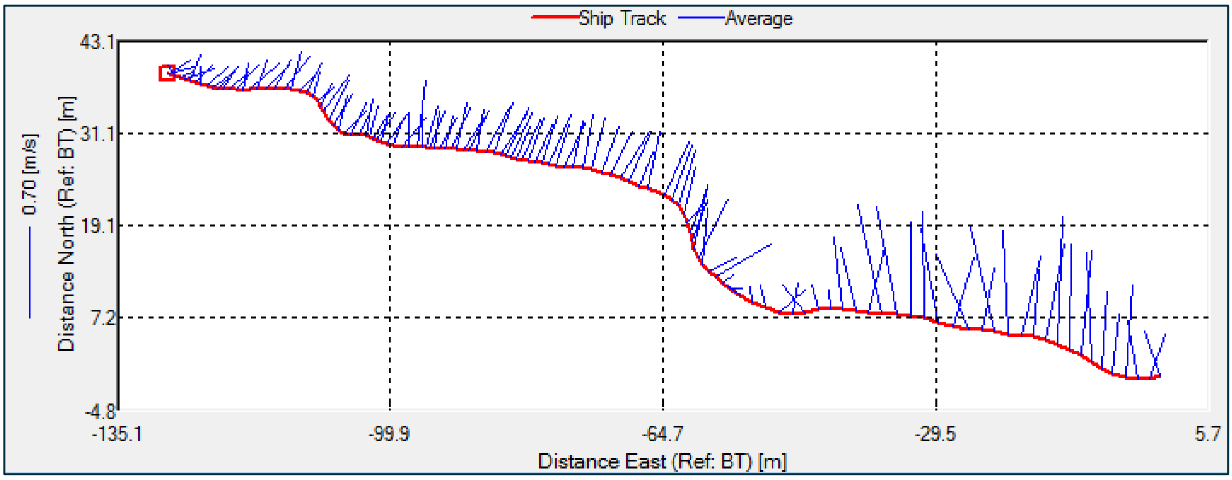


Figure 24. CrookhavenSpring039 19/05/2015 1:05

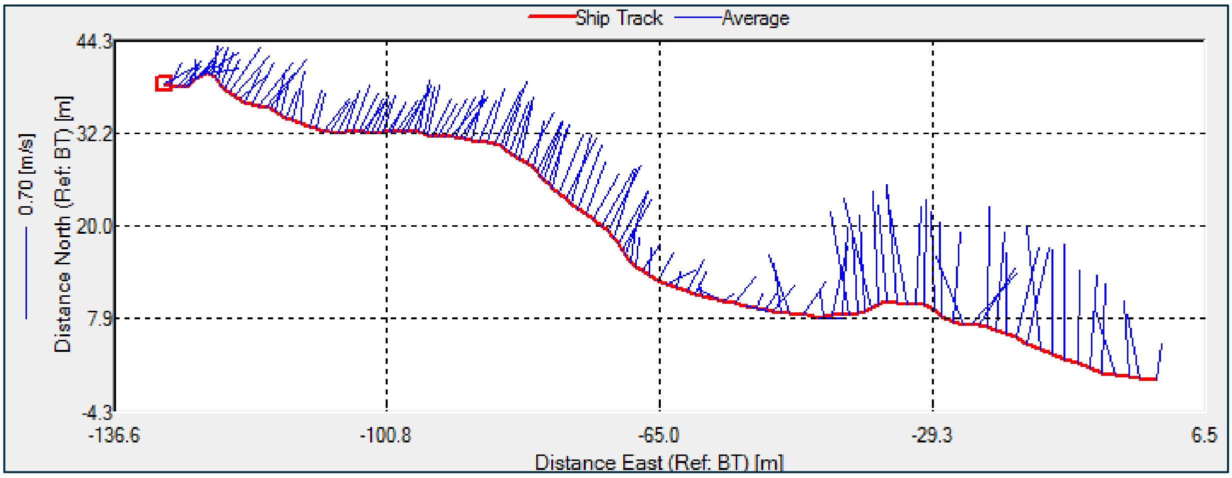


Figure 25. CrookhavenSpring042 19/05/2015 2:07

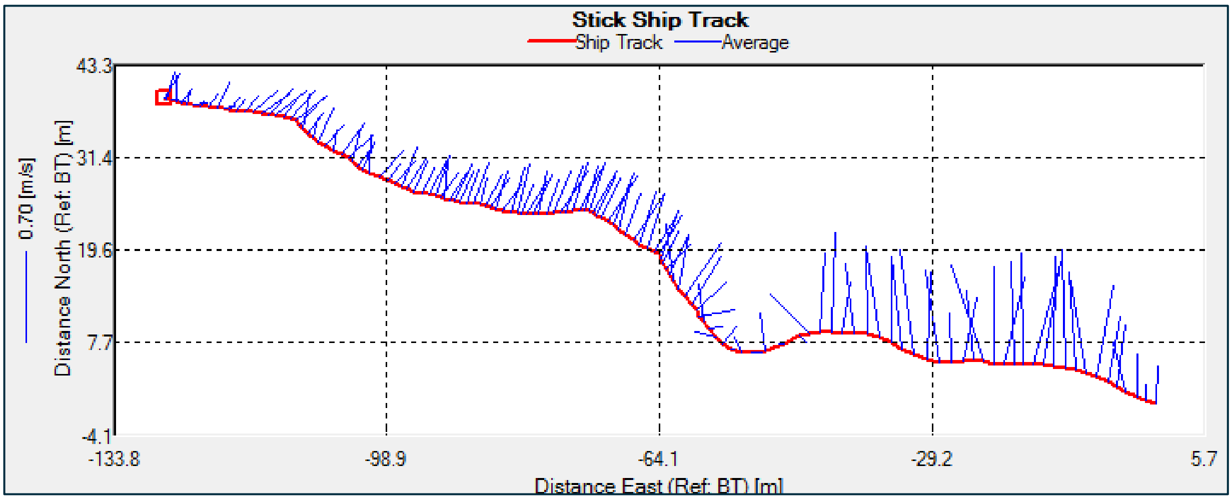


Figure 26. CrookhavenSpring044 19/05/2015 2:30

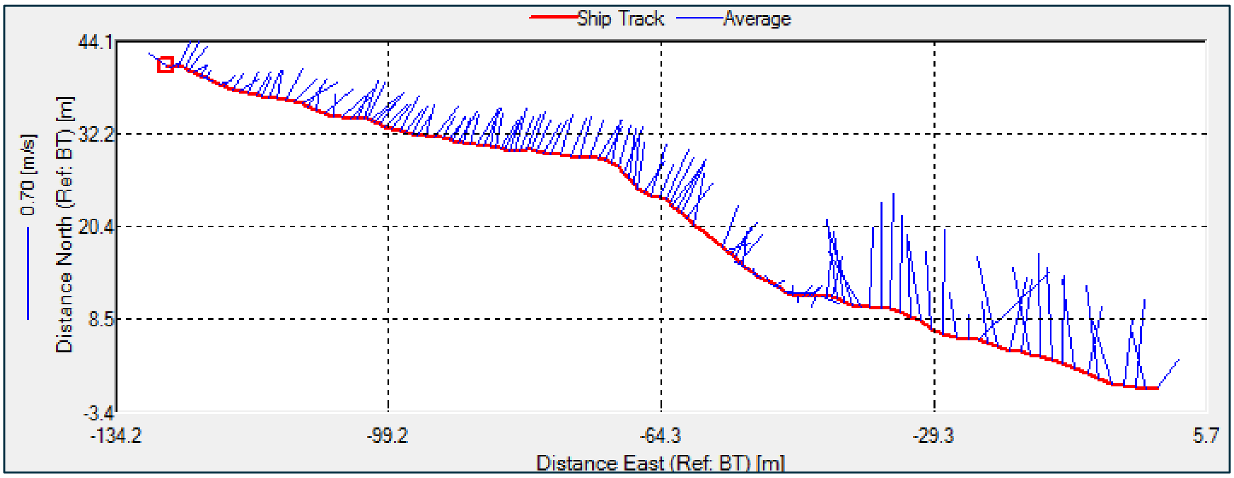


Figure 27. CrookhavenSpring045 19/05/2015 3:03

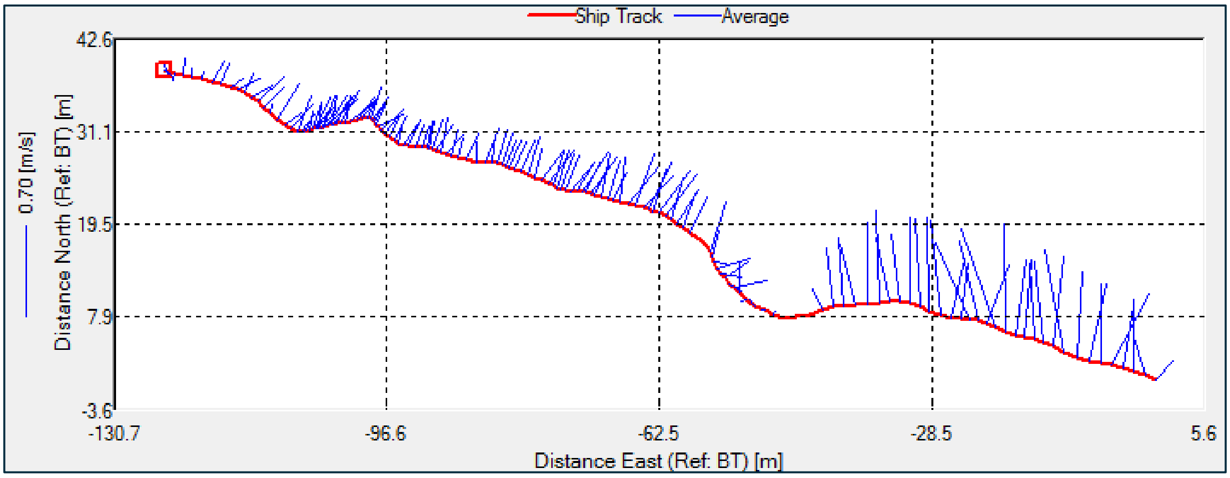


Figure 28. CrookhavenSpring046 19/05/2015 3:10

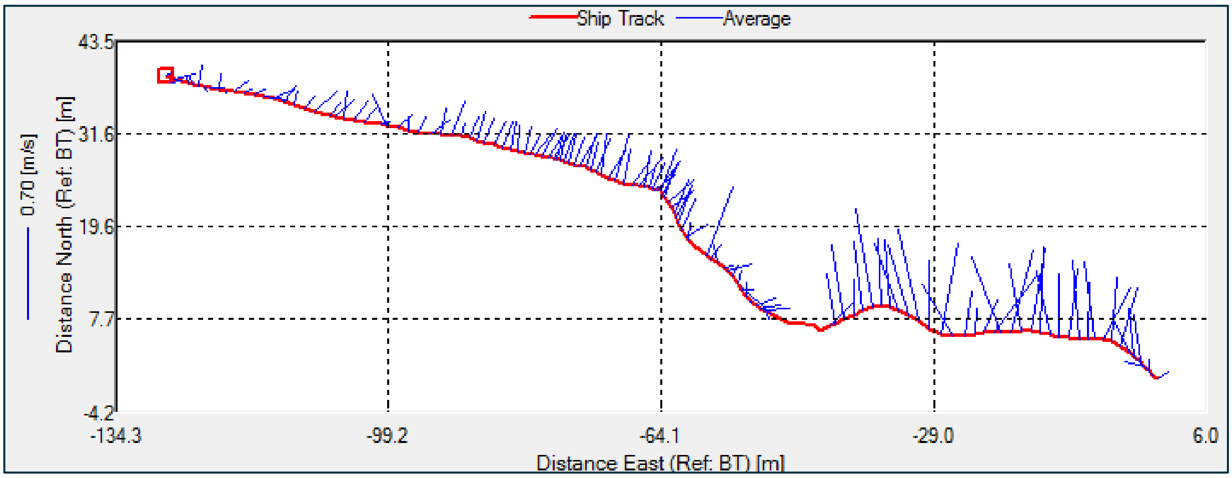


Figure 29. CrookhavenSpring048 19/05/2015 3:32

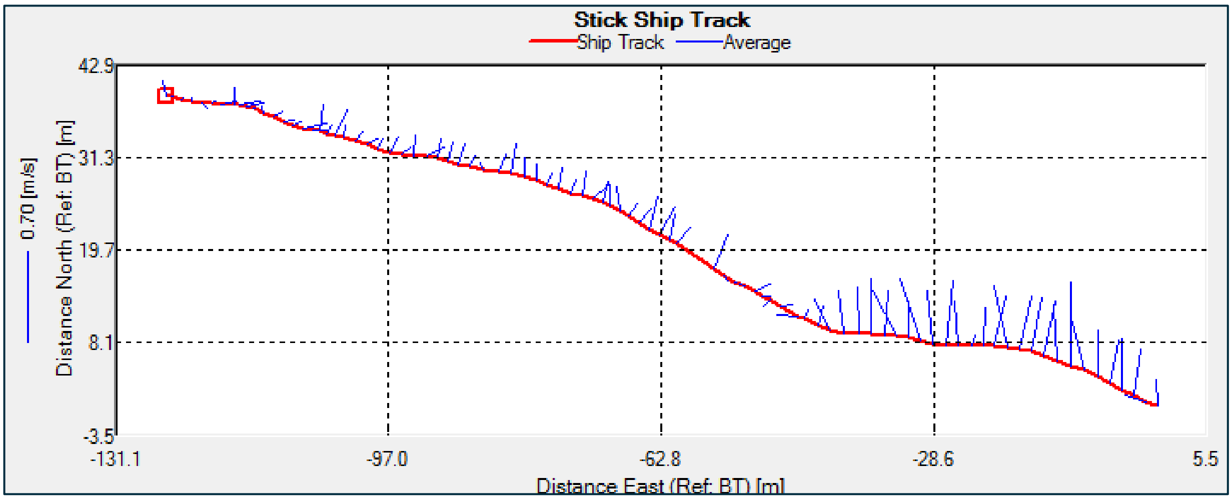


Figure 30. CrookhavenSpring049 19/05/2015 4:03

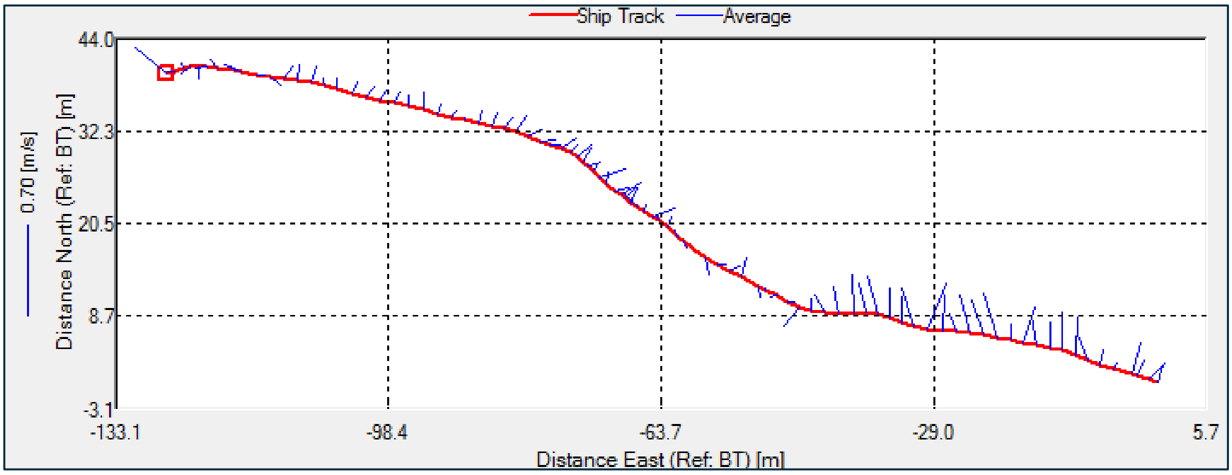


Figure 31. CrookhavenSpring052 19/05/2015 4:41

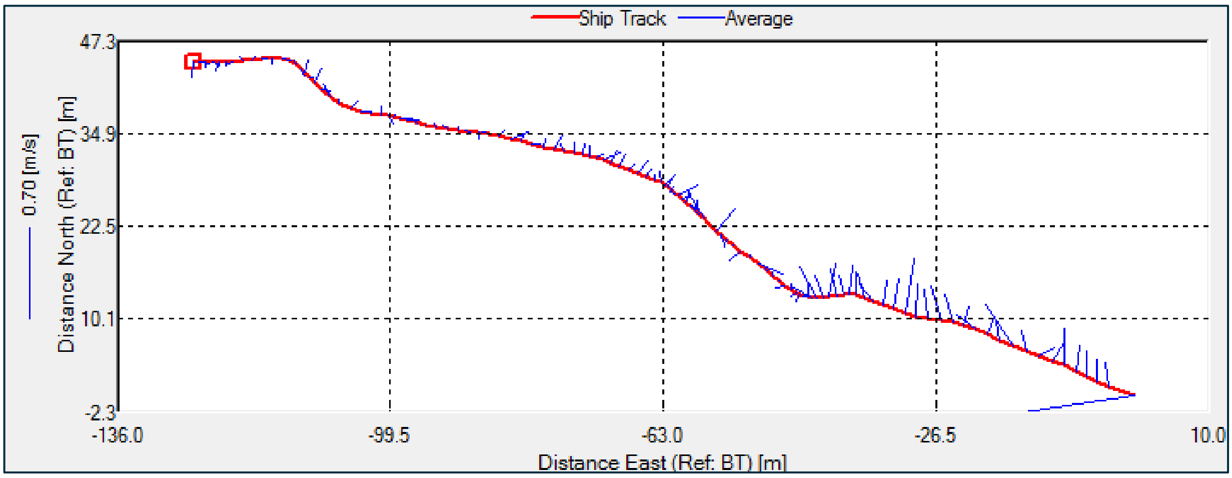


Figure 32. CrookhavenSpring053 19/05/2015 5:00

3.3.2 2D Velocity Profiles – Spring Tide Exercise – Upstream Transect

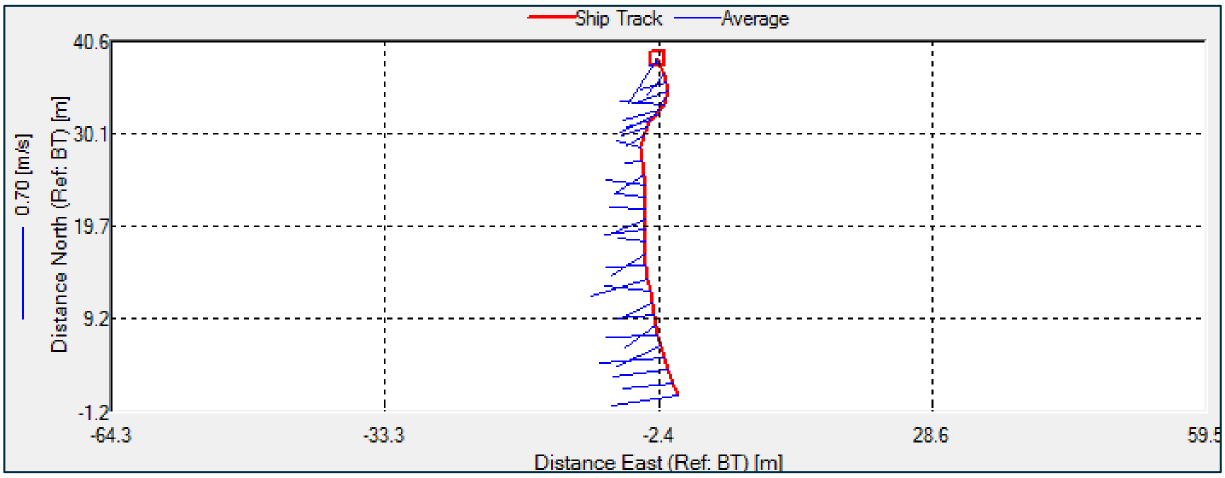


Figure 33. CrookhavenSpring009 18/05/2015 17:31

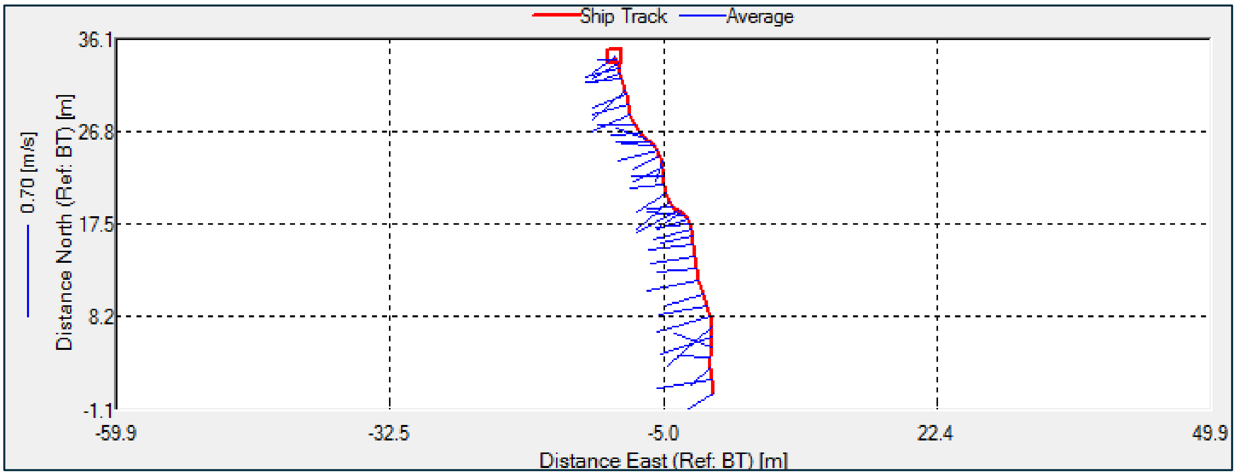


Figure 34. CrookhavenSpring010 18/05/2015 17:35

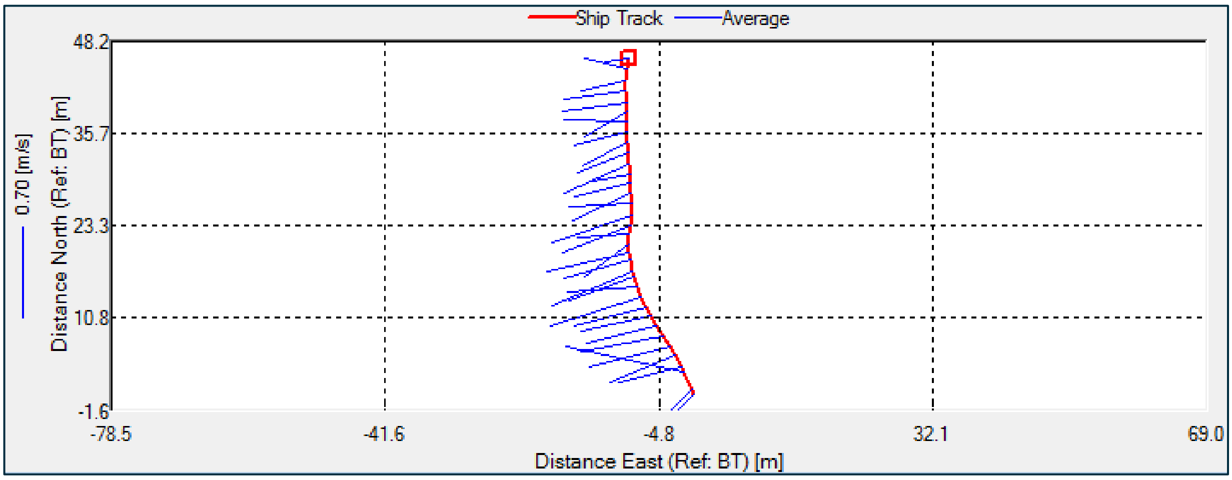


Figure 35. CrookhavenSpring013 18/05/2015 18:34

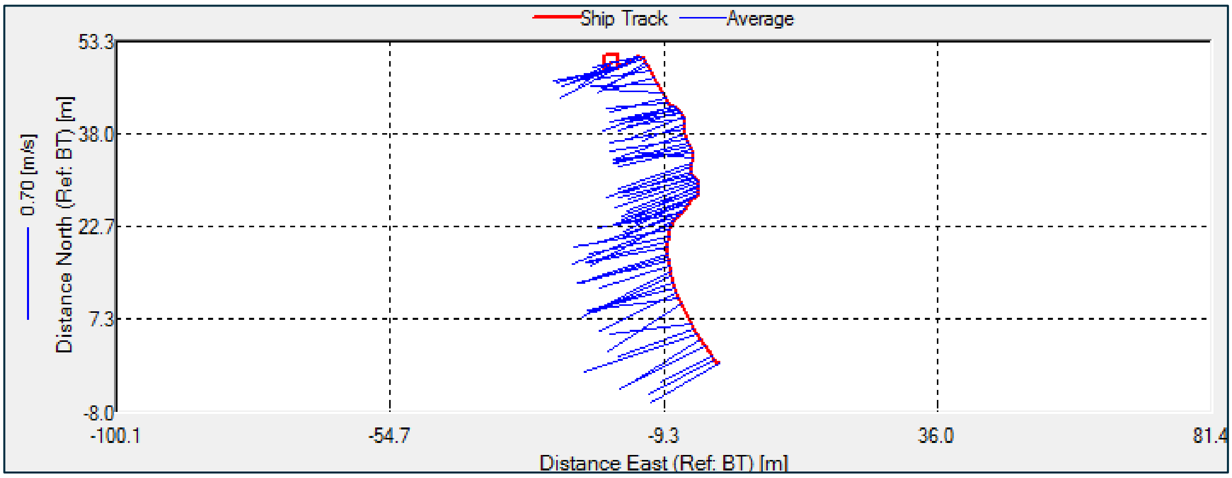


Figure 36. CrookhavenSpring016 18/05/2015 19:18

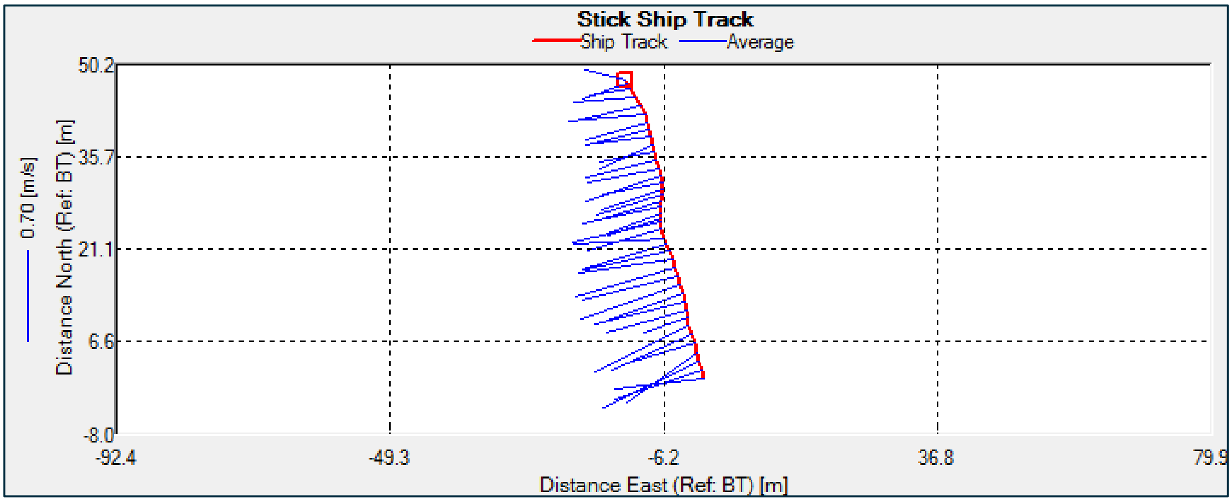


Figure 37. CrookhavenSpring019 18/05/2015 20:26

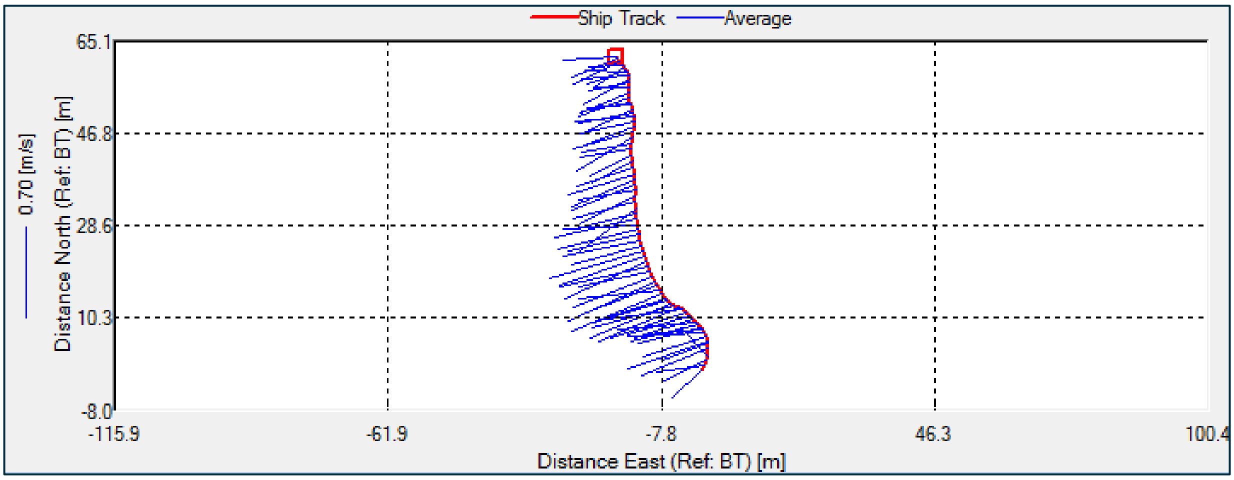


Figure 38. CrookhavenSpring020 18/05/2015 20:31

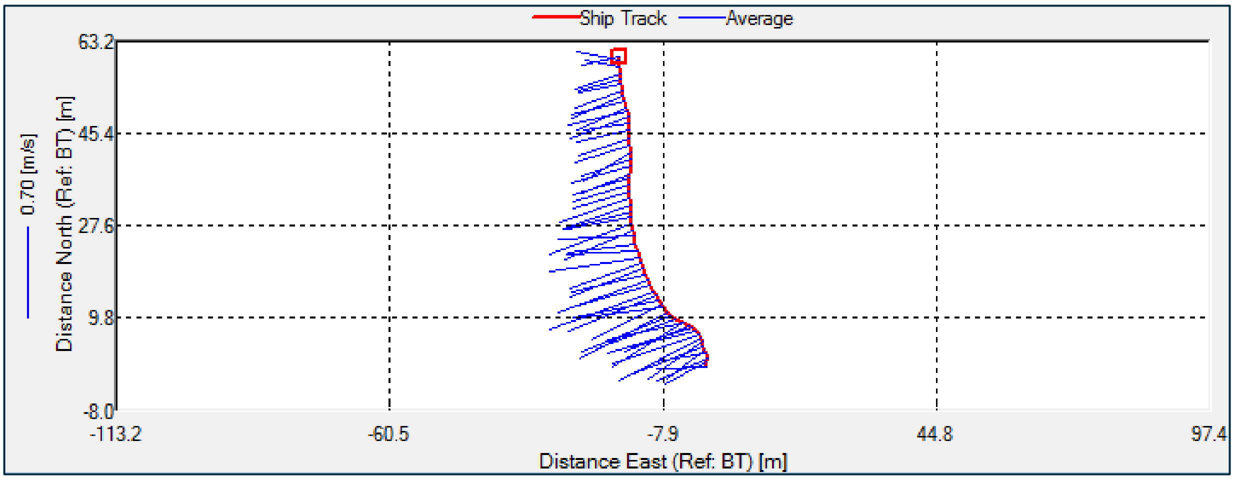


Figure 39. CrookhavenSpring022 18/05/2015 21:21

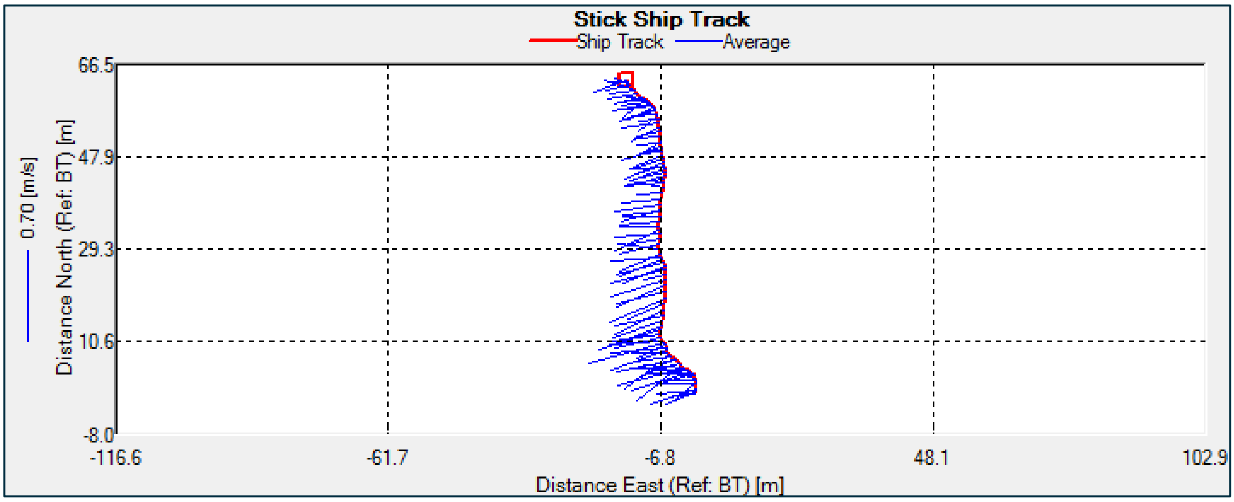


Figure 40. CrookhavenSpring026 18/05/2015 22:35

