Cairns Shipping Development Project

Ports North

APPENDIX D.4

Draft : Environmental Impact Statement

Appendix D.4

Water Quality Model Development and Calibration Report

Cairns Shipping Development Project Model Development and Calibration

Reference: R.B20180.003.03.Modelling_Report.docx
Date: October 2014
Confidential

Cairns Shipping Development Project Model Development and Calibration

Prepared for:	Ports North
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

Offices

Brisbane
Denver
London
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Document Control Sheet

BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane 4000
Queensland Australia
PO Box 203 Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.bmtwbm.com.au

Document:	R.B20180.003.03.Modelling_Report.docx
Title:	Cairns Shipping Development Project Model Development and Calibration
Project Manager:	Matthew Barnes
Author:	Matthew Barnes
Client:	Ports North
Client Contact:	
Client Reference:	

Synopsis:

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0 1 2 3	28/10/2013 07/11/2013 29/08/2014 22/10/2014	IAT	[signature]	MPB	[signature]

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
Ports North	PDF	PDF	PDF	PDF							
BMT WBM File	PDF	PDF	PDF	PDF							
BMT WBM Library	PDF	PDF	PDF	PDF							

Executive Summary

The Cairns Shipping Development Project (CSDP) involves upgrading of the following Port infrastructure:

- Widening and deepening of the existing outer shipping channel, which will result in some lengthening of the existing channel.
- Widening and deepening of the existing inner harbour channel and cruise shipping swing basin and establishment of a new shipping swing basin to enable future expansion of the HMAS Cairns Navy base.
- Structural upgrade of the existing cruise shipping wharves 1-5 to accommodate larger and heavier cruise ships.
- Provision and upgrade of ship services to the cruise shipping wharves, including fuel supply, potable water and fire fighting services.

A key part of the harbour and channel development works will involve capital dredging of approximately 4.4 million m^3 (Mm^3) of *in-situ* material with associated marine placement.

A suite of numerical modelling tools to assist the environmental assessment of activities associated with the CSDP have been developed, comprising of:

- Digital Elevation Model covering the Port of Cairns, Trinity Inlet, Trinity Bay and the surrounding Great Barrier Reef Lagoon.
- TUFLOW FV 3D hydrodynamic model covering the Port of Cairns, Trinity Inlet, Trinity Bay and the surrounding Great Barrier Reef Lagoon.
- SWAN nested wave modelling system for coupling with the hydrodynamic and sediment transport model.
- TUFLOW FV 3D sediment transport model (coupled with the hydrodynamic and wave models).

The modelled hydrodynamics, waves and sediment transport are influenced by various boundary condition inputs derived from targeted data recordings, regional models and global models which represent the following forcing:

- Wind;
- Tides;
- Ocean currents, salinity and temperature;
- Air temperature, radiation, precipitation and humidity; and
- Fluvial discharge.

This technical report describes the development of the numerical modelling tools for the CSDP including the numerous data inputs. Model calibration is a key part of the numerical model development work and was primarily undertaken utilising data recorded during deployments of data recording instruments for the CSDP EIS in 2013. This data collection involved the deployment of various fixed-location instruments for continuous recording of water levels, currents, waves, salinity, temperature and turbidity.

Model Calibration and Validation

Calibration of the hydrodynamic, wave and sediment transport models was conducted for the simulation period from 1st March 2013 to 29th June 2013.

Hydrodynamic model calibration principally considered the ability of the model to predict both water levels and currents over multiple tidal cycles and a range of wind conditions. The following conclusions were made about the hydrodynamic model calibration performance:

- Water level predictive skill was generally very good across the calibration period, including both spring and neap tides.
- Current speeds and directions were generally well predicted by the numerical model, including both neap and spring tide periods and a range of wind speeds and directions.
- The influence of ocean circulation on the currents within the GBR lagoon were occasionally noticeable within the hydrodynamic model but at all times were less significant than tide and/or local wind forcing.

Wave model calibration principally considered the model ability to predict wave heights, periods and directions. The following conclusions were made about the wave model calibration performance:

- Significant wave height and direction was generally well predicted over the calibration period
- The wave model predicts periods of dominant sea and swell states at each location and this is reflected in comparisons with the peak wave period recordings. At times, the peak wave period is over-predicted and represents times when slightly too much offshore swell energy is propagated into Great Barrier Reef lagoon. This typically occurs during periods of low wind-driven wave energy with corresponding significant wave heights less than 0.5m. This is not expected to have any significant consequence on subsequent assessments.
- Comparison of recorded and predicted wave directional energy spectrum suggests the predicted directional spread of wave energy is somewhat narrower than recorded. Again, this is not expected to have any significant consequence on subsequent assessments.

The Sediment Transport model calibration principally considered the model ability to predict the ambient Total Suspended Solids (TSS) response to a range of tidal, wind and wave conditions. The following conclusions were made about the Sediment Transport model calibration performance:

- The response in the TSS signal due to wind-driven wave and current events is well represented in the model with respect to both magnitude and timing at the offshore location.
- The recorded TSS concentration at inner channel locations exhibits a clear tidal signal comprised of semi-diurnal and spring-neap variations. These are reasonably well captured by the model. At times, the model under predicts the TSS signal at the inshore locations, some of which can be attributed to the influence of biological sources of turbidity (e.g. algae and detritus) which are present in the data but not simulated by the model.

- Generally, given the significant complexities of modelling ambient sediment transport processes, TSS concentration prediction throughout the calibration period is considered adequate for assessing the impacts to water quality associated with the proposed dredging.

The ability of the modelling system to represent sediment plumes due to dredging activities was calibrated against data obtained from a targeted plume monitoring campaign undertaken during routine maintenance dredging activities in 2011. This exercise demonstrated the ability of the model to adequately represent dredge plume advection and dispersion following the application of appropriate dredge plume source terms to the model.

An independent model validation assessment was undertaken for the period from July to October 2013. The outcomes of the validation assessment generally confirmed the calibration phase conclusions about hydrodynamic, wave and sediment transport model performance,

An additional model validation exercise considered the models ability to predict the behaviour of catchment runoff plumes originating from the Barron River. It was concluded that the modelling system qualitatively reproduces features of Barron River flood plumes. Under certain wind conditions, fluvial plumes are predicted to influence water quality at far field locations including Double Island and Green Island.

Impact Assessments

The calibrated and validated numerical models were then applied to the assessment of a number of potential project related impacts. The potential impact of capital dredging works were assessed by considering a number of scenarios related to the anticipated generation, dispersion, settling and re-suspension of dredge-related sediment plumes. The magnitude, extent and duration of impacts were directly assessed by simultaneously simulating both the ambient and dredging related contributions to suspended sediment in the water column.

Base case and alternative case scenarios were assessed that simulated the entire CSDP dredging program based on a combination of a medium sized TSHD and a single BHD operating in the inner harbour. The base and alternative cases differed with respect to the methodology for removal of sediment from the inner harbour area with the alternative case assuming a greater role for the TSHD. Both the base case and alternative case assumed that the TSHD dredging would be undertaken with no overflow dredging. The magnitude and extent of impacts associated with the base and alternative cases were generally low and within the limits of natural variation away from the immediate dredge footprint. The magnitude and extent of impacts associated with DMPA placement were also unlikely to have a detrimental impact on identified sensitive receptors.

Two “worst case” assessments were undertaken in order to consider the additional impacts associated with limited overflow dredging that may be required by the project under certain operational circumstances (such as encountering unexpected stiff material). While the magnitude and extent of impacts associated with the “worst case” scenarios are somewhat greater than the no overflow cases it is anticipated that these can be adequately managed through the application of dredge management procedures based on reactive monitoring.

A 12 month period was simulated following the completion of the capital dredging program in order to identify the ongoing impacts associated with dredge material re-suspension, dispersion and settling. Increases to turbidity and deposition of dredge material re-suspending from the DMPA is undetectable within the context of the ambient water quality climate. The quantity of material dispersed from the DMPA over a 12 month period following the completion of the capital dredge program was predicted using the model. The quantity of material outside of the DMPA perimeter at the end of the 12 month period is relatively low, corresponding to less than 0.1% of the initial DMPA mass. These results suggest a highly retentive DMPA for the range of conditions experienced over a typical (non-extreme) 12 month period.

A “worst case” re-suspension assessment was undertaken by simulating a one-month period including severe Tropical Cyclone Yasi. The DMPA material contribution to elevated levels of suspended sediment and subsequent sedimentation through this event was shown to be very minor in the context of the levels generated by ambient material re-suspension and settling during the same event. The quantity of material outside of the DMPA perimeter at the end of the “worst case” re-suspension assessment remains relatively low, corresponding to approximately 1.1% of the initial DMPA mass. These results suggest that there is very low risk to the GBR lagoon water quality posed by re-suspension from the DMPA site selected in approximately 18-23m water depth for the CSDP project.

In the context of coastal processes, the impacts associated with the CSDP are generally related to the proposed dredging works. These works entail widening the existing channel (to 130m in the outer channel), deepening to a declared depth of -9.4mLAT, which also involves extending the dredged channel by around 1km offshore.

Numerical modelling assessments were undertaken to identify any potential impacts to the following key coastal processes:

- Hydrodynamics
- Waves
- Morphology and Sedimentation
- Shoreline and Beach System.

Specially, the modelling assessment results show that:

- There will be minor (unmeasurable) impact to currents and tidal flows in Trinity Bay and Trinity Inlet
- Generally, impacts on tidal currents are highly localised and in the immediate vicinity of the target dredge area where some local realignment and modification of current speeds will occur
- There will be no detectable increase to storm tide vulnerability to adjacent areas
- There will be minor (unmeasurable) modification to wave propagation in the vicinity of the developed channel area and no detectable impact to wave conditions at far field areas
- There will be an increase of approximately 25% to the annual channel siltation and maintenance dredge requirements
- There will be no detectable impact to sediment transport pathways and beach processes.

An independent peer review of the numerical models developed for the CSDP EIS and their application was undertaken on two occasions by Emeritus Professor Colin J Apelt. The reviewer considered the numerical tools to be adequate and suitable for assessing impacts associated with the project. The final peer review report is included as

Finally, it should be noted that the numerical models developed and modelling assessments undertaken for the CSDP EIS are considered to be in accordance with the Great Barrier Reef Marine Park Authority (GBRMPA) "Guidelines on Hydrodynamic Modelling". A detailed cross-check against the guidelines was included in Section 2.4 of this report.

Contents

Executive Summary i

1 Introduction 1

1.1 Background 1
1.2 Objectives and Purpose 1
1.3 Proposed Port Development for Assessment 1
1.3.1 Channel Upgrade 1
1.3.2 Swing Basin Upgrade 2
1.3.3 Capital Dredging 2
1.3.4 Maintenance Dredging 2
1.4 Offshore Disposal 2

2 Numerical Model Descriptions 5

2.1 Hydrodynamic (TUFLOW FV) 5
2.1.1 Advection Dispersion Modelling 5
2.1.2 Model Domain, Mesh and Bathymetry 5
2.1.3 Boundary Conditions 9
2.1.3.1 Wetting and Drying 9
2.1.3.2 Wind 9
2.1.3.3 Tide 11
2.1.3.4 Regional Currents, Salinity and Temperature 11
2.1.3.5 Air Temperature, Radiation, Precipitation and Humidity 12
2.1.3.6 Fluvial Discharge 12
2.2 Waves (SWAN) 14
2.2.1 Model Domain and Bathymetry 14
2.2.2 Boundary Conditions 16
2.2.2.1 Swell 16
2.2.2.2 Wind 16
2.3 Sediment Transport (ST) 16
2.4 GBRMPA Guidelines Cross-check 17

3 Model Calibration 21

3.1 Baseline Calibration Data 21
3.2 Calibration Period Characteristics 25
3.2.1 Wind 25
3.2.2 Fluvial Discharge 27
3.2.3 Waves 27

