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Emailed	X	Michael Barry
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Contact:		Daniel Dhiacou / Andrew Norris
Our Ref:		P1203365JC26V03
Pages:		38
cc.		John Toon, Robert Byrne, Christopher Ritchie

November 18, 2015

BMT WBM
Attn: Michael Barry
By Email

Dear Michael,

RE: ESTUARY HYDRODYNAMIC AND SOLUTE TRANSPORT MODEL CALIBRATION – WEST CULBURRA ESTUARINE MANAGEMENT STUDY (MP 09_0088)

1.0 INTRODUCTION

This document has been prepared to outline the additional calibration works undertaken for the estuary hydrodynamic and solute transport model ('estuary model') in support of the above Major Project application. Field data has been collected and used to update and further calibrate the previously established estuarine processes model at the site in consultation with BMT WBM. Ongoing correspondence with BMT WBM has been relied upon to further increase the quality of model calibration. We seek your comments to confirm the calibration model is now acceptable for development impact assessment modelling for MP 09_0088.

2.0 ESTUARINE PROCESSES MODEL CHANGES

2.1 Previous Studies

The previous Tuflow Classic Advection Dispersion (AD) model established at the site was used as the basis for further estuary model calibration. Details of the model setup and adopted parameters are provided in the 'Estuarine Management Study' ('EMS', P1203365JR02V03, August 2014).

Previously undertaken MUSIC water quality modelling was updated with rainfall and evaporation data over the simulation period to provide inputs to the estuarine model. Details of the water quality modelling methodology and results are provided in the 'Water Cycle Management Report' ('WCMR', P1203365JR01V05, August 2014).

2.2 Calibration Data

Recent Crookhaven River monitoring of tidal flows, water levels and salinity was used to further calibrate the Tuflow AD model. Details of the collection regime and data analysis are provided in the 'Final Summary of Crookhaven River Data Collection' (P1203365JC22V01, July 2015) and monitoring locations are summarised in Attachment A Figure 1. We note:

- The adopted NSW OEH conversion factor for electrical conductivity to salinity concentration (0.64) has been modified after receipt of lab testing data of site

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samples. The lab tested factor conversion factor at each monitoring location has been adopted for this assessment and range between 0.70 and 0.80.

- As noted in the 'Final Summary of Crookhaven River Data Collection', negative 'spikes' exist in the monitored salinity logger data at Location 3 Curleys Bay and are likely device recording errors. These 'spikes' have been removed to enable better representation of expected concentrations and allow comparison with modelled concentrations.

- Location 2 Billys Island salinity logger data:

  - Available local data (Aquadata website, 2015) suggests salinities near Billy's Island reduce to as low as 5 g/L following large rainfall events.

  - In mid-late April 2015 a large rainfall event caused Location 1 Culburra Road bridge monitored salinity to decrease significantly, and Shoalhaven River salinity was < 10 g/L for almost 2 weeks based on private data provided by Mr. Robert Thorne (and presented to the peer reviewer).

  - We expect that after this rainfall event and considering monitored concentrations upstream and downstream of Billys Island are significantly reduced, that Billys Island salinity will also be significantly impacted.

  - Observed concentrations over the monitoring period do not show this response to the mid-late April 2015 or other rainfall events, instead steadily declining over the 10.5 weeks. We conclude that this monitoring data does not fully represent salinity conditions in the wider Crookhaven River at this location, but rather represents specific localised conditions. This may be due to the CTD being located within a 'dead spot' which did not experience expected Crookhaven River tidal exchange. It is also possible that there may have been a degree of stratification: the CTD was installed close to the riverbed at -0.5 mAHD (to capture level data at very low tides) and may have monitored a denser saltwater wedge whilst a freshwater wedge on top went unmonitored.

  - The data is considered unlikely to represent wider Crookhaven River salinity at Billys Island, and has therefore been excluded from calibration analysis.

2.3 Calibrated Model Construction

2.3.1 Simulation Setup

The model was run for a period of 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 the calibration monitoring data set commencing 17 April, 2015.

2.3.2 Hydraulic Setup

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

1. 25m x 25m topographic/bathymetric grid based on topography data sourced from LIDAR (LPI, 2010) and bathymetric data (NSW OEH, 2012).

2. Establishment of model extents to provide an adequately large model domain as shown in Attachment A Figure 2:

   a. The downstream model extent was placed across the Crookhaven River between Greenwell Point and Orient Point, and coincided with the Manly Hydraulics Laboratory (MHL) Greenwell Point tidal monitoring gauge.

   b. The upstream model extent was placed at the tidal limit as shown in NSW OEH bathymetry maps (2012). 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. An area upstream and 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. Boundary conditions:

   a. Downstream boundary at Greenwell Point based on tidal water level data provided by MHL (2015) over the simulation period.

   b. Upstream flow boundaries based on hydrological and site sub-catchments consistent with water quality modelling (WCMR) as shown in Attachment A Figure 2.

      i. A total of 21 flow boundaries were utilised in foreshore areas to account for all upstream flow arriving at the Crookhaven River.

      ii. Rainfall and evapotranspiration data was sourced from Nowra RAN (station ID 068072). Monthly mean pan factors were utilised to convert evapotranspiration data for input to MUSIC based on McMahon, Peel, Lowe, Srikanthan and McVicar (date omitted), *Supplementary Material to paper Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: A pragmatic synthesis.*

      iii. Soil parameters of the four largest catchments (predominately flowing to upstream of Location 1 Culburra Road bridge) have been modified from the WCMR to increase the ratio of baseflow to stormflow to account for characteristics of these catchments, including multiple swamps and large areas of flat agricultural land which have been significantly modified and consist of multiple farm dams and rerouted drainage channels. Changes to modelling 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%. Total outflow volume from each catchment is the same as before, but inflows are delivered over an extended period to replicate expected prolonged delivery of baseflow.

      iv. We have researched gauge data within Crookhaven River to compare with input hydrographs but note this 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 and grid cells were at documented invert levels.

5. Assigning Manning's roughness coefficients based on SIX Maps Viewer (2014) and Nearmap (2012) aerials as shown in Table 1. We note that materials include foreshore areas where catchment runoff enters Crookhaven River.

6. Incorporation of the flood gate as a 1D element within the 2D domain with size and invert levels based on survey data provided by Allen Price & Scarratts (2015). A blockage of 90% was adopted based on the at-site debris potential and the range of blockages given by the procedure in Australian Rainfall & Runoff (AR&R 2013) *Project 11 – Blockage of Hydraulic Structures Stage 2 Report*.

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 properly modelled.

Table 1: 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

2.3.3 Advection Dispersion Setup

The following model construction was utilised 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.

2. Minimum dispersion coefficients of 25 m^2/s upstream of Location 2 Billys Island and 0 m^2/s downstream of this location.

3. Initial salinity concentrations of 5,000 – 35,000 mg/L based on spatially varying approximate salinity concentration averages in the estuary as shown in Attachment A Figure 2.

4. Stormflow salinity concentrations assigned as 100 mg/L during flow events as per discussions with BMT WBM (June 18, 2014).

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

2.3.4 Downstream Salinity Boundary Condition

The boundary condition was established as follows:

1. Daily salinity concentration data near the Greenwell Point model boundary provided by Mr. Robert Thorne (2015) and as summarised in a University of New South Wales Water Research Laboratory (UNSW WRL) Shoalhaven River salinity modelling report (2006) was compared to antecedent rainfall at three BOM 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 UNSW WRL's 1997/1998 monitoring data as presented in Attachment A Figure 3. The developed relationship was then used to estimate Greenwell Point salinity over the simulation period based on available rainfall and Tallowa Dam storage data. The estimated salinity over the simulation period is presented in Attachment A Figure 3 and was applied at the Greenwell Point boundary. Private data over this period provided by Mr. Robert Thorne had reasonable agreement to the developed relationship and has been presented to the peer reviewer.

3.0 CALIBRATION

3.1 Overview

Table 2 summarises parameters iteratively modified and optimised during calibration. Various combinations of the parameters within the given ranges were used, and almost 90 total simulations were run iteratively to achieve the adopted 'best case' calibration. The combination of parameters summarised in Section 2.3 and in the adopted values in Table 2 provided the best hydrodynamic and advection dispersion calibration to the monitoring data as discussed in the following sections.

Table 2: 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	Straight / rotated	Straight [2]
Crookhaven River invert specification	Manually specified / grid specified	Manually specified [3]
Model extents	Bathymetry extent / tidal limit / upstream of flood gate	Tidal limit and upstream of flood gate [4]
Flood gate	Exclusion / inclusion	Inclusion [5]
Flood gate blockage	0% – 90%	90% [6]
Mannings roughness coefficients	0.04 ≤ 0.1 m, 0.01 > 0.1m to 0.06 constant	0.04 ≤ 0.1 m, 0.03 > 0.1m [7]
Longitudinal/transverse dispersion coefficients	100/10 m^2/s to 10,000/1,000 m^2/s	5,000/500 m^2/s [8]
Factored hydrographs	12.5% to 100% of MUSIC output	50% of MUSIC output [9]
Upstream inflow salinity concentration	100 – 5,000 mg/L	100 mg/L [10]
Greenwell Point salinity parametrisation	Constant / synthetic	Synthetic [11] (see Section 2.3.4)
Initial salinity	Constant / spatially varying	Spatially varying [12]
Minimum dispersion	0 – 100 m^2/s, constant / spatially varying	0 – 25m^2/s, spatially varying [13]

Notes

1. Water level and salinity calibration for 17.5m x 17.5m grid is comparable to the 25m x 25m grid, while 50m x 50m grid provides marginally poorer overall calibration.
2. There were no appreciable differences using a rotated grid.
3. Manual z-line specification ensured grid cells were at Crookhaven River inverts and provided better tidal exchange calibration.
4. Enabled better simulation of tidal exchange and flood gate salinity effects.
5. Enabled intermittent freshwater inflow and better calibration to salinity at Location 1 Culburra Road bridge.
6. Provided best salinity calibration at Location 1 Culburra Road bridge.
7. Provided best tidal exchange calibration.
8. Provided best overall salinity calibration.
9. Provided best overall salinity calibration.
10. There were no appreciable differences to the shapes/patterns of salinity calibration.

11. Enabled better modelling of salinity dynamics. Various iterations of the synthetic salinity boundary were used before adoption of the relationship in Section 2.3.4 which provided the best overall salinity calibration.
12. Provided best overall salinity calibration.
13. Provided best overall salinity calibration.

3.2 Water Level Calibration Results

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 A Figure 4 to Figure 18. 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 3.

Correlation between observed and modelled temporal water levels shows excellent calibration ($R^2 > 0.965$) 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 at the downstream boundary are similarly well replicated by the model.

Table 3: Water level correlation between observed and modelled water levels at each location.

Location	Correlation Coefficient (R^2)
1. Culburra Road bridge (CTD data)	0.981
2. Billys Island (CTD data)	0.969
3. Curleys Bay (CTD data)	0.967
4. Goodnight Island (CTD data)	0.989
Greenwell Point (Manly Hydraulics data)	1.000

3.3 Flow Calibration Results

Tuflow modelled flows compared to ADCP measured flows during neap and spring tides at Greenwell Point (GP) and upstream adjacent to Billy's Island (US) are summarised in Attachment A Figure 19 and tidal exchange calibration is summarised in Table 4.

Results show excellent calibration at both locations for both monitored tides. The full range of tidal inflows and outflows is reproduced at Greenwell Point for both spring and neap flood and ebb tides, and modelled tidal volumes closely match monitored volumes. The modelled tidal prism at the US transect are overpredicted. We note that the ADCP report (Haskoning, 2015) 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 believe the US ADCP estimated tidal exchanges may have been 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 4: Tidal exchange calibration results for neap and spring ebb and flood tides at both ADCP monitored locations.

					Difference			
	Estimated ($m^3 \times 10^6$) [1]		Modelled ($m^3 \times 10^6$) [2]		($m^3 \times 10^6$)		(%)	
	Location		Location		Location		Location	
Tide	US	GP	US	GP	US	GP	US	GP
Neap – Flood	3.212	1.366	3.063	1.164	-0.149	-0.202	-5%	-15%
Neap – Ebb	2.360	0.587	2.460	0.982	0.100	0.395	4%	67%
Spring – Flood	5.033	1.788	4.882	1.819	-0.151	0.031	-3%	2%
Spring – Ebb	5.225	1.269	4.882	1.853	-0.343	0.584	-7%	46%

Notes

1. Estimated tidal exchange as provided in the ADCP report (Haskoning, 2015).
2. Tuflow modelled tidal exchange.

3.4 Salinity Calibration Results

Measured salinity concentrations over the 10.5 week monitoring period (Attachment A Figure 20) is compared to all modelled salinity concentrations in Attachment A Figure 21 and at each individual location in Attachment A Figure 22 to Figure 25. 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 the catchment will have a large amount of storage due to previously mentioned catchment characteristics including multiple swamps and large areas of flat 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 we believe is 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.
- 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 at monitoring locations. This may be due to three dimensional mixing

processes occurring in the estuary which are not incorporated in the TUFLOW classic calculations.

- Dispersion coefficients were increased above typical values (1,000/100 m^2/s) to compensate for potential 3D effects in order to achieve better salinity calibration.

- Higher longitudinal/transverse dispersion coefficients of up to 10,000/1,000 m^2/s and a minimum dispersion coefficient of up to 100 m^2/s were trialled, and whilst these gave closer salinity gradient calibration at Location 1, Location 3 salinity gradient calibration was worsened. Conversely, lower dispersion coefficients worsened Location 1 salinity gradient but made Location 3 salinity gradient better.

- Best overall calibration was achieved with longitudinal/transverse dispersion coefficients of 5,000/500 m^2/s and a 25 m^2/s minimum dispersion upstream of Billys Island. These values give a slightly overestimated salinity gradient at Location 1 (refer Attachment A Figure 22) and a slightly underestimated Location 3 salinity gradient (refer Attachment A Figure 24), which was considered the best balance for salinity gradient calibration of all iterations. Summary of monitored and modelled salinity amplitudes on the diurnal tide is provided in Table 5.

- The diurnal salinity amplitude and salinity gradient are slightly overestimated overall. We note that the UNSW WRL (2006) Shoalhaven River salinity modelling report had similar calibration results with salinity gradient and diurnal amplitude also overpredicted. We are yet to view an 'industry standard' calibration report which accurately replicates diurnal salinity gradient using Tuflow AD in a similar estuarine environment.

- We note that the high salinity gradient may indicate short-term mixing processes are not being replicated by the model which may be due to 3D effects. If this is the case and mixing is being underpredicted, then any additional pollutants being added to the estuary would be modelled as staying in the system for longer than in reality. This therefore represents a conservative approach for impact assessment, as any additional pollutants discharges from the development to the estuary would spend an overpredicted amount of time in the estuary before being flushed out.