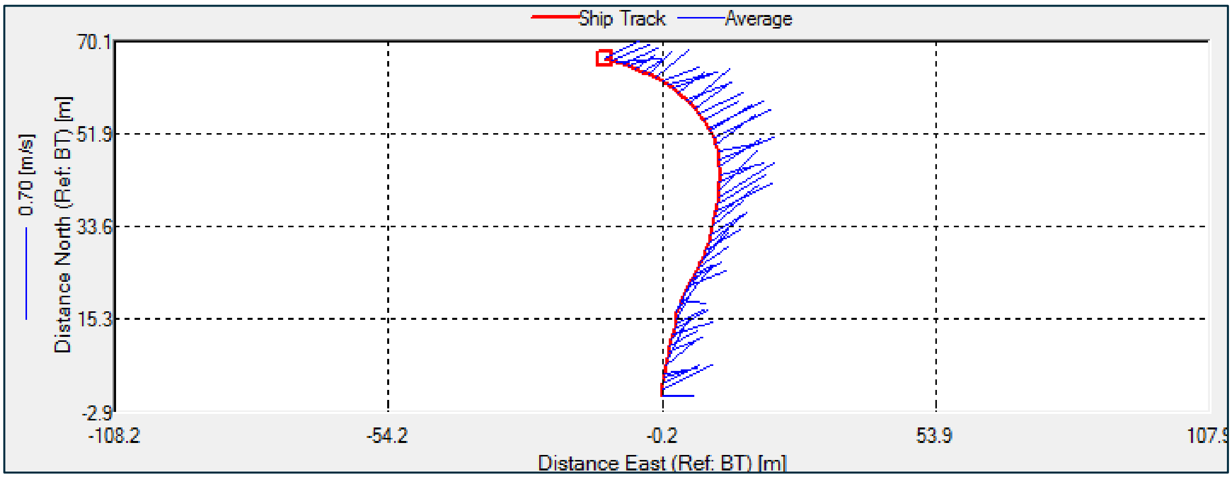


Figure 41. CrookhavenSpring032 18/05/2015 23:28

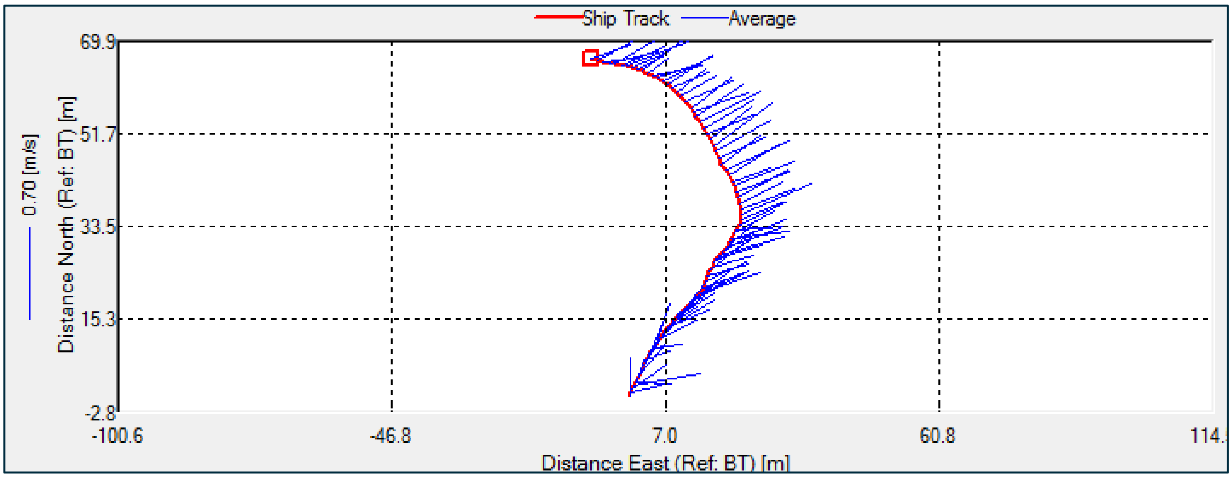


Figure 42. CrookhavenSpring033 18/05/2015 23:32

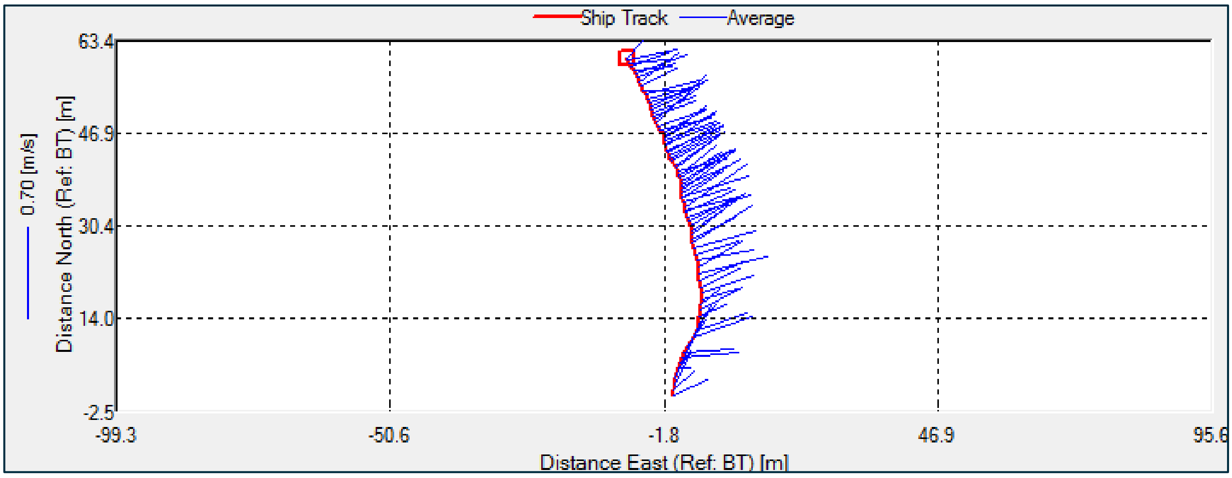


Figure 43. CrookhavenSpring036 19/05/2015 0:30

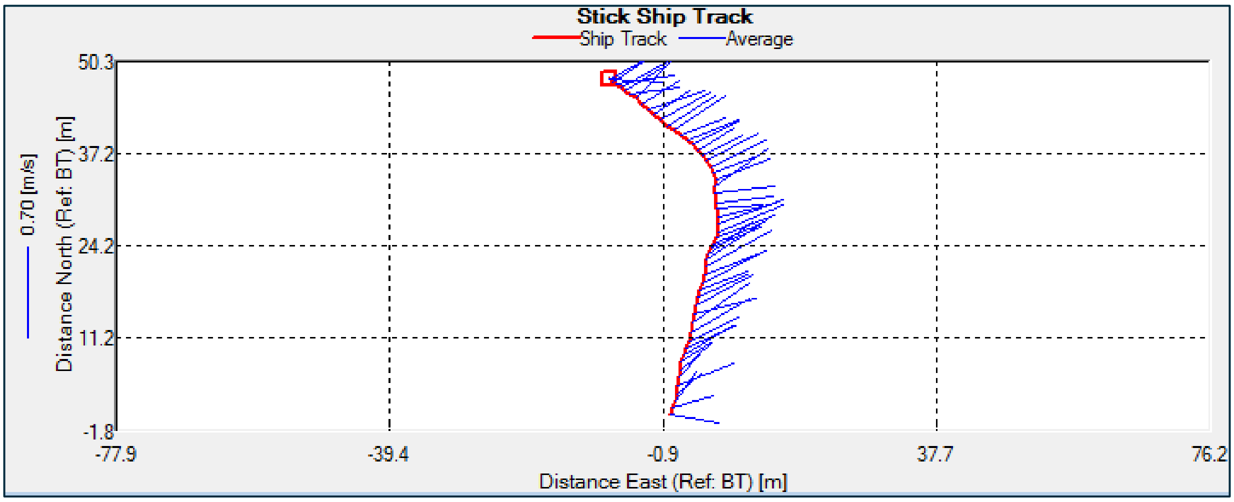


Figure 44. CrookhavenSpring037 19/05/2015 0:34

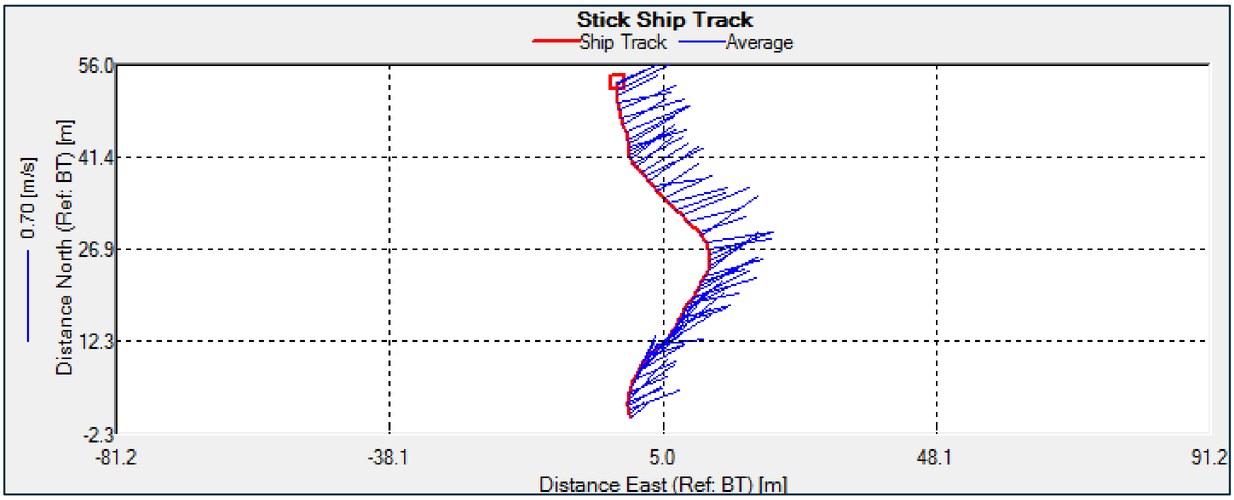


Figure 45. CrookhavenSpring037 19/05/2015 1:27

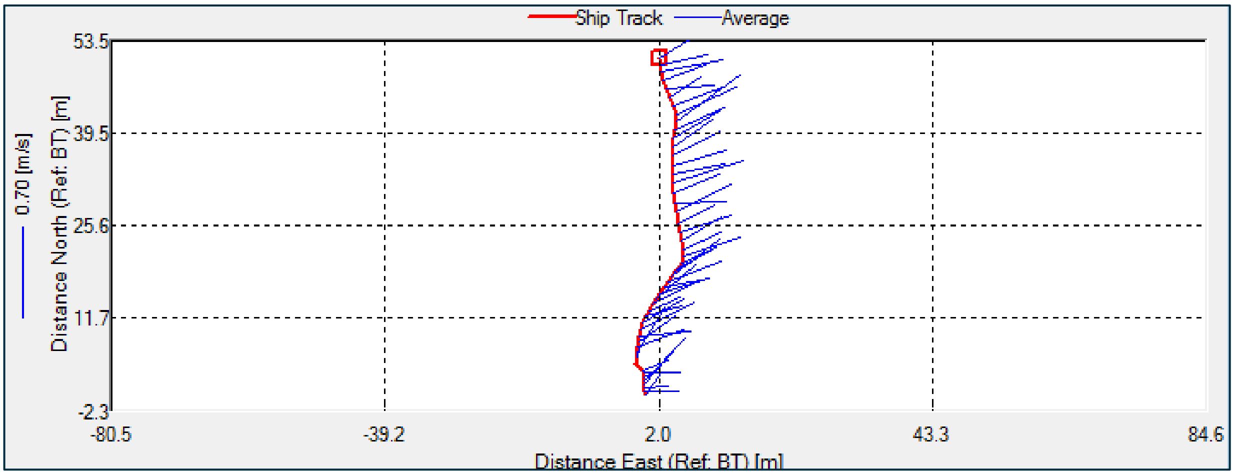


Figure 46.CrookhavenSpring041 19/05/2015 1:30

Royal HaskoningDHV

3.3.3 2D Velocity Profiles – Neap Tide Exercise – Greenwell Point

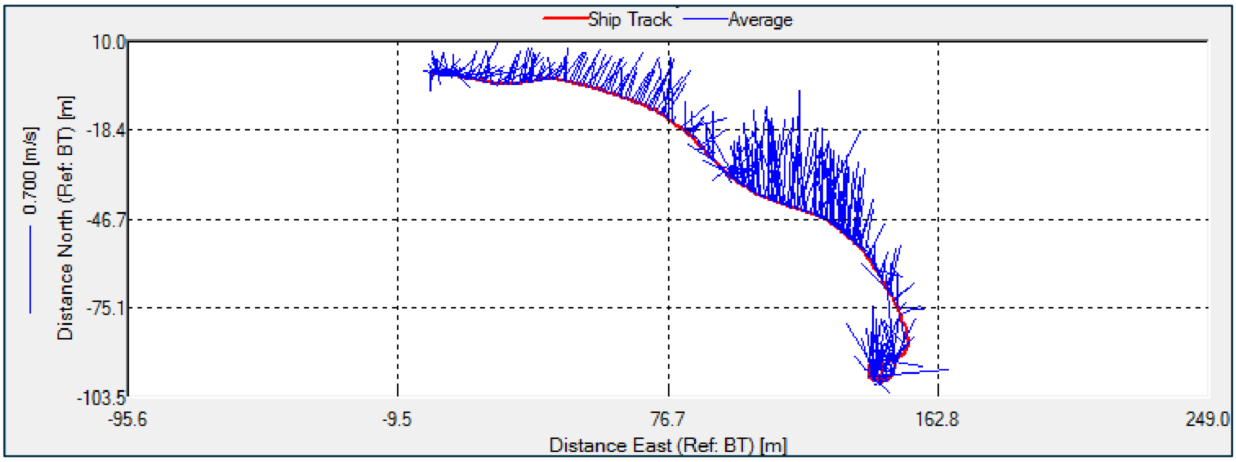


Figure 47. CrookhavenNeap2001 11/05/2015 8:11

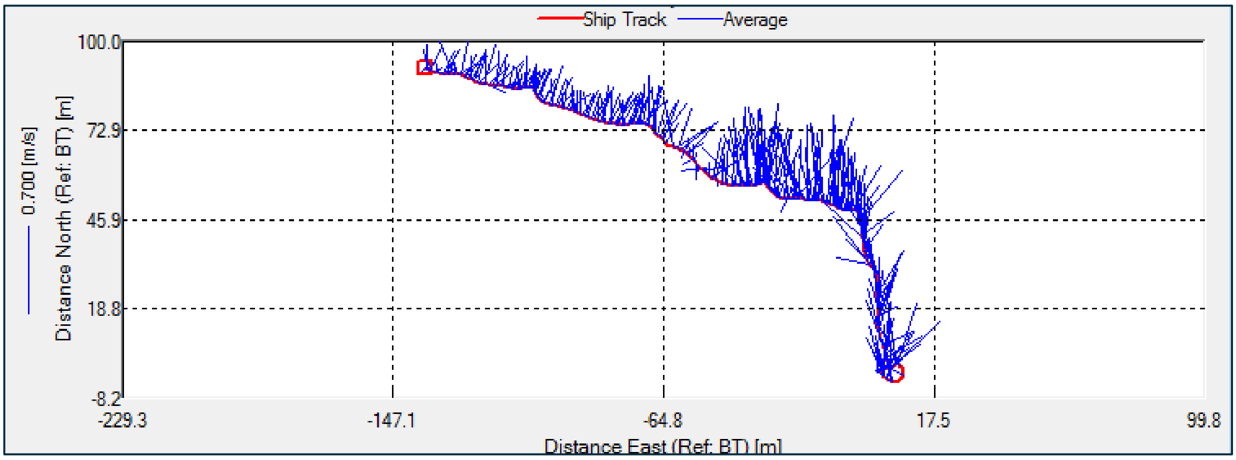


Figure 48. CrookhavenNeap2002 11/05/2015 8:39

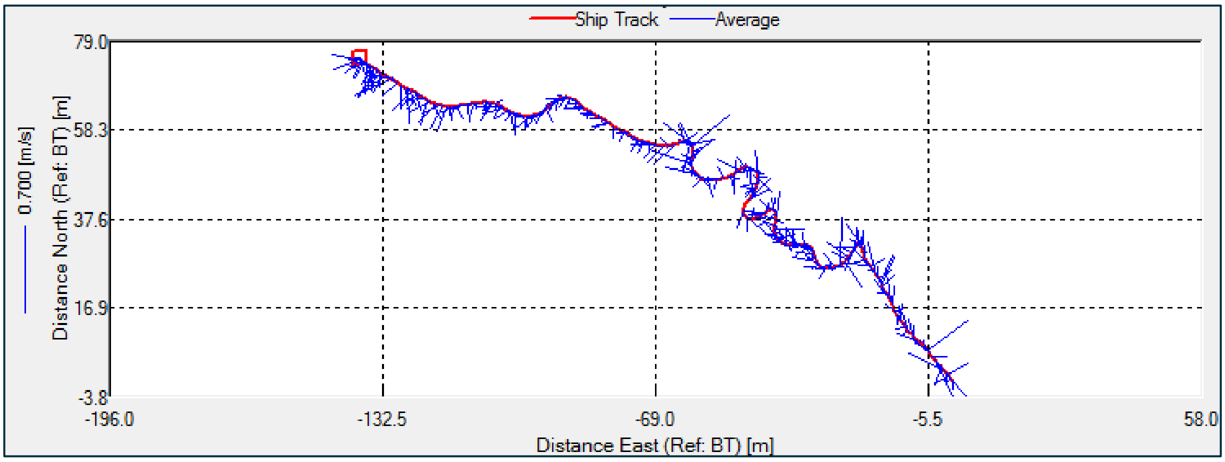


Figure 49. CrookhavenNeap2005 11/05/2015 9:59

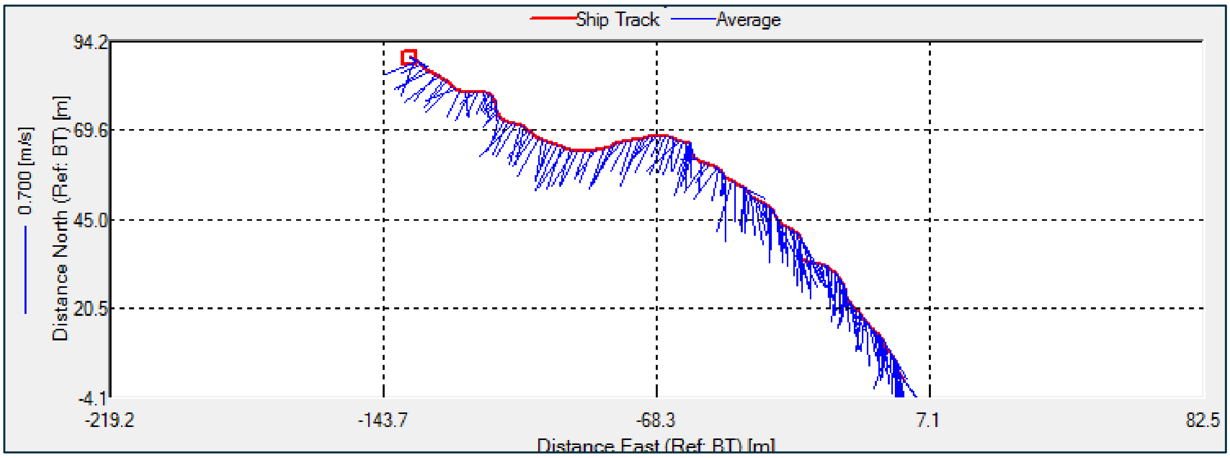


Figure 50. CrookhavenNeap1000 11/05/2015 11:12

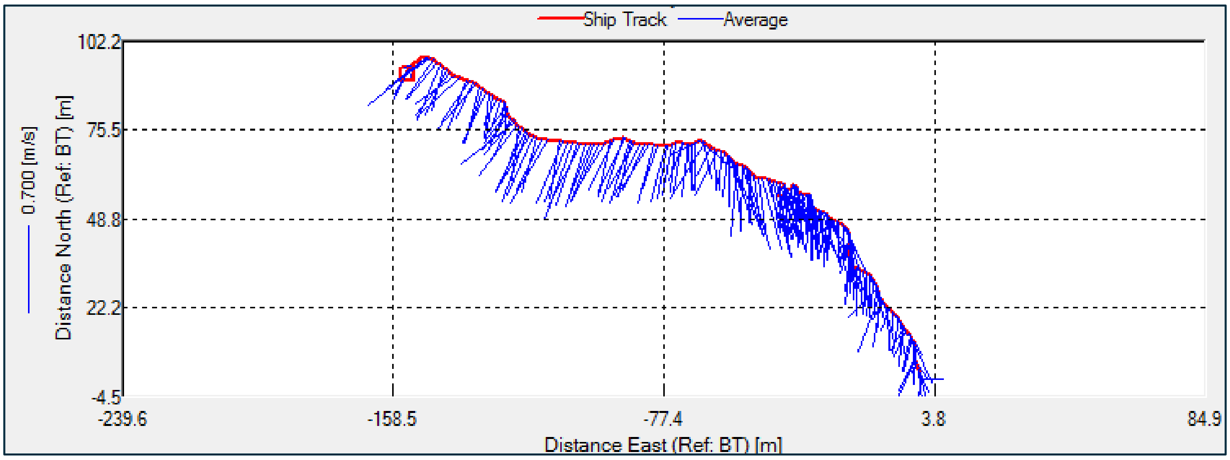


Figure 51. CrookhavenNeap1003 11/05/2015 11:53

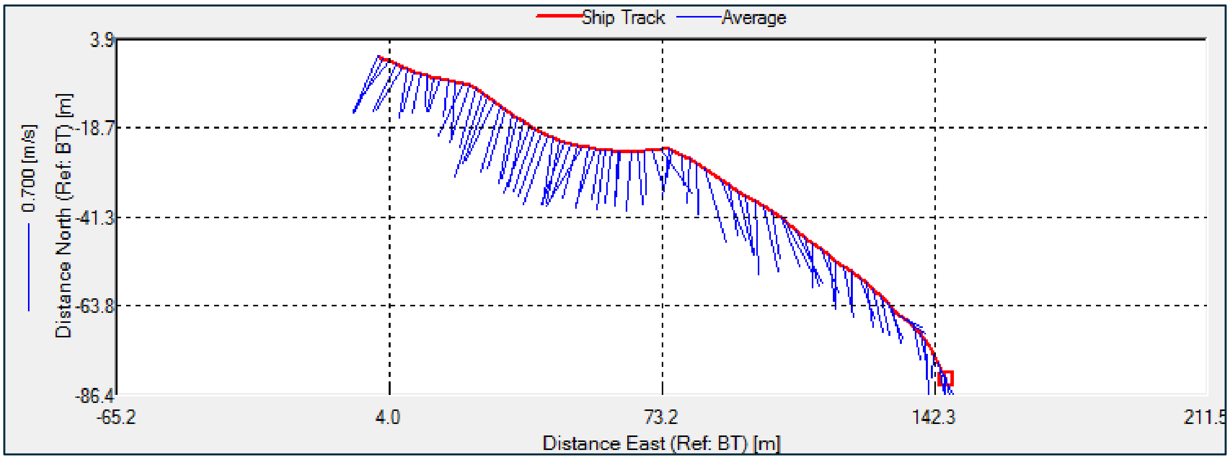


Figure 52. CrookhavenNeap1004 11/05/2015 12:02

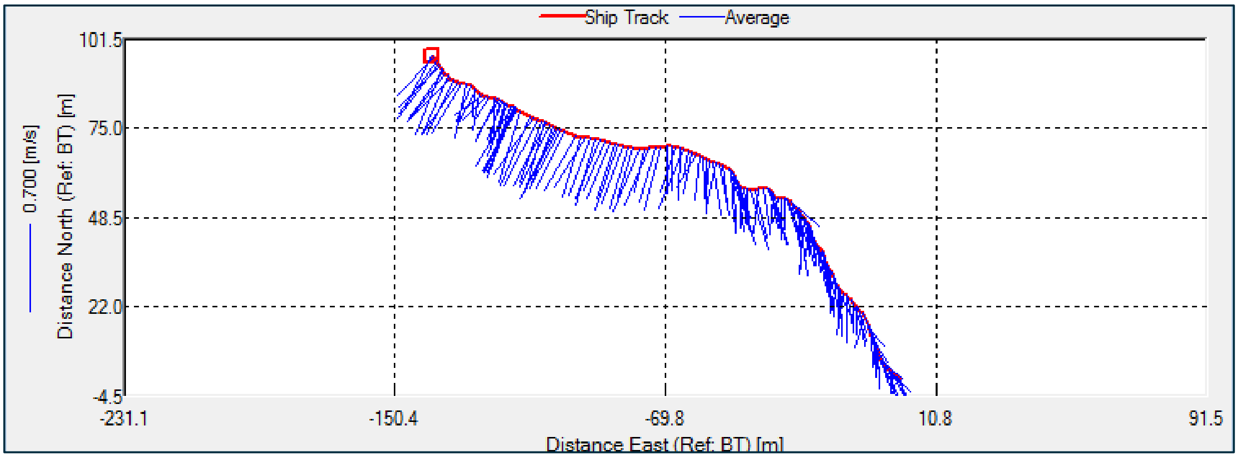


Figure 53. CrookhavenNeap1007 11/05/2015 13:07

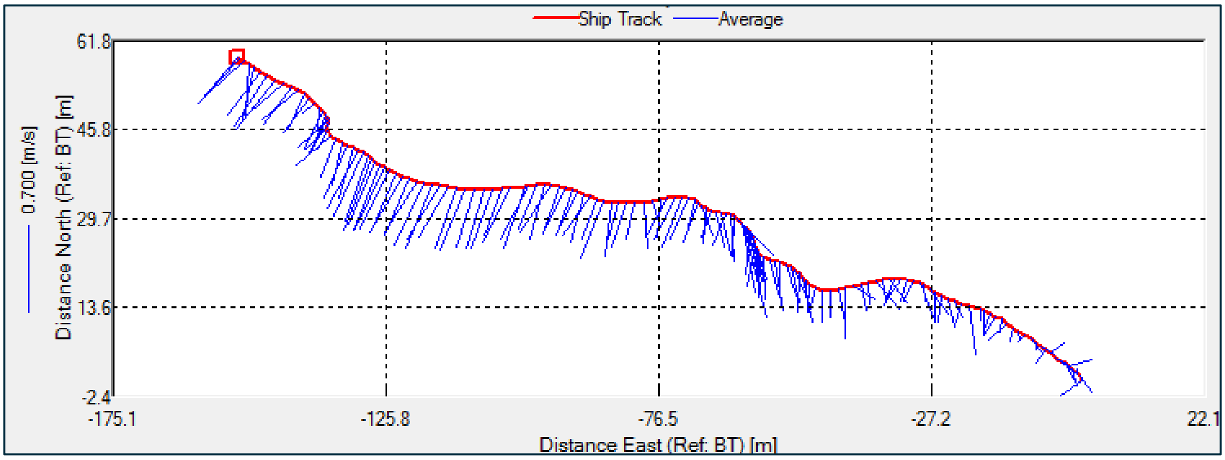


Figure 54. CrookhavenNeap1010 11/05/2015 13:53

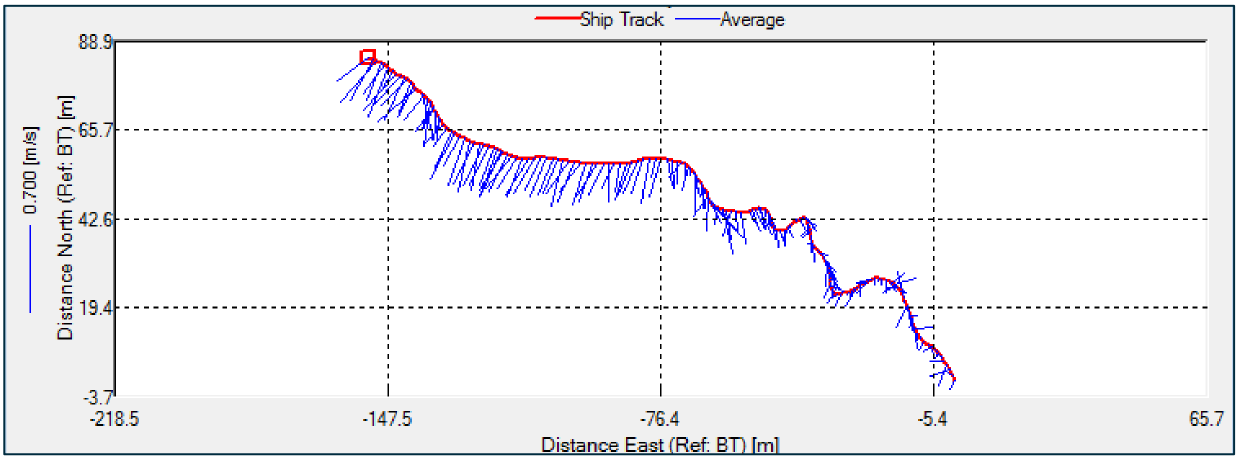


Figure 55. CrookhavenNeap1012 11/05/2015 14:48

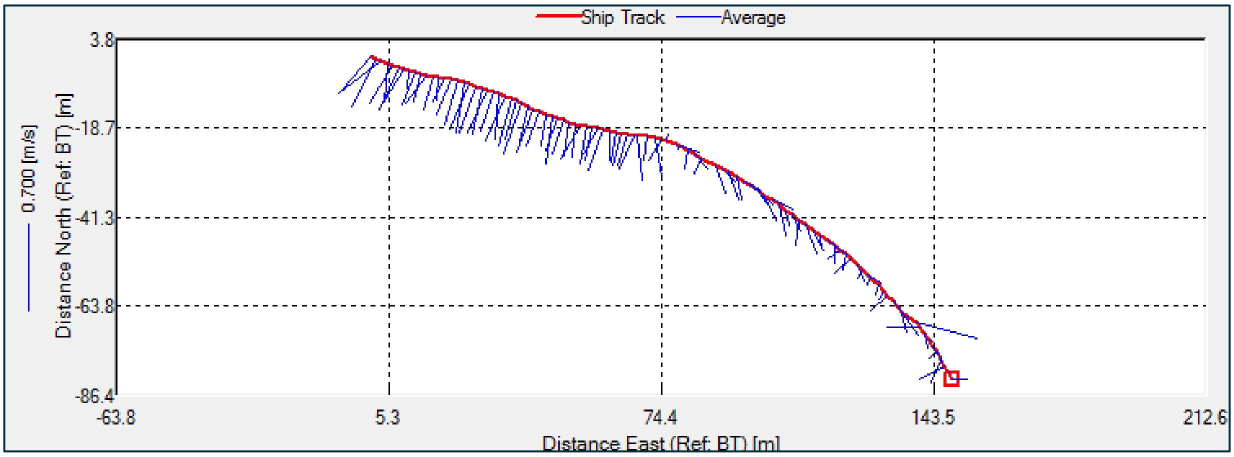


Figure 56. CrookhavenNeap1013 11/05/2015 14:54

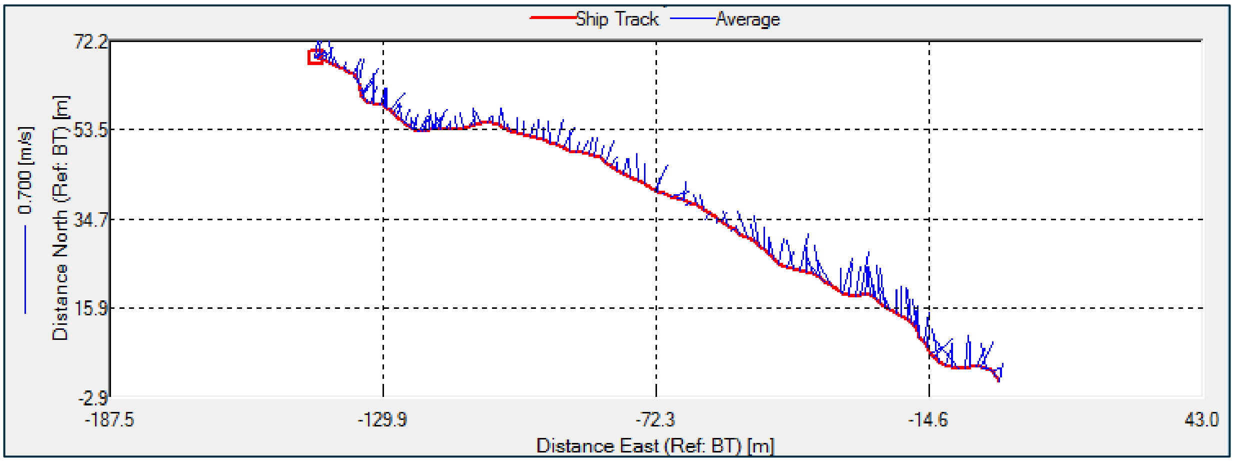


Figure 57. CrookhavenNeap1016 11/05/2015 16:02

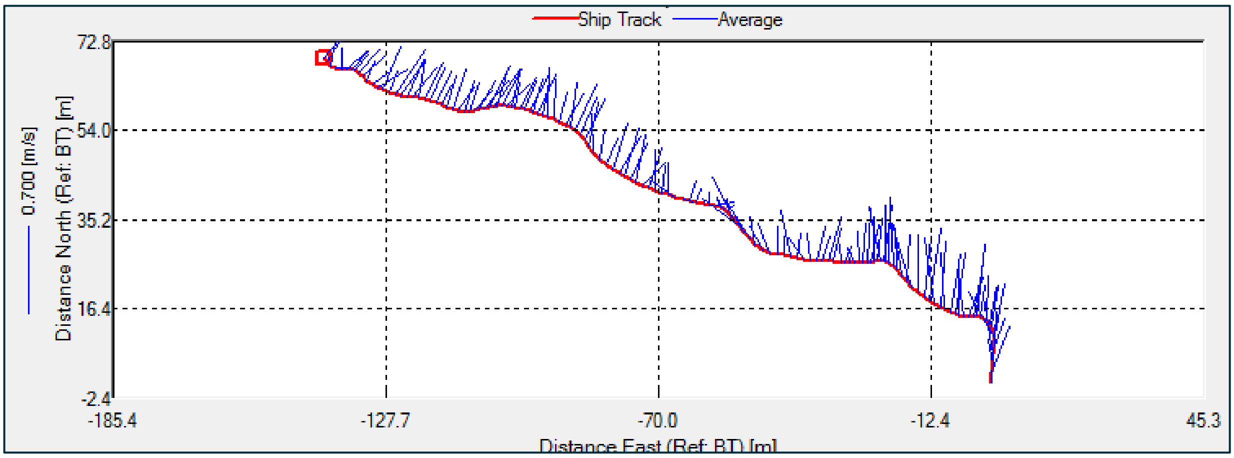