3.3 Hydrodynamic Model Calibration 29
3.3.1 Hydrodynamic Model Parameterisation 29
3.3.2 Hydrodynamic Model Calibration Results 29
3.3.2.1 Site 1 DMPA 32
3.3.2.2 Site 2 38
3.3.2.3 Site 3 Beacon C7 43
3.3.2.4 Site 4 Beacon C11 48
3.3.3 Water Temperature Calibration 53
3.4 Wave Model Calibration 54
3.4.1 Wave Model Parameterisation 54
3.4.2 Wave Model Calibration Results 55
3.4.2.1 Cairns Wave Buoy 56
3.4.2.2 Targeted Wave Recordings 57
3.5 Sediment Re-suspension Model Calibration 65
3.5.1 Sediment Re-suspension Model Parameterisation 65
3.5.2 Sediment Re-suspension Model Calibration Results 68
3.5.2.1 Targeted Turbidity Recordings 68
3.5.2.2 Channel Sedimentation Calibration 70
4 Dredge Plume Advection-Dispersion Calibration 72
4.1 Targeted Plume Monitoring Program 72
4.1.1 Data Processing 72
4.2 Model Parameters 73
5 Model Validation 84
5.1 Baseline Validation Data 84
5.2 Validation Period Characteristics 84
5.2.1 Wind 84
5.2.2 Waves 86
5.3 Hydrodynamic Model Validation 86
5.3.1 Hydrodynamic Model Validation Results 87
5.3.1.1 Site 1 DMPA 87
5.3.1.2 Site 3 Beacon C7 92
5.3.1.3 Cairns Port Gauge and Swallows Landing 97
5.3.2 Temperature and Salinity Validation 98
5.4 Wave Model Validation 99
5.4.1 Wave Model Validation Results 99
5.5 Sediment Re-suspension Model Validation 102
5.5.1 Sediment Re-suspension Model Validation Results 102

5.5.2 Targeted Turbidity Recordings 102
5.6 Barron River Plume 2011 Hindcasting 104
5.6.1 Overview 104
5.6.2 Fluvial Inputs and Model Parameterisation 105
5.6.3 Barron River Plume Results 106
6 Dredging Impact Assessment 111
6.1 Introduction 111
6.2 Methodology 111
6.2.1 Modelled Sediment Fractions 111
6.2.2 Dredging Programme Schematisation 112
6.2.3 Dredge Plume Source Rates 116
6.2.4 Simulation Periods 117
6.2.5 Assessment Methodology 120
6.2.5.1 Timeseries Analysis 120
6.2.5.2 Percentile Analysis 120
6.2.5.3 Zone of Influence Analysis 123
6.3 Base Case Capital Program 124
6.3.1 Description 124
6.3.2 Results 125
6.4 Alternative Case Capital Program 131
6.4.1 Description 131
6.4.2 Results 131
6.5 “Worst Case” Soft Material Dredging 137
6.5.1 Description 137
6.5.2 Results 137
6.6 “Worst Case” Stiff Material Dredging 143
6.6.1 Description 143
6.6.2 Results 143
6.7 12 month Re-suspension Scenario 149
6.7.1 Description 149
6.7.2 Results 149
6.8 “Worst Case” Re-suspension Scenario 155
6.8.1 Results 155
6.9 Discussion 161
6.9.1 Base Case Capital Program 161
6.9.2 Alternative Case Capital Program 161
6.9.3 “Worst Case” Soft Material Dredging 162

6.9.4 "Worst Case" Stiff Material Dredging 162
6.9.5 12 Month Re-suspension Scenario 162
6.9.6 "Worst Case" Re-suspension Scenario 163
7 Coastal Processes Impact Assessment 164
7.1 Introduction 164
7.2 Hydrodynamic Impacts 167
7.2.1 Tidal Current Field Impacts 167
7.2.2 Water Level Impacts 175
7.2.3 Tidal Flow and Volume Impacts 178
7.2.4 Bed Shear Stress Impacts 180
7.2.5 Extreme Water Level Impacts 183
7.3 Wave Impacts 185
7.4 Morphology and Sedimentation Impacts 191
7.4.1 Littoral Sediment Transport 191
7.4.2 Marine Sediment Transport 191
7.4.3 Channel Siltation 193
8 References 194
Appendix A Peer Review Report A-1
Appendix B Example TUFLOW FV Simulation Control File B-1
Appendix C Calibration Period Current Time Series Plot C-1
Appendix D Calibration Period Current Polar Plots D-1
Appendix E Calibration Period Current Q-Q Plots E-1
Appendix F Validation Period Current Time Series Plots F-1
Appendix G Validation Period Current Polar Plots G-1
Appendix H Validation Period Current Q-Q Plots H-1
Appendix I Turbidity Timeseries Plots I-1

List of Figures

Figure 1-1 Study Area 4
Figure 2-1 TUFLOW FV Model Mesh and Bathymetry 7
Figure 2-2 TUFLOW FV Hydrodynamic Model Mesh Detail 8
Figure 2-3 Weather Station Locations 10
Figure 2-4 Illustration of Constructed Wind Field Methodology 11
Figure 2-5 TUFLOW FV Coral Sea Model Extent 13
Figure 2-6 SWAN Nested Wave Model Extents 15

Figure 3-1	NTU-TSS Relationship Established for the Study Area	22
Figure 3-2	Data Recording Locations	23
Figure 3-3	Offshore Wind Roses – February to June 2013 Simulation Period (top) and February to June Long Term Average (bottom)	26
Figure 3-4	Cairns Aero Wind Rose – February to June 2013 Simulation Period (top) and February to June Long Term Average (bottom)	26
Figure 3-5	Cairns Buoy Wave Rose – February to June 2013 Simulation Period	28
Figure 3-6	Predicted Peak Flood (top) and Peak Ebb (bottom) Surface Current Patterns	31
Figure 3-7	Hydrodynamic Model Calibration 3D Depth Average – Site 1 DMPA	34
Figure 3-8	Hydrodynamic Model Calibration Current Velocity Layers – Site 1 DMPA	35
Figure 3-9	Hydrodynamic Model Calibration Current Direction Layers – Site 1 DMPA	36
Figure 3-10	Current Polar Plot Validation – Site 1 DMPA	37
Figure 3-11	Hydrodynamic Model Calibration 3D Depth Average – Site 2	39
Figure 3-12	Hydrodynamic Model Calibration Current Velocity Layers – Site 2	40
Figure 3-13	Hydrodynamic Model Calibration Current Direction Layers – Site 2	41
Figure 3-14	Current Polar Plot Validation – Site 2	42
Figure 3-15	Hydrodynamic Model Calibration 3D Depth Average – Site 3 Beacon C7	44
Figure 3-16	Hydrodynamic Model Calibration Current Velocity Layers – Site 3 Beacon C7	45
Figure 3-17	Hydrodynamic Model Calibration Current Direction Layers – Site 3 Beacon C7	46
Figure 3-18	Current Polar Plot Validation – Site 3 Beacon C7	47
Figure 3-19	Hydrodynamic Model Calibration 3D Depth Average – Site 4 Beacon C11	49
Figure 3-20	Hydrodynamic Model Calibration Current Velocity Layers – Site 4 Beacon C11	50
Figure 3-21	Hydrodynamic Model Calibration Current Direction Layers – Site 4 Beacon C11	51
Figure 3-22	Current Polar Plot Validation – Site 4 Beacon C11	52
Figure 3-23	Hydrodynamic Model Calibration Near Bed Temperature – Site 1 DMPA	53
Figure 3-24	Hydrodynamic Model Calibration Near Bed Temperature – Site 2	53
Figure 3-25	Hydrodynamic Model Calibration Near Bed Temperature – Site 3 Beacon C7	54
Figure 3-26	Hydrodynamic Model Calibration Near Bed Temperature – Site 4 Beacon C11	54
Figure 3-27	Example Wave Energy Spectrum showing Dominant Swell (left) and Wind Generated Sea (right) States	56
Figure 3-28	SWAN Wave Model Calibration – Cairns Wave Buoy	57
Figure 3-29	SWAN Wave Model Calibration – Site 1 DMPA	59
Figure 3-30	SWAN Wave Model Calibration – Site 2	60
Figure 3-31	SWAN Wave Model Calibration – Site 3 Beacon C7	61
Figure 3-32	SWAN Wave Model Calibration – Site 4 Beacon C11	62

Figure 3-33	Recorded (left) and Predicted (right) 2D Wave Energy Spectrum: Dominant Swell State	63
Figure 3-34	Recorded (left) and Predicted (right) 2D Wave Energy Spectrum: Dominant Sea State	64
Figure 3-35	“Pre-Warm Up” and “Post-Warm Up” Bed Sediment Distributions	67
Figure 3-36	Sediment Re-suspension Calibration – DMPA	69
Figure 3-37	Sediment Re-suspension Calibration – Site 2	69
Figure 3-38	Sediment Re-suspension Calibration – Beacon C7	69
Figure 3-39	Sediment Re-suspension Calibration – Beacon C11	70
Figure 3-40	Estimated and Measured Annual Siltation of Shipping Channel	71
Figure 4-1	TSS-NTU Relationship August 2011 Dredge Plume Monitoring	73
Figure 4-2	Maintenance Dredging Plume Validation, 30/08/2011 09:24: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	75
Figure 4-3	Maintenance Dredging Plume Validation, 30/08/2011 09:29: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	76
Figure 4-4	Maintenance Dredging Plume Validation, 30/08/2011 09:41: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	77
Figure 4-5	Maintenance Dredging Plume Validation, 30/08/2011 09:50: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	78
Figure 4-6	Maintenance Dredging Plume Validation, 30/08/2011 10:10: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	79
Figure 4-7	DMPA Plume Validation, 28/08/2011 11:32: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	80
Figure 4-8	DMPA Plume Validation, 28/08/2011 11:47: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	81
Figure 4-9	DMPA Plume Validation, 28/08/2011 12:07: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	82
Figure 4-10	DMPA Plume Validation, 28/08/2011 12:27: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)	83
Figure 5-1	Offshore Wind Roses – June to November 2013 Simulation Period (top) and June to November Long Term Average (bottom)	85
Figure 5-2	Cairns Aero Wind Roses – June to November 2013 Simulation Period (top) and June to November Long Term Average (bottom)	85
Figure 5-3	Cairns Buoy Wave Rose –June to October 2013 Simulation Period	86

Figure 5-4	Hydrodynamic Model Validation 3D Depth Average – Site 1 DMPA	88
Figure 5-5	Hydrodynamic Model Validation Current Velocity Layers – Site 1 DMPA	89
Figure 5-6	Hydrodynamic Model Validation Current Direction Layers – Site 1 DMPA	90
Figure 5-7	Current Polar Plot Validation – Site 1 DMPA	91
Figure 5-8	Hydrodynamic Model Validation 3D Depth Average – Beacon C7	93
Figure 5-9	Hydrodynamic Model Validation Current Velocity Layers – Beacon C7	94
Figure 5-10	Hydrodynamic Model Validation Current Direction Layers – Beacon C7	95
Figure 5-11	Current Polar Plot Validation – Site 3 Beacon C7	96
Figure 5-12	Hydrodynamic Model Validation Water Level – Cairns Port Gauge	97
Figure 5-13	Hydrodynamic Model Validation Water Level – Swallows Landing	97
Figure 5-14	Hydrodynamic Model Validation Near Bed Temperature – Site 1 DMPA	98
Figure 5-15	Hydrodynamic Model Validation Near Bed Temperature – Site 3 Beacon C7	98
Figure 5-16	Hydrodynamic Model Validation Surface Salinity – Site 3 Beacon C7	99
Figure 5-17	SWAN Wave Model Validation – Site 1 DMPA	100
Figure 5-18	SWAN Wave Model Validation – Site 3 Beacon C7	101
Figure 5-19	Sediment Re-suspension Validation – Trinity Bay	103
Figure 5-20	Sediment Re-suspension Validation – Yorkeys Knob	103
Figure 5-21	Sediment Re-suspension Validation – Palm Beach	103
Figure 5-22	Wet Tropics Plume Type Mean TSS Concentrations (from: Delvin et al., 2012b)	105
Figure 5-23	Barron River at Myola Recorded Daily Mean Discharge (top) and Estimated Mean TSS (bottom)	106
Figure 5-24	Barron River Flood Plume on 05/02/2011 - MODIS Satellite Image (top) and Predicted Surface TSS with Wind Vectors (bottom)	107
Figure 5-25	Barron River Flood Plume with West South-Westerly Winds - Surface Salinity (top) and Surface TSS (bottom)	109
Figure 5-26	Barron River Flood Plume with North-Easterly Winds - Surface Salinity (top) and Surface TSS (bottom)	110
Figure 6-1	Channel Design and Dredge Footprint Sub Areas	115
Figure 6-2	Base Case Capital Assessment period wind rose (right) compared with the long term average (left) for these months.	118
Figure 6-3	12 Month Re-suspension Assessment period wind rose (right) compared with the long term average (left).	118
Figure 6-4	CSDP Base Case Schedule Assuming No Overflow (Pro-Dredging, 2014)	119
Figure 6-5	Trinity Bay Baseline Turbidity Statistics	122
Figure 6-6	Base Case Capital Program 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)	126
Figure 6-7	Base Case Capital Program 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)	127