Table 5: Comparison of monitored and modelled salinity amplitudes at all locations on diurnal tide.

	Approximate Salinity Amplitude on Diurnal Tide (g/L)	
Location	**Monitored – Attachment A Figure 20**	**Modelled – Attachment A Figure 21**
1. Culburra Road bridge [1]	0.5 – 5.0	0.5 – 10.0
2. Billys Island	NA [2]	0.5 – 5.0
3. Curleys Bay [1]	1.0 – 5.0	0.0 – 2.5
4. Goodnight Island	NA [3]	0.5 – 5.0

Notes

1. Ignores negative 'spikes' in the monitoring data as discussed in the 'Final Summary of Crookhaven River Data Collection' and modelled 'spikes' as discussed in this section.
2. Salinity logger data has been excluded from this analysis as discussed in Section 2.2.
3. Salinity logger data unavailable as discussed in the 'Final Summary of Crookhaven River Data Collection'.

The following description of results at each location is provided:

- o <u>Overall results at all locations</u> – Attachment A Figure 20 vs Figure 21

  - Modelled salinity concentrations at Locations 2, 3 and 4 are sensitive to the synthetic salinity boundary condition at Greenwell Point, whereas Location 1 salinity is less sensitive.

  - The model underestimates short-term mixing processes (reflected by the overpredicted salinity gradient / diurnal amplitude) but replicates broad scale long-term salinity trends (reflected by the generally well calibrated recovery timing and pattern of responses at all locations).

- o <u>Location 1 Culburra Road bridge</u> – Attachment A Figure 22

  - 67% of the total 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 from 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 salinity concentration has matching recovery timing and pattern to observed concentrations, although salinity levels are slightly underpredicted after the mid-late April 2015 rainfall event before recovery.

  - The predicted salinities are within the margin of error resulting from conversion from electrical conductivity to concentration (OEH factor vs. lab tested factors), and we therefore conclude that modelled salinity is within acceptable uncertainty bounds.

  - The modelled salinity gradient and amplitude of diurnal salinity variation is slightly overestimated, however as discussed previously we conclude this is acceptable as the dispersion values used provide the best overall salinity gradient calibration at all locations.

  - We note several negative 'spikes' in Location 1 modelled salinity concentration, which occurred for all model iterations with minimum dispersion. These 'spikes' are not aligned with periods of high rainfall and their presence does not have a logical explanation. However, use of minimum dispersion was necessary to calibrate salinity amplitudes, and we consider this benefit outweighs the presence of the 'spikes' introduced.

- o <u>Location 2 Billys Island</u> – Attachment A Figure 23

  - 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 concentrations upstream (at Location 1 Culburra Road bridge) and downstream (at Location 4 Goodnight Island and in private data provided by Mr. Robert Thorne).

- Location 3 Curleys Bay – Attachment A Figure 24
    - 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, however are slightly underpredicted.
- Location 4 Goodnight Island – Attachment A Figure 25
    - 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 private data provided by Mr. Robert Thorne for this period.
    - Location 4 salinity is controlled predominately by the adopted Greenwell Point boundary condition relationship.

4.0 SUMMARY AND RECOMMENDATIONS

The calibration of flows and water levels indicates estuarine hydrodynamics are very well represented within the model. Modelled salinities are also generally well represented and capture long-term broad scale mixing processes adequately. Overall, estuarine characteristics and dynamics are replicated by the model and agree well with monitored data.

The purpose for establishment of the model is to enable impact assessment for changed pollutant delivery to the estuary. We accept the model has limitations in its prediction of short-term mixing processes. However, we believe that the modelled underprediction of mixing will lead to conservative results when impact assessment is undertaken. As this is the purpose of the study, and considering the scale and nature of the development, we therefore consider that the Tuflow model is adequately calibrated in terms of hydrodynamics and advection dispersion for the purposes of progressing with the development impact assessment.

We propose to continue with modelling of the previously agreed scenarios using the calibrated model parameters, noting that impact assessment will likely yield conservative results.

We would appreciate your review and comments to confirm your agreement with the suitability of the model for impact assessment. Pending your comments, we will continue with Tuflow AD modelling and impact analysis.

If you have any queries, or believe there are other modelling issues which may require discussion, please do not hesitate to contact our offices.

For and on behalf of

MARTENS & ASSOCIATES PTY LTD

DANIEL DHIACOU
BEng (Hons1), DipEngPrac
Civil & Environmental Engineer

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Director/Project Manager

ATTACHMENT A – FIGURES

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Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	SURVEYED DATA COLLECTION LOCATIONS	Drawing No: FIGURE 1
Approved:	AN		
Date:	17.11.2015		
Scale:	As shown		Job No: P1203365

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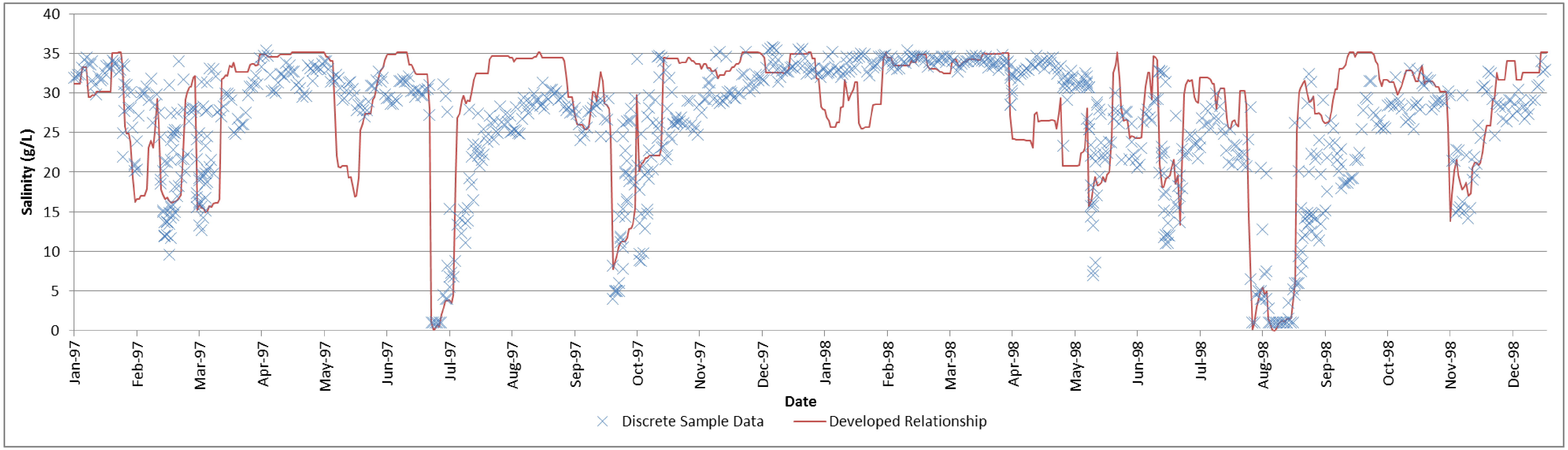
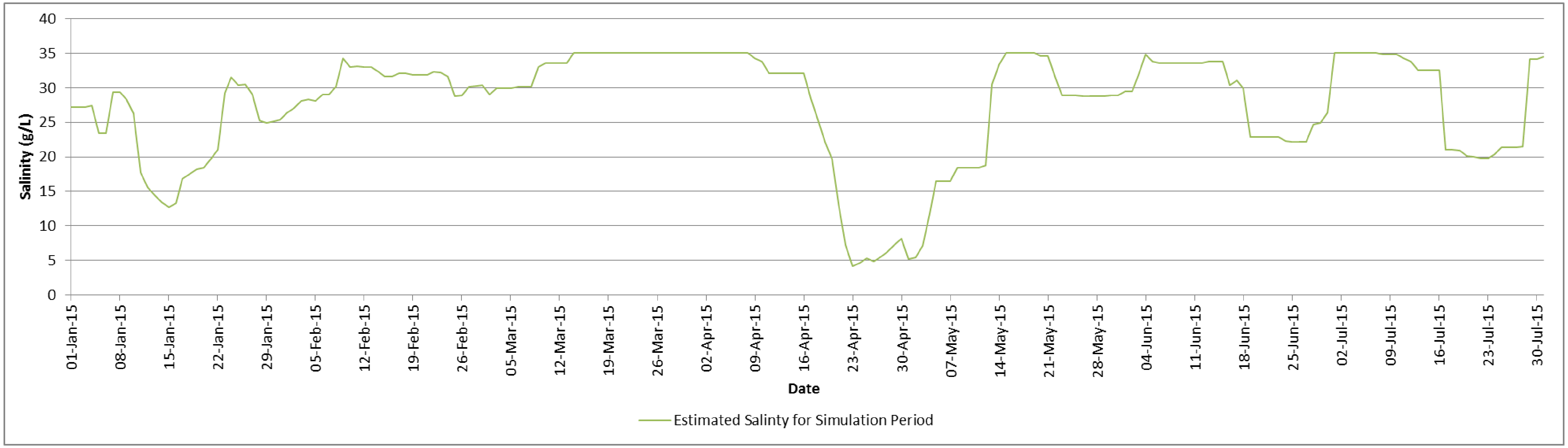
Martens & Associates Pty Ltd	ABN 85 070 240 890	Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**TUFLOW MODEL EXTENTS, BOUNDARY CONDITION LOCATIONS AND INITIAL SALINITY ZONES**	Drawing No: **FIGURE 2**
Approved:	AN		
Date:	17.11.2015		
Scale:	As shown		Job No: P1203365





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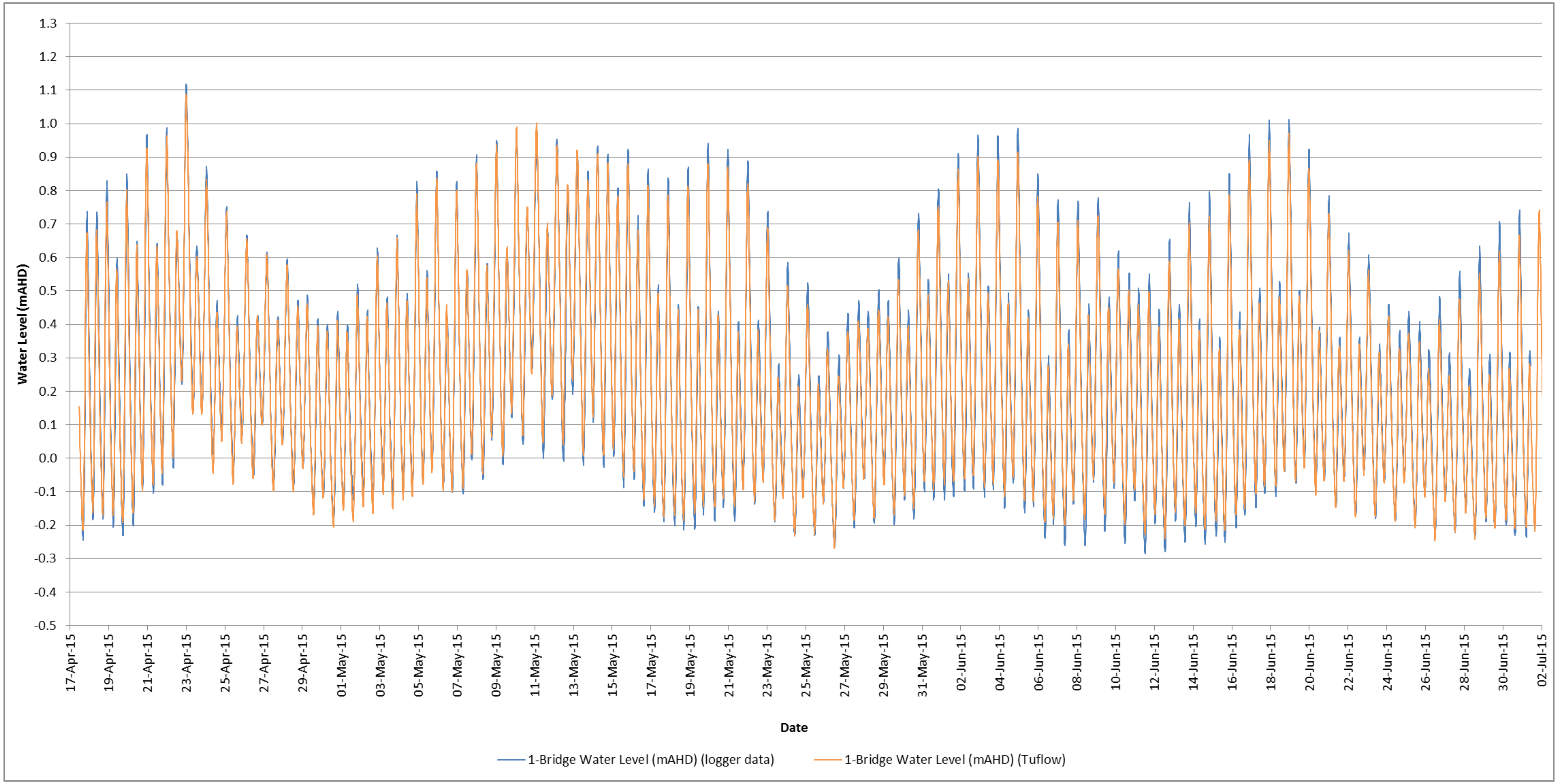
Drawn:	DD
Approved:	AN
Date:	17.11.2015
Scale:	NA