Figure 58. CrookhavenNeap1018 11/05/2015 17:05

Royal HaskoningDHV

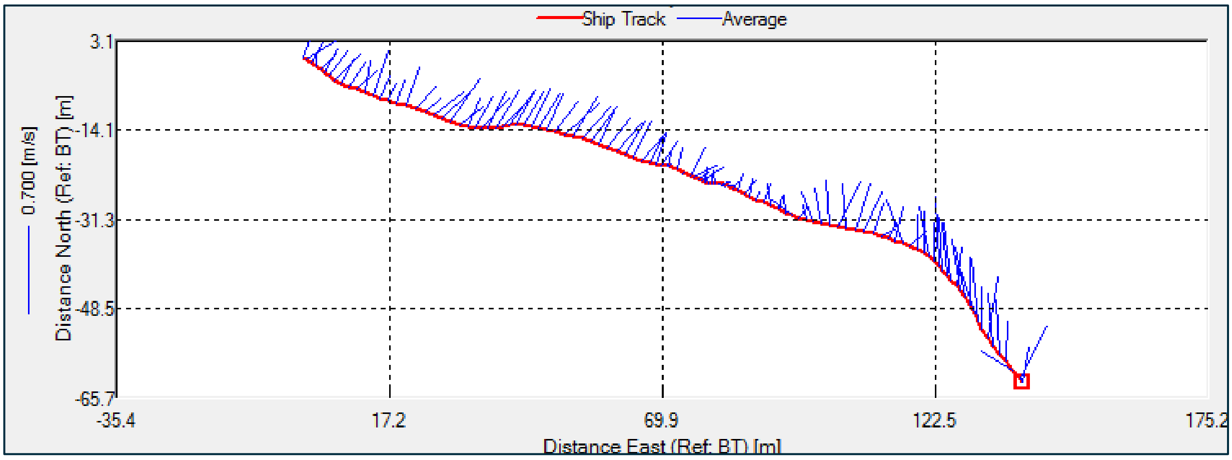


Figure 59. CrookhavenNeap1021 11/05/2015 18:11

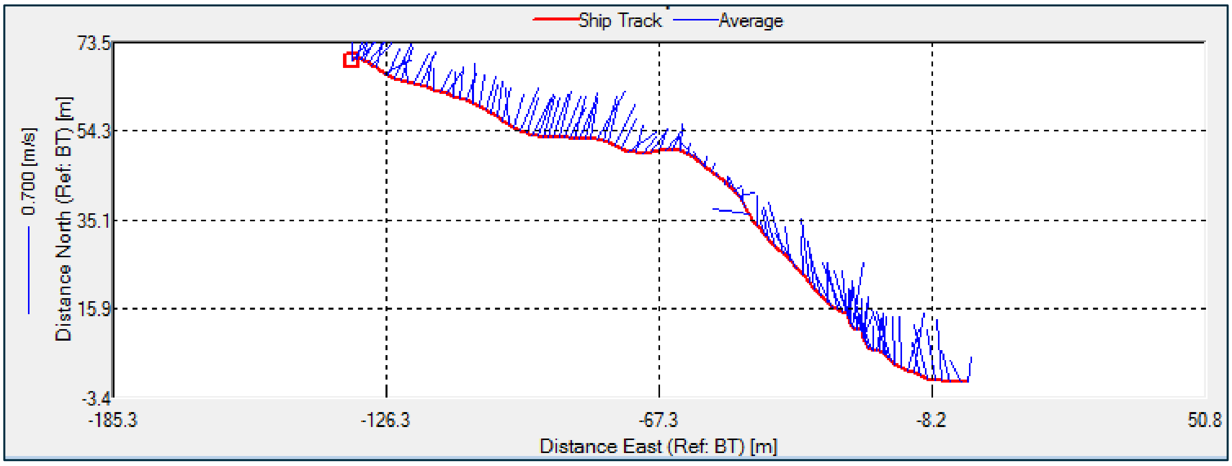


Figure 60. CrookhavenNeap1025 11/05/2015 19:09

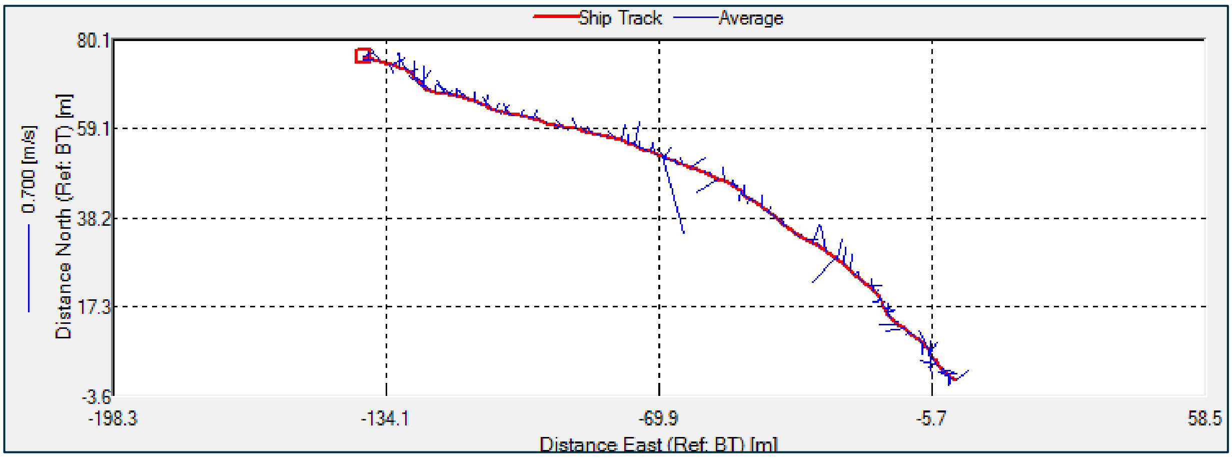


Figure 61. CrookhavenNeap1027 11/05/2015 21:11

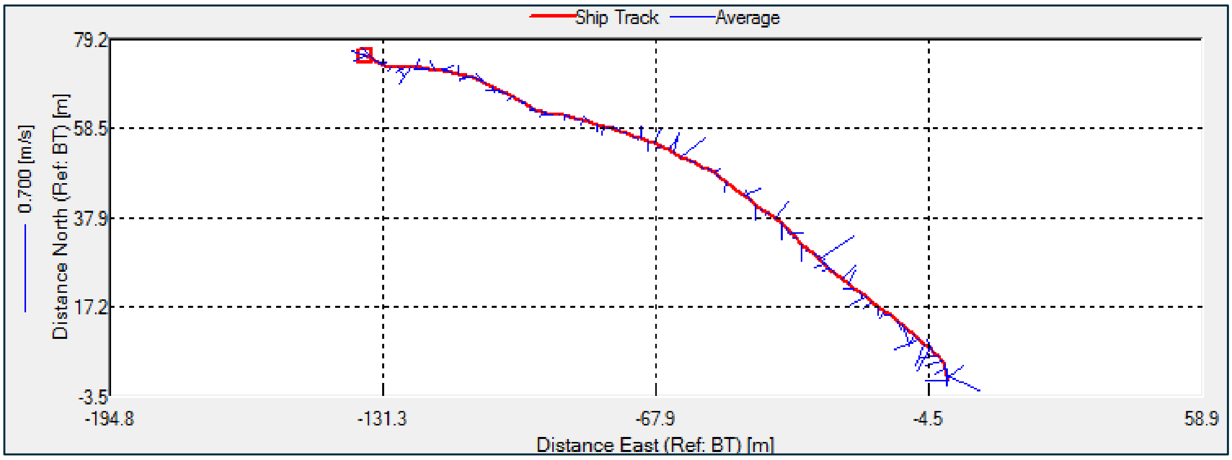


Figure 62. CrookhavenNeap1029 11/05/2015 21:22

3.3.4 2D Velocity Profiles – Neap Tide Exercise – Upstream Transect

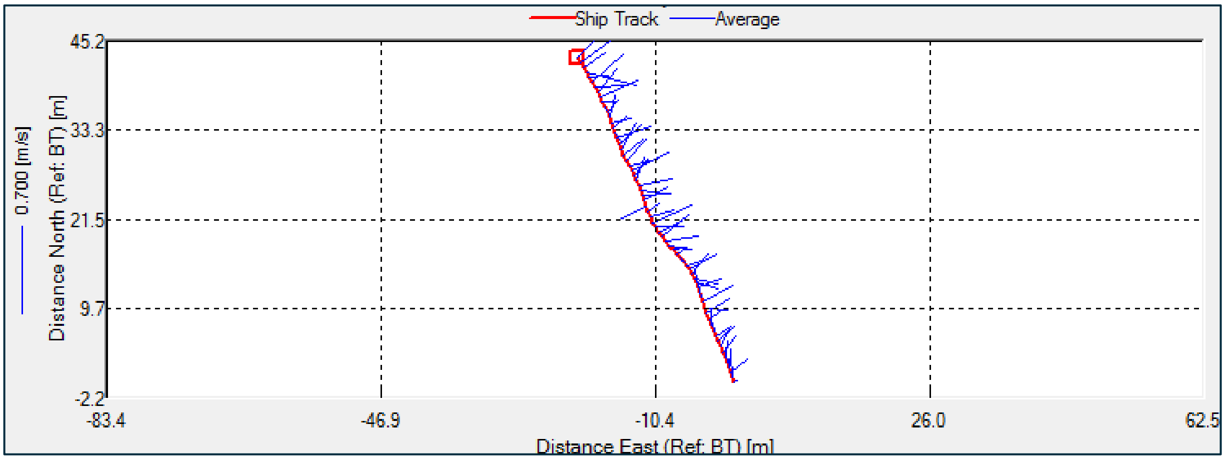


Figure 63. CrookhavenNeap2003 11/05/2015 9:32

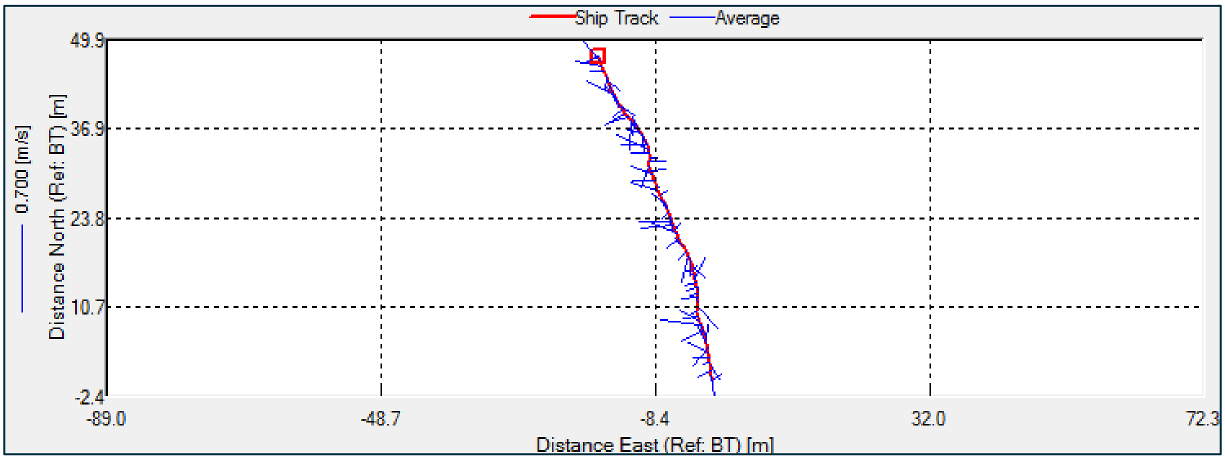


Figure 64. CrookhavenNeap2006 11/05/2015 10:27

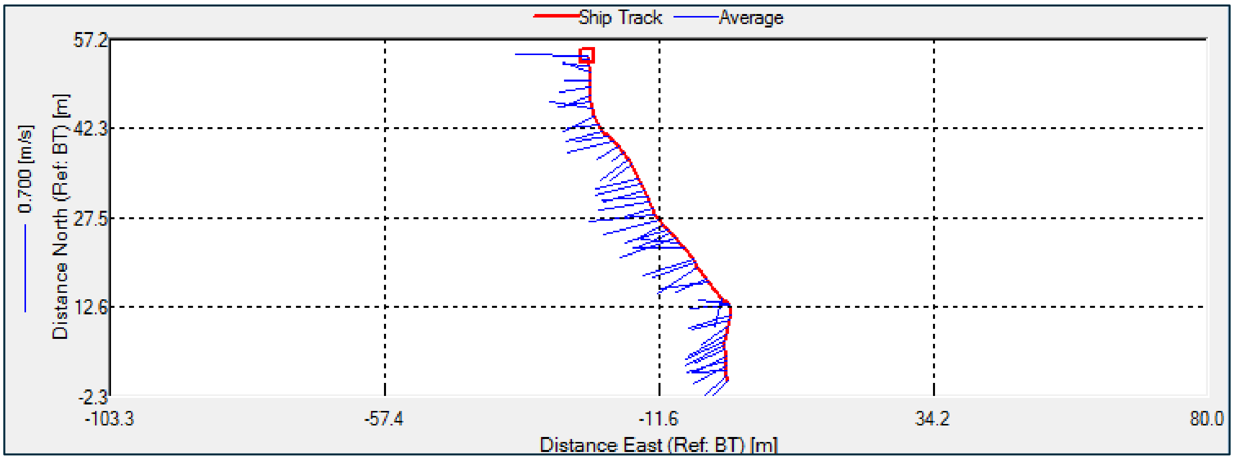


Figure 65. CrookhavenNeap1001 11/05/2015 11:32

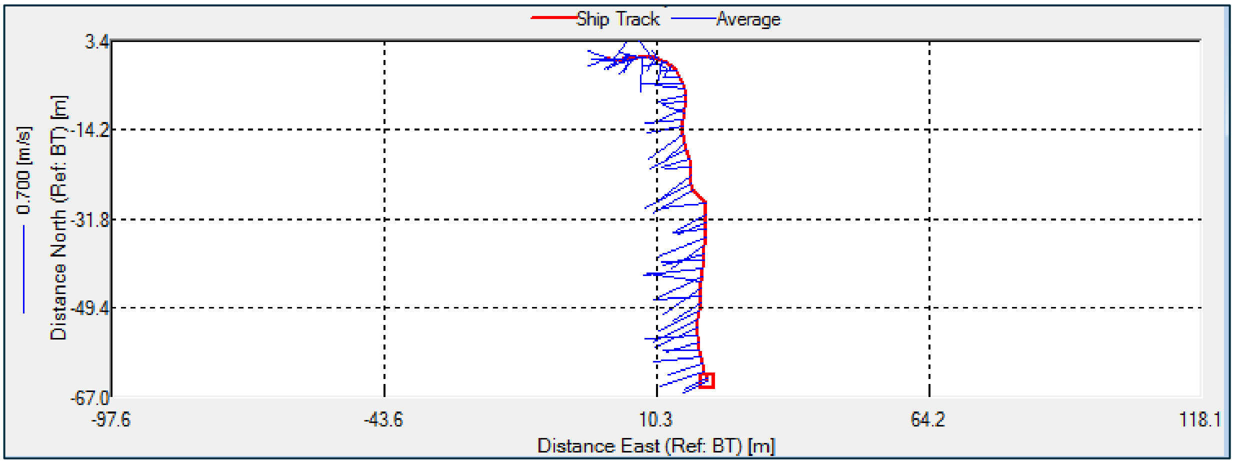


Figure 66. CrookhavenNeap1002 11/05/2015 11:35

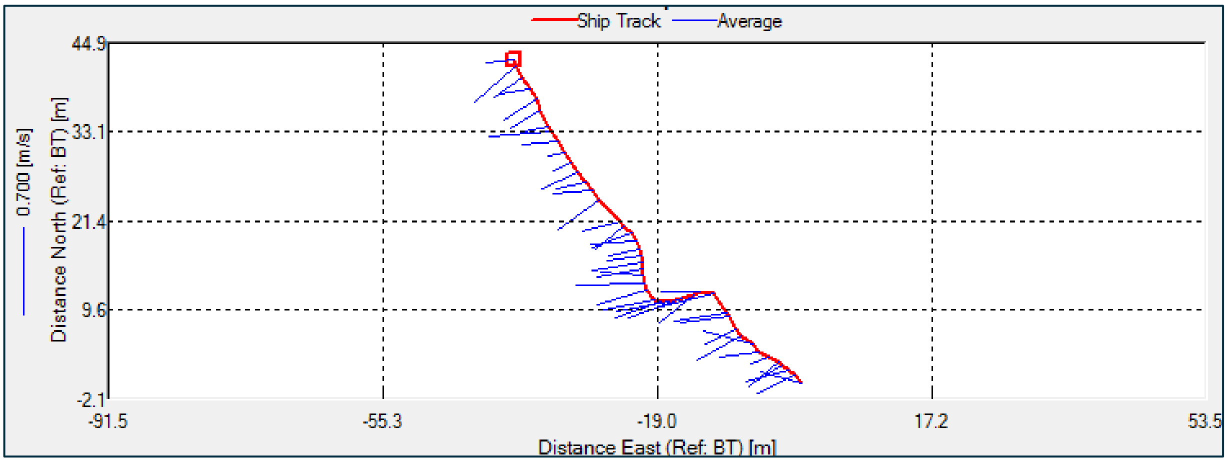


Figure 67. CrookhavenNeap1006 11/05/2015 12:27

Royal HaskoningDHV

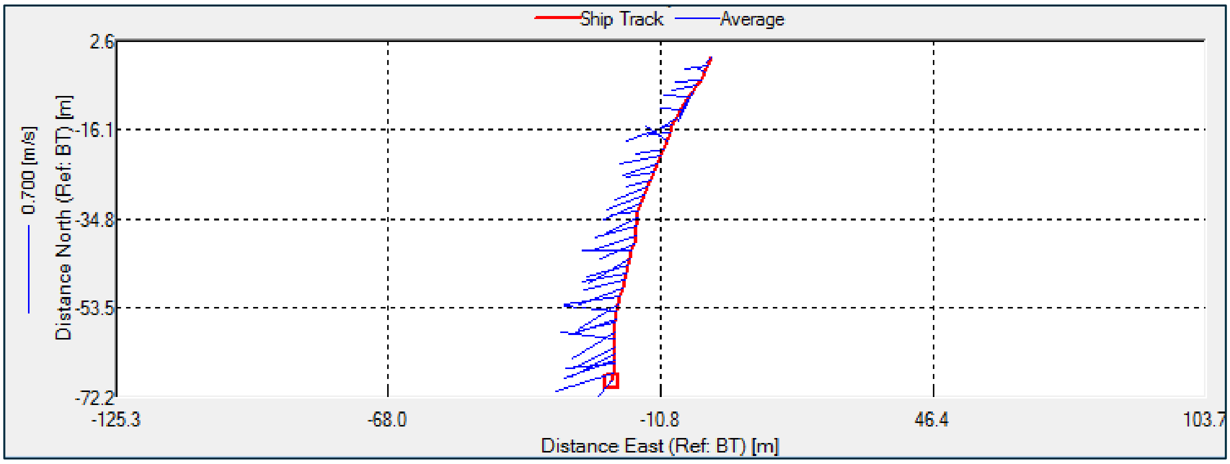


Figure 68. CrookhavenNeap1011 11/05/2015 14:11

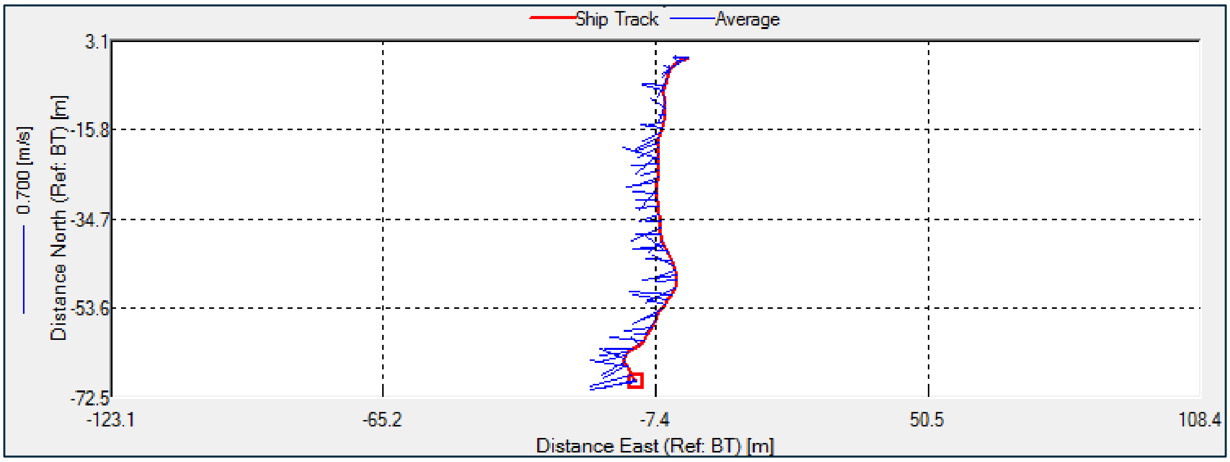


Figure 69. CrookhavenNeap1014 11/05/2015 15:15

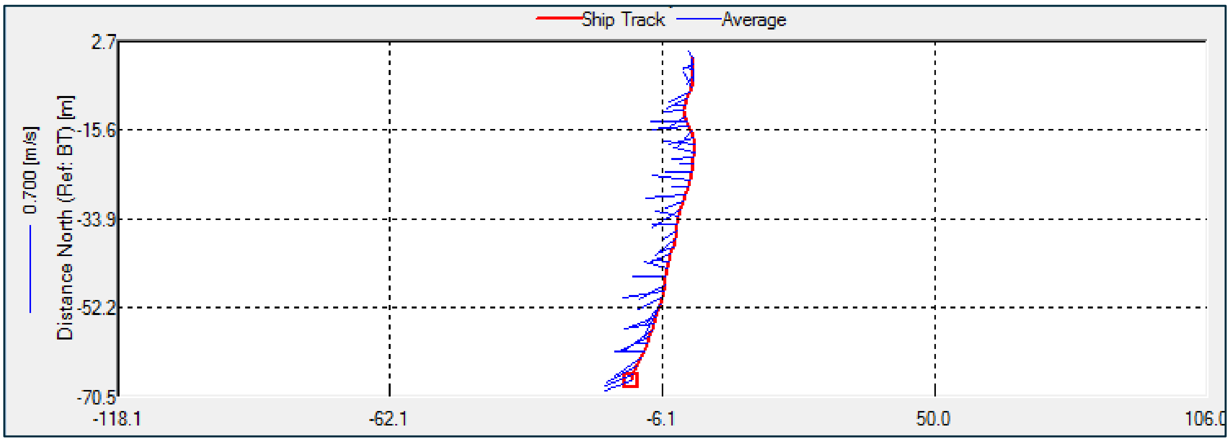


Figure 70. CrookhavenNeap1015 11/05/2015 15:20

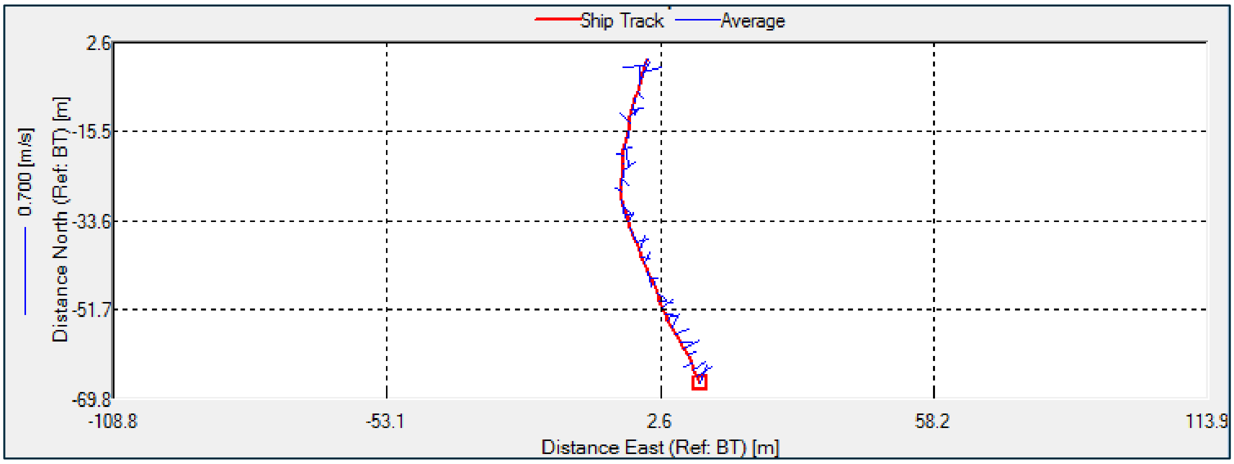


Figure 71. CrookhavenNeap1017 11/05/2015 16:20

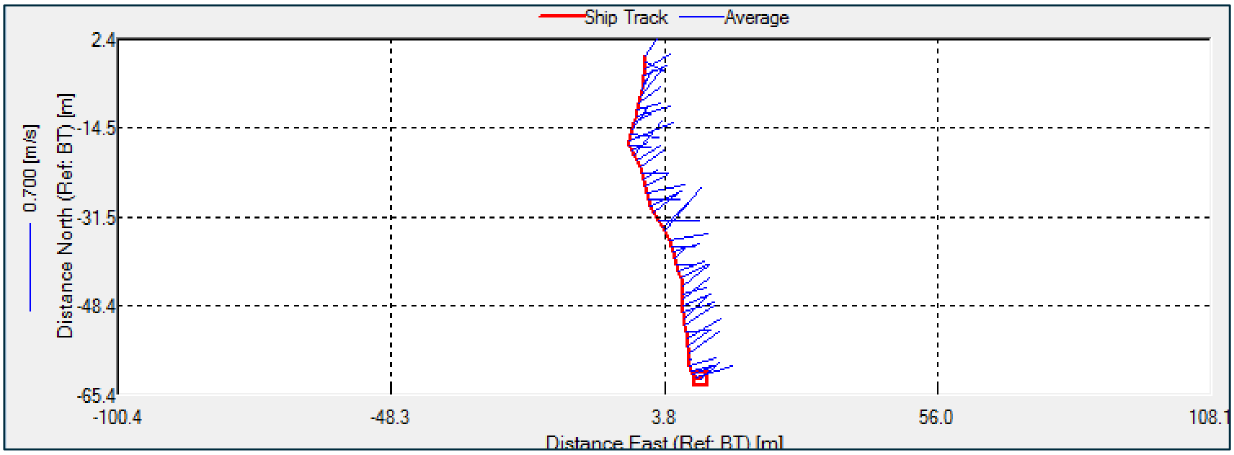


Figure 72. CrookhavenNeap1019 11/05/2015 17:22

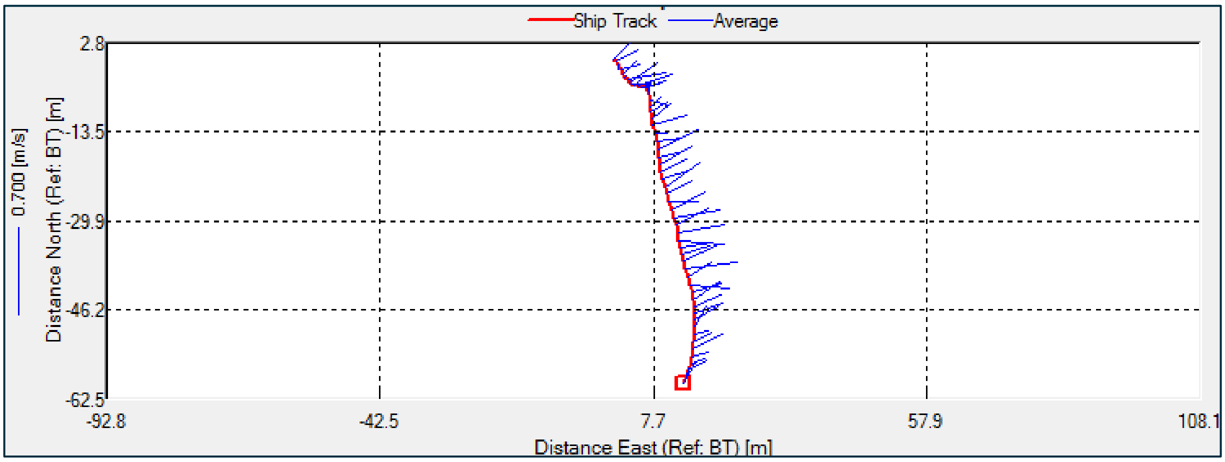


Figure 73. CrookhavenNeap1023 11/05/2015 18:39

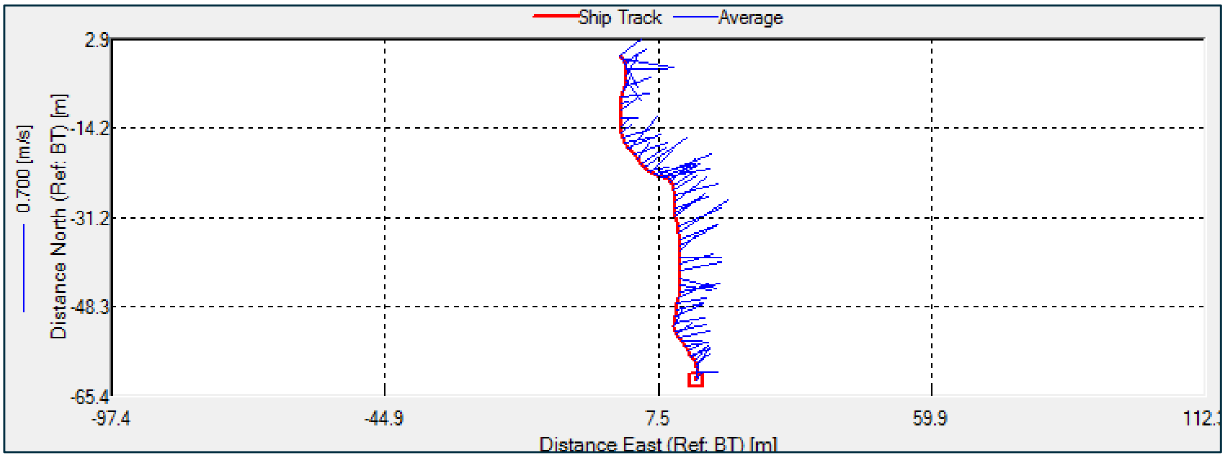


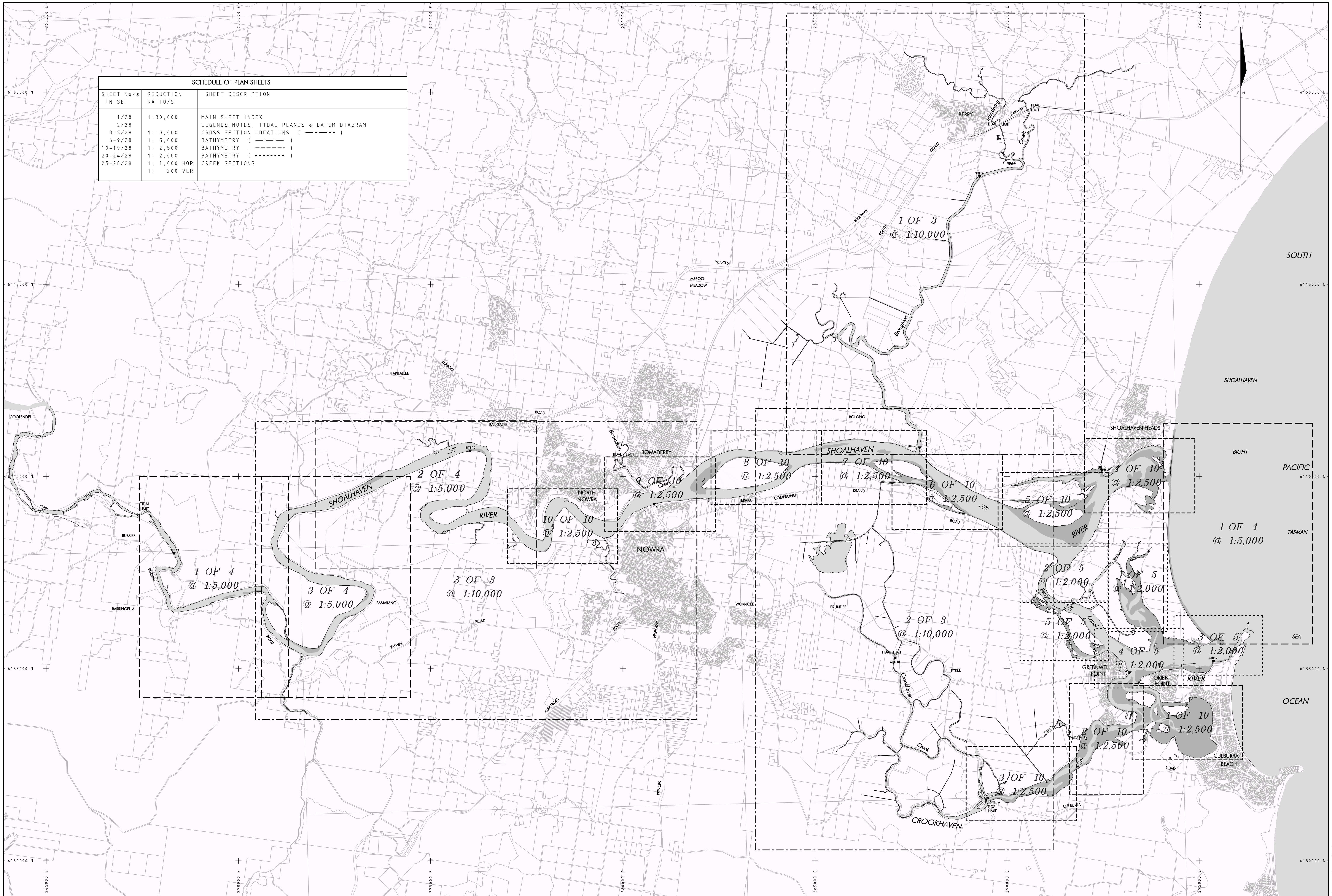
Figure 74. CrookhavenNeap1017 11/05/2015 18:44