Figure 6-8 Base Case Capital Program 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 128
Figure 6-9 Base Case Capital Program 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 129
Figure 6-10 Base Case Capital Program Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom) 130
Figure 6-11 Alternative Case Capital Program 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 132
Figure 6-12 Alternative Case Capital Program 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 133
Figure 6-13 Alternative Case Capital Program 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 134
Figure 6-14 Alternative Case Capital Program 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 135
Figure 6-15 Alternative Case Capital Program Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom) 136
Figure 6-16 “Worst Case” Soft Material Dredging 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 138
Figure 6-17 “Worst Case” Soft Material Dredging 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 139
Figure 6-18 “Worst Case” Soft Material Dredging 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 140
Figure 6-19 “Worst Case” Soft Material Dredging 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 141
Figure 6-20 “Worst Case” Soft Material Dredging Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom) 142
Figure 6-21 “Worst Case” Stiff Material Dredging 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 144
Figure 6-22 “Worst Case” Stiff Material Dredging 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 145
Figure 6-23 “Worst Case” Stiff Material Dredging 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 146
Figure 6-24 “Worst Case” Stiff Material Dredging 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 147
Figure 6-25 “Worst Case” Stiff Material Dredging Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom) 148
Figure 6-26 12mo Re-suspension Period 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 150
Figure 6-27 12mo Re-suspension Period 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 151
Figure 6-28 12mo Re-suspension Period 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 152

Figure 6-29 12mo Re-suspension Period 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 153
Figure 6-30 12mo Re-suspension Period Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom) 154
Figure 6-31 “Worst Case” Re-suspension Period 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 156
Figure 6-32 “Worst Case” Re-suspension Period 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 157
Figure 6-33 “Worst Case” Re-suspension Period 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 158
Figure 6-34 “Worst Case” Re-suspension Period 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom) 159
Figure 6-35 “Worst Case” Re-suspension Period Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom) 160
Figure 7-1 Cairns Shipping Channel and Surrounds Bed Elevation: Existing case (left); Developed case (middle) and Difference (right) 165
Figure 7-2 Impact Reporting Points and Transect Locations 166
Figure 7-3 Modelled Spring Tide Flood Currents and Impacts. Existing case (left); Developed case (middle) and Impacts (right) 169
Figure 7-4 Modelled Spring Tide Flood Currents and Impacts – zoomed. Existing case (left); Developed case (middle) and Impacts (right) 170
Figure 7-5 Modelled Spring Tide Ebb Currents and Impacts. Existing case (left); Developed case (middle) and Impacts (right) 171
Figure 7-6 Modelled Spring Tide Ebb Currents and Impacts – zoomed. Existing case (left); Developed case (middle) and Impacts (right) 172
Figure 7-7 Existing and Developed Case Current Speed Timeseries (Points 1 to 3) 173
Figure 7-8 Existing and Developed Case Current Speed Timeseries (Points 3 to 6) 174
Figure 7-9 Existing and Developed Case Current Speed Timeseries (Point 7) 175
Figure 7-10 Existing and Developed Case Water Level Timeseries (Points 1 to 3) 176
Figure 7-11 Existing and Developed Case Water Level Timeseries (Points 4 to 6) 177
Figure 7-12 Existing and Developed Case Water Level Timeseries (Point 7). 178
Figure 7-13 Existing and Developed Case Flow Timeseries at the Transects shown in Figure 7-2 179
Figure 7-14 Modelled 95%ile Current Related Bed Shear Stress (N/m2) and Impacts. Existing case (left); Developed case (middle) and Impacts (right) 181
Figure 7-15 Modelled 95%ile Current Related Bed Shear Stress (N/m2) – zoom. Existing case (left); Developed case (middle) and Impacts (right) 182
Figure 7-16 Existing and Developed Case Surge Level Timeseries (Point 1 – Inner Port). 183
Figure 7-17 Modelled Peak Surge Level (m): Existing case (left); Developed case (middle) and Impacts (right) 184
Figure 7-18 100m Grid Modelled Typical South-Easterly Wave Case (09/04/2013 13:00) 186

Figure 7-19	100m Grid Modelled Typical Northerly Wave Case (24/01/2013 07:00)	186
Figure 7-20	25m Grid Typical South-Easterly Wave Case: Base case (top); Developed case (middle); Difference (bottom)	187
Figure 7-21	25m Grid Northerly Wave Case: Base case (top); Developed case (middle); Difference (bottom)	188
Figure 7-22	Existing Case and Developed Case Wave Parameter Timeseries Comparison (Nearshore Location Point 3 in Figure 7-2)	189
Figure 7-23	Existing Case and Developed Case Wave Parameter Timeseries Comparison (Nearshore Location Point 4 in Figure 7-2)	190
Figure 7-24	Modelled Net Sediment Transport (m3/m/year): Existing case (left); Developed case (middle) and Impacts (right)	192
Figure 7-25	Modelled Existing Case and Developed Case Channel Siltation	193
Figure B-1	Example TUFLOW FV Hydrodynamic Model Simulation Control File (continued over page)	B-2
Figure B-2	Example TUFLOW FV Hydrodynamic Model Simulation Control File (continued from previous page)	B-3
Figure C-1	Top 50% and Bottom 50% Current Calibration – DMPA 01/03/2013 to 15/03/2013	C-2
Figure C-2	Top 50% and Bottom 50% Current Calibration – DMPA 15/03/2013 to 01/04/2013	C-3
Figure C-3	Top 50% and Bottom 50% Current Calibration –DMPA 01/04/2013 to 15/04/2013	C-4
Figure C-4	Top 50% and Bottom 50% Current Calibration – DMPA 15/04/2013 to 01/05/2013	C-5
Figure C-5	Top 50% and Bottom 50% Current Calibration – DMPA 01/05/2013 to 15/05/2013	C-6
Figure C-6	Top 50% and Bottom 50% Current Calibration – DMPA 15/05/2013 to 01/06/2013	C-7
Figure C-7	Top 50% and Bottom 50% Current Calibration – DMPA 01/06/2013 to 15/06/2013	C-8
Figure C-8	Top 50% and Bottom 50% Current Validation – Site 2 01/03/2013 to 15/03/2013	C-9
Figure C-9	Top 50% and Bottom 50% Current Calibration – Site 2 15/03/2013 to 01/04/2013	C-10
Figure C-10	Top 50% and Bottom 50% Current Calibration – Site 2 15/04/2013 to 01/05/2013	C-11
Figure C-11	Top 50% and Bottom 50% Current Calibration – Site 2 15/04/2013 to 01/05/2013	C-12
Figure C-12	Top 50% and Bottom 50% Current Calibration – Site 2 01/05/2013 to 15/05/2013	C-13
Figure C-13	Top 50% and Bottom 50% Current Calibration – Site 2 15/05/2013 to 01/06/2013	C-14

Figure C-14	Top 50% and Bottom 50% Current Calibration – Site 2 01/06/2013 to 15/06/2013	C-15
Figure C-15	Top 50% and Bottom 50% Current Calibration – Beacon C7 01/03/2013 to 15/03/2013	C-16
Figure C-16	Top 50% and Bottom 50% Current Calibration – Beacon C7 15/03/2013 to 01/04/2013	C-17
Figure C-17	Top 50% and Bottom 50% Current Calibration – Beacon C7 01/04/2013 to 15/04/2013	C-18
Figure C-18	Top 50% and Bottom 50% Current Calibration – Beacon C7 15/04/2013 to 01/05/2013	C-19
Figure C-19	Top 50% and Bottom 50% Current Calibration – Beacon C7 01/05/2013 to 15/05/2013	C-20
Figure C-20	Top 50% and Bottom 50% Current Calibration – Beacon C7 15/05/2013 to 01/06/2013	C-21
Figure C-21	Top 50% and Bottom 50% Current Calibration – Beacon C7 01/06/2013 to 15/06/2013	C-22
Figure C-22	Top 50% and Bottom 50% Current Calibration – Beacon C11 01/03/2013 to 15/03/2013	C-23
Figure C-23	Top 50% and Bottom 50% Current Calibration – Beacon C11 15/03/2013 to 01/04/2013	C-24
Figure C-24	Top 50% and Bottom 50% Current Calibration – Beacon C11 01/04/2013 to 15/04/2013	C-25
Figure C-25	Top 50% and Bottom 50% Current Calibration – Beacon C11 15/04/2013 to 01/05/2013	C-26
Figure C-26	Top 50% and Bottom 50% Current Calibration – Beacon C11 01/05/2013 to 15/05/2013	C-27
Figure C-27	Top 50% and Bottom 50% Current Calibration – Beacon C11 15/05/2013 to 01/06/2013	C-28
Figure C-28	Top 50% and Bottom 50% Current Calibration – Beacon C11 01/06/2013 to 15/06/2013	C-29
Figure D-1	Current Polar Plot Calibration – DMPA Top 2m of Water Column	D-2
Figure D-2	Current Polar Plot Calibration – DMPA Bottom 2m of Water Column	D-3
Figure D-3	Current Polar Plot Calibration – Site 2 Top 2m of Water Column	D-4
Figure D-4	Current Polar Plot Calibration – Site 2 Bottom 2m of Water Column	D-5
Figure D-5	Current Polar Plot Calibration – Beacon C7 Top 2m of Water Column	D-6
Figure D-6	Current Polar Plot Calibration – Beacon C7 Bottom 2m of Water Column	D-7
Figure D-7	Current Polar Plot Calibration – Beacon C11 Top 2m of Water Column	D-8
Figure D-8	Current Polar Plot Calibration – Beacon C11 Bottom 2m of Water Column	D-9
Figure E-1	Current Q-Q Plot – DMPA	E-2
Figure E-2	Current Q-Q Plot – Site 2	E-3
Figure E-3	Current Q-Q Plot – Beacon C7	E-4

Figure E-4	Current Q-Q Plot – Beacon C11	E-5
Figure F-1	Top 50% and Bottom 50% Current Validation – DMPA 01/07/2013 to 15/07/2013	F-2
Figure F-2	Top 50% and Bottom 50% Current Validation – DMPA 01/07/2013 to 15/07/2013	F-3
Figure F-3	Top 50% and Bottom 50% Current Validation – DMPA 16/07/2013 to 01/08/2013	F-4
Figure F-4	Top 50% and Bottom 50% Current Validation – DMPA 01/08/2013 to 15/08/2013	F-5
Figure F-5	Top 50% and Bottom 50% Current Validation – DMPA 15/08/2013 to 01/09/2013	F-6
Figure F-6	Top 50% and Bottom 50% Current Validation – DMPA 01/09/2013 to 15/09/2013	F-7
Figure F-7	Top 50% and Bottom 50% Current Validation – DMPA 15/07/2013 to 01/10/2013	F-8
Figure F-8	Top 50% and Bottom 50% Current Validation – DMPA 01/10/2013 to 15/10/2013	F-9
Figure F-9	Top 50% and Bottom 50% Current Validation – Beacon C7 01/07/2013 to 15/07/2013	F-10
Figure F-10	Top 50% and Bottom 50% Current Validation – Beacon C7 15/07/2013 to 01/08/2013	F-11
Figure F-11	Top 50% and Bottom 50% Current Validation – Beacon C7 01/08/2013 to 15/08/2013	F-12
Figure F-12	Top 50% and Bottom 50% Current Validation – Beacon C7 15/08/2013 to 01/09/2013	F-13
Figure F-13	Top 50% and Bottom 50% Current Validation – Beacon C7 01/09/2013 to 15/09/2013	F-14
Figure F-14	Top 50% and Bottom 50% Current Validation – Beacon C7 15/09/2013 to 01/10/2013	F-15
Figure F-15	Top 50% and Bottom 50% Current Validation – Beacon C7 01/10/2013 to 15/10/2013	F-16
Figure G-1	Current Polar Plot Calibration – Site 1 Bottom 2m of Water Column	G-2
Figure G-2	Current Polar Plot Calibration – Site 1 Tom 2m of Water Column	G-3
Figure G-3	Current Polar Plot Calibration – Site 3 Bottom 2m of Water Column	G-4
Figure G-4	Current Polar Plot Calibration – Site 3 Top 2m of Water Column	G-5
Figure H-1	Current Q-Q Plot – DMPA	H-2
Figure H-2	Current Q-Q Plot – Beacon C7	H-3
Figure I-1	Turbidity Timeseries Locations	I-2
Figure I-2	Base Case Capital Program Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)	I-3