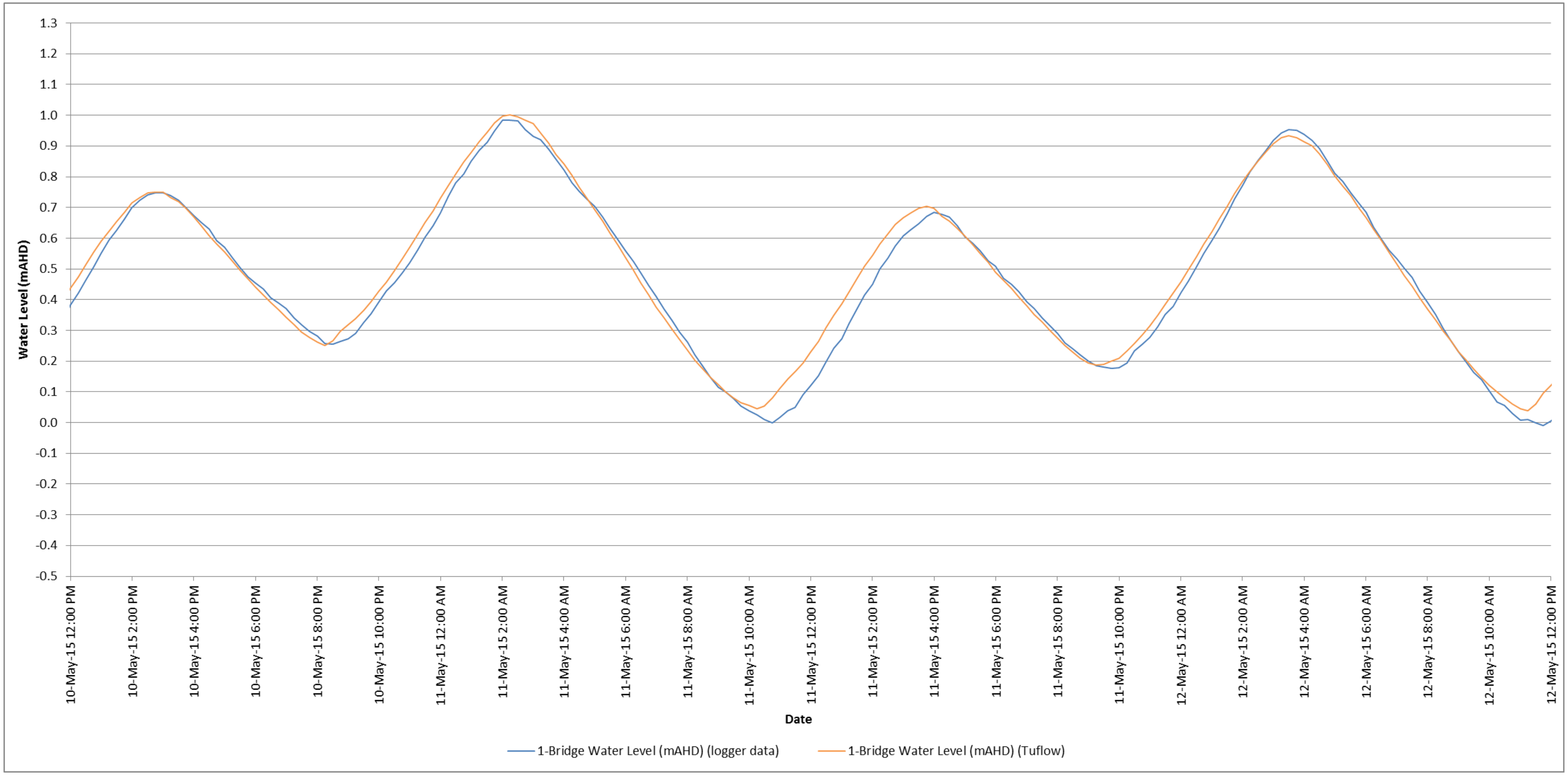
Environment | Water | Wastewater | Geotechnical | Civil | Management

SHOALHAVEN RIVER SYNTHETIC SALINITY BOUNDARY CONDITION
(TOP) DATA USED TO DEVELOP RELATIONSHIP
(BOTTOM) RELATIONSHIP DURING SIMULATION

Drawing No:
FIGURE 3
Job No: P1203365



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 4**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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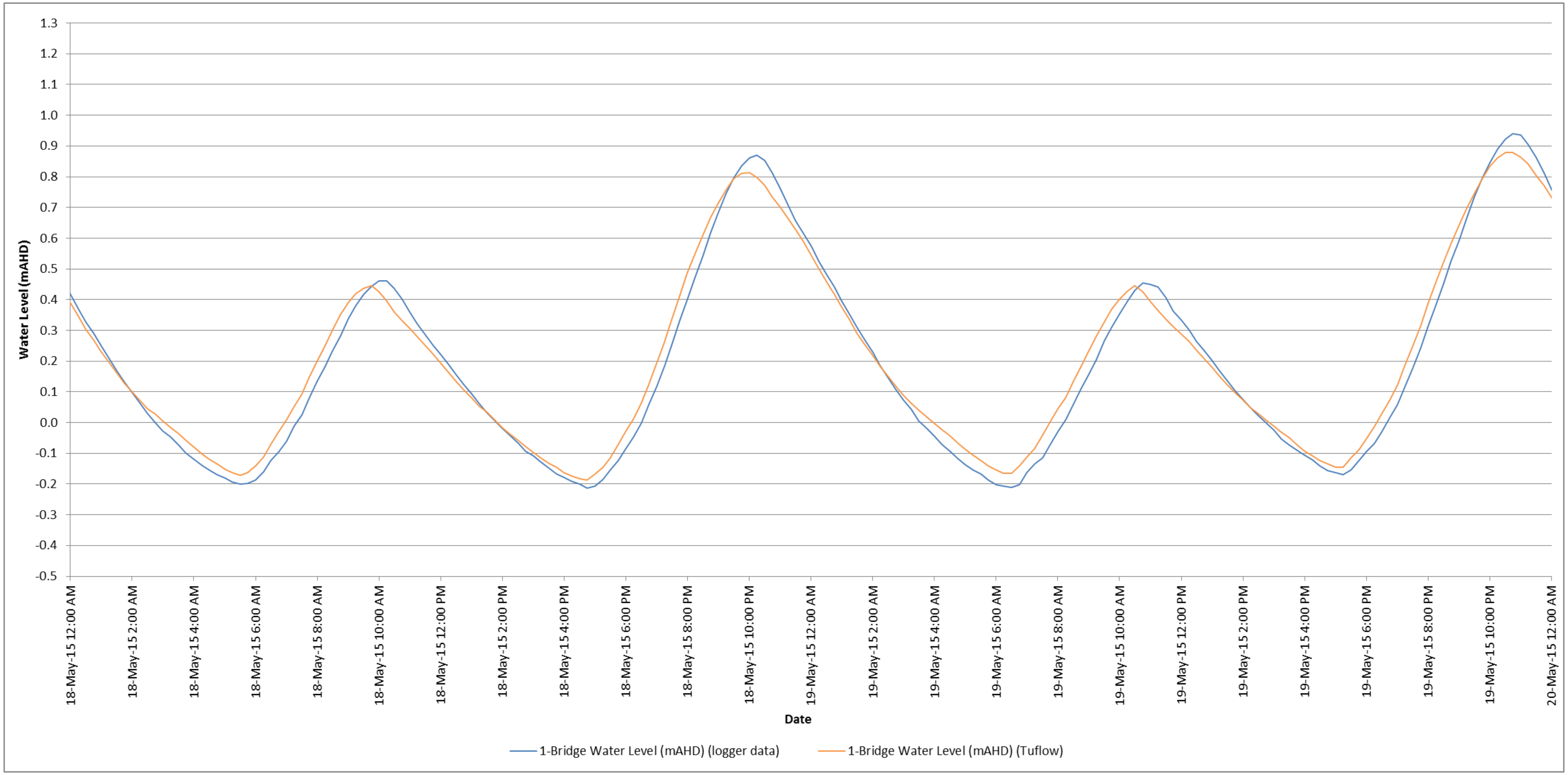
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 5**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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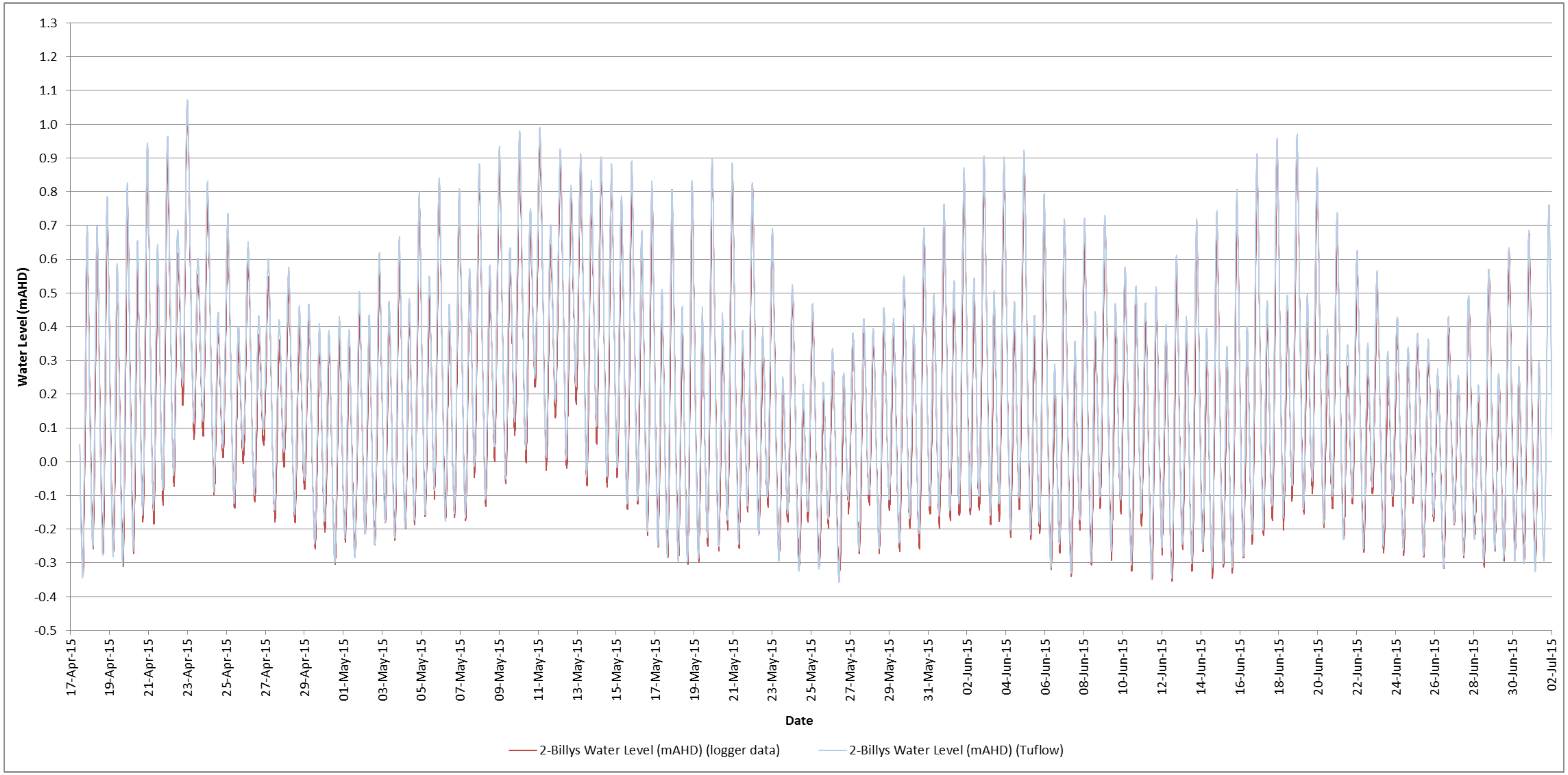
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 6**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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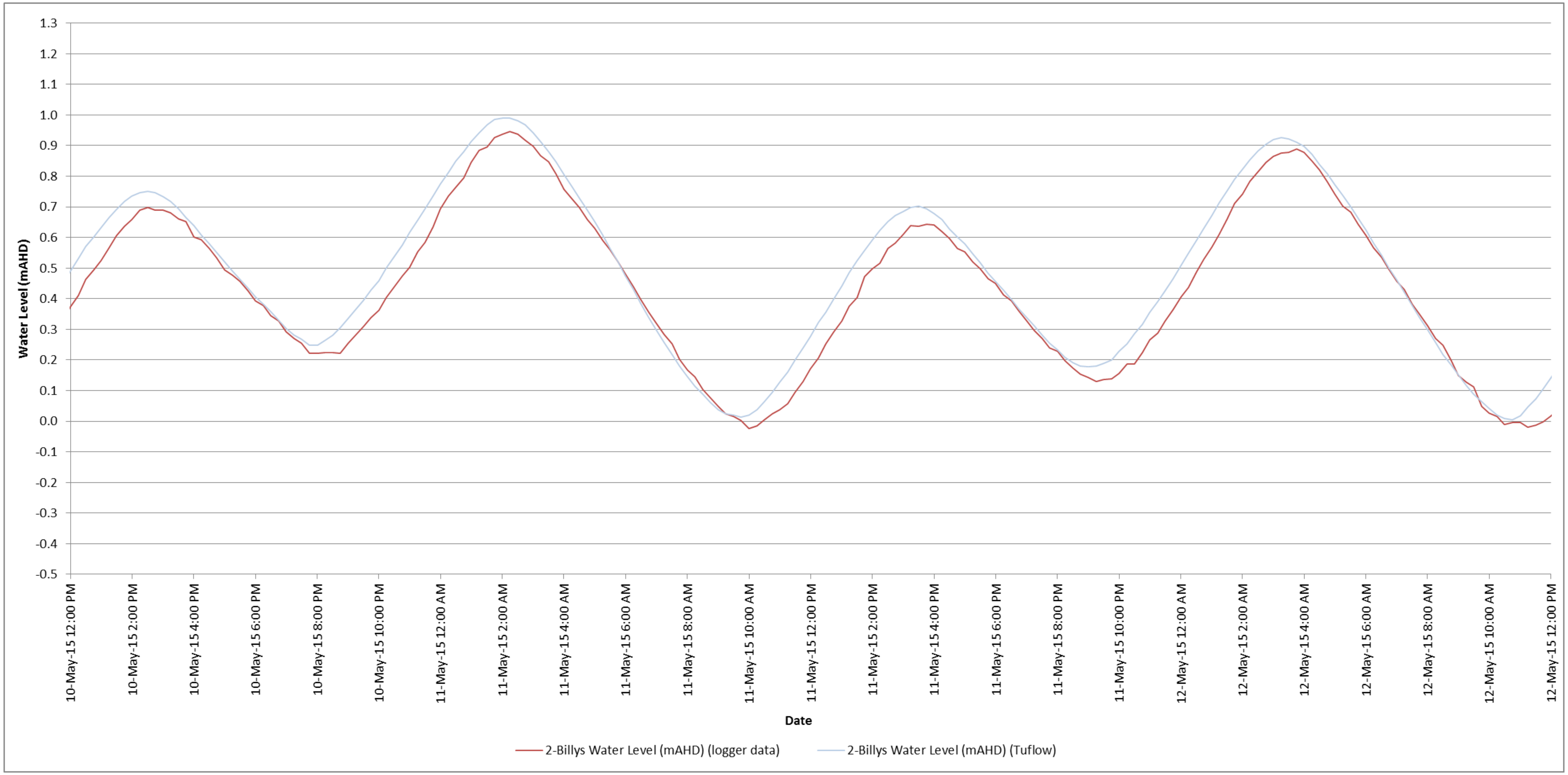
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 2 – BILLY'S ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 7**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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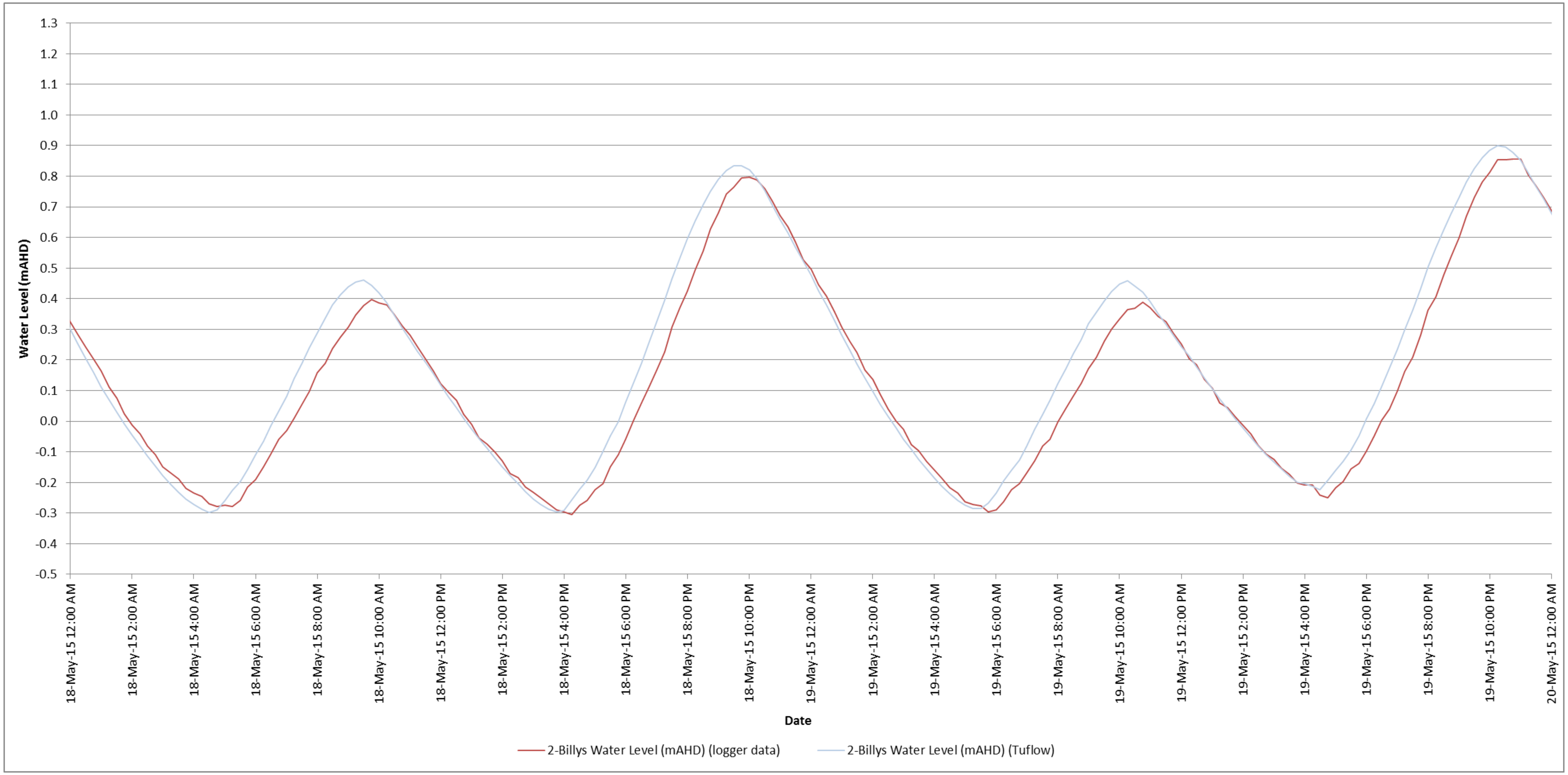
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE** **LOCATION 2 – BILLY'S ISLAND** **CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 8**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		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 – BILLY'S ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 9**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365