4 References

L.Chen, "Unified Theory on Power Laws for flow resistance," *Journal of Hydraulic Engineering*, Vol 117, No. ,1991, pp. 371-389.

Teleydyne RD Instruments, "Win River II User's Guide" P/N 957-6231-00 (February 2007)

16 Attachment I: Bathymetry Data (NSW Office of Environment and Heritage, 2012)



SCHEDULE OF PLAN SHEETS

SHEET No/s IN SET	REDUCTION RATIO/S	SHEET DESCRIPTION
1/28	1:30,000	MAIN SHEET INDEX
2/28		LEGENDS, NOTES, TIDAL PLANES & DATUM DIAGRAM
3-5/28	1:10,000	CROSS SECTION LOCATIONS (— - — - -)
6-9/28	1: 5,000	BATHYMETRY (— — —)
10-19/28	1: 2,500	BATHYMETRY (------)
20-24/28	1: 2,000	BATHYMETRY (--------)
25-28/28	1: 1,000 HOR 1: 200 VER	CREEK SECTIONS

MK	DETAILS OF AMENDMENTS	APPROVED	DATE

PLAN PREPARED BY
DEPARTMENT OF COMMERCE
SURVEYING & SPATIAL INFORMATION SERVICES
LEVEL 14 McKELL BUILDING
2-24 RAWSON PLACE SYDNEY
TEL: (02) 9372 7907 FAX: (02) 9372 7922

DATUM: AUSTRALIAN HEIGHT DATUM

CAUTION
THIS PLAN HAS BEEN PRODUCED AT THE SCALE/S SHOWN BELOW FOR THE PURPOSE OF ESTUARY MANAGEMENT AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE.

0 300 600 1200 1800 2400 3000
REDUCTION RATIO 1:30,000 METRES
AT A0 SHEET SIZE

CO-ORDINATES	-	MGA ZONE 56
CONTOUR INTERVAL	-	0.5 METRE
SURVEYOR	-	S.HOLTZNAGEL
SURVEY DATE/S	-	SEPT 2005 - NOV 2006
PROJECT CONTROLLER	-	M.FITZHENRY
CADD OPERATOR	-	R.CASAGRANDE
PLAN EXAMINER	-	A.R.GORDON
JOB NUMBER	-	1025100

ORTA RECENS QUAM PURA NITES

Department of Natural Resources

ESTUARY MANAGEMENT PROGRAM

SURVEYOR	-	S.HOLTZNAGEL 22/12/2008
PROJECT CONTROLLER	-	M.FITZHENRY 22/12/2008
PLAN EXAMINER	-	A.R.GORDON 22/12/2008