Figure I-3 Base Case Capital Program Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-4
Figure I-4 Base Case Capital Program Bottom 1m Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-5
Figure I-5 Base Case Capital Program Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-6
Figure I-6 Alternative Case Capital Program Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-7
Figure I-7 Alternative Case Capital Program Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-8
Figure I-8 Alternative Case Capital Program Bottom 1m Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-9
Figure I-9 Alternative Case Capital Program Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-10
Figure I-10 “Worst Case” Soft Material Dredging Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-11
Figure I-11 “Worst Case” Soft Material Dredging Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-12
Figure I-12 “Worst Case” Soft Material Dredging Bottom 1mTurbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-13
Figure I-13 “Worst Case” Soft Material Dredging Bottom 1mTurbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-14
Figure I-14 “Worst Case” Stiff Material Dredging Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-15
Figure I-15 “Worst Case” Stiff Material Dredging Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-16
Figure I-16 “Worst Case” Stiff Material Dredging Bottom 1mTurbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-17
Figure I-17 “Worst Case” Stiff Material Dredging Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-18
Figure I-18 12mo Re-suspension Period Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-19
Figure I-19 12mo Re-suspension Period Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-20
Figure I-20 12mo Re-suspension Period Bottom 1mTurbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-21
Figure I-21 12mo Re-suspension Period Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-22
Figure I-22 “Worst Case” DMPA Re-suspension Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-23
Figure I-23 “Worst Case” DMPA Re-suspension Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-24

Figure I-24 “Worst Case” DMPA Re-suspension Bottom 1m Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom) I-25
Figure I-25 “Worst Case” DMPA Re-suspension Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom) I-26

List of Tables

Table 2-1 GBRMPA Guidelines Cross-Check Summary 18
Table 3-1 Model Calibration Continuous Data Recording Locations and Instruments Summary 24
Table 3-2 Simulation Period and Long Term Average Barron River Flow Summary 27
Table 3-3 Top 10 Significant Wave Heights Recorded at the Cairns Buoy prior to the 2012/2013 Wet Season (data provided by DSITIA) 28
Table 3-4 Summary of TUFLOW FV Model Configuration and Parameterisations 29
Table 3-5 Summary of SWAN Model Configuration and Parameterisations 55
Table 3-6 Characteristics of Simulated Sediment Classes 65
Table 5-1 Barron River TSS Annual Loads (data provided by RRRC) 105
Table 6-1 Characteristics of Simulated Sediment Classes 111
Table 6-2 Volumes of material to be removed per area and per soil classification (Pro-Dredging, 2014) 113
Table 6-3 Adopted TSHD production parameters (Pro-Dredging, 2014) 114
Table 6-4 Adopted BHD production parameters (Pro-Dredging, 2014) 114
Table 6-5 Adopted TSHD Plume Source Parameters (Pro-Dredging, 2014) 116
Table 6-6 Adopted BHD Plume Source Parameters (Pro-Dredging, 2014) 117
Table 6-7 Dredge Plume Sediment Fraction Breakdown (Golder, 2013) 117
Table 6-8 Turbidity percentile contour limits 122
Table 6-9 Sedimentation percentile contour limits 123
Table 6-10 Predicted Dispersion from the DMPA over a 12-month Period 163
Table 6-11 Predicted Dispersion from the DMPA during Worst Case Conditions 163
Table 7-1 Tidal Prism Impacts 178

1 Introduction

1.1 Background

Far North Queensland Ports Corporation Limited (trading as Ports North) has initiated planning for the Cairns Shipping Development Project (CSDP). The aim of this project is to expand tourism cruise ship opportunities by allowing larger cruise vessels to enter the Port of Cairns.

The CSDP involves upgrading of the following Port infrastructure:

- Widening and deepening of the existing outer shipping channel, which will result in some lengthening of the existing channel.
- Widening and deepening of the existing inner harbour channel and cruise shipping swing basin and establishment of a new shipping swing basin to enable future expansion of the HMAS Cairns Navy base.
- Structural upgrade of the existing cruise shipping wharves 1-5 to accommodate larger and heavier cruise ships.
- Provision and upgrade of ship services to the cruise shipping wharves, including fuel supply, potable water and fire fighting services.

A key part of the harbour and channel development works will involve capital dredging of approximately 4.4 million m^3 (Mm^3) of *in-situ* material. This report presents the development of numerical models and the initial stage of model calibration. These tools are to assist the environmental assessment of the proposed activities associated with the CSDP.

1.2 Objectives and Purpose

Key objectives of the hydrodynamic modelling assessment of the CSDP:

(1) Development of a suite of numerical modelling tools capable of simulating the hydrodynamic, wave and sedimentation processes relevant to the study area.

(2) Assessment of the implications of the specific shipping channel design with respect to currents, coastal processes and sedimentation.

(3) Assessment of turbid plume dispersion associated with dredging (including dredge material placement) for consideration of potential environmental impacts.

(4) Documentation of the modelling and findings.

1.3 Proposed Port Development for Assessment

A map showing the existing channel outline and the proposed upgrade is provided in Figure 1-1.

1.3.1 Channel Upgrade

The existing outer channel at the Port of Cairns is approximately 11.2km in length, 90m wide with a declared depth of -8.3mLAT. The inner channel extends for 2.4km in length and has variable width due to requirements for bends and swing basins.

The upgraded channel design is based on widening the existing channel to 130m and increasing the declared depth to -9.4mLAT. It also includes an extension of the existing channel for approximately 1km offshore.

The channel will extend outside of the nominated widths due to the channel batters, which will extend from the channel bed to the natural seabed level at a typical slope of 1 in 4. Furthermore, the channel will be dredged to depths greater than the declared depth in some areas (up to a maximum of 1.7m) to allow for siltation between maintenance dredging campaigns.

1.3.2 Swing Basin Upgrade

The proposed dredging will also include an expansion of the existing Crystal swing basin adjacent to Wharves 1-3 for specific use by cruise ships. Furthermore, a relocation of the existing main swing basin to a location further south close to Tropical Reef Shipyard is proposed to provide future capacity for expansion of HMAS Cairns and to provide a wider and deeper inner channel for the full length of the Inner Port. The relocated main swing basin will be designated as the “Smith’s Creek” swing basin.

1.3.3 Capital Dredging

It is anticipated that the following dredging plant will be required:

- At least one medium size trailing suction hopper dredge (TSHD) with hopper capacity of about 3,000m^3 to 6,000m^3;
- Backhoe dredger, barges with tugs and bed leveller; and
- Work boats / survey boat.

An estimated total capital dredge volume of 4.4Mm^3 will be required for the channel and swing basin upgrades. The main component of the dredge volume is related to dredging of the Outer Channel.

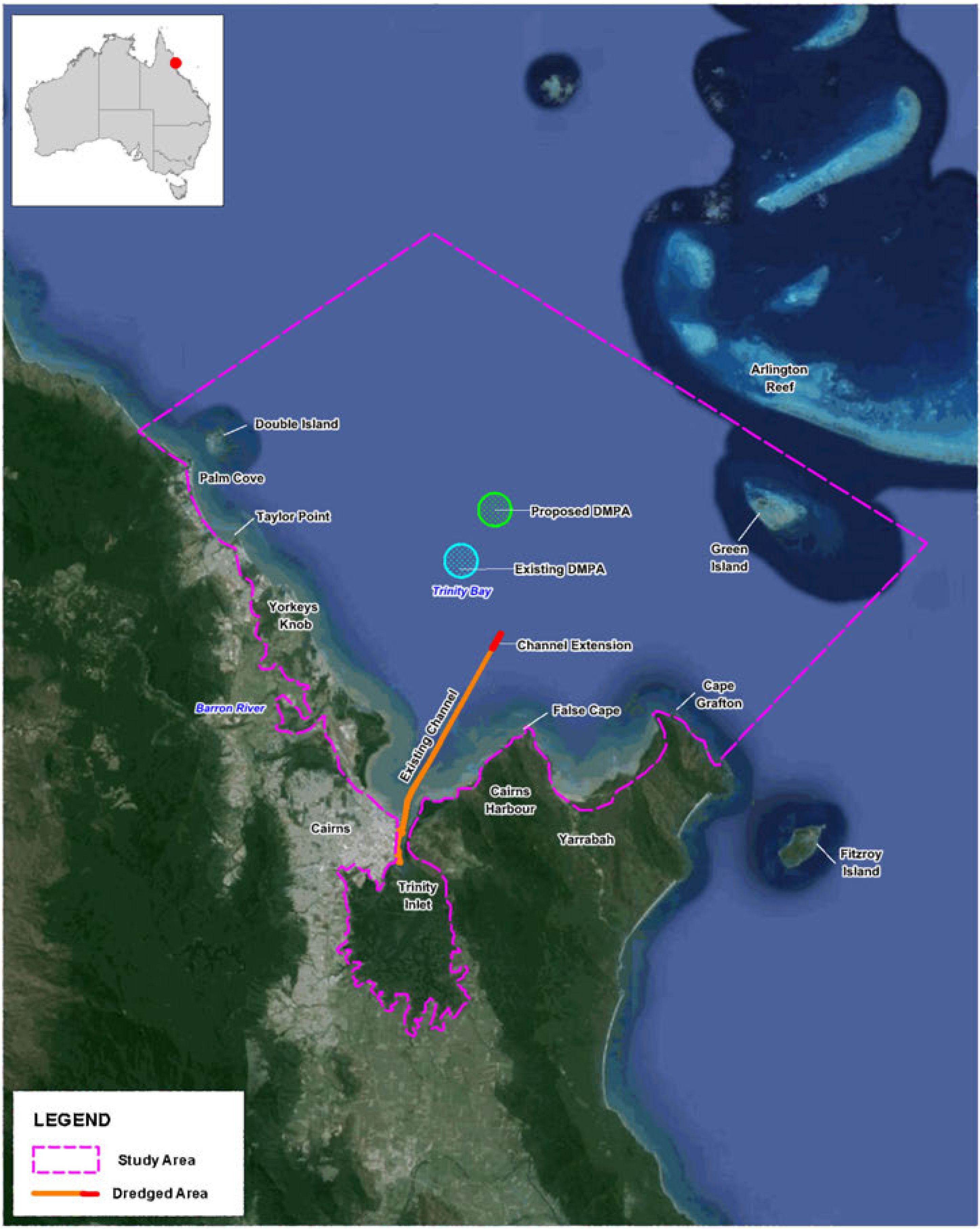
1.3.4 Maintenance Dredging

The current channel maintenance dredging programme is undertaken predominantly by the TSHD *Brisbane* and it is envisaged that future channel maintenance dredging will also be undertaken using this TSHD.

1.4 Offshore Disposal

A variety of Dredge Material Placement Area (DMPA) options (both terrestrial and marine) have been assessed in detail as part of the CSDP EIS. This process identified a new marine DMPA site for detailed impact assessment (refer to CSDP EIS Appendix D – Assessment of Dredge Material Placement Options). Figure 1-1 shows the existing DMPA and the proposed marine DMPA assessed as part of the CSDP EIS.

It is noted that the effects of disposal activities at the existing DMPA have been extensively studied. Previous investigations showed that the existing DMPA is performing satisfactorily and not resulting in ongoing impacts to nearby sensitive areas (e.g. Carter et al. 2002, Environment North 2005, WorleyParsons 2010). In comparison to the existing DMPA, the new marine DMPA assessed as part of the CSDP EIS is located further offshore in deeper water. This location was selected to minimise the likelihood of placed material re-suspension.



Title: **Study Area**

Figure: 1-1

Rev: A

N

0 5 10km

Approx.Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_007_Study Area.wor

2 Numerical Model Descriptions

Multiple numerical models have been used to undertake the coastal hydrodynamic and sedimentation process assessments relevant to the CSDP. These tools are introduced and described in this Section.