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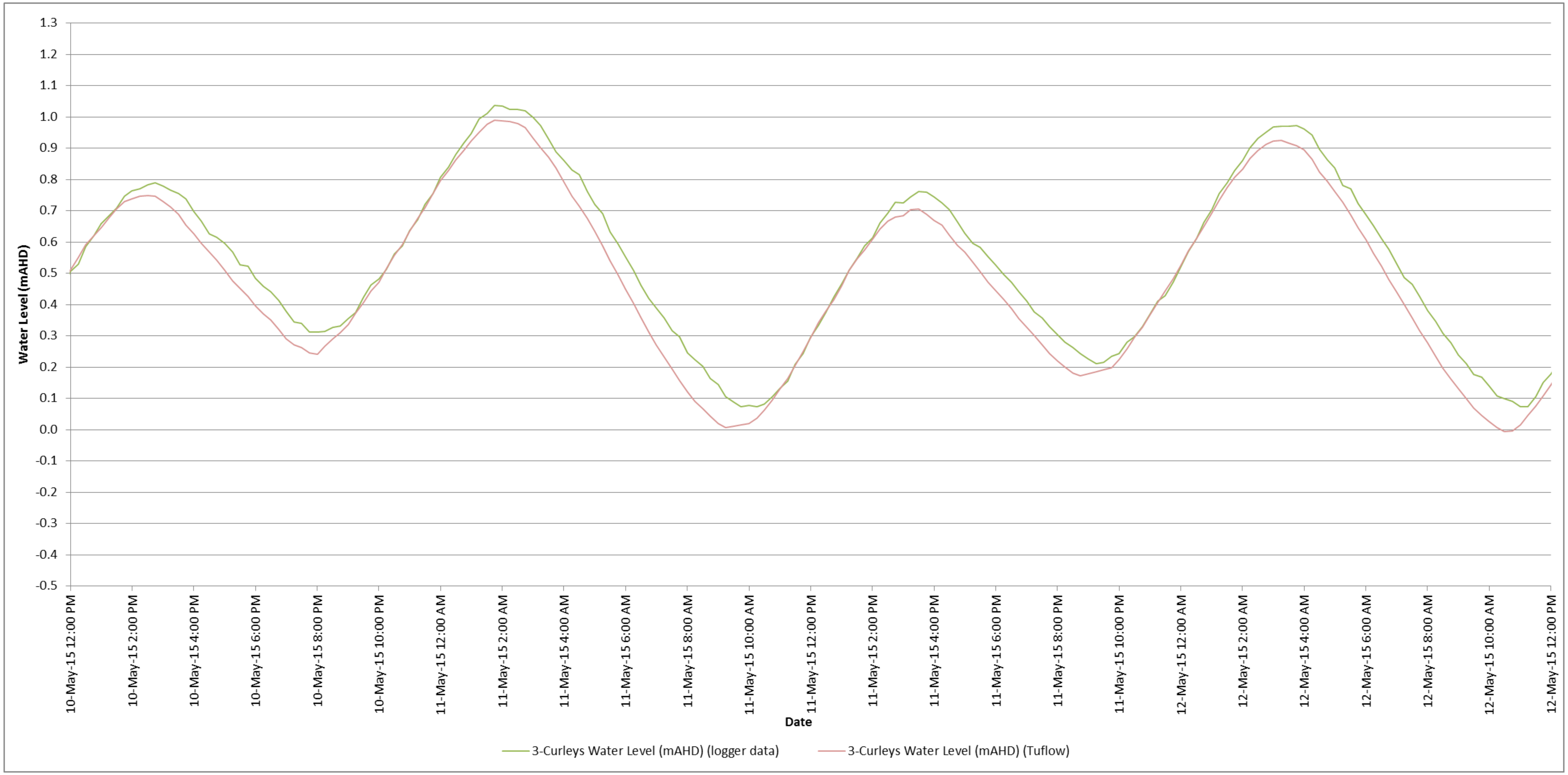
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 3 – CURLEY'S BAY CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 10**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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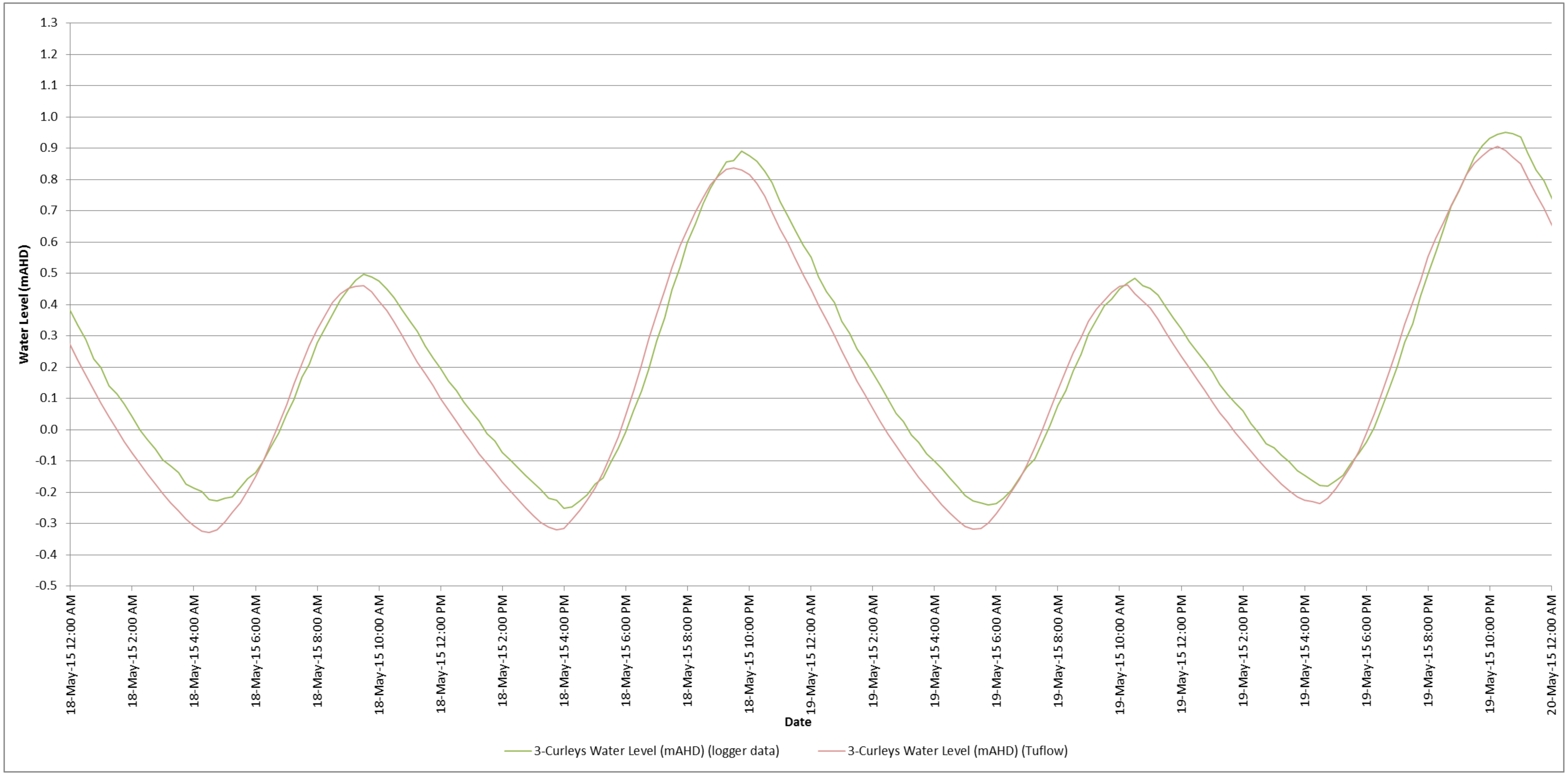
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – NEAP TIDE LOCATION 3 – CURLEY'S BAY CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 11**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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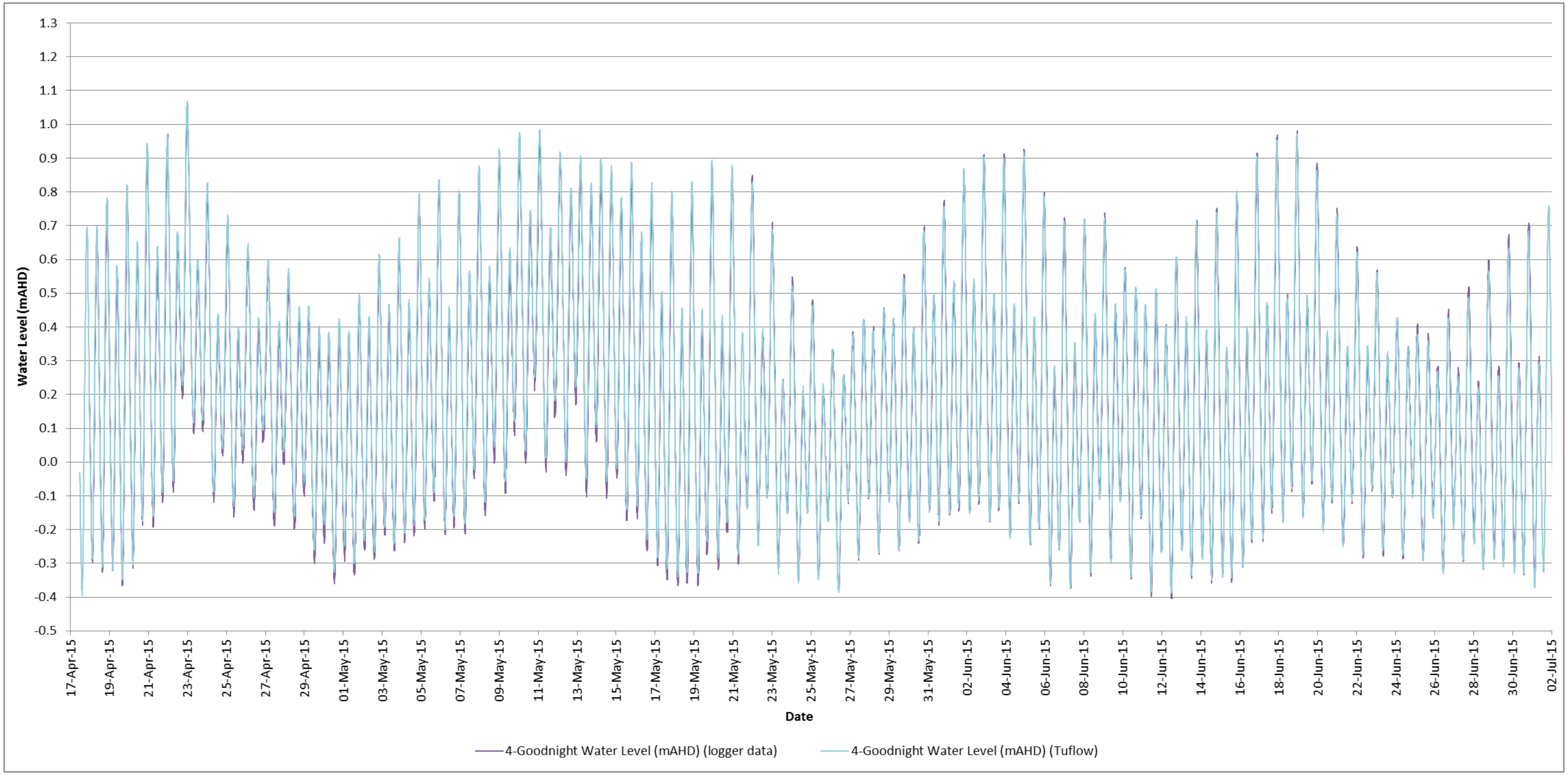
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 3 – CURLEY'S BAY CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 