SHOALHAVEN RIVER HYDROGRAPHIC SURVEY SEPTEMBER 2005 - NOVEMBER 2006

MAIN SHEET INDEX PLAN

SHEET No 1 / 1
1:30,000 INDEX
No IN SET 1 / 28
PLAN ROOM CAT No 56228

$FILE$ $username$ $DATE$ $TIME$

MK	DETAILS OF AMENDMENTS	APPROVED	DATE

PLAN PREPARED BY
DEPARTMENT OF COMMERCE
SURVEYING & SPATIAL INFORMATION SERVICES
LEVEL 14 McKELL BUILDING
2-24 RAWSON PLACE SYDNEY
TEL: (02) 9372 7907 FAX: (02) 9372 7922

DATUM: AUSTRALIAN HEIGHT DATUM

CAUTION
THIS PLAN HAS BEEN PRODUCED AT THE SCALE/S SHOWN BELOW FOR THE PURPOSE OF ESTUARY MANAGEMENT AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE.

0 100 200 400 600 800 1,000
REDUCTION RATIO 1:10,000 METRES
AT A0 SHEET SIZE

CO-ORDINATES	-	MGA ZONE 56
CONTOUR INTERVAL	-	0.5 METRE
SURVEYOR	-	S.HOLTZNAGEL
SURVEY DATE/S	-	SEPT 2005 - NOV 2006
PROJECT CONTROLLER	-	M.FITZHENRY
CADD OPERATOR	-	R.CASAGRANDE
PLAN EXAMINER	-	A.R.GORDON
JOB NUMBER	-	1025100

Department of Natural Resources

ESTUARY MANAGEMENT PROGRAM

SURVEYOR	-	S.HOLTZNAGEL 22/12/2008
PROJECT CONTROLLER	-	M.FITZHENRY 22/12/2008
PLAN EXAMINER	-	A.R.GORDON 22/12/2008

SHOALHAVEN RIVER HYDROGRAPHIC SURVEY SEPTEMBER 2005 - NOVEMBER 2006

CROSS SECTION LOCATION PLAN

SHEET No 2/ 3
1:10,000 SERIES
No IN SET 4/ 28
PLAN ROOM CAT No 56228

MK	DETAILS OF AMENDMENTS	APPROVED	DATE

PLAN PREPARED BY
DEPARTMENT OF COMMERCE
SURVEYING & SPATIAL INFORMATION SERVICES
LEVEL 14 McKELL BUILDING
2-24 RAWSON PLACE SYDNEY
TEL: (02) 9372 7907 FAX: (02) 9372 7922

DATUM: AUSTRALIAN HEIGHT DATUM

CAUTION
THIS PLAN HAS BEEN PRODUCED AT THE SCALE/S SHOWN BELOW FOR THE PURPOSE OF ESTUARY MANAGEMENT AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE.