2.1 Hydrodynamic (TUFLOW FV)

The hydrodynamic modelling component of these assessments has been undertaken using the TUFLOW FV software, which is developed and distributed by BMT WBM (http://www.tuflow.com/Tuflow%20FV.aspx). TUFLOW FV is a numerical hydrodynamic model for the two-dimensional (2D) and three-dimensional (3D) Non-Linear Shallow Water Equations (NLSWE). The model is suitable for solving a wide range of hydrodynamic systems ranging in scale from open channels and floodplains, through estuaries to coasts and oceans.

The Finite-Volume (FV) numerical scheme employed by TUFLOW FV is capable of solving the NLSWE on both structured rectilinear grids and unstructured meshes comprised of triangular and quadrilateral elements. The flexible mesh allows for seamless boundary fitting along complex coastlines or open channels as well as accurately and efficiently representing complex bathymetries with a minimum number of computational elements. The flexible mesh capability is particularly efficient at resolving a range of scales in a single model without requiring multiple domain nesting. Further details regarding the numerical scheme employed by TUFLOW FV are provided in the TUFLOW FV Science Manual (BMT WBM, 2013).

2.1.1 Advection Dispersion Modelling

A system for modelling the natural re-suspension of sediment and the advection and dispersion of a sediment plume produced during dredging has been developed as part of this study using the Sediment Transport (ST) module of TUFLOW FV coupled with the 3D hydrodynamic and spectral wave models.

To accurately capture advection and dispersion, the model requires input of dispersion coefficients and sediment characteristics. These inputs determine the resultant spread of fluid and suspended matter throughout the model domain. The choice of dispersion coefficients is discussed in Section 3.5.1.

The turbulence model (GOTM, refer Section 2.1.3.4) was coupled with the hydrodynamic model for the purposes of deriving vertical turbulent mixing parameters.

The ST module is described in Section 2.3.

2.1.2 Model Domain, Mesh and Bathymetry

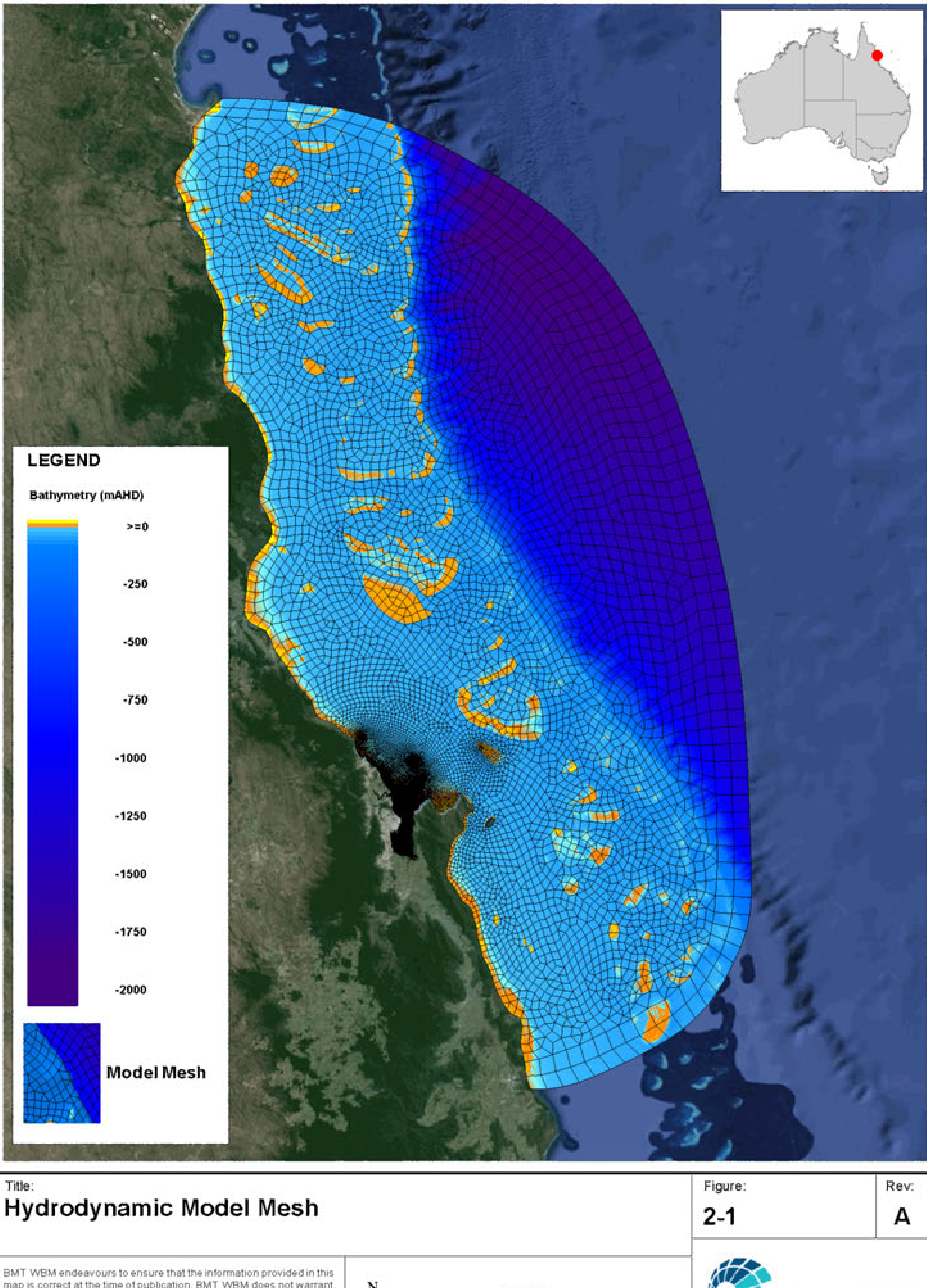
The hydrodynamic model domain is shown in Figure 2-1 and extends from Innisfail in the south to beyond Cooktown and includes the Great Barrier Reef lagoon, offshore reefs, Trinity Inlet and the lower Barron River.

The model consists of 33,336 surface mesh cells with resolution varying from 5km (mesh cell side length) at the offshore boundary, increasing to 20m in the vicinity of shipping channels and port infrastructure. Figure 2-2 shows detail of the model mesh in the vicinity of the Port of Cairns.

Figure 2-1 and Figure 2-2 also show the model bathymetry (note with different bathymetry elevation colour schemes) which has been derived from the following sources, listed in decreasing order of priority:

- Hydrographic surveys of the Port of Cairns, Cairns shipping channel and DMPA provided by Ports North;
- Australian Hydrographic Service Navigation Chart AUS264 (Cairns Southern Sheet);
- Australian Hydrographic Service Navigation Chart AUS263 (Cairns Northern Sheet);
- Australian Hydrographic Service Navigation Chart AUS262 (Approaches to Cairns); and
- James Cook University Project 3DGBR (Beaman, 2010).

A hybrid z-coordinate vertical grid configuration with 4 surface "sigma" layers was adopted for the CSDP hydrodynamic model. The z-coordinate scheme, with variable bottom layer thickness, is generally better at simulating the stratified ocean environment than a terrain following sigma-coordinate scheme. The multiple surface "sigma" layers allows for a higher resolution of the water surface boundary layer while tracking tidal water surface variations. The vertical grid had 11 layers representing the top 10m of the water column and 24 layers representing the top 50m. The deepest sections of the coastal model domain (>2000m deep) were represented with 34 layers.



Title:

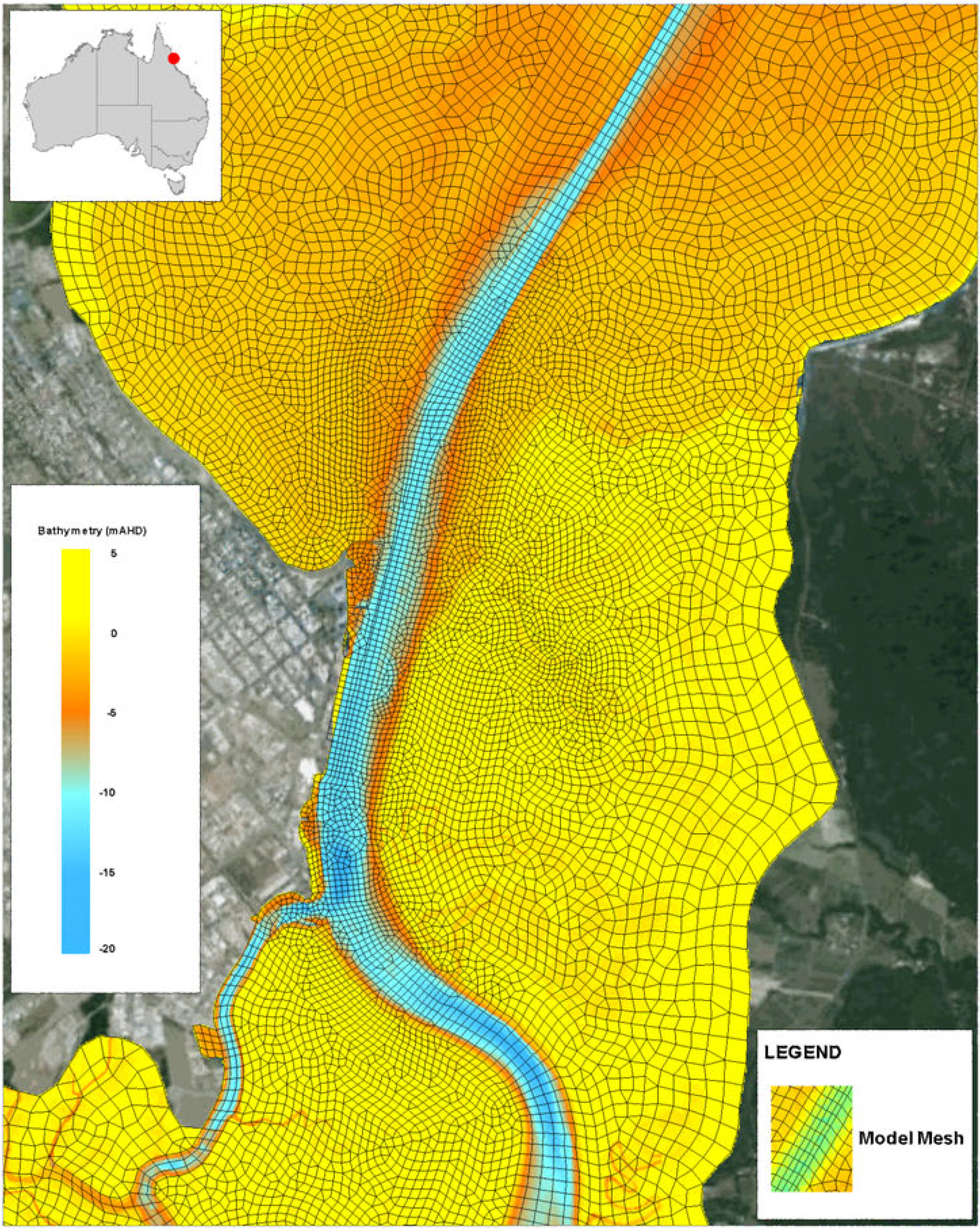
Hydrodynamic Model Mesh

Figure: 2-1

Rev: A

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_002_TUFLOW_extents.wor



Title:

TUFLOW FV Hydrodynamic Model Mesh Detail

Figure: 2-2

Rev: A

N

0 1 2km

Approx.Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_005_TUFLOWFV_detail.wor

2.1.3 Boundary Conditions

The local hydrodynamics estimated by TUFLOW FV are influenced by boundary condition inputs. Information regarding appropriate boundary condition forcing for the study area was obtained from the following sources:

- Local data recordings;
- Output from a regional tide model developed by BMT WBM; and
- Output from global models developed by third-parties.

Details of the specific information sources used to develop boundary conditions applied to the hydrodynamic model is provided below.