12**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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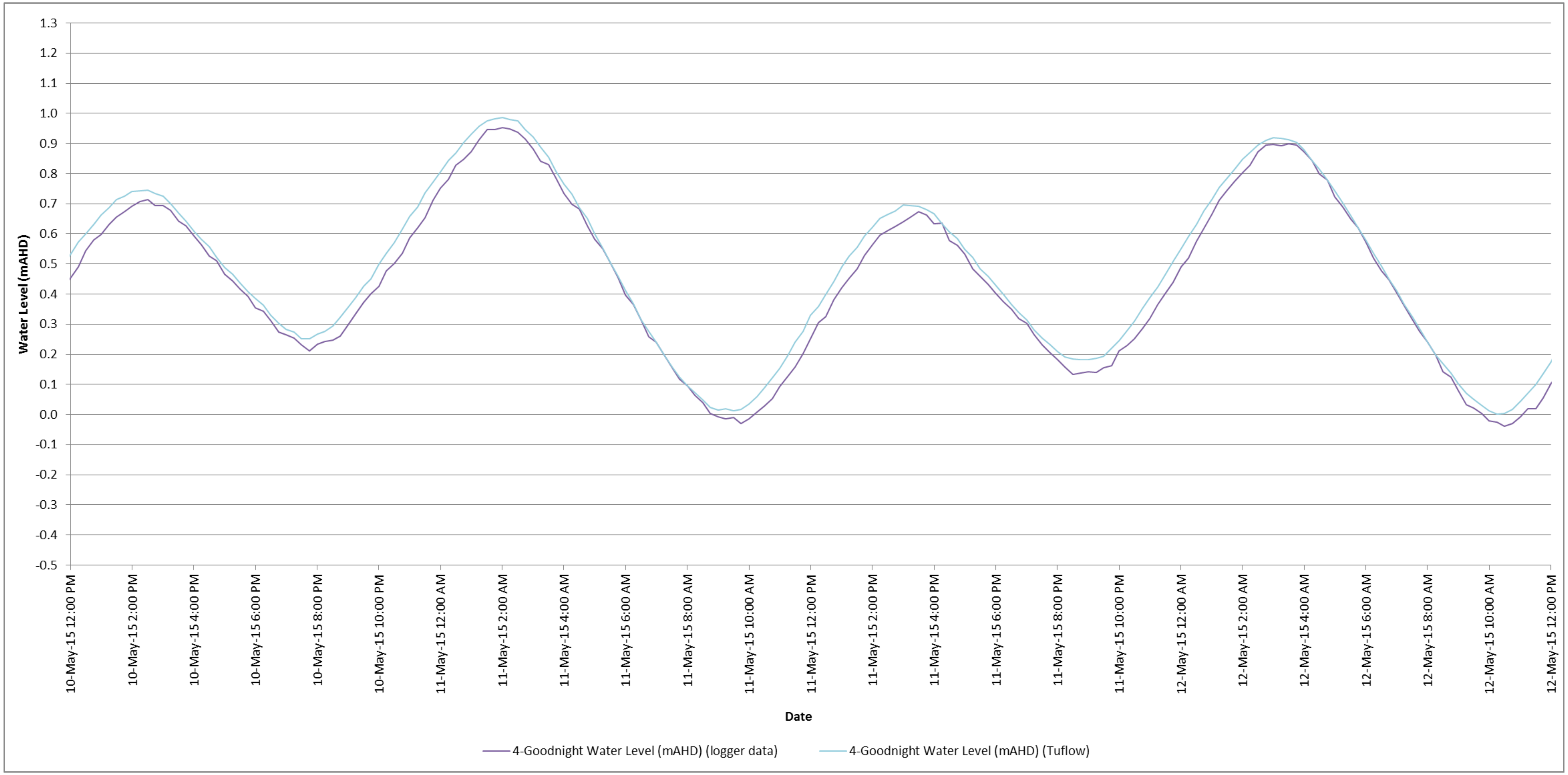
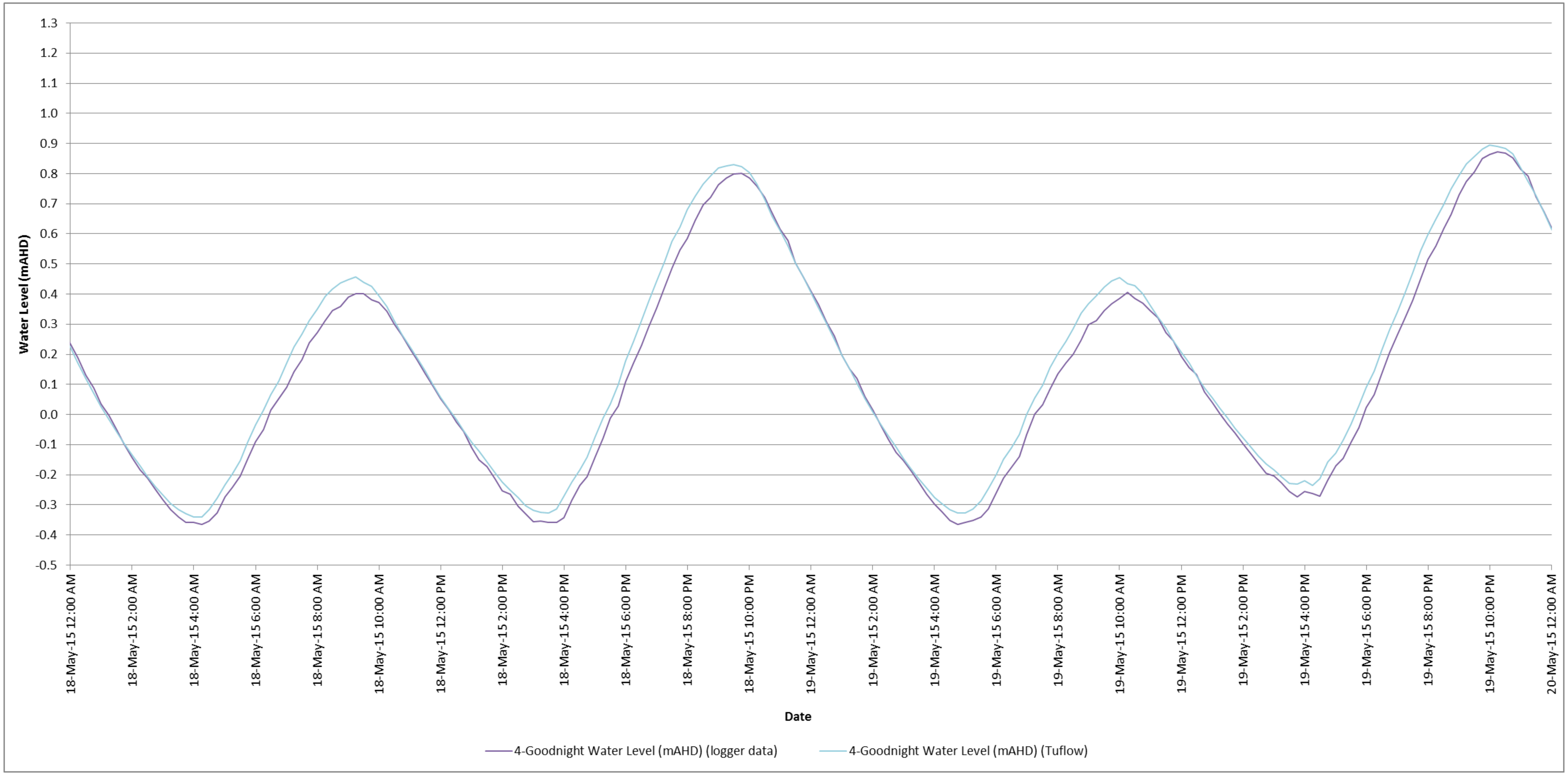
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 13**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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 14**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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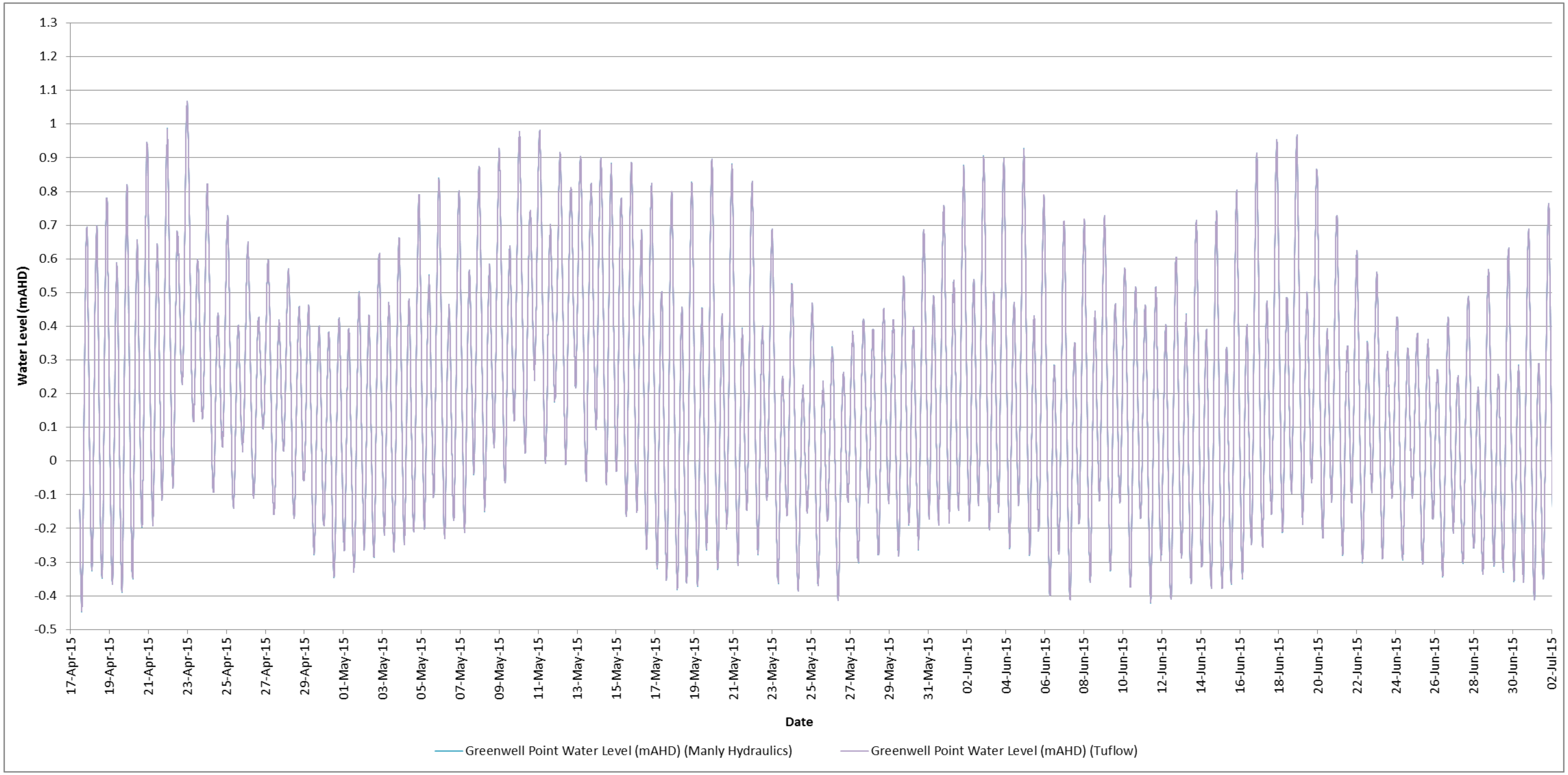
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 15**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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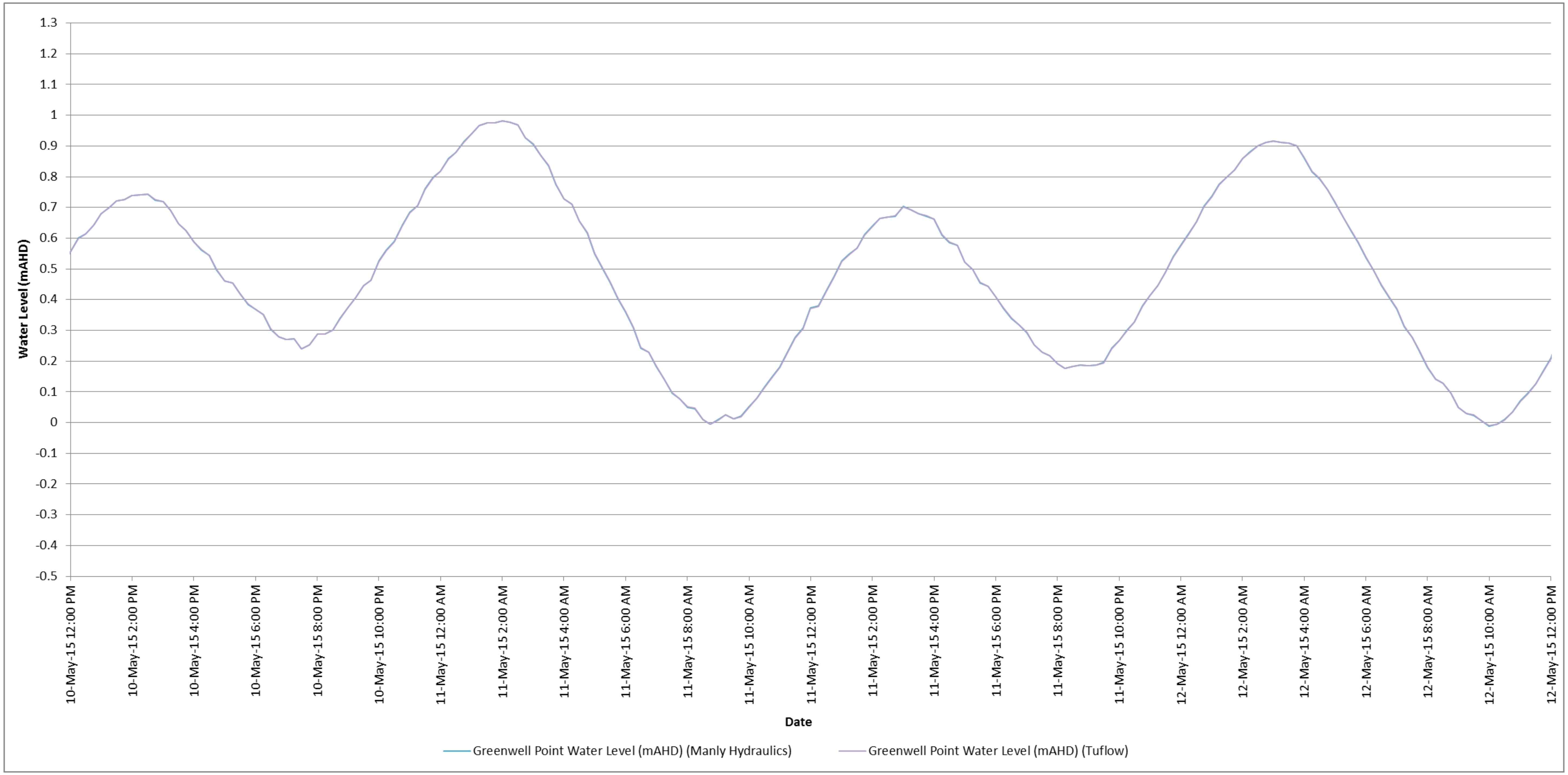
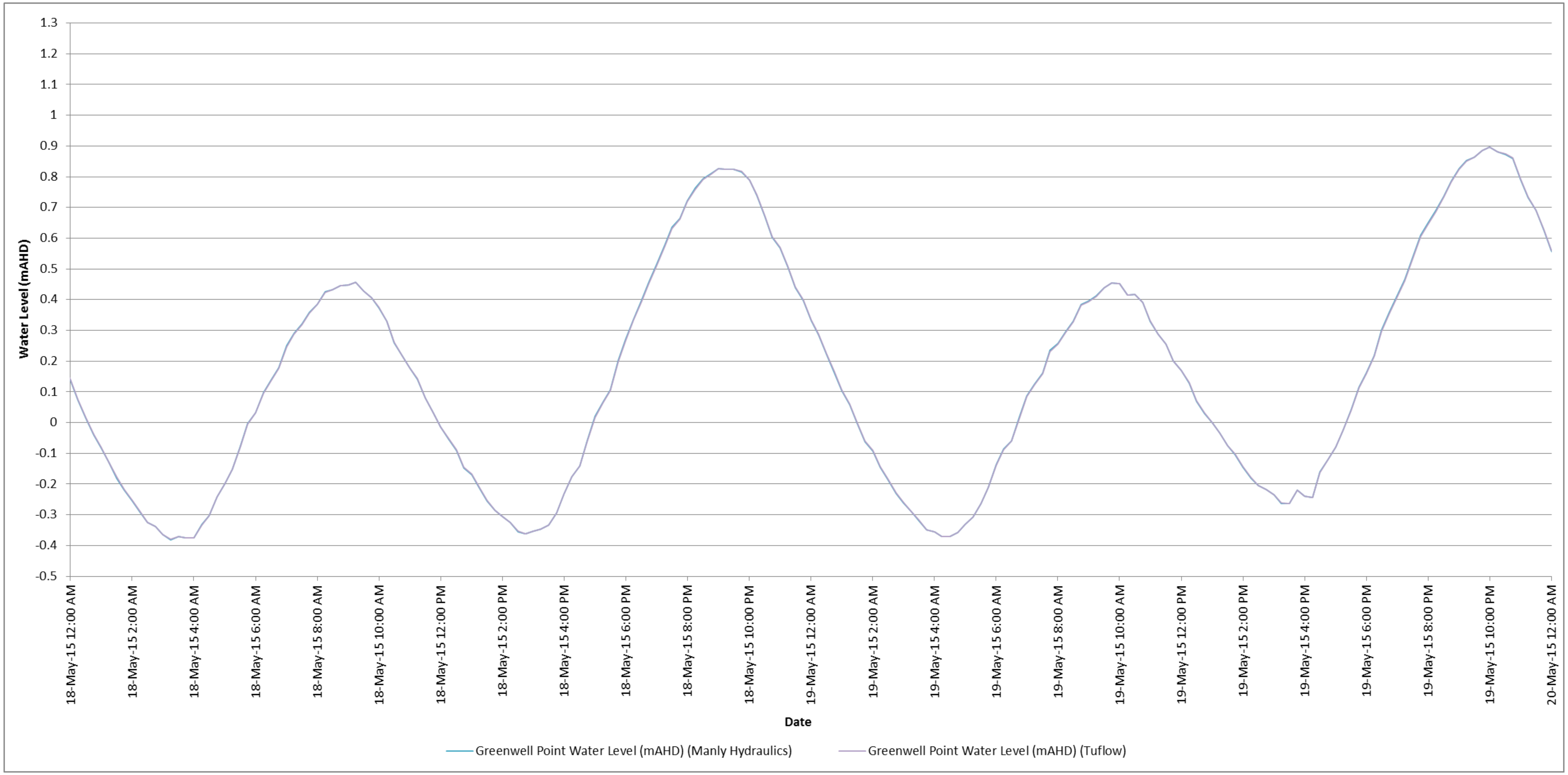