0 25 50 100 150 200 250
REDUCTION RATIO 1:2,500 METRES
AT A0 SHEET SIZE

CO-ORDINATES	-	MGA ZONE 56
CONTOUR INTERVAL	-	0.5 METRE
SURVEYOR	-	S.HOLTZNAGEL
SURVEY DATE/S	-	SEPT 2005 - NOV 2006
PROJECT CONTROLLER	-	M.FITZHENRY
CADD OPERATOR	-	R.CASAGRANDE
PLAN EXAMINER	-	A.R.GORDON
JOB NUMBER	-	1025100

Department of Natural Resources

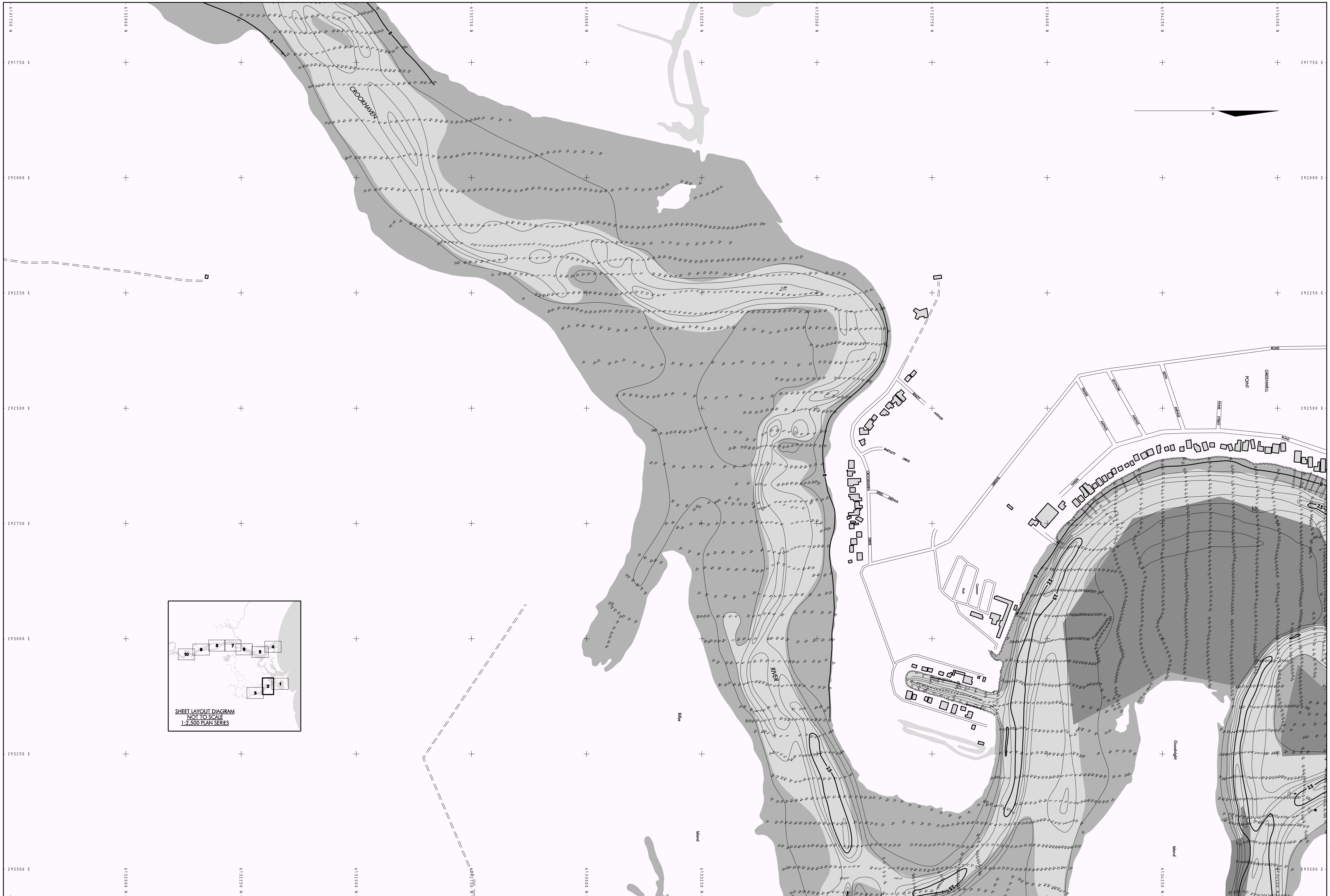
ESTUARY MANAGEMENT PROGRAM

SURVEYOR	-	S.HOLTZNAGEL	22/12/2008
PROJECT CONTROLLER	-	M.FITZHENRY	22/12/2008
PLAN EXAMINER	-	A.R.GORDON	22/12/2008

SHOALHAVEN RIVER HYDROGRAPHIC SURVEY SEPTEMBER 2005 - NOVEMBER 2006

BATHYMETRY

SHEET No 1/ 10
1:2,500 SERIES
No IN SET 10/ 28
PLAN ROOM CAT No 56228



MK	DETAILS OF AMENDMENTS	APPROVED	DATE

PLAN PREPARED BY
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TEL: (02) 9372 7907 FAX: (02) 9372 7922

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CAUTION
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0 25 50 100 150 200 250
REDUCTION RATIO 1:2,500 METRES
AT A0 SHEET SIZE

CO-ORDINATES	-	MGA ZONE 56
CONTOUR INTERVAL	-	0.5 METRE
SURVEYOR	-	S.HOLTZNAGEL
SURVEY DATE/S	-	SEPT 2005 - NOV 2006
PROJECT CONTROLLER	-	M.FITZHENRY
CADD OPERATOR	-	R.CASAGRANDE
PLAN EXAMINER	-	A.R.GORDON
JOB NUMBER	-	1025100

Department of Natural Resources

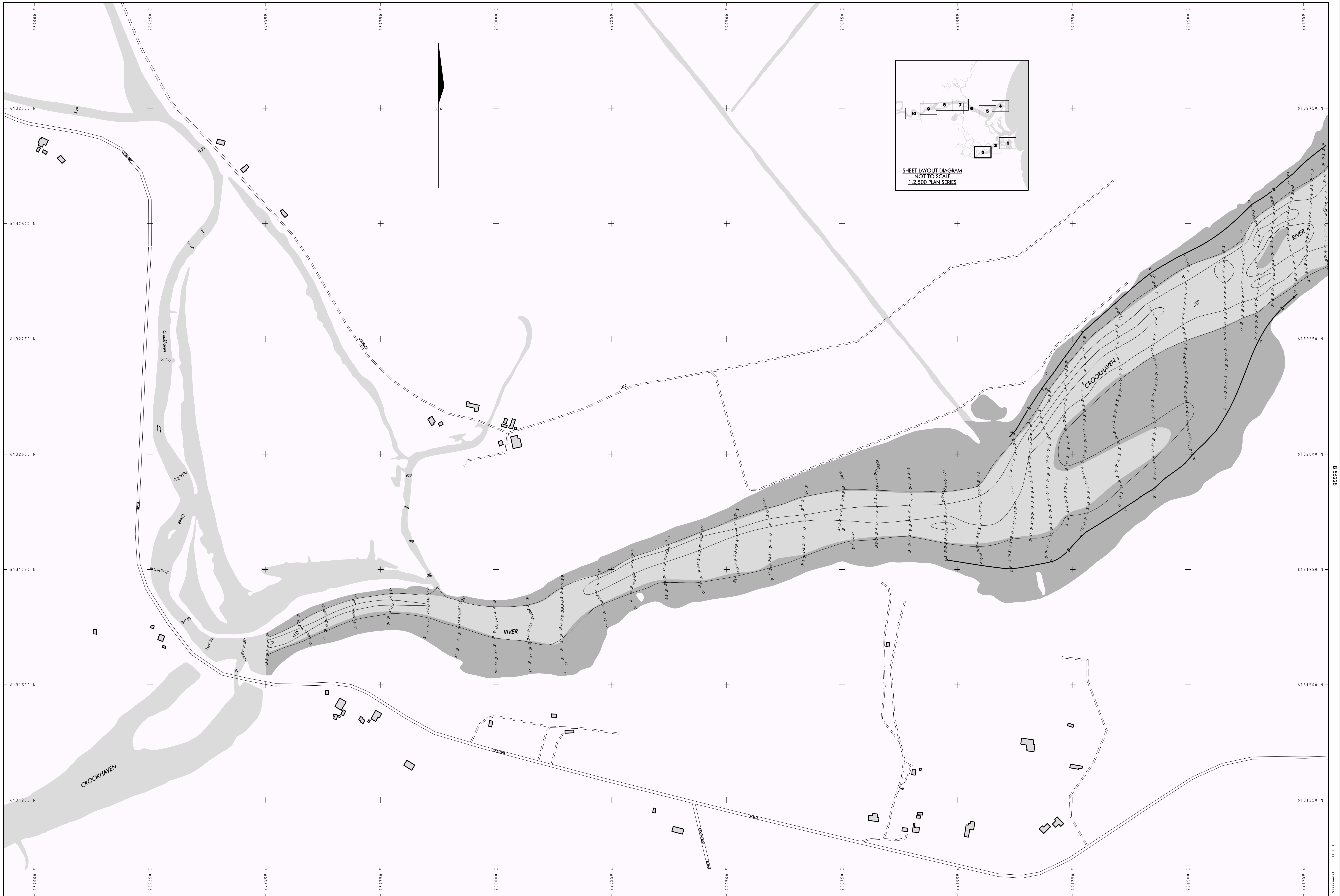
ESTUARY MANAGEMENT PROGRAM

SURVEYOR	-	S.HOLTZNAGEL	22/12/2008
PROJECT CONTROLLER	-	M.FITZHENRY	22/12/2008
PLAN EXAMINER	-	A.R.GORDON	22/12/2008

SHOALHAVEN RIVER HYDROGRAPHIC SURVEY SEPTEMBER 2005 - NOVEMBER 2006

BATHYMETRY

SHEET No 2/ 10
1:2,500 SERIES
No IN SET 11/ 28
PLAN ROOM CAT No 56228



MK	DETAILS OF AMENDMENTS	APPROVED	DATE

PLAN PREPARED BY
DEPARTMENT OF COMMERCE
SURVEYING & SPATIAL INFORMATION SERVICES
LEVEL 14 McKELL BUILDING
2-24 RAWSON PLACE SYDNEY
TEL: (02) 9372 7907 FAX: (02) 9372 7922

DATUM: AUSTRALIAN HEIGHT DATUM

CAUTION
THIS PLAN HAS BEEN PRODUCED AT THE SCALE/S SHOWN BELOW FOR THE PURPOSE OF ESTUARY MANAGEMENT AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE.

0 25 50 100 150 200 250
REDUCTION RATIO 1:2,500 METRES
AT A0 SHEET SIZE

CO-ORDINATES	-	MGA ZONE 56
CONTOUR INTERVAL	-	0.5 METRE
SURVEYOR	-	S.HOLTZNAGEL
SURVEY DATE/S	-	SEPT 2005 - NOV 2006
PROJECT CONTROLLER	-	M.FITZHENRY
CADD OPERATOR	-	R.CASAGRANDE
PLAN EXAMINER	-	A.R.GORDON
JOB NUMBER	-	1025100

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Department of Natural Resources

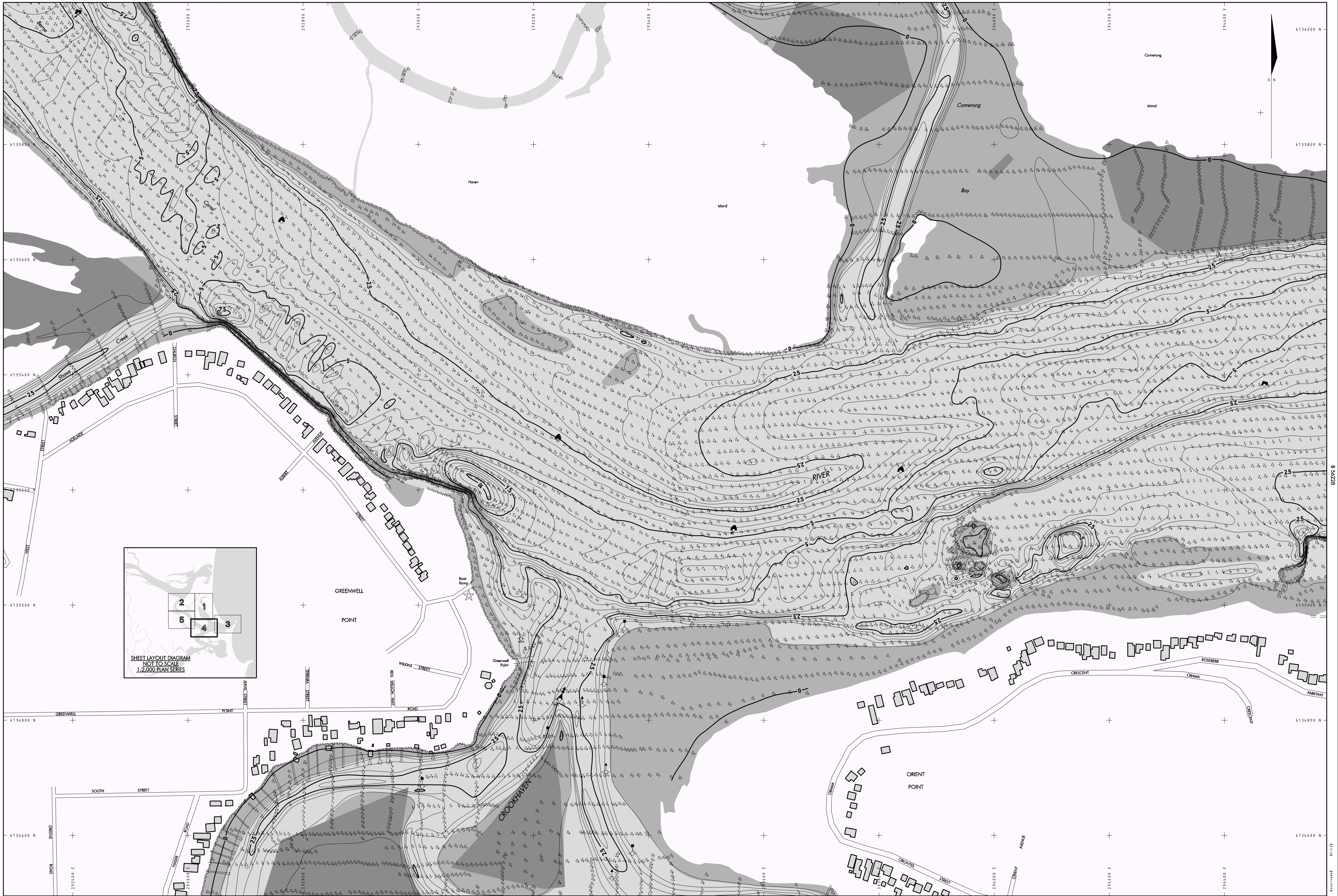
ESTUARY MANAGEMENT PROGRAM

SURVEYOR	-	S.HOLTZNAGEL 22/12/2008
PROJECT CONTROLLER	-	M.FITZHENRY 22/12/2008
PLAN EXAMINER	-	A.R.GORDON 22/12/2008

SHOALHAVEN RIVER HYDROGRAPHIC SURVEY SEPTEMBER 2005 - NOVEMBER 2006

BATHYMETRY

SHEET No 3 / 10
1:2,500 SERIES
No IN SET 12 / 28
PLAN ROOM CAT No 56228



MK	DETAILS OF AMENDMENTS	APPROVED	DATE

PLAN PREPARED BY
DEPARTMENT OF COMMERCE
SURVEYING & SPATIAL INFORMATION SERVICES
LEVEL 14 McKELL BUILDING
2-24 RAWSON PLACE SYDNEY
TEL: (02) 9372 7907 FAX: (02) 9372 7922

DATUM: AUSTRALIAN HEIGHT DATUM

CAUTION
THIS PLAN HAS BEEN PRODUCED AT THE SCALE/S SHOWN BELOW FOR THE PURPOSE OF ESTUARY MANAGEMENT AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE.

0 20 40 80 120 160 200
REDUCTION RATIO 1:2,000 METRES
AT A0 SHEET SIZE

CO-ORDINATES	-	MGA ZONE 56
CONTOUR INTERVAL	-	0.5 METRE
SURVEYOR	-	S.HOLTZNAGEL
SURVEY DATE/S	-	SEPT 2005 - NOV 2006
PROJECT CONTROLLER	-	M.FITZHENRY
CADD OPERATOR	-	R.CASAGRANDE
PLAN EXAMINER	-	A.R.GORDON
JOB NUMBER	-	1025100

Department of Natural Resources

ESTUARY MANAGEMENT PROGRAM

SURVEYOR	-	S.HOLTZNAGEL 22/12/2008
PROJECT CONTROLLER	-	M.FITZHENRY 22/12/2008
PLAN EXAMINER	-	A.R.GORDON 22/12/2008

SHOALHAVEN RIVER HYDROGRAPHIC SURVEY SEPTEMBER 2005 - NOVEMBER 2006

BATHYMETRY

SHEET No 4 / 5
1:2,000 SERIES
No IN SET 23 / 28
PLAN ROOM CAT No 56228

17 Attachment J: Tuflow Model Output Statistics

Table 32: Tuflow model [M01] key statistics at observation points – average year (1967) with infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M01] Model Summary (mg/L)	Median	25333	26040	26290	26063	26118	0.279	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.2	25.1	25.1	25.2	25.1
	Mean	23697	23961	24067	23977	23973	0.307	0.286	0.280	0.290	0.288	0.034	0.029	0.028	0.030	0.029	26.2	25.4	25.3	25.8	25.7
	90th Percentile [3]	12457	11241	11537	12353	12191	0.373	0.314	0.298	0.322	0.315	0.046	0.035	0.032	0.037	0.035	27.4	26.1	25.8	26.5	26.2
	95th Percentile [3]	7343	5970	5674	6185	6008	0.472	0.345	0.316	0.346	0.336	0.069	0.043	0.037	0.046	0.043	30.7	27.2	26.4	27.9	27.5
	99th Percentile [3]	3218	2587	2381	2691	2569	0.697	0.458	0.395	0.531	0.510	0.135	0.063	0.055	0.080	0.076	41.8	29.7	30.5	38.0	35.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 33: Tuflow model [M02] key statistics at observation points – average year (1967) with infiltration, using D2 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M02] Model Summary (mg/L)	Median	24469	25004	25778	25260	25384	0.287	0.281	0.277	0.287	0.285	0.030	0.029	0.028	0.029	0.029	26.0	25.5	25.3	25.7	25.6
	Mean	23163	23505	23930	23667	23679	0.350	0.311	0.294	0.316	0.314	0.044	0.035	0.031	0.035	0.035	27.7	26.2	25.9	26.9	26.8
	90th Percentile [3]	12332	12322	12273	13550	13394	0.519	0.401	0.340	0.403	0.391	0.077	0.055	0.042	0.056	0.054	31.3	28.6	27.2	29.5	29.0
	95th Percentile [3]	8920	6792	6776	7947	7738	0.707	0.461	0.376	0.437	0.424	0.124	0.070	0.051	0.066	0.062	38.8	31.1	28.7	31.6	31.1
	99th Percentile [3]	4348	3171	3161	4056	3930	0.979	0.594	0.496	0.728	0.730	0.205	0.088	0.076	0.114	0.111	53.7	34.6	35.0	49.1	47.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 34: Tuflow model [M03] key statistics at observation points – average year (1967) with infiltration, using D3 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M03] Model Summary (mg/L)	Median	26316	26596	26652	26602	26608	0.273	0.271	0.271	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	24033	24087	24112	24101	24084	0.280	0.276	0.274	0.275	0.275	0.028	0.027	0.027	0.027	0.027	25.3	25.1	25.1	25.2	25.2
	90th Percentile [3]	11476	10381	10572	11006	10550	0.287	0.278	0.275	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.3	25.2	25.1	25.2	25.2
	95th Percentile [3]	5489	5284	5059	5141	5115	0.302	0.289	0.282	0.286	0.285	0.032	0.030	0.028	0.029	0.029	25.9	25.4	25.3	25.6	25.5
	99th Percentile [3]	2260	2074	1967	1987	1983	0.448	0.371	0.340	0.354	0.349	0.076	0.053	0.045	0.048	0.048	32.6	28.5	28.0	28.5	28.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 35: Tuflow model [M04] key statistics at observation points – dry year (1968) with infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M04] Model Summary (mg/L)	Median	28815	29137	29058	28896	28822	0.271	0.271	0.270	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.0	25.0	25.0	25.0	25.0
	Mean	26510	26478	26491	26536	26519	0.274	0.271	0.271	0.272	0.272	0.027	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.1	25.1
	90th Percentile [3]	14741	14234	14069	14355	14261	0.280	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.3	25.1	25.1	25.2	25.2
	95th Percentile [3]	12367	11869	11810	12211	12107	0.285	0.275	0.273	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.4	25.1	25.1	25.5	25.3
	99th Percentile [3]	5553	4448	4002	4639	4556	0.298	0.278	0.280	0.303	0.294	0.031	0.028	0.028	0.031	0.030	26.3	25.3	25.6	27.1	26.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 36: Tuflow model [M05] key statistics at observation points – wet year (1969) with infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M05] Model Summary (mg/L)	Median	20197	20725	20718	20640	20649	0.309	0.288	0.283	0.297	0.293	0.032	0.029	0.028	0.030	0.029	25.8	25.3	25.3	25.6	25.5
	Mean	18775	19391	19508	19281	19288	0.345	0.298	0.290	0.307	0.304	0.038	0.030	0.029	0.032	0.031	27.0	25.6	25.6	26.3	26.2
	90th Percentile [3]	4716	3525	3486	3766	3625	0.467	0.340	0.317	0.347	0.339	0.057	0.037	0.033	0.038	0.037	30.4	26.9	26.4	27.4	27.1
	95th Percentile [3]	2907	2306	2168	2426	2342	0.540	0.362	0.333	0.375	0.364	0.069	0.041	0.036	0.043	0.041	33.3	27.6	27.1	29.5	28.7
	99th Percentile [3]	1828	1190	1077	1269	1208	0.688	0.406	0.366	0.489	0.479	0.093	0.049	0.042	0.060	0.057	38.8	29.1	29.3	39.6	38.1