2.1.3.1 Wetting and Drying

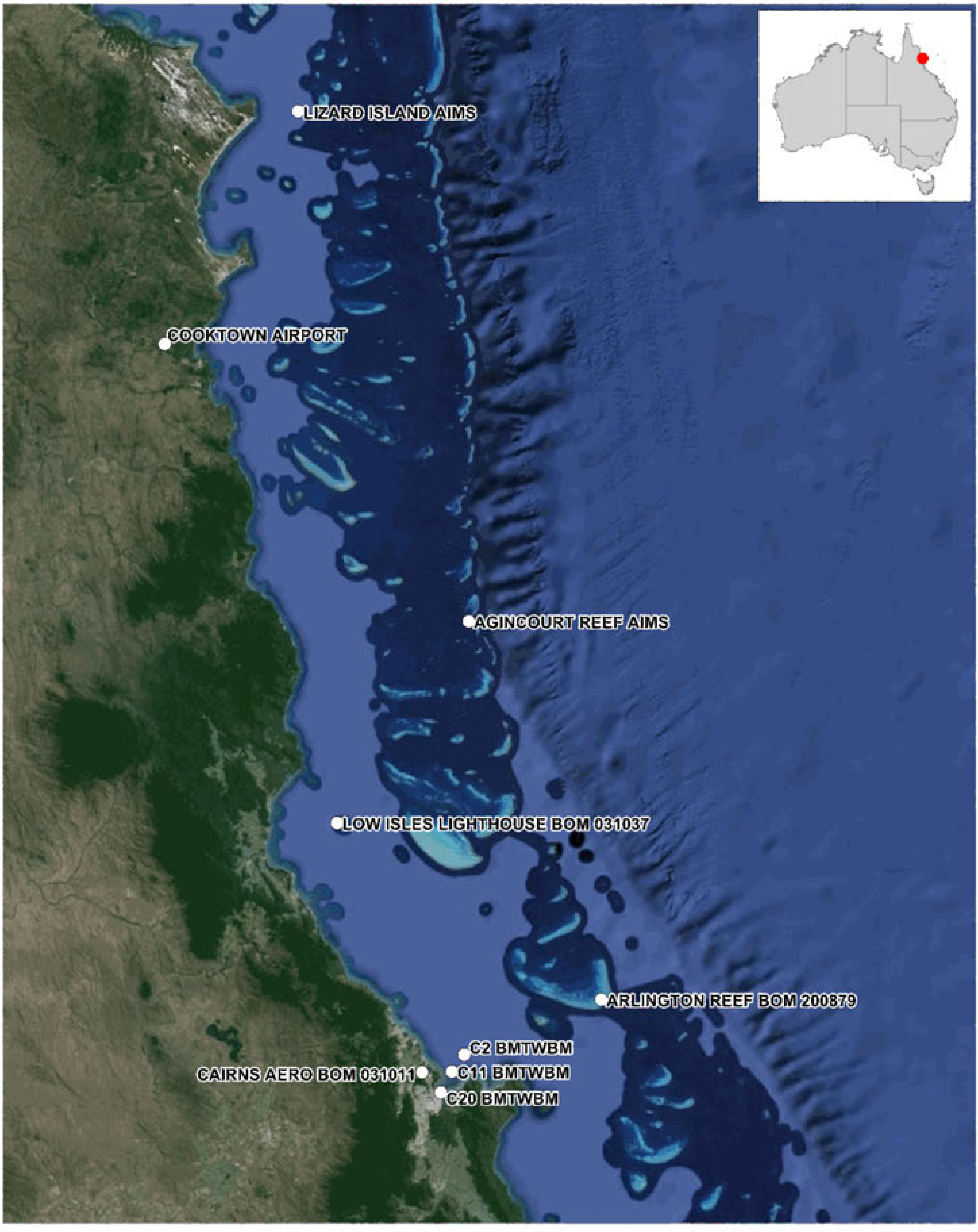
TUFLOW FV simulates the wetting and drying of intertidal areas. The minimum wetting and drying depths were set to 0.01m and 0.1m respectively. Numerically, the drying value corresponds to a minimum depth below which the mesh cell is dropped from computations (subject to the status of surrounding cells). The wet value corresponds to a minimum depth below which cell momentum is set to zero, in order to avoid unphysical velocities at very low depths.

2.1.3.2 Wind

The wind boundary condition applied to both the hydrodynamic and wave model (refer Section 2.2) was derived from targeted measurements along the existing shipping channel commissioned by Ports North and historical wind records supplied by:

- Commonwealth Bureau of Meteorology (BOM); and
- Australian Institute of Marine Science (AIMS) (http://www.aims.gov.au/docs/data/data.html).

The locations of the various weather stations and their names are indicated in Figure 2-3. The wind data was converted to 10m above mean sea level following the log-law conversion described in the Coastal Engineering Manual (U.S. Army Corps of Engineers, 2002). The processed weather station data was interpolated temporally and spatially on to a grid covering the model domain using scattered interpolation techniques. The constructed wind field methodology is illustrated in Figure 2-4. While this approach provides a very good representation of the wind field throughout the study area that is suitable for hydrodynamic and wave modelling purposes, it is noted that the precise details of the transition of winds over-land to over-sea are not captured.



Title:
Weather Station Locations

Figure: 2-3

Rev: A

BMT WBM
www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_003_weather_stations .wor

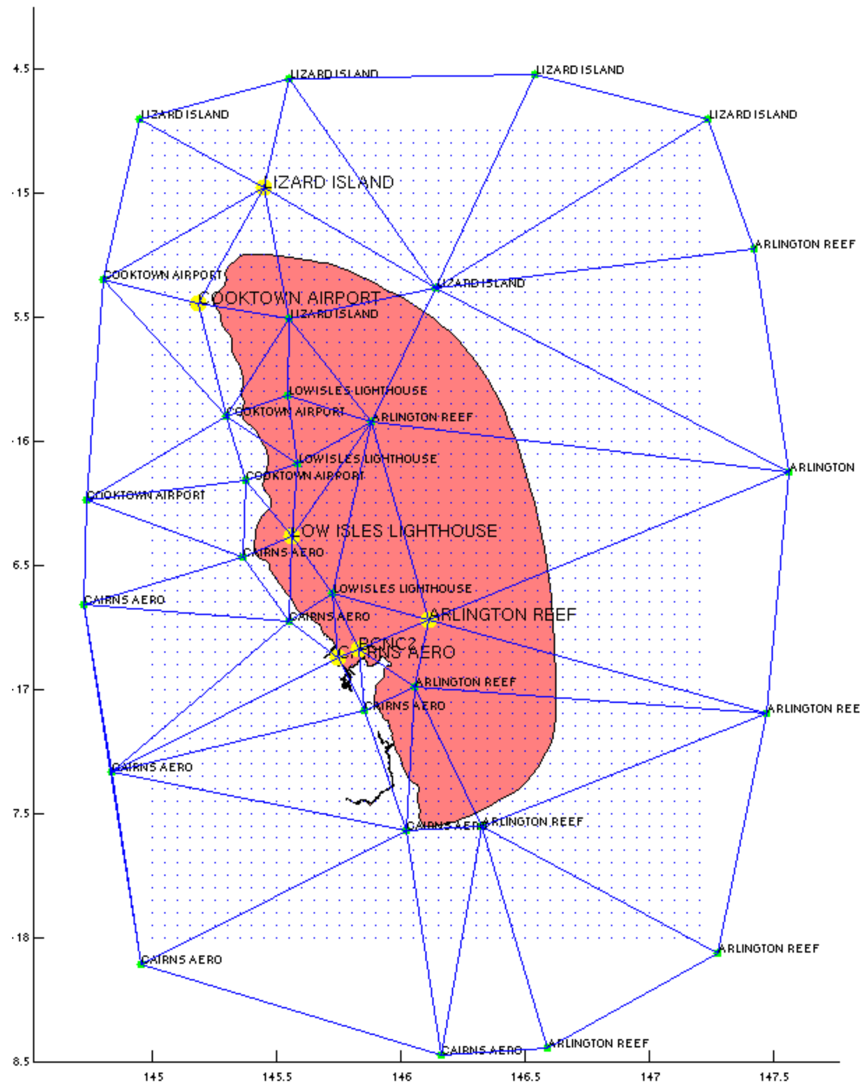


Figure 2-4 Illustration of Constructed Wind Field Methodology

2.1.3.3 Tide

The developed model extent included an open boundary that required temporal definition of water surface elevations. Due to the large extent of the model domain, tidal elevations vary spatially and temporally along the length of the offshore boundary. Tidal data along the offshore boundary was extracted from a calibrated tide model of the Coral Sea developed by BMT WBM. The spatial extent of the Coral Sea model and the encompassed Cairns model are shown in Figure 2-5. The Coral Sea tide model boundary conditions were generated using tidal constituents supplied by the Bureau of Meteorology, National Tide Centre (NTC). The locations for NTC tidal constituent data are indicated by the yellow diamonds in Figure 2-5.

2.1.3.4 Regional Currents, Salinity and Temperature

The model calibration process suggested regional current forcing from the East Australian Current (EAC) influenced the study area at certain times. Furthermore, 3D temperature and salinity stratification effects are also expected to influence vertical velocity structures and hence overall circulation throughout the study area. The model was therefore provided with regional current forcing (residual water level, current magnitude and direction), temperature and salinity profiles at the open boundary. These were derived from the ocean general circulation model, HYCOM (http://hycom.org/) and varied both in space (longitude, latitude and elevation) and time.

The General Ocean Turbulence Model (GOTM) was coupled with the 3D TUFLOW FV hydrodynamic model in order to simulate the vertical mixing processes in the presence of density stratification (http://www.gotm.net/).

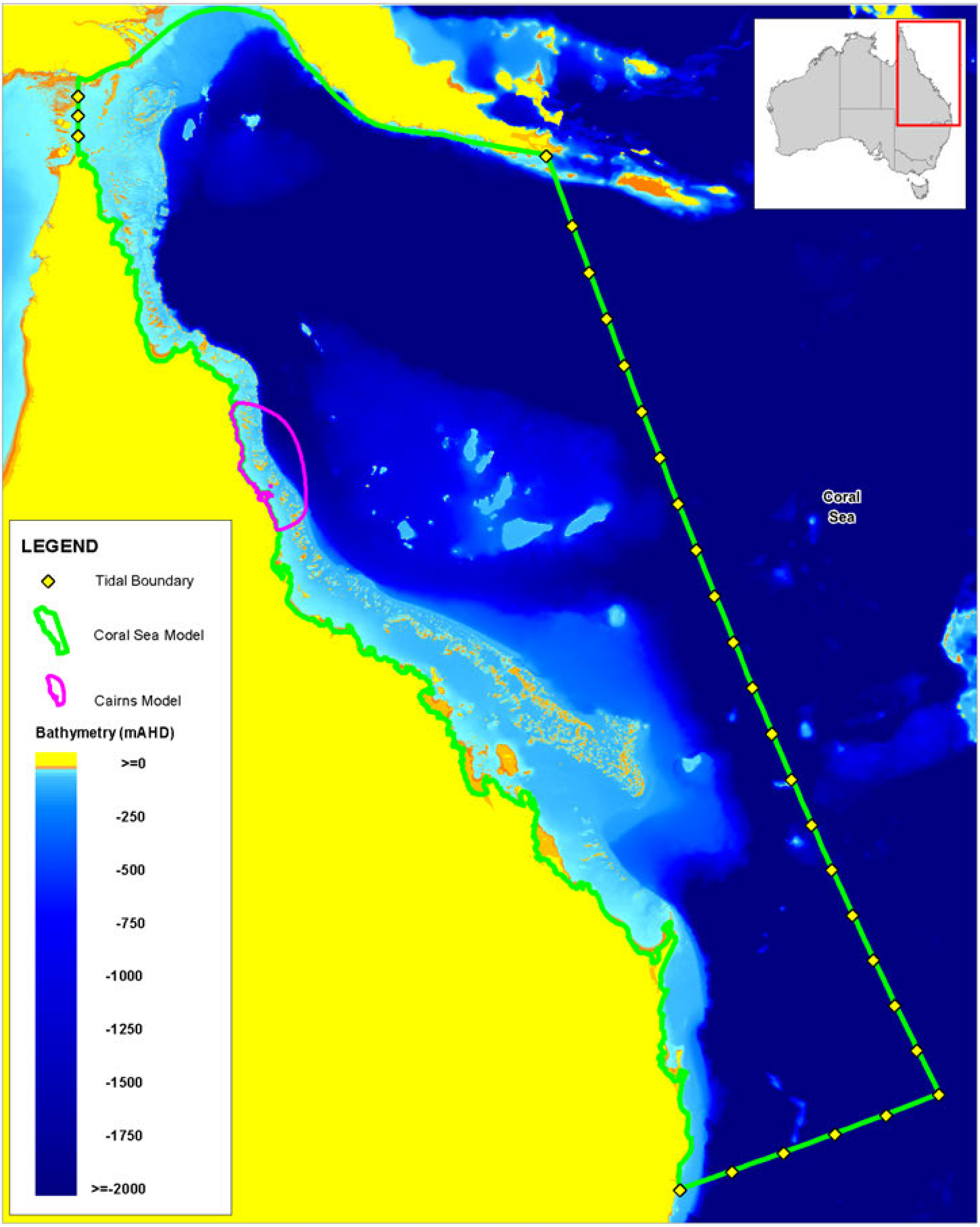
The model was warmed up for a minimum period of 6 weeks prior to all calibration and impact assessments, in order to develop the internal salinity and temperature distributions contributing to density stratification.