Martens & Associates Pty Ltd	ABN 85 070 240 890	**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**WATER LEVEL CALIBRATION LOCATION 5 – GREENWELL POINT MHL DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 16**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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 17**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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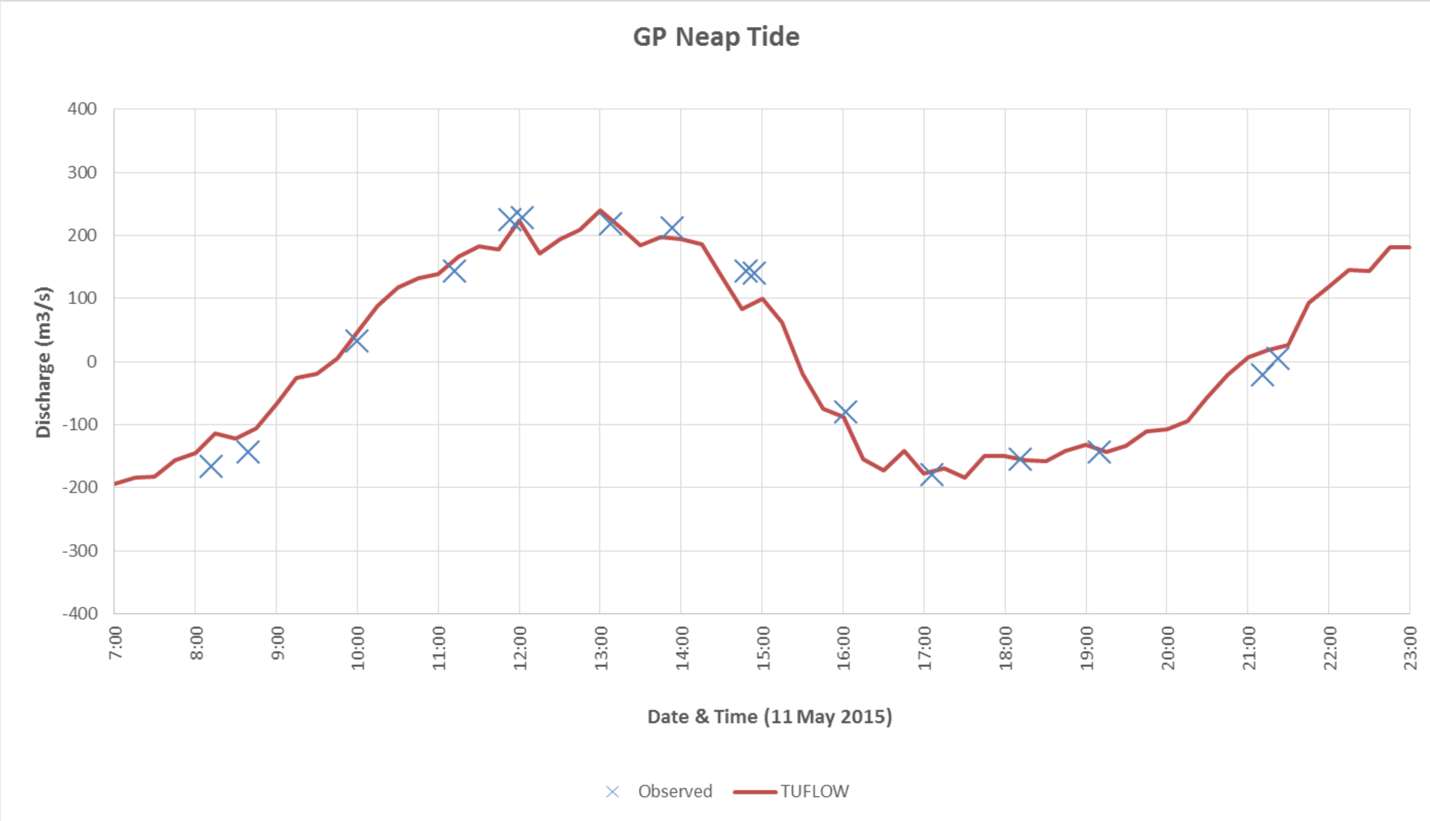
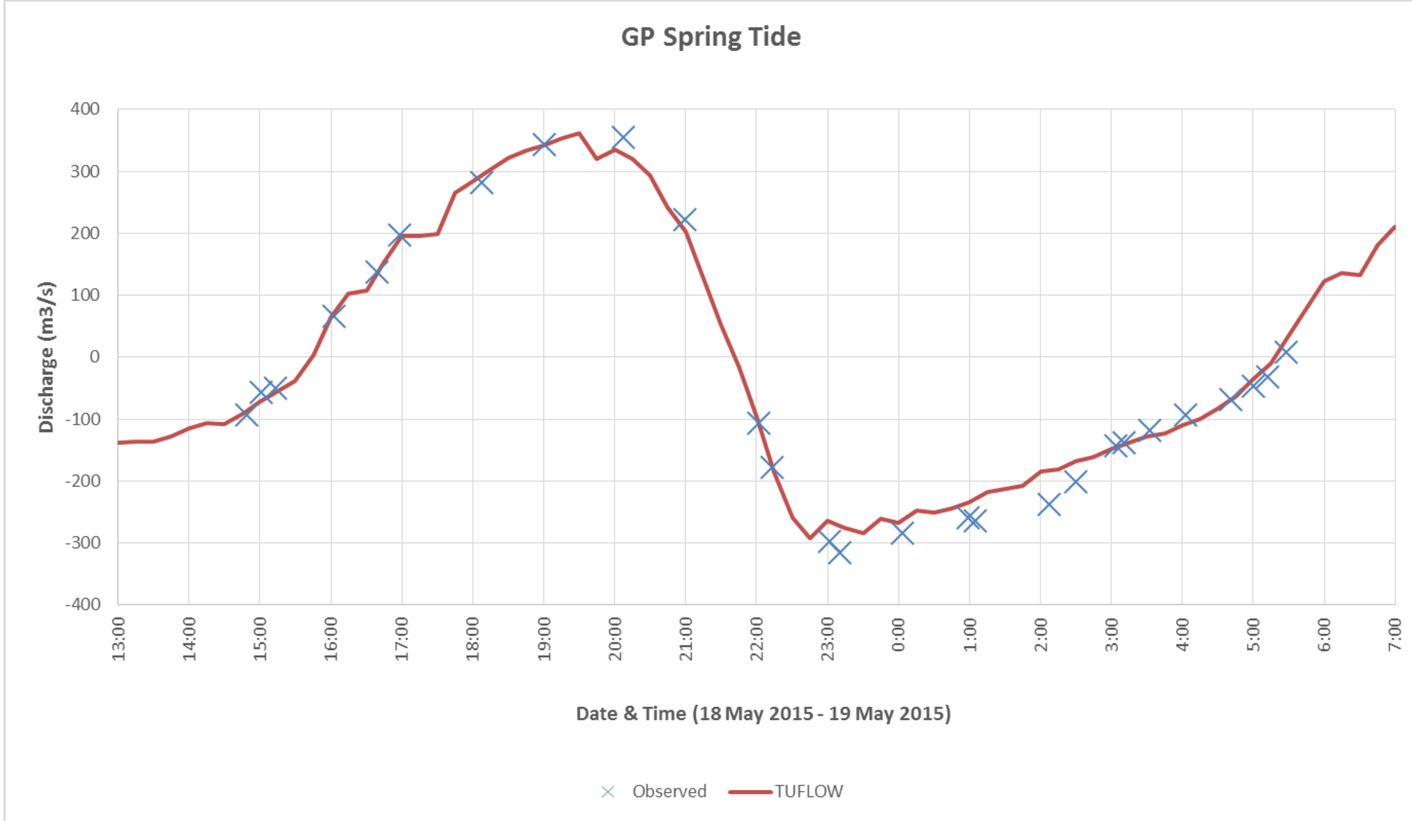
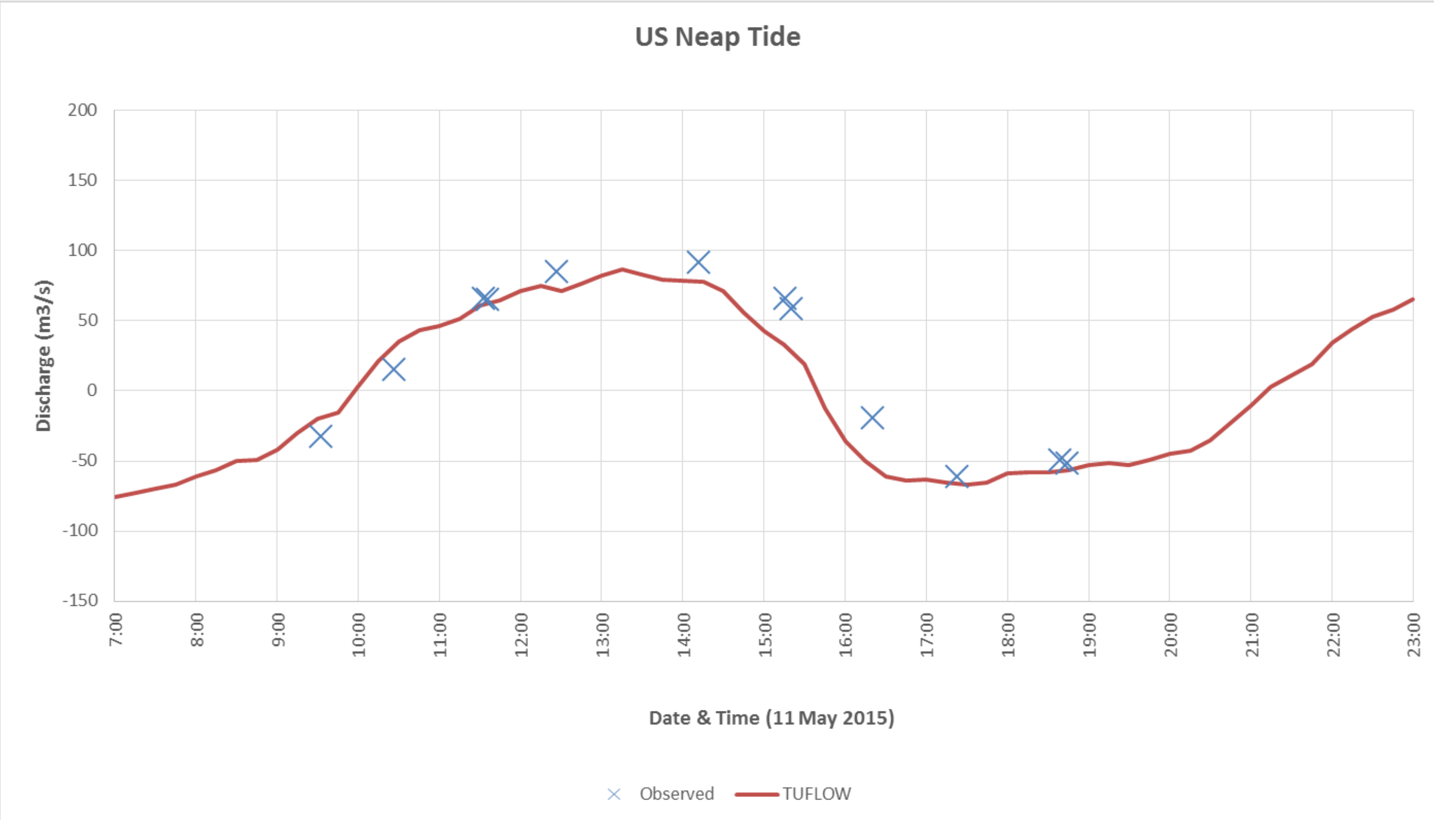
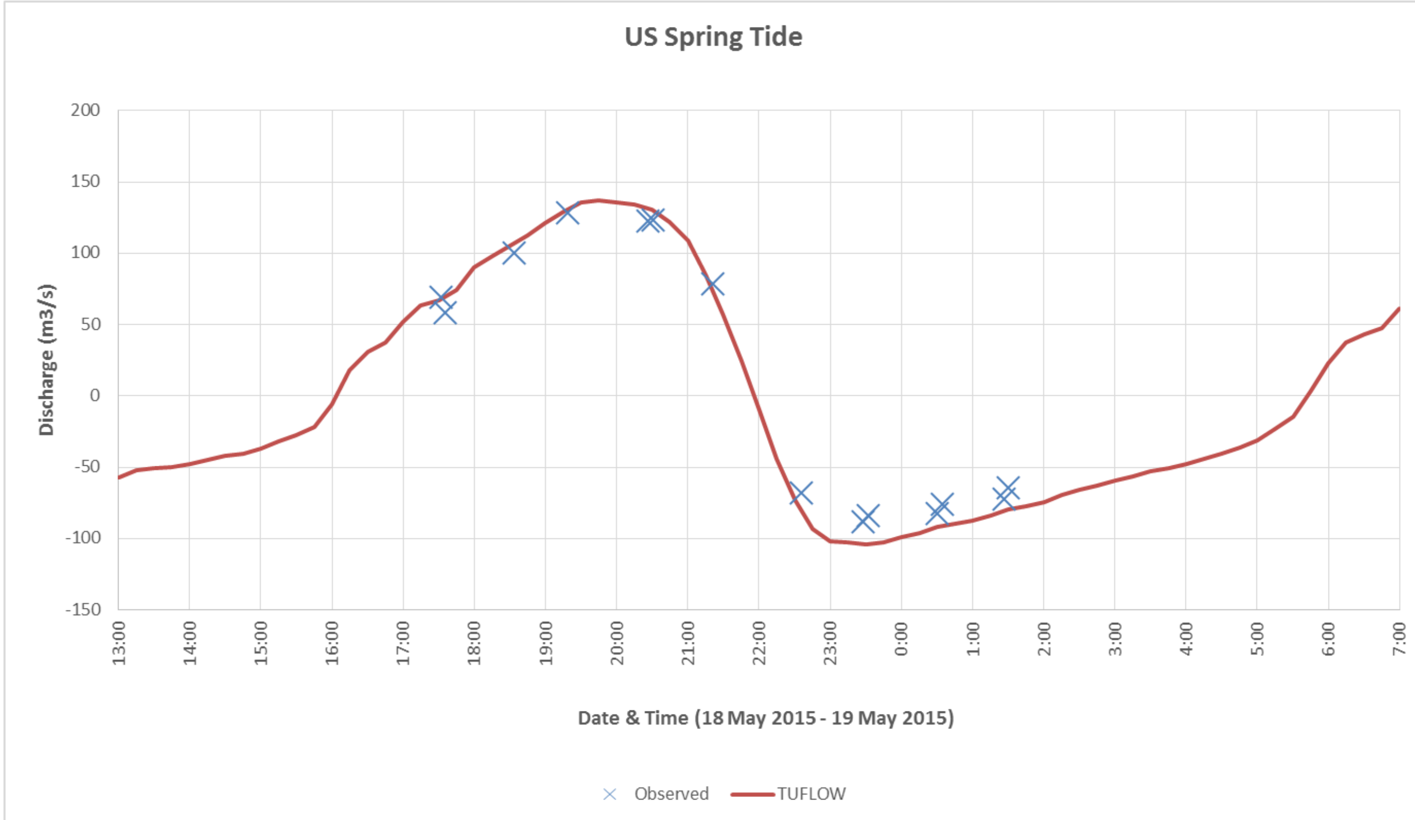
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**WATER LEVEL CALIBRATION – SPRING TIDE LOCATION 5 – GREENWELL POINT MHL DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 18**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