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 37: Tuflow model [M06] key statistics at observation points – local wet month (20 Oct – 20 Nov 1969) with infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M06] Model Summary (mg/L)	Median	27916	27932	27986	27812	27832	0.278	0.272	0.274	0.284	0.280	0.027	0.026	0.026	0.028	0.027	25.1	25.0	25.1	25.4	25.2
	Mean	27895	26750	27868	27200	27052	0.279	0.277	0.278	0.314	0.322	0.027	0.027	0.027	0.032	0.033	25.2	24.6	25.4	27.8	28.1
	90th Percentile [3]	27704	23826	27500	25439	25599	0.287	0.294	0.290	0.399	0.390	0.028	0.028	0.029	0.045	0.042	25.6	25.0	26.6	34.8	33.1
	95th Percentile [3]	27646	21860	27332	24646	23935	0.290	0.317	0.294	0.445	0.489	0.028	0.030	0.029	0.051	0.054	25.8	25.1	26.8	38.3	38.6
	99th Percentile [3]	27542	19033	26816	22013	15377	0.294	0.350	0.309	0.581	1.036	0.029	0.033	0.031	0.070	0.125	25.9	25.3	27.6	48.5	63.3

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 38: Tuflow model [M07] key statistics at observation points – local wet month (20 Oct – 20 Nov 1969) with infiltration, using D2 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M07] Model Summary (mg/L)	Median	27952	27639	27858	27284	27332	0.279	0.272	0.276	0.305	0.298	0.026	0.026	0.027	0.031	0.030	25.1	24.9	25.1	26.1	25.8
	Mean	27880	24663	27667	26169	25874	0.280	0.284	0.283	0.355	0.377	0.027	0.027	0.028	0.038	0.040	25.2	23.9	25.7	30.2	31.1
	90th Percentile [3]	27567	17233	26884	22247	22455	0.290	0.332	0.307	0.529	0.535	0.028	0.031	0.031	0.065	0.061	25.7	25.0	27.5	43.5	42.4
	95th Percentile [3]	27494	14661	26717	20627	19865	0.292	0.403	0.313	0.593	0.683	0.029	0.036	0.032	0.074	0.081	26.0	25.6	28.2	49.5	51.7
	99th Percentile [3]	27353	9442	26122	17728	6949	0.295	0.456	0.328	0.740	1.456	0.029	0.044	0.034	0.092	0.184	26.4	26.3	29.1	59.1	94.9

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 39: Tuflow model [M08] key statistics at observation points – local wet month (20 Oct – 20 Nov 1969) with infiltration, using D3 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M08] Model Summary (mg/L)	Median	28016	27999	28042	28011	28014	0.273	0.272	0.272	0.274	0.273	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	27978	27789	28013	27872	27802	0.275	0.274	0.273	0.281	0.285	0.027	0.026	0.026	0.027	0.028	25.1	25.0	25.2	25.6	25.9
	90th Percentile [3]	27824	27389	27914	27549	27479	0.282	0.278	0.278	0.295	0.295	0.027	0.027	0.027	0.029	0.029	25.3	25.1	25.4	26.6	26.7
	95th Percentile [3]	27745	26440	27826	27166	27003	0.286	0.281	0.281	0.327	0.320	0.028	0.027	0.027	0.033	0.033	25.5	25.3	25.8	28.0	29.0
	99th Percentile [3]	27600	25440	27536	25799	24492	0.292	0.309	0.292	0.415	0.493	0.028	0.029	0.029	0.045	0.054	25.7	25.5	26.7	33.0	42.2

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 40: Tuflow model [M09] key statistics at observation points – average year (1967) with infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M09] Model Summary (mg/L)	Median	25334	25953	26274	26061	26118	0.279	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.2	25.1	25.1	25.2	25.1
	Mean	23697	23938	24062	23977	23972	0.307	0.285	0.280	0.290	0.288	0.034	0.029	0.028	0.030	0.029	26.2	25.3	25.3	25.8	25.7
	90th Percentile [4]	12456	11391	11520	12352	12190	0.372	0.314	0.298	0.322	0.315	0.046	0.035	0.032	0.037	0.035	27.4	26.0	25.7	26.5	26.2
	95th Percentile [4]	7350	6056	5673	6184	6016	0.472	0.344	0.316	0.347	0.336	0.069	0.043	0.037	0.046	0.043	30.6	27.0	26.4	27.9	27.5
	99th Percentile [4]	3210	2637	2378	2687	2565	0.699	0.453	0.395	0.531	0.510	0.135	0.064	0.055	0.079	0.075	41.8	28.5	30.5	38.0	35.4
Change from Existing [M01] (mg/L)	Median	0	-88	-16	-2	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	1	-22	-5	0	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	90th Percentile [4]	-1	151	-16	-1	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	95th Percentile [4]	7	85	-2	-1	8	-0.001	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.2	0.0	0.0	0.0
	99th Percentile [4]	-9	50	-3	-4	-4	0.002	-0.006	-0.001	0.000	-0.001	0.001	0.001	0.000	-0.001	0.000	0.1	-1.1	0.0	0.0	-0.1
Change from Existing [M01] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%
	99th Percentile [4]	0%	2%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	1%	0%	-1%	0%	0%	-4%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 41: Tuflow model [M10] key statistics at observation points – average year (1967) with infiltration, using D2 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M10] Model Summary (mg/L)	Median	24468	24884	25771	25261	25385	0.287	0.281	0.277	0.287	0.285	0.030	0.029	0.028	0.029	0.029	26.0	25.4	25.3	25.7	25.6
	Mean	23164	23453	23922	23665	23676	0.350	0.311	0.294	0.316	0.314	0.044	0.035	0.031	0.035	0.035	27.7	26.0	25.9	26.9	26.7
	90th Percentile [4]	12340	12441	12264	13548	13394	0.519	0.400	0.340	0.403	0.391	0.077	0.054	0.042	0.056	0.054	31.3	28.1	27.2	29.5	29.0
	95th Percentile [4]	8915	6812	6766	7960	7725	0.706	0.460	0.376	0.437	0.424	0.124	0.071	0.051	0.066	0.062	38.7	30.5	28.6	31.6	31.1
	99th Percentile [4]	4356	3445	3146	4045	3922	0.979	0.566	0.494	0.724	0.728	0.205	0.088	0.075	0.113	0.111	53.6	33.3	34.8	49.0	47.3
Change from Existing [M02] (mg/L)	Median	-1	-120	-7	1	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	Mean	1	-52	-8	-2	-3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	90th Percentile [4]	8	119	-9	-2	-1	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.5	0.0	0.0	0.0
	95th Percentile [4]	-5	20	-11	13	-13	-0.001	-0.002	-0.001	0.000	-0.001	0.000	0.002	0.000	0.000	0.000	-0.1	-0.6	0.0	0.0	0.0
	99th Percentile [4]	9	274	-15	-11	-8	0.000	-0.028	-0.001	-0.003	-0.002	0.000	0.000	0.000	-0.002	0.000	-0.1	-1.3	-0.2	-0.1	-0.1
Change from Existing [M02] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%
	90th Percentile [4]	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-2%	0%	0%	0%
	95th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	-2%	0%	0%	0%
	99th Percentile [4]	0%	9%	0%	0%	0%	0%	-5%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	-4%	-1%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 42: Tuflow model [M11] key statistics at observation points – average year (1967) with infiltration, using D3 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M11] Model Summary (mg/L)	Median	26318	26594	26654	26600	26607	0.273	0.271	0.271	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	24033	24088	24110	24101	24084	0.280	0.275	0.274	0.275	0.275	0.028	0.027	0.027	0.027	0.027	25.3	25.1	25.1	25.2	25.2
	90th Percentile [4]	11480	10393	10573	11018	10550	0.286	0.279	0.275	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.3	25.2	25.1	25.3	25.2
	95th Percentile [4]	5490	5305	5059	5141	5115	0.302	0.288	0.282	0.286	0.285	0.032	0.030	0.028	0.029	0.029	25.9	25.4	25.3	25.6	25.5
	99th Percentile [4]	2271	2104	1967	1983	1981	0.448	0.376	0.340	0.354	0.349	0.076	0.053	0.044	0.048	0.047	32.6	28.8	28.0	28.5	28.4
Change from Existing [M03] (mg/L)	Median	2	-2	1	-2	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	0	2	-1	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	4	12	2	12	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	0	21	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	99th Percentile [4]	11	30	1	-3	-2	0.000	0.005	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.0	0.3	0.0	0.0	0.0
Change from Existing [M03] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 43: Tuflow model [M12] key statistics at observation points – dry year (1968) with infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M12] Model Summary (mg/L)	Median	28816	29134	29059	28889	28824	0.271	0.271	0.270	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.0	25.0	25.0	25.0	25.0
	Mean	26510	26469	26488	26534	26519	0.274	0.271	0.271	0.272	0.272	0.027	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.1	25.1
	90th Percentile [4]	14738	14231	14069	14355	14260	0.280	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.3	25.1	25.1	25.2	25.2
	95th Percentile [4]	12366	11868	11810	12205	12105	0.285	0.275	0.273	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.4	25.1	25.1	25.5	25.3
	99th Percentile [4]	5555	4445	3994	4631	4556	0.298	0.279	0.280	0.303	0.294	0.031	0.028	0.028	0.031	0.030	26.3	25.3	25.6	27.1	26.4
Change from Existing [M04] (mg/L)	Median	1	-3	1	-6	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	0	-9	-3	-1	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	-3	-3	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	-1	-2	0	-6	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	99th Percentile [4]	2	-3	-8	-8	1	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
Change from Existing [M04] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 44: Tuflow model [M13] key statistics at observation points – wet year (1969) with infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M13] Model Summary (mg/L)	Median	20195	20689	20714	20637	20650	0.308	0.288	0.283	0.297	0.294	0.032	0.029	0.028	0.030	0.029	25.8	25.3	25.3	25.6	25.5
	Mean	18776	19380	19503	19282	19288	0.345	0.298	0.290	0.308	0.304	0.038	0.030	0.029	0.032	0.031	27.0	25.6	25.6	26.4	26.2
	90th Percentile [4]	4720	3531	3490	3767	3625	0.467	0.339	0.317	0.347	0.340	0.057	0.037	0.033	0.038	0.037	30.4	26.8	26.4	27.5	27.1
	95th Percentile [4]	2912	2367	2164	2426	2341	0.539	0.360	0.332	0.375	0.367	0.068	0.041	0.036	0.043	0.041	33.3	27.5	27.0	29.8	29.0
	99th Percentile [4]	1830	1182	1076	1269	1209	0.687	0.412	0.365	0.488	0.494	0.093	0.050	0.042	0.059	0.058	38.8	29.3	29.3	39.5	38.7
Change from Existing [M05] (mg/L)	Median	-2	-36	-4	-3	1	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	1	-11	-5	1	0	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.1
	90th Percentile [4]	4	6	4	0	1	0.000	-0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.1	0.0
	95th Percentile [4]	5	61	-4	0	-1	-0.002	-0.002	0.000	0.001	0.003	0.000	0.000	0.000	0.000	0.001	0.0	0.0	0.0	0.3	0.3
	99th Percentile [4]	2	-7	-1	0	1	-0.001	0.006	-0.001	-0.001	0.015	0.000	0.001	0.000	-0.001	0.001	0.0	0.2	0.0	-0.1	0.5
Change from Existing [M05] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	3%	0%	0%	0%	0%	-1%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	1%	1%
	99th Percentile [4]	0%	-1%	0%	0%	0%	0%	1%	0%	0%	3%	0%	2%	0%	-1%	1%	0%	1%	0%	0%	1%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 45: Tuflow model [M14] key statistics at observation points – local wet year (20 Oct – 20 Nov 1969) with infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M14] Model Summary (mg/L)	Median	27919	27880	27965	27809	27830	0.278	0.274	0.274	0.284	0.280	0.027	0.026	0.026	0.028	0.027	25.1	25.0	25.1	25.4	25.2
	Mean	27893	27112	27857	27205	27052	0.279	0.278	0.277	0.313	0.322	0.027	0.027	0.027	0.032	0.033	25.2	24.7	25.4	27.8	28.1
	90^{th} Percentile [4]	27700	25565	27503	25482	25617	0.287	0.290	0.289	0.397	0.390	0.028	0.028	0.029	0.044	0.042	25.6	25.0	26.5	34.7	33.0
	95^{th} Percentile [4]	27622	24004	27329	24676	23952	0.290	0.301	0.293	0.439	0.491	0.028	0.029	0.029	0.050	0.054	25.8	25.0	26.7	38.3	38.6
	99^{th} Percentile [4]	27498	18017	26704	22343	15437	0.294	0.347	0.308	0.571	1.030	0.029	0.031	0.031	0.069	0.124	25.9	25.2	27.5	48.3	63.1
Change from Existing [M06] (mg/L)	Median	2	-51	-21	-3	-2	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-3	362	-11	5	0	0.000	0.001	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.1	0.0	0.0	0.0
	90^{th} Percentile [4]	-4	1738	3	43	18	0.000	-0.004	0.000	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	-0.1	-0.1
	95^{th} Percentile [4]	-23	2144	-3	31	17	0.000	-0.016	-0.001	-0.006	0.002	0.000	-0.001	0.000	-0.001	0.000	0.0	0.0	0.0	0.0	0.0
	99^{th} Percentile [4]	-44	-1016	-112	330	60	0.000	-0.004	-0.001	-0.010	-0.005	0.000	-0.002	0.000	-0.001	-0.001	0.0	-0.1	-0.1	-0.2	-0.3
Change from Existing [M06] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	90^{th} Percentile [4]	0%	7%	0%	0%	0%	0%	-1%	0%	-1%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%
	95^{th} Percentile [4]	0%	10%	0%	0%	0%	0%	-5%	0%	-1%	0%	0%	-4%	0%	-1%	0%	0%	0%	0%	0%	0%
	99^{th} Percentile [4]	0%	-5%	0%	1%	0%	0%	-1%	0%	-2%	0%	0%	-7%	0%	-2%	0%	0%	0%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90^{th}, 95^{th} and 99^{th} percentile values are given for TN, TP and TSS. For salinity the 10^{th}, 5^{th} and 1^{st} percentile values are given (respectively) to assess the impact of freshening.

Table 46: Tuflow model [M15] key statistics at observation points – local wet year (20 Oct – 20 Nov 1969) with infiltration, using D2 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M15] Model Summary (mg/L)	Median	27942	27442	27835	27264	27318	0.279	0.275	0.276	0.304	0.298	0.026	0.026	0.027	0.031	0.030	25.1	24.8	25.1	26.1	25.8
	Mean	27863	25199	27613	26174	25863	0.280	0.288	0.283	0.353	0.376	0.027	0.027	0.028	0.038	0.040	25.2	23.7	25.6	30.2	31.1
	90th Percentile [4]	27522	19304	26832	22251	22474	0.290	0.326	0.306	0.521	0.534	0.028	0.031	0.031	0.063	0.061	25.6	25.0	27.5	43.6	42.3
	95th Percentile [4]	27468	17695	26599	20721	19847	0.292	0.380	0.312	0.583	0.685	0.029	0.034	0.032	0.073	0.081	25.9	25.0	28.1	49.5	51.7
	99th Percentile [4]	27362	10215	25855	18197	7003	0.295	0.437	0.327	0.715	1.454	0.029	0.039	0.034	0.089	0.184	26.3	25.0	29.0	59.1	95.0
Change from Existing [M07] (mg/L)	Median	-10	-196	-23	-19	-14	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	Mean	-17	536	-54	6	-11	0.000	0.004	0.000	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.3	0.0	0.0	0.0
	90th Percentile [4]	-46	2071	-51	4	19	0.000	-0.006	-0.001	-0.008	-0.001	0.000	0.000	0.000	-0.002	0.000	-0.1	0.0	-0.1	0.0	-0.1
	95th Percentile [4]	-26	3034	-119	95	-18	0.000	-0.023	-0.001	-0.010	0.002	0.000	-0.003	0.000	-0.001	0.000	-0.1	-0.6	-0.1	0.0	0.0
	99th Percentile [4]	9	773	-266	468	54	0.000	-0.019	-0.001	-0.026	-0.002	0.000	-0.004	0.000	-0.003	0.000	0.0	-1.3	-0.1	0.0	0.1
Change from Existing [M07] (%)	Median	0%	-1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	2%	0%	0%	0%	0%	1%	0%	-1%	0%	0%	1%	0%	-1%	0%	0%	-1%	0%	0%	0%
	90th Percentile [4]	0%	12%	0%	0%	0%	0%	-2%	0%	-2%	0%	0%	-2%	0%	-2%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	21%	0%	0%	0%	0%	-6%	0%	-2%	0%	0%	-7%	0%	-1%	0%	0%	-2%	0%	0%	0%
	99th Percentile [4]	0%	8%	-1%	3%	1%	0%	-4%	0%	-3%	0%	0%	-10%	0%	-4%	0%	0%	-5%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 47: Tuflow model [M16] key statistics at observation points – local wet year (20 Oct – 20 Nov 1969) with infiltration, using D3 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M16] Model Summary (mg/L)	Median	28017	28005	28042	28012	28013	0.273	0.273	0.272	0.274	0.273	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	27977	27883	28013	27876	27802	0.275	0.274	0.273	0.281	0.285	0.027	0.026	0.026	0.027	0.028	25.1	25.0	25.1	25.6	25.9
	90th Percentile [4]	27818	27741	27924	27563	27484	0.282	0.277	0.278	0.295	0.295	0.027	0.027	0.027	0.029	0.029	25.3	25.2	25.4	26.6	26.7
	95th Percentile [4]	27739	27273	27824	27178	26990	0.286	0.281	0.281	0.325	0.321	0.028	0.027	0.027	0.033	0.033	25.5	25.4	25.8	28.0	28.9
	99th Percentile [4]	27599	25011	27535	25857	24445	0.292	0.308	0.292	0.413	0.488	0.028	0.029	0.029	0.045	0.054	25.7	25.5	26.7	33.0	42.1
Change from Existing [M08] (mg/L)	Median	1	6	-1	1	-2	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-1	94	0	4	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	-7	352	10	14	5	0.000	-0.001	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.1	0.0	0.0	0.0
	95th Percentile [4]	-7	833	-2	12	-12	0.000	-0.001	0.000	-0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	-0.1
	99th Percentile [4]	0	-429	0	58	-46	0.000	0.000	-0.001	-0.002	-0.005	0.000	-0.001	0.000	0.000	0.000	0.0	0.0	0.0	-0.1	-0.1
Change from Existing [M08] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	-2%	0%	0%	0%	0%	0%	0%	-1%	-1%	0%	-2%	0%	0%	0%	0%	0%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 48: Tuflow model [M17] key statistics at observation points – average year (1967) without infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M17] Model Summary (mg/L)	Median	25337	26046	26290	26064	26120	0.279	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.2	25.1	25.1	25.2	25.1
	Mean	23697	23954	24070	23977	23974	0.307	0.287	0.280	0.290	0.288	0.034	0.029	0.028	0.030	0.029	26.2	25.4	25.3	25.8	25.7
	90th Percentile [3]	12456	11051	11541	12353	12190	0.373	0.314	0.299	0.322	0.315	0.046	0.035	0.032	0.037	0.035	27.4	26.1	25.8	26.5	26.2
	95th Percentile [3]	7339	5938	5682	6186	6008	0.473	0.347	0.316	0.347	0.336	0.069	0.044	0.037	0.046	0.043	30.7	27.3	26.4	27.9	27.5
	99th Percentile [3]	3211	2568	2379	2682	2567	0.700	0.503	0.396	0.536	0.511	0.135	0.066	0.055	0.080	0.076	41.9	30.0	30.6	38.3	35.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 49: Tuflow model [M18] key statistics at observation points – average year (1967) without infiltration, using D2 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M18] Model Summary (mg/L)	Median	24469	25003	25784	25268	25392	0.287	0.282	0.277	0.288	0.285	0.030	0.029	0.028	0.029	0.029	26.0	25.5	25.3	25.7	25.6
	Mean	23164	23511	23933	23669	23680	0.350	0.313	0.294	0.317	0.314	0.044	0.035	0.031	0.036	0.035	27.7	26.2	25.9	26.9	26.8
	90th Percentile [3]	12312	12317	12273	13548	13394	0.519	0.402	0.340	0.404	0.390	0.077	0.055	0.042	0.056	0.054	31.3	28.7	27.2	29.5	29.0
	95th Percentile [3]	8921	6834	6788	7951	7739	0.709	0.469	0.376	0.438	0.425	0.124	0.072	0.051	0.066	0.062	38.8	31.2	28.7	31.7	31.1
	99th Percentile [3]	4359	3259	3165	4059	3932	0.979	0.635	0.498	0.744	0.732	0.205	0.090	0.076	0.115	0.111	53.6	34.8	35.1	49.6	47.5

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 50: Tuflow model [M19] key statistics at observation points – average year (1967) without infiltration, using D3 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M19] Model Summary (mg/L)	Median	26317	26598	26653	26601	26608	0.273	0.272	0.271	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	24032	24086	24112	24101	24084	0.280	0.276	0.274	0.275	0.275	0.028	0.027	0.027	0.027	0.027	25.3	25.2	25.1	25.2	25.2
	90th Percentile [3]	11471	10381	10741	11006	10549	0.287	0.279	0.275	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.3	25.2	25.1	25.2	25.2
	95th Percentile [3]	5489	5285	5059	5141	5115	0.302	0.289	0.282	0.286	0.285	0.032	0.030	0.028	0.029	0.029	25.9	25.4	25.3	25.6	25.5
	99th Percentile [3]	2266	2075	1966	1983	1981	0.448	0.378	0.340	0.355	0.349	0.076	0.054	0.045	0.048	0.048	32.6	28.7	28.0	28.5	28.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 51: Tuflow model [M20] key statistics at observation points – dry year (1968) without infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M20] Model Summary (mg/L)	Median	28816	29137	29058	28895	28822	0.271	0.271	0.270	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.0	25.0	25.0	25.0	25.0
	Mean	26510	26478	26490	26535	26520	0.274	0.271	0.271	0.272	0.272	0.027	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.1	25.1
	90th Percentile [3]	14740	14234	14069	14355	14261	0.280	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.3	25.1	25.1	25.2	25.2
	95th Percentile [3]	12367	11869	11810	12208	12107	0.285	0.275	0.273	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.4	25.2	25.1	25.5	25.3
	99th Percentile [3]	5554	4454	3994	4631	4554	0.298	0.283	0.280	0.305	0.294	0.031	0.028	0.028	0.031	0.030	26.3	25.3	25.6	27.2	26.4