2.1.3.5 Air Temperature, Radiation, Precipitation and Humidity

Atmospheric heat fluxes and water column heat dynamics were simulated internally within TUFLOW FV. Boundary condition data including air temperature, long and short wave radiation, precipitation and relative humidity were derived from global NCEP model reanalyses (http://www.ncep.noaa.gov/). These model input fields were spatially uniform but varied in time in order to represent both seasonal and higher-frequency variations (e.g. diurnal).

2.1.3.6 Fluvial Discharge

Freshwater flow characteristics (mean discharge, salinity and temperature) in the Barron, Russell and Mulgrave Rivers were obtained from DNRM via the online “Watershed” data delivery service (http://watermonitoring.derm.qld.gov.au/host.htm).



Title:

TUFLOW FV Coral Sea Model Extent

Figure: 2-5

Rev: A

N

0 250 500km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_009_TUFLOWFV_Coral_Sea_model.wor

2.2 Waves (SWAN)

The wave modelling component of these assessments has been undertaken using the spectral wave model SWAN.

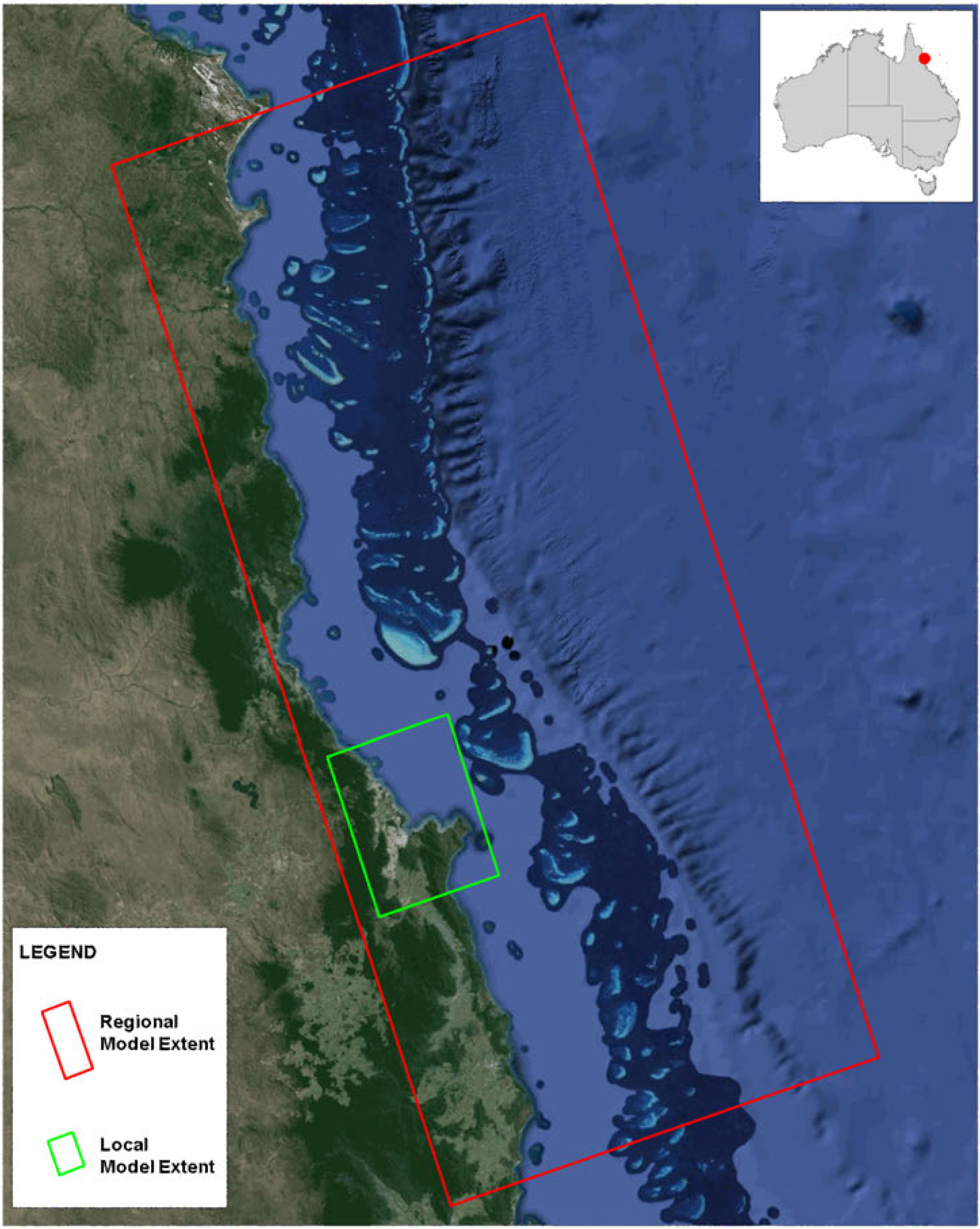
SWAN (Delft University of Technology, 2006) is a third-generation spectral wave model, which is capable of simulating the generation of waves by wind, dissipation by whitecapping, depth-induced wave breaking, bottom friction and wave-wave interactions in both deep and shallow water. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. This is a global industry standard modelling package that has been applied with reliable results to many investigations worldwide.

For sediment re-suspension and dispersion modelling the SWAN wave model was coupled with the 3D TUFLOW FV hydrodynamic and advection-dispersion models. This required the wave simulations to be completed separately, with the model output stored at hourly intervals on regular grids. During the subsequent sediment re-suspension and dispersion simulations, the wave conditions were linearly interpolated spatially from the grids to the TUFLOW FV mesh.

2.2.1 Model Domain and Bathymetry

A nested grid wave modelling approach has been adopted and is shown in Figure 2-6. The nested system comprises a regional (500m grid resolution) model covering the Great Barrier Reef lagoon and extending beyond the continental shelf. Wave propagation and forces imposed on the seabed in the vicinity of the Port of Cairns have been assessed using a local sub-model (100m grid resolution).

The wave model bathymetry has been derived from the same sources adopted for hydrodynamic modelling. The Digital Elevation Model (DEM) constructed from these combined sources is presented together with the hydrodynamic model mesh in Section 2.1.2.



Title:
Wave Model Nested Grids

Figure: 2-6

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

Kilometer
0 25 50km

BMT WBM
www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_001_SWAN_extents .wor

2.2.2 Boundary Conditions

Wave parameters in coastal areas estimated by SWAN are determined from the model inputs specified by the user. Appropriately representing the swell and wind conditions relevant to the study area are key inputs. The boundary conditions developed for the CSDP wave assessments are described below.

2.2.2.1 Swell

Offshore swell conditions were derived from global Wavewatch III model output (http://polar.ncep.noaa.gov/waves/) and applied to the offshore boundary of the regional wave model. The swell conditions were specified as spatially uniform but variable in time wave parameters (significant wave height, peak period, peak direction).

2.2.2.2 Wind

The constructed wind field applied to the TUFLOW FV hydrodynamic model and described in Section 2.1.3.2 was also applied to the wave models.

2.3 Sediment Transport (ST)

The resuspension, dispersion and settling of the natural bed sediments throughout the study area was estimated using the TUFLOW FV ST module coupled with the calibrated wave and hydrodynamic models. Various assessments also simulated the additional resuspension, dispersion and settling of sediment released into the water column and placed on the bed by proposed dredging activities.

The ST module allows for the simulation of multiple sediment fractions in suspension and within the bed. Ambient sediments have been represented by four (4) fractions ranging from cohesive clays and silts to non-cohesive sand fractions. Dredging related sediments have been represented by an additional four (4) fractions where applicable.

Bed shear stress is calculated in the ST model from the non-linear interaction of currents and waves using the procedure of Soulsby (1997). A Root-Mean-Square combined wave-current bed shear stress is used as the representative value in the sediment erosion and deposition calculations.

The modelled rate of sediment deposition, Q_d (g/m^2/s), is a function of the near-bed sediment concentration (TSS), the still-water fall velocity and the bed shear stress (τ_b), according to Equation 2-1. As such, sediment settling may be reduced below its still water value by the action of bed shear stress and associated mixing in the water column. Non-cohesive sediment fractions were modelled without a critical shear stress for deposition, meaning that they can potentially settle at all times regardless of the bed shear stress.

$$Q_d = w_s.TSS.\max\left(0, 1 - \frac{\tau_b}{\tau_{cd}}\right)$$

Equation 2-1

The rate of erosion, Q_e (g/m^2/s), is calculated according to Equation 2-2. Erosion will occur in response to the combined wave-current driven bed shear stress (τ_b) when this exceeds a critical threshold (τ_{ce}).

$$Q_e = E.\max\left(0, \frac{\tau_b}{\tau_{ce}} - 1\right)$$

Equation 2-2

It is commonly considered that the behaviour of sand-mud mixtures with sand content >90% will be dominated by the sand processes, with the mud being released from or trapped within the sand interstices (e.g. Whitehouse et al., 2000). Sediments with >5-15% mud content will tend to become cohesive with behaviour dominated by the finer fraction (e.g. Mitchener & Torfs, 1996). The majority of surficial bed sediments within the study area comprise sand-mud mixtures (>50% mud content) where the erosion properties are dominated by the cohesive sediment fractions. For this reason a common critical erosion threshold and rate-coefficient was applied across all cohesive and non-cohesive sediment fractions.

The ST model was extensively calibrated and validated using ambient suspended sediment measurements, as described in Sections 3.5 (calibration) and Section 5.5 (validation). Through the calibration process, ST model parameters were adjusted in order to provide the best agreement possible between model predictions and measurements. A critical component of the calibration process was the initialisation of bed material composition (i.e. the relative proportions of each sediment fraction at each computational node within the model domain). This was best achieved through running “bed warmup” simulations, which were undertaken prior to running the predictive assessments.

The General Ocean Turbulence Model (previously described in Section 3.3.1) was used to control the vertical mixing of sediment. A Smagorinsky model was used for the estimation of the horizontal sediment diffusivity.

2.4 GBRMPA Guidelines Cross-check

The following table provides a cross-check of the modelling approach applied in the CSDP EIS with the GBRMPA hydrodynamic modelling guidelines (GBRMPA, 2012).