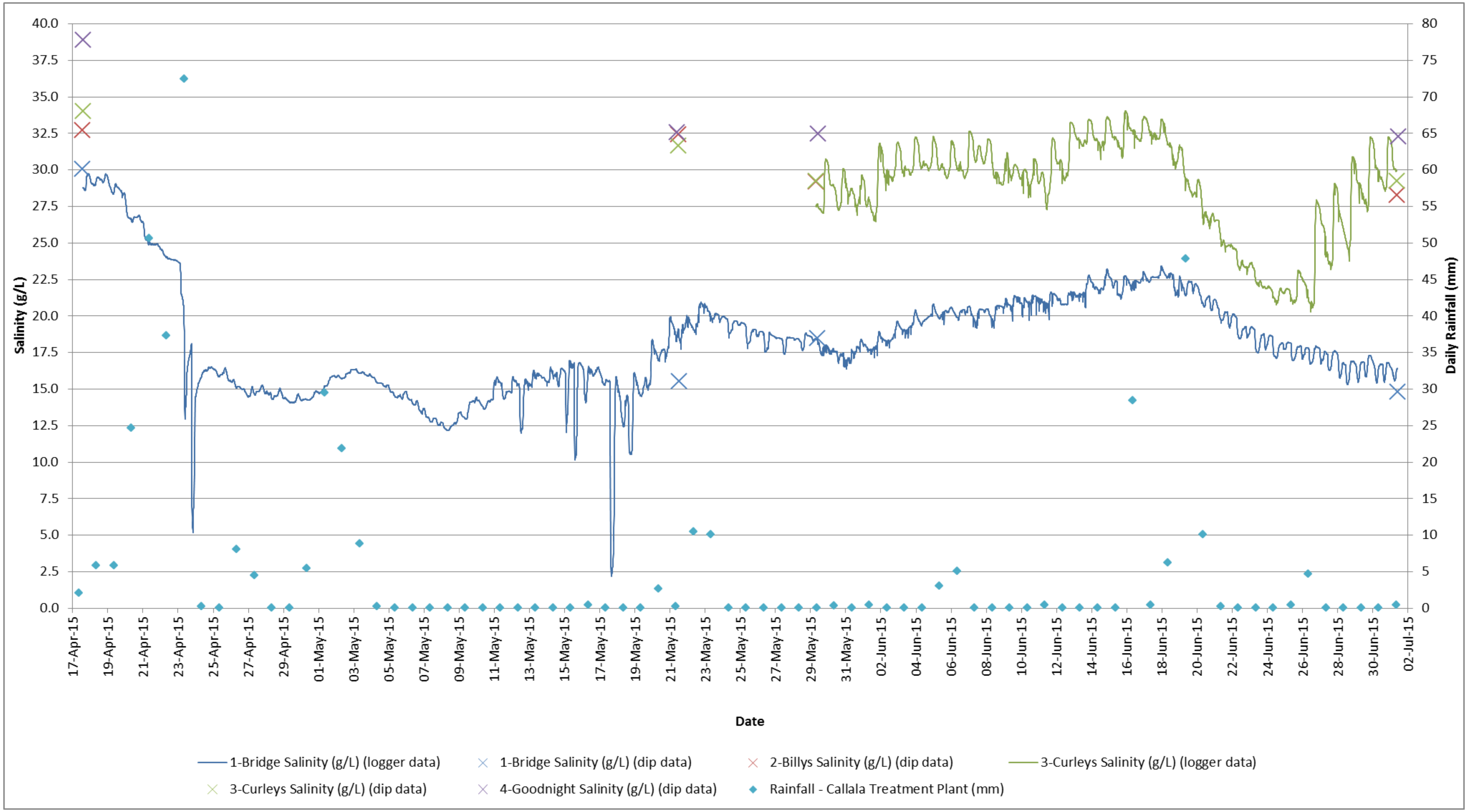






Note:
1. Positive discharge relates to water entering the estuary. Negative discharge relates to water leaving the estuary.