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 52: Tuflow model [M21] key statistics at observation points – wet year (1969) without infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M21] Model Summary (mg/L)	Median	20198	20724	20719	20642	20651	0.308	0.289	0.283	0.297	0.293	0.032	0.029	0.028	0.030	0.029	25.8	25.3	25.3	25.6	25.5
	Mean	18775	19397	19509	19281	19287	0.345	0.300	0.290	0.308	0.304	0.038	0.031	0.029	0.032	0.031	27.0	25.7	25.6	26.3	26.2
	90th Percentile [3]	4719	3528	3482	3767	3625	0.467	0.342	0.317	0.347	0.339	0.057	0.037	0.033	0.038	0.037	30.4	26.9	26.4	27.4	27.1
	95th Percentile [3]	2909	2307	2165	2425	2343	0.539	0.365	0.333	0.375	0.364	0.068	0.041	0.036	0.043	0.041	33.3	27.6	27.1	29.6	28.7
	99th Percentile [3]	1828	1187	1078	1270	1200	0.687	0.432	0.367	0.491	0.479	0.093	0.050	0.042	0.060	0.057	38.8	29.2	29.4	39.6	38.0

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 53: Tuflow model [M22] key statistics at observation points – local wet month (20 Oct – 20 Nov 1969) without infiltration, using D1 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M22] Model Summary (mg/L)	Median	27917	27926	27981	27814	27831	0.278	0.274	0.274	0.284	0.280	0.027	0.026	0.026	0.028	0.027	25.1	25.0	25.1	25.4	25.2
	Mean	27895	26736	27866	27199	27055	0.279	0.284	0.278	0.314	0.322	0.027	0.027	0.027	0.032	0.033	25.2	24.8	25.4	27.9	28.1
	90th Percentile [3]	27703	23750	27502	25436	25648	0.287	0.309	0.291	0.402	0.391	0.028	0.030	0.029	0.045	0.042	25.6	25.0	26.6	35.0	33.1
	95th Percentile [3]	27645	21763	27321	24628	23897	0.290	0.337	0.295	0.445	0.490	0.028	0.032	0.029	0.051	0.054	25.8	25.4	26.8	38.5	38.6
	99th Percentile [3]	27541	18858	26818	21984	15402	0.294	0.380	0.309	0.580	1.030	0.029	0.036	0.031	0.071	0.124	26.0	25.7	27.6	48.4	63.0

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 54: Tuflow model [M23] key statistics at observation points – local wet month (20 Oct – 20 Nov 1969) without infiltration, using D2 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M23] Model Summary (mg/L)	Median	27953	27583	27859	27296	27318	0.279	0.276	0.277	0.306	0.299	0.027	0.027	0.027	0.031	0.030	25.1	24.9	25.2	26.2	25.9
	Mean	27880	24657	27667	26176	25878	0.280	0.304	0.284	0.359	0.377	0.027	0.029	0.028	0.038	0.040	25.3	24.3	25.7	30.3	31.1
	90th Percentile [3]	27567	17251	26887	22211	22547	0.290	0.372	0.309	0.541	0.537	0.028	0.035	0.031	0.066	0.061	25.7	25.0	27.6	43.7	42.3
	95th Percentile [3]	27494	14561	26722	20651	19786	0.293	0.434	0.315	0.609	0.686	0.029	0.040	0.032	0.076	0.081	26.0	26.5	28.2	49.6	51.8
	99th Percentile [3]	27353	9473	26125	17716	6975	0.296	0.533	0.330	0.746	1.454	0.029	0.049	0.034	0.097	0.183	26.4	27.3	29.1	59.1	95.0

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 55: Tuflow model [M24] key statistics at observation points – local wet month (20 Oct – 20 Nov 1969) without infiltration, using D3 dispersion coefficients for pre development.

		Pollutant																			
		Salinity					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [1]																			
Statistic		Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5	Obs1	Avg2 [2]	Obs3	Obs4	Obs5
[M24] Model Summary (mg/L)	Median	28016	27997	28043	28011	28013	0.273	0.273	0.272	0.274	0.273	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	27978	27784	28013	27870	27802	0.275	0.275	0.273	0.281	0.285	0.027	0.026	0.026	0.027	0.028	25.1	25.0	25.2	25.6	25.9
	90th Percentile [3]	27824	27307	27913	27551	27474	0.282	0.279	0.278	0.296	0.296	0.027	0.027	0.027	0.029	0.029	25.3	25.1	25.4	26.6	26.7
	95th Percentile [3]	27745	26430	27824	27155	27007	0.286	0.285	0.281	0.326	0.322	0.028	0.028	0.027	0.033	0.033	25.5	25.4	25.8	28.0	28.9
	99th Percentile [3]	27600	25466	27538	25741	24453	0.292	0.315	0.292	0.415	0.488	0.028	0.030	0.029	0.045	0.054	25.7	25.6	26.7	33.0	42.0

Notes

1. Observation points given in Attachment A PS01-AZ06.
2. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
3. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 56: Tuflow model [M25] key statistics at observation points – average year (1967) without infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M25] Model Summary (mg/L)	Median	25333	25954	26274	26060	26118	0.279	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.2	25.1	25.1	25.2	25.1
	Mean	23697	23927	24062	23979	23973	0.307	0.289	0.280	0.290	0.288	0.034	0.030	0.028	0.030	0.029	26.1	25.4	25.3	25.8	25.7
	90th Percentile [4]	12454	11233	11518	12353	12191	0.372	0.316	0.299	0.323	0.315	0.046	0.035	0.032	0.037	0.035	27.4	26.0	25.8	26.5	26.3
	95th Percentile [4]	7350	5963	5669	6191	6018	0.472	0.349	0.316	0.347	0.336	0.069	0.044	0.037	0.046	0.043	30.7	27.2	26.4	27.9	27.5
	99th Percentile [4]	3211	2609	2378	2679	2564	0.698	0.538	0.396	0.534	0.510	0.135	0.072	0.055	0.080	0.075	41.7	29.0	30.5	38.0	35.3
Change from Existing [M17] (mg/L)	Median	-5	-92	-16	-4	-2	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	0	-27	-8	2	0	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	-3	182	-22	1	0	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	12	25	-12	5	10	-0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	99th Percentile [4]	-1	41	-1	-3	-2	-0.001	0.036	0.000	-0.002	-0.001	-0.001	0.006	0.000	0.000	0.000	-0.2	-0.9	-0.1	-0.3	-0.1
Change from Existing [M17] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	2%	0%	0%	0%	0%	7%	0%	0%	0%	0%	9%	0%	0%	0%	0%	-3%	0%	-1%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 57: Tuflow model [M26] key statistics at observation points – average year (1967) without infiltration, using D2 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M26] Model Summary (mg/L)	Median	24475	24903	25767	25258	25387	0.287	0.285	0.278	0.288	0.285	0.030	0.029	0.028	0.029	0.029	26.0	25.5	25.3	25.7	25.6
	Mean	23163	23445	23921	23666	23677	0.350	0.318	0.294	0.317	0.314	0.044	0.036	0.031	0.036	0.035	27.7	26.1	25.9	26.9	26.8
	90th Percentile [4]	12339	12333	12251	13547	13394	0.519	0.404	0.340	0.405	0.391	0.077	0.055	0.042	0.057	0.054	31.3	28.3	27.2	29.5	29.0
	95th Percentile [4]	8914	6797	6765	7961	7731	0.708	0.478	0.377	0.438	0.424	0.124	0.073	0.051	0.066	0.062	38.7	30.6	28.6	31.6	31.1
	99th Percentile [4]	4351	3294	3163	4055	3931	0.978	0.706	0.498	0.733	0.730	0.204	0.098	0.077	0.115	0.111	53.5	33.6	34.8	49.3	47.3
Change from Existing [M18] (mg/L)	Median	6	-100	-17	-10	-5	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-1	-66	-12	-3	-3	0.000	0.005	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
	90th Percentile [4]	28	16	-22	-1	0	0.000	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.4	0.0	0.0	0.0
	95th Percentile [4]	-7	-37	-23	10	-8	0.000	0.009	0.001	0.000	-0.001	0.000	0.002	0.000	0.000	0.000	-0.1	-0.6	0.0	-0.1	0.0
	99th Percentile [4]	-8	35	-1	-4	-1	-0.001	0.071	0.000	-0.011	-0.002	-0.001	0.008	0.000	-0.001	0.000	-0.1	-1.2	-0.3	-0.3	-0.2
Change from Existing [M18] (%)	Median	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	1%	0%	0%	-1%	0%	0%	0%
	95th Percentile [4]	0%	-1%	0%	0%	0%	0%	2%	0%	0%	0%	0%	2%	0%	0%	0%	0%	-2%	0%	0%	0%
	99th Percentile [4]	0%	1%	0%	0%	0%	0%	11%	0%	-1%	0%	0%	9%	0%	-1%	0%	0%	-4%	-1%	-1%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 58: Tuflow model [M27] key statistics at observation points – average year (1967) without infiltration, using D3 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M27] Model Summary (mg/L)	Median	26315	26594	26651	26600	26607	0.273	0.272	0.271	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	24032	24089	24110	24101	24084	0.280	0.276	0.274	0.275	0.275	0.028	0.027	0.027	0.027	0.027	25.3	25.2	25.1	25.2	25.2
	90th Percentile [4]	11474	10393	10736	11031	10550	0.287	0.279	0.275	0.277	0.277	0.028	0.027	0.027	0.027	0.027	25.3	25.2	25.1	25.3	25.2
	95th Percentile [4]	5490	5305	5060	5141	5114	0.302	0.290	0.282	0.286	0.285	0.032	0.030	0.028	0.029	0.029	25.9	25.4	25.3	25.6	25.5
	99th Percentile [4]	2265	2112	1966	1982	1981	0.449	0.387	0.340	0.354	0.350	0.076	0.055	0.044	0.048	0.047	32.6	28.9	28.0	28.5	28.4
Change from Existing [M19] (mg/L)	Median	-2	-4	-2	-2	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	0	3	-2	0	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	3	12	-5	24	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	1	20	1	0	-1	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	99th Percentile [4]	-1	37	-1	0	0	0.001	0.009	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.0	0.2	0.0	0.0	0.0
Change from Existing [M19] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	2%	0%	0%	0%	0%	2%	0%	0%	0%	0%	2%	0%	0%	0%	0%	1%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 59: Tuflow model [M28] key statistics at observation points – dry year (1968) without infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M28] Model Summary (mg/L)	Median	28815	29134	29057	28889	28824	0.271	0.271	0.270	0.271	0.271	0.026	0.026	0.026	0.026	0.026	25.0	25.0	25.0	25.0	25.0
	Mean	26510	26468	26488	26535	26519	0.274	0.272	0.271	0.273	0.272	0.027	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.1	25.1
	90th Percentile [4]	14739	14230	14069	14355	14260	0.280	0.274	0.273	0.275	0.274	0.027	0.027	0.026	0.027	0.027	25.3	25.1	25.1	25.2	25.2
	95th Percentile [4]	12366	11868	11809	12206	12106	0.285	0.275	0.273	0.277	0.276	0.028	0.027	0.027	0.027	0.027	25.4	25.2	25.1	25.5	25.3
	99th Percentile [4]	5553	4445	3996	4645	4557	0.298	0.295	0.280	0.306	0.294	0.031	0.030	0.028	0.031	0.030	26.3	25.3	25.6	27.1	26.4
Change from Existing [M20] (mg/L)	Median	0	-3	0	-6	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	0	-10	-2	0	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	-2	-3	0	0	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	-1	-2	-1	-1	-1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	99th Percentile [4]	0	-9	2	14	2	0.000	0.012	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.0	0.0	0.0	-0.1	0.0
Change from Existing [M20] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 60: Tuflow model [M29] key statistics at observation points – wet year (1969) without infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M29] Model Summary (mg/L)	Median	20196	20655	20712	20641	20651	0.309	0.290	0.283	0.297	0.293	0.032	0.029	0.028	0.030	0.029	25.8	25.3	25.3	25.6	25.5
	Mean	18774	19384	19503	19282	19287	0.345	0.303	0.290	0.307	0.304	0.038	0.031	0.029	0.032	0.031	27.0	25.7	25.6	26.3	26.2
	90th Percentile [4]	4719	3540	3491	3766	3623	0.468	0.346	0.317	0.347	0.339	0.057	0.038	0.033	0.038	0.037	30.4	26.9	26.4	27.4	27.1
	95th Percentile [4]	2908	2367	2164	2426	2338	0.539	0.370	0.333	0.375	0.364	0.068	0.042	0.036	0.043	0.041	33.2	27.7	27.0	29.5	28.7
	99th Percentile [4]	1831	1181	1076	1270	1209	0.687	0.461	0.366	0.490	0.479	0.093	0.055	0.042	0.059	0.057	38.7	29.4	29.3	39.6	38.0
Change from Existing [M21] (mg/L)	Median	-2	-69	-7	-1	-1	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-1	-13	-7	0	0	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	0	11	9	-1	-2	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	-1	61	-1	1	-5	0.000	0.004	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.0	0.0	0.0	-0.1	0.0
	99th Percentile [4]	3	-6	-2	0	9	0.000	0.029	0.000	-0.002	0.000	0.000	0.005	0.000	-0.001	0.000	-0.1	0.2	0.0	0.0	-0.1
Change from Existing [M21] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	3%	0%	0%	0%	0%	1%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	0%	0%	0%	1%	0%	7%	0%	0%	0%	0%	10%	0%	-1%	0%	0%	1%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 61: Tuflow model [M30] key statistics at observation points – local wet year (20 Oct – 20 Nov 1969) without infiltration, using D1 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M30] Model Summary (mg/L)	Median	27918	27889	27965	27813	27823	0.278	0.275	0.274	0.284	0.280	0.027	0.026	0.026	0.028	0.027	25.1	25.0	25.1	25.4	25.2
	Mean	27892	27095	27856	27202	27054	0.279	0.288	0.278	0.313	0.322	0.027	0.028	0.027	0.032	0.033	25.2	24.8	25.4	27.8	28.1
	90th Percentile [4]	27702	25523	27483	25462	25599	0.287	0.318	0.291	0.400	0.391	0.028	0.032	0.029	0.045	0.043	25.6	25.0	26.6	34.8	33.0
	95th Percentile [4]	27622	24013	27283	24706	23850	0.290	0.341	0.295	0.442	0.491	0.028	0.034	0.029	0.051	0.054	25.8	25.0	26.8	38.4	38.6
	99th Percentile [4]	27497	17567	26756	22357	15424	0.294	0.388	0.309	0.576	1.030	0.029	0.037	0.031	0.069	0.124	25.9	25.3	27.5	48.6	63.0
Change from Existing [M22] (mg/L)	Median	1	-37	-16	-1	-8	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-3	359	-11	3	-1	0.000	0.004	0.000	-0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.0	0.1	0.0	0.0	0.0
	90th Percentile [4]	-1	1772	-18	26	-49	0.000	0.009	0.001	-0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.0	0.0	0.0	-0.1	0.0
	95th Percentile [4]	-23	2250	-38	78	-47	0.000	0.004	0.000	-0.003	0.001	0.000	0.002	0.000	0.000	0.000	0.0	-0.3	0.0	-0.1	0.0
	99th Percentile [4]	-44	-1291	-63	373	21	0.000	0.008	0.000	-0.004	0.000	0.000	0.001	0.000	-0.002	0.000	0.0	-0.4	-0.1	0.3	0.0
Change from Existing [M22] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	7%	0%	0%	0%	0%	3%	0%	-1%	0%	0%	7%	0%	-1%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	10%	0%	0%	0%	0%	1%	0%	-1%	0%	0%	6%	0%	-1%	0%	0%	-1%	0%	0%	0%
	99th Percentile [4]	0%	-7%	0%	2%	0%	0%	2%	0%	-1%	0%	0%	4%	0%	-2%	0%	0%	-2%	0%	1%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

Table 62: Tuflow model [M31] key statistics at observation points – local wet year (20 Oct – 20 Nov 1969) without infiltration, using D2 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M31] Model Summary (mg/L)	Median	27942	27419	27838	27284	27319	0.279	0.281	0.278	0.306	0.299	0.027	0.027	0.027	0.031	0.030	25.1	24.9	25.1	26.2	25.8
	Mean	27864	25199	27619	26181	25868	0.280	0.323	0.285	0.359	0.377	0.027	0.031	0.028	0.038	0.040	25.2	24.1	25.7	30.3	31.1
	90^{th} Percentile [4]	27524	19389	26822	22283	22452	0.291	0.426	0.310	0.540	0.535	0.028	0.043	0.032	0.065	0.061	25.6	25.0	27.5	43.8	42.3
	95^{th} Percentile [4]	27470	17780	26624	20707	19712	0.294	0.462	0.317	0.606	0.686	0.029	0.048	0.032	0.075	0.081	25.9	25.0	28.1	50.0	51.8
	99^{th} Percentile [4]	27364	10278	25793	18052	7018	0.297	0.521	0.331	0.726	1.452	0.029	0.052	0.035	0.092	0.183	26.3	25.0	29.1	59.6	94.9
Change from Existing [M23] (mg/L)	Median	-11	-164	-21	-12	1	0.000	0.005	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-16	542	-48	5	-10	0.000	0.019	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.0	-0.2	0.0	0.0	0.0
	90^{th} Percentile [4]	-43	2138	-65	72	-95	0.000	0.054	0.002	-0.001	-0.002	0.000	0.008	0.000	0.000	0.000	0.0	0.0	-0.1	0.2	0.0
	95^{th} Percentile [4]	-24	3219	-98	56	-74	0.001	0.028	0.002	-0.003	0.001	0.000	0.007	0.000	-0.001	0.000	0.0	-1.4	-0.1	0.4	0.0
	99^{th} Percentile [4]	11	805	-331	336	43	0.000	-0.012	0.001	-0.020	-0.002	0.000	0.003	0.000	-0.005	0.000	0.0	-2.3	0.0	0.6	-0.1
Change from Existing [M23] (%)	Median	0%	-1%	0%	0%	0%	0%	2%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	2%	0%	0%	0%	0%	6%	0%	0%	0%	0%	9%	0%	0%	0%	0%	-1%	0%	0%	0%
	90^{th} Percentile [4]	0%	12%	0%	0%	0%	0%	15%	1%	0%	0%	0%	22%	1%	0%	0%	0%	0%	0%	0%	0%
	95^{th} Percentile [4]	0%	22%	0%	0%	0%	0%	7%	1%	-1%	0%	0%	18%	0%	-1%	0%	0%	-5%	0%	1%	0%
	99^{th} Percentile [4]	0%	8%	-1%	2%	1%	0%	-2%	0%	-3%	0%	0%	7%	0%	-5%	0%	0%	-8%	0%	1%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90^{th}, 95^{th} and 99^{th} percentile values are given for TN, TP and TSS. For salinity the 10^{th}, 5^{th} and 1^{st} percentile values are given (respectively) to assess the impact of freshening.

Table 63: Tuflow model [M32] key statistics at observation points – local wet year (20 Oct – 20 Nov 1969) without infiltration, using D3 dispersion coefficients for post development.

		Pollutant																			
		Salinity [1]					Total Nitrogen (TN)					Total Phosphorous (TP)					Total Suspended Solids (TSS)				
		Observation Point [2]																			
Statistic		Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5	Obs1	Avg2 [3]	Obs3	Obs4	Obs5
[M32] Model Summary (mg/L)	Median	28017	28005	28041	28011	28012	0.273	0.273	0.272	0.274	0.273	0.026	0.026	0.026	0.026	0.026	25.1	25.0	25.0	25.0	25.0
	Mean	27977	27870	28014	27876	27803	0.275	0.275	0.273	0.281	0.285	0.027	0.027	0.026	0.027	0.028	25.1	25.0	25.1	25.6	25.9
	90th Percentile [4]	27818	27719	27924	27569	27482	0.282	0.281	0.278	0.295	0.295	0.027	0.027	0.027	0.029	0.029	25.3	25.2	25.4	26.6	26.7
	95th Percentile [4]	27739	27244	27825	27196	27018	0.286	0.283	0.281	0.325	0.321	0.028	0.028	0.027	0.033	0.033	25.5	25.4	25.8	28.0	28.9
	99th Percentile [4]	27599	24846	27552	25885	24457	0.292	0.317	0.292	0.415	0.488	0.028	0.030	0.029	0.045	0.054	25.7	25.5	26.7	33.0	42.0
Change from Existing [M24] (mg/L)	Median	1	8	-2	0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	Mean	-1	86	1	6	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	90th Percentile [4]	-7	412	11	18	9	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	95th Percentile [4]	-7	814	1	41	11	0.000	-0.002	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0
	99th Percentile [4]	0	-619	15	144	4	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	-0.1	0.0	0.0	0.0
Change from Existing [M24] (%)	Median	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Mean	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	90th Percentile [4]	0%	2%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
	95th Percentile [4]	0%	3%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%
	99th Percentile [4]	0%	-2%	0%	1%	0%	0%	1%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%

Notes

1. Negative changes for salinity represent a freshening effect due to a reduction in salinity concentration. Positive changes represent an increase in salinity concentration.
2. Observation points given in Attachment A PS01-AZ06.
3. The average concentrations at each time step at three points (Obs2.1, Obs2.2 and Obs2.3) are used to generate Avg2 statistics.
4. The 90th, 95th and 99th percentile values are given for TN, TP and TSS. For salinity the 10th, 5th and 1st percentile values are given (respectively) to assess the impact of freshening.

18 Attachment K: Tuflow Model Output Plots – With Infiltration

19 Attachment L: Tuflow Model Output Plots – Without Infiltration