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 19**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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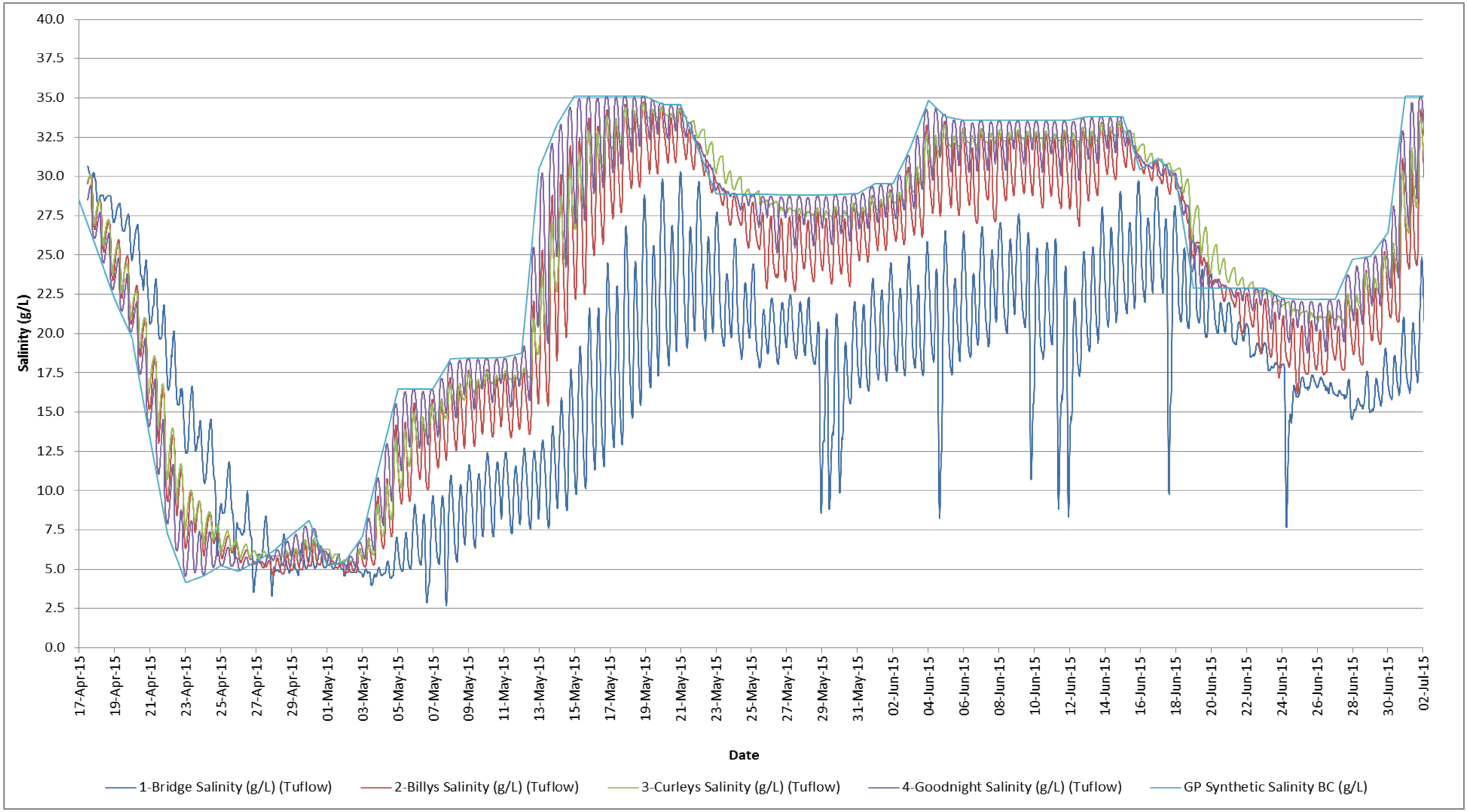
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**ALL MEASURED SALINITY CONCENTRATIONS LOGGER AND DIP DATA**	Drawing No: **FIGURE 20**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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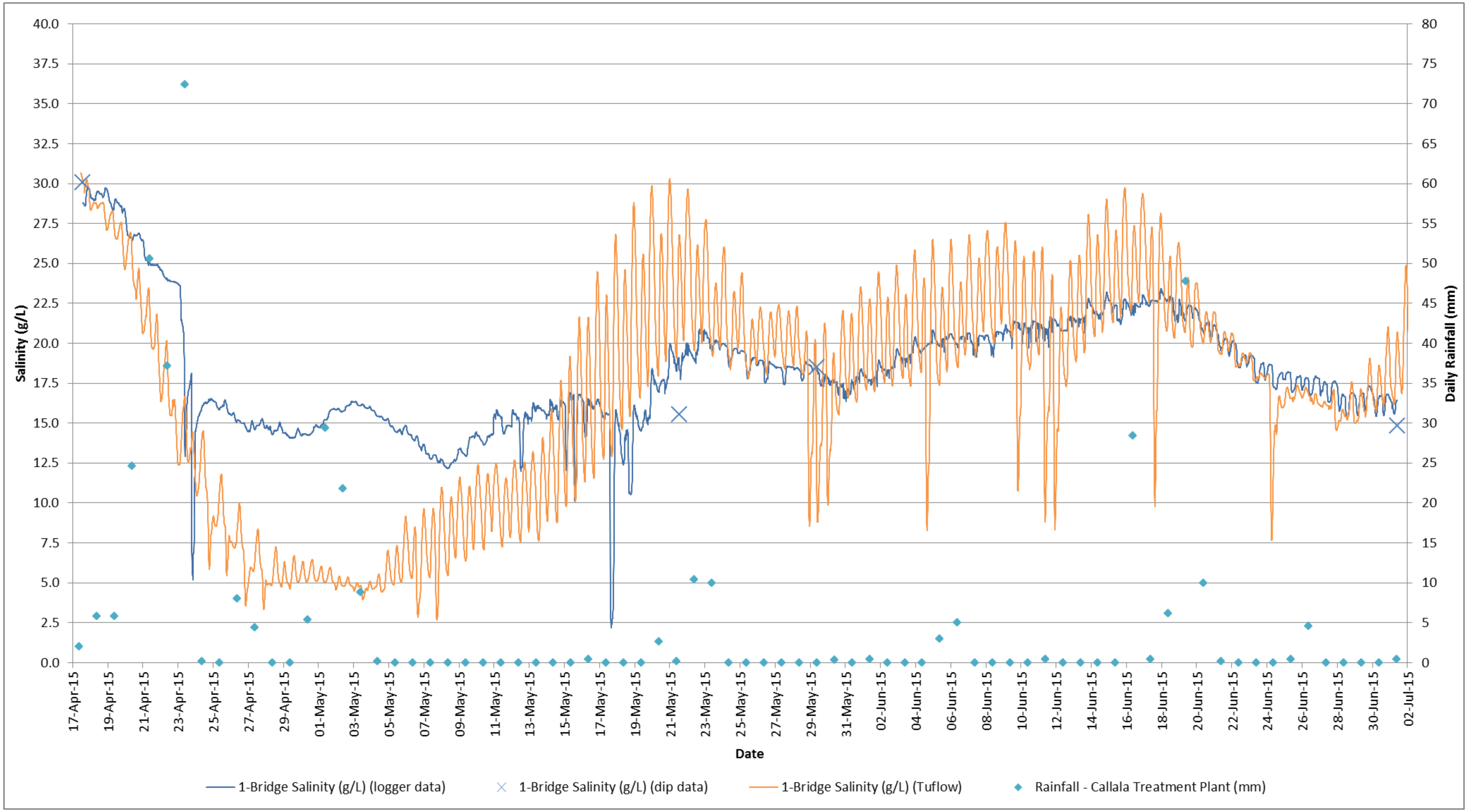
Martens & Associates Pty Ltd ABN 85 070 240 890		**Environment | Water | Wastewater | Geotechnical | Civil | Management**	
Drawn:	DD	**ALL MODELLED SALINITY CONCENTRATIONS AND DEVELOPED SALINITY RELATIONSHIP AT MODEL BOUNDARY**	Drawing No: **FIGURE 21**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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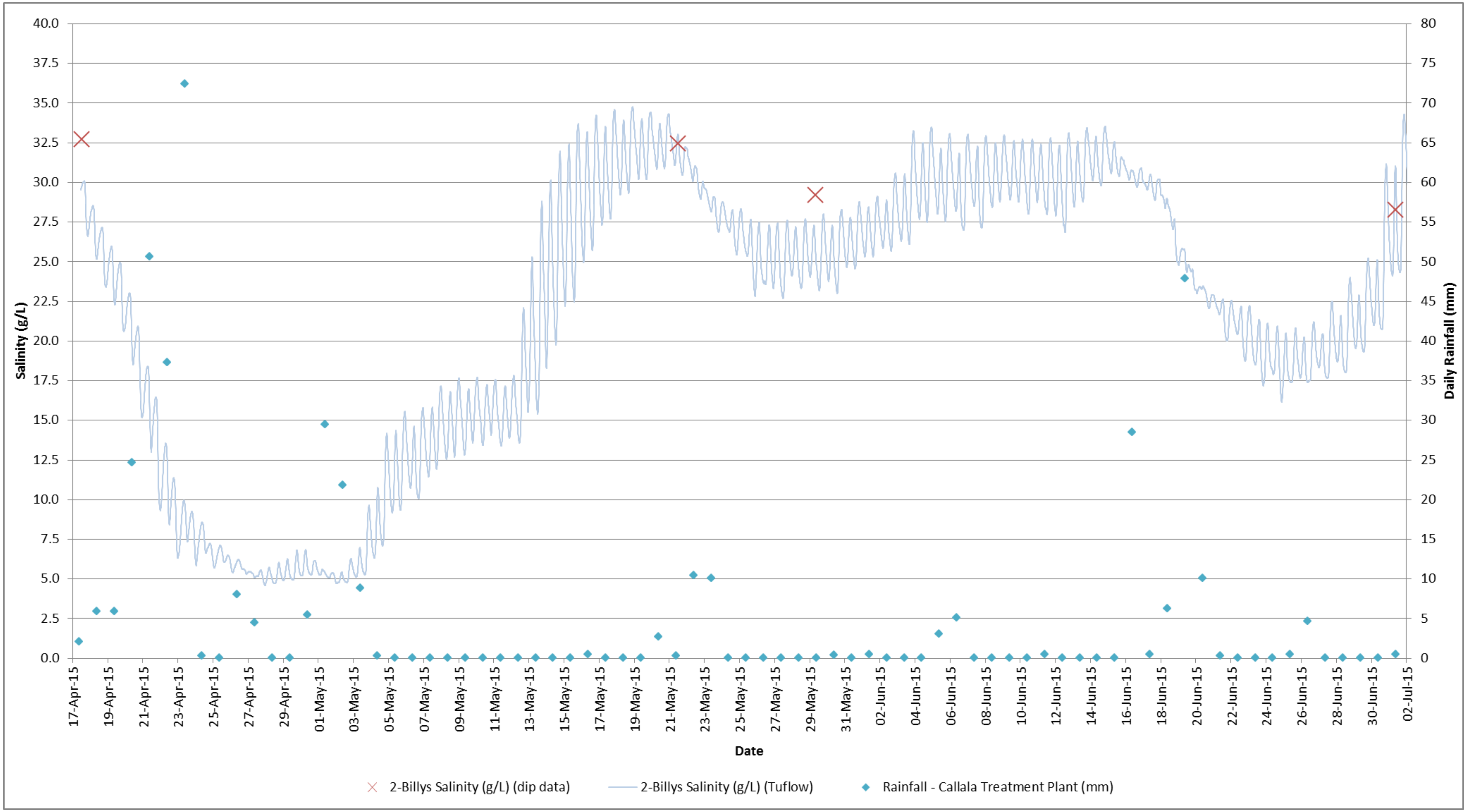
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**SALINIY CALIBRATION LOCATION 1 – CULBURRA ROAD BRIDGE CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 22**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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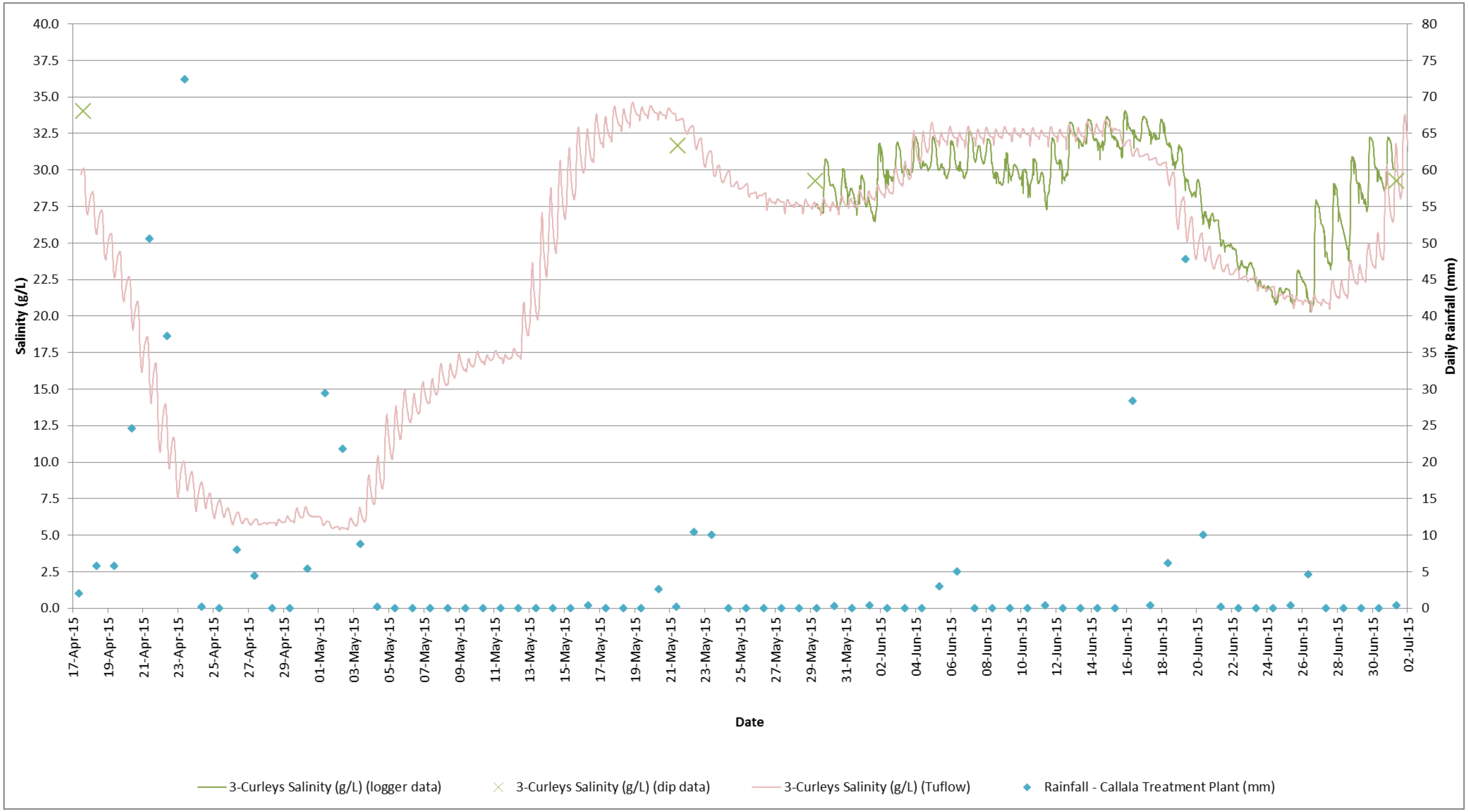
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	**SALINIY CALIBRATION LOCATION 2 – BILLY'S ISLAND CTD DATA VS TUFLOW MODELLING**	Drawing No: **FIGURE 23**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



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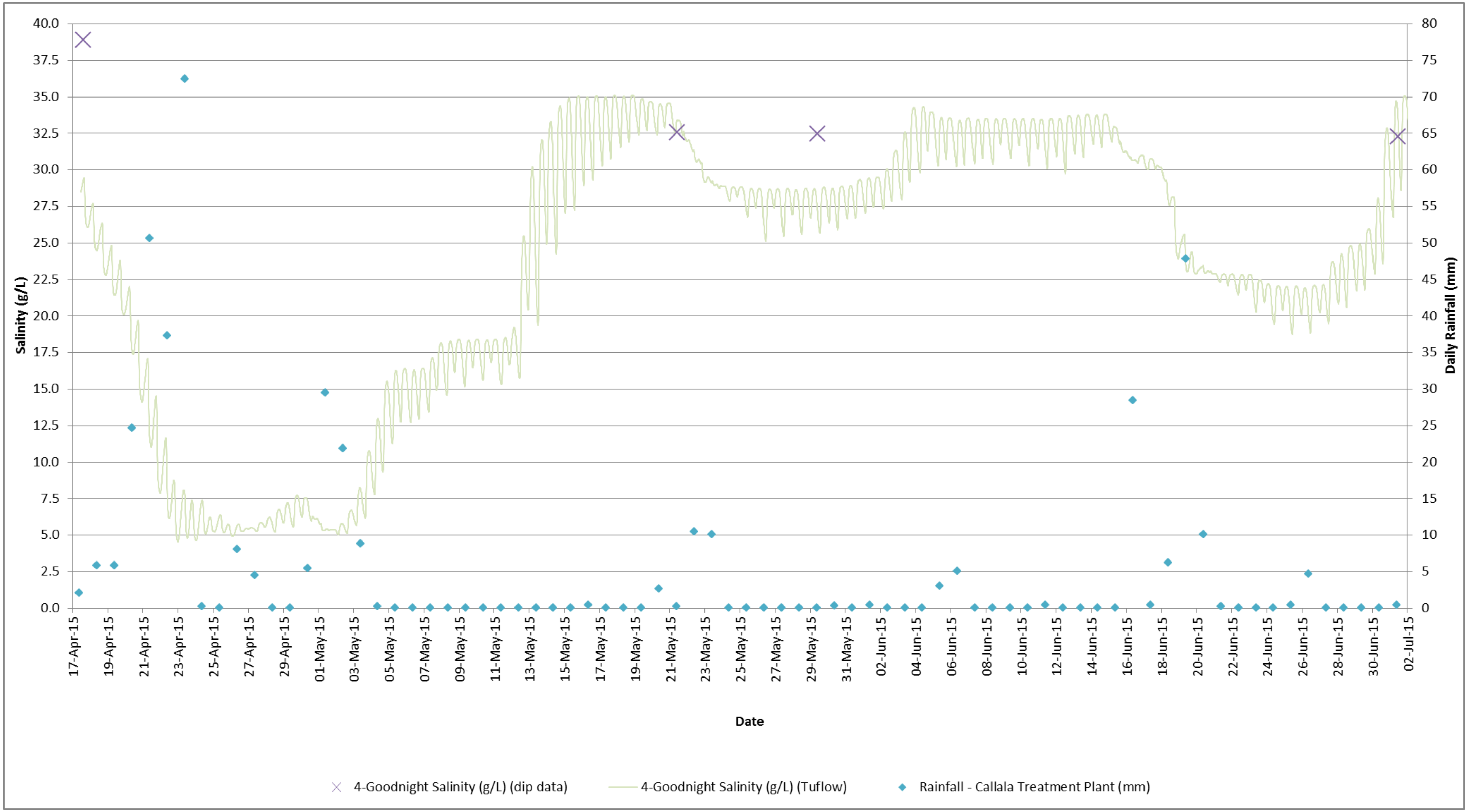
Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	SALINIY CALIBRATION LOCATION 3 – CURLEY'S BAY CTD DATA VS TUFLOW MODELLING	Drawing No: **FIGURE 24**
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365



martens

Martens & Associates Pty Ltd ABN 85 070 240 890		Environment | Water | Wastewater | Geotechnical | Civil | Management	
Drawn:	DD	SALINIY CALIBRATION LOCATION 4 – GOODNIGHT ISLAND CTD DATA VS TUFLOW MODELLING	Drawing No: FIGURE 25
Approved:	AN		
Date:	17.11.2015		
Scale:	NA		Job No: P1203365