Table 2-1 GBRMPA Guidelines Cross-Check Summary

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
2, 5	3D Hydrodynamic Model	All EIS modelling assessments undertaken using 3D TUFLOW FV HD Model.	2.1
5	3D Sediment Plume Modelling	All EIS plume modelling assessments undertaken using 3D TUFLOW FV ST Model.	2.3
6	Tidal forcing	Model uses spatially varying tidal forcing.	2.1.3.3
6	Wind forcing	Spatially/temporally varying windfield.	2.1.3.2
6	Wave forcing	SWAN wave model coupled with HD and ST models.	2.2
6	Ocean Current Forcing	Model simulates ocean currents. Uses HYCOM forcing at open boundaries.	2.1.3.4
6	Stratification represented	GOTM turbulence model with salinity/temperature density coupling. Barron River flows.	2.1.3.4
7	Hydrodynamic Calibration	HD model calibration undertaken. Independent validation undertaken.	3.3 5.3
7	Sediment Plume Calibration	ST model calibrated against long-term ambient turbidity datasets. Model validation performed against 2011 maintenance dredging monitoring data.	3.5 4 5.5
8	Wave-Current induced bed shear stress	Represented using Soulsby (1997).	2.3
8	Wave-induced mud fluidization	Wave induced resuspension mechanism included. Model calibrated/validated to suspended sediment measurements over multiple wave events.	3.5 4 5.5
10, 11, 12	Baseline Data	6-12 month baseline hydrodynamic datasets. 12 month baseline water quality dataset.	3.1 5.1
13a-c	Sediment Transport Modelling of multiple particle sizes	4 ambient sediment size fractions represented.	3.5.1 6.2.1
13d	Sediment size of material to be dredged	Additional 4 dredge sediment size fractions represented.	6.2.1
13e	Accurately represent ambient conditions	Model calibration/validation shows acceptable performance over a range of ambient conditions.	3 5

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
13e	Representative impact assessment periods.	Consideration of representativeness of impact assessment period in context of long-term climate.	3.2 5.2
13f	Represent dredging sediment sources	Advice about likely CSDP sources obtained from Pro Dredge (2014).	6.2.3
13g	Duration of simulations	Base case and alternative case simulations were conducted for entire CSDP dredging program.	6.2.4
14c	Model horizontal resolution	Flexible mesh model (TUFLOW FV) with sufficiently high resolution in key areas of interest. Sufficiently large domain to consider long term and far field fate of sediment.	2.1.2
14a-b	Model vertical scheme/resolution	Hybrid z-coordinate scheme with sigma surface layers. Up to 34 layers depending on depth.	2.1.2
15	Range of impact levels assessed	Range of physical impacts assessed in modelling report. Water Quality and Marine Ecology impacts derived from model outputs as described in these respective EIS chapters.	6 7
2, 3, 4, 16	Spatially based impact assessments	Model output used to derive spatial percentile contours of change to turbidity and sedimentation as a result of dredging activities. Spatial Zone of Influence also derived from model output.	6.3.2 6.4.2 6.5.2 6.6.2 6.7.2
16	Extent, severity & Duration of impacts assessed	A moving 30 day window analysis of the model output was used to derive the extent, severity and duration of turbidity impacts in the context of ambient turbidity statistics derived from baseline data. See also the Water Quality and Marine Ecology chapters.	6.2.5
9	Impact zoning scheme	Model outputs used to inform an impact zoning scheme as described in the Water Quality and Marine Ecology chapters.	EIS Chapter 5 and Chapter 7
16	"Best Case" and "Worst Case" Scenarios	Best Case and Worst Case Scenarios assessed and suggest that limited overflow should be pursued as an impact mitigation strategy.	6.3 6.5 6.6 6.8

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
17	Impact thresholds	Impact thresholds derived from site specific baseline water quality data and biological criteria derived from literature. These are detailed in the Water Quality and Marine Ecology chapters.	6.2.5
18	Sensitive receptors	Impact zones have been overlaid on sensitive habitat maps in Water Quality and Marine Ecology chapters.	EIS Chapter 5 and Chapter 7
19	Map output	Impact zone maps will be made available to GBRMPA in a suitable GIS format.	NA
20	Mid-depth and near sea floor turbidity impacts assessed	Turbidity impact maps have been prepared for depth-average and nearbed.	6.3.2 6.4.2 6.5.2 6.6.2 6.7.2
20	Sedimentation assessed	Sedimentation rate increases due to dredging and total sedimentation attributable to dredging have been derived.	6.3.2 6.4.2 6.5.2 6.6.2 6.7.2
20	Timeseries outputs	Timeseries outputs of turbidity at key locations.	Appendix I
21	Units consistency	Water Quality modelling assessments output in turbidity units (consistent with baseline datasets). Sedimentation assessments output in rate units of mg/cm^2/day.	NA
22	DMPA site justified	DMPA Options assessment undertaken and reported separately.	NA
23	Independent peer review	Independent peer review completed by Emeritus Professor Colin J Apelt	Appendix A

3 Model Calibration

3.1 Baseline Calibration Data

The collection of data to support the CSDP commenced in February 2013 and involved the deployment of various fixed-location instruments for continuous recording of water levels, currents, waves, salinity, temperature and turbidity. In addition, atmospheric conditions (wind, temperature, relative humidity, light, rainfall and barometric pressure) have been recorded at three locations along the shipping channel. This information is required to further develop an understanding of coastal processes relevant to the study area and provides data for model calibration and validation purposes.

Continuous data recording locations referred to throughout this report are indicated in Figure 3-2. The type of instruments deployed at each location varies and is summarised in Table 3-1 with a full description of the data collection campaign described in BMT WBM (2014). The following data types have been used for numerical model calibration and validation:

Water Level Data

The water level variation due to tidal and atmospheric forcing is derived from pressure sensors mounted on Seabird, Greenspan or Acoustic Doppler Current Profiler (ADCP) instruments. The data has been reduced to datum using additional data from the Cairns Standard Port gauge.

Current Data

Current data has been obtained using fixed, bottom-mounted Nortek AWAC or Teledyne RD Instrument Sentinel Workhorse ADCP equipment. These instruments were configured to continuously record the vertical current profile (current magnitude and direction) in 0.5m bins throughout the water column. The recorded data has been depth-averaged over the entire water column and also over the top, middle and bottom 33.3% of the water column for model calibration purposes. The current directions are in the nautical convention for currents: 0º is north and clockwise is positive with the bearing indicating the direction currents are heading.

Wave Data

The ADCP instruments deployed for the CSDP also record local wave conditions. The wave recordings have been processed to provide time series of Significant Wave Height (H_{sig}), Peak Wave Period (T_p) and Wave Direction. Additional wave data from the Cairns Wave Buoy (non-directional) operated by the Department of Environment Heritage and Protection (DEHP) has also been used for wave model calibration. Wave directions are in the nautical convention for waves: 0º is north and clockwise is positive with the bearing indicating the direction waves are propagating from.

Total Suspended Solids (TSS) Data

Continuous measurements of near bed turbidity have been obtained using fixed, bottom-mounted YSI 6600 EDS Nephelometer instruments. The recorded turbidity levels in Nephelometric Turbidity Units (NTU) were converted into Total Suspended Sediment (TSS) concentrations using an NTU-TSS relationship based on 84 co-located *in-situ* turbidity measurements and water samples. The measurements and samples were collected as part of the CSDP baseline data collection (BMT

WBM, 2014) and during a previous dredge plume monitoring campaign (BMT WBM, 2011). The ultimate dataset includes nearshore and offshore locations and both dredging and non-dredging periods. The derived NTU-TSS relationship specific to the study area is shown in Figure 3-1.

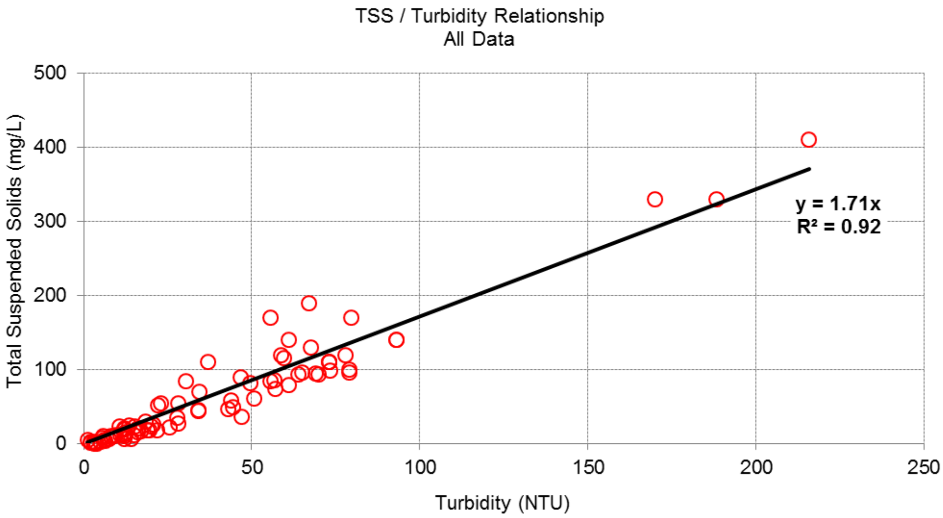
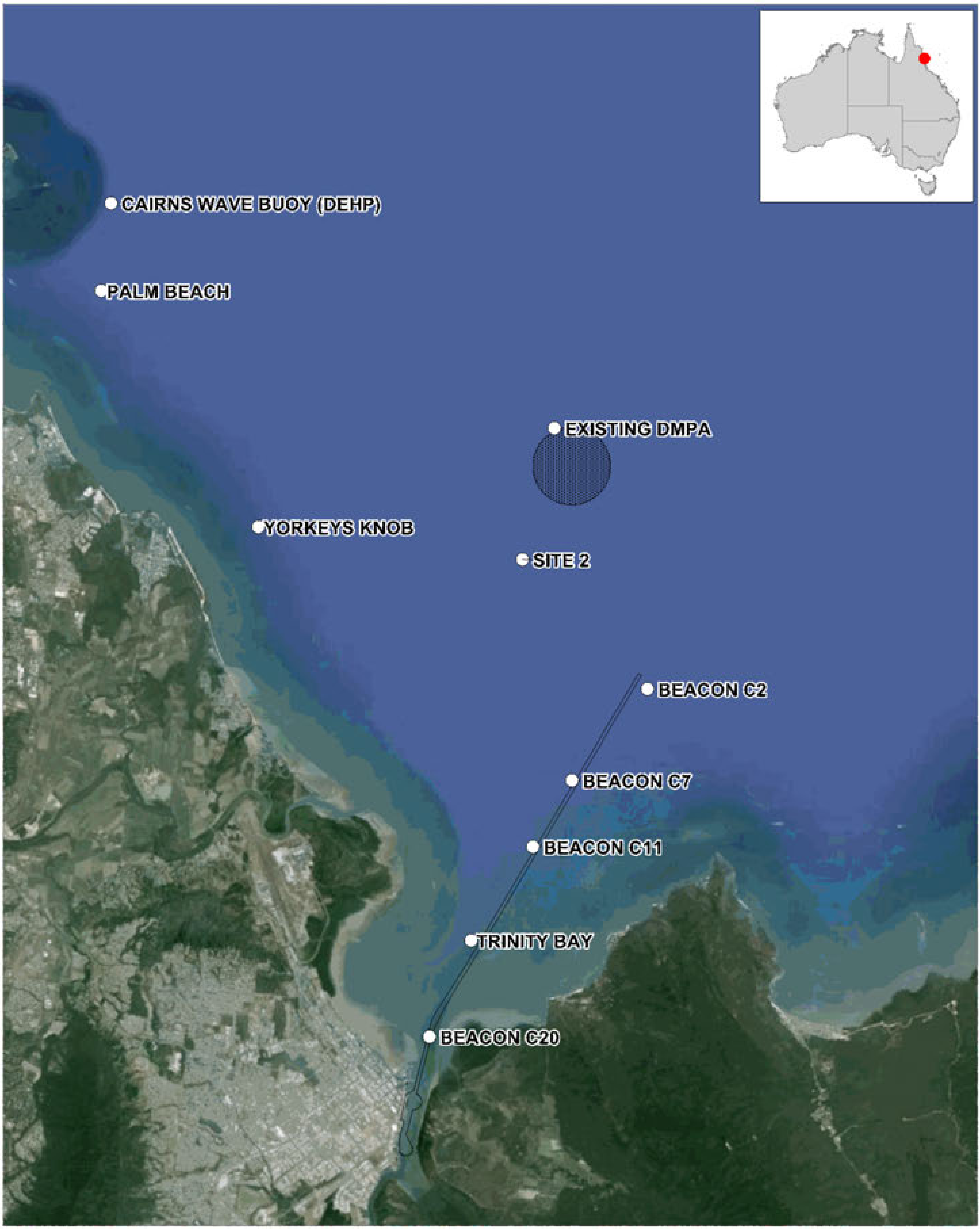


Figure 3-1 NTU-TSS Relationship Established for the Study Area



Title:

Data Recording Locations

Figure: 3-2

Rev: A

N

0 1.5 3km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_004_data_locations_with_WO.wor

Table 3-1 Model Calibration Continuous Data Recording Locations and Instruments Summary

Location and Coordinates (decimal degrees)	Deployment Period	Mooring Type	Tide Recorder	ADCP	Nephelometer	CTD	Data Redundancy or Additional Data
Existing DMPA 145.8104, -16.7804	15/02/2013 – 15/04/2014	MSI Trawl resistant bed mounted frame	20m range Seabird Model SBE26 plus	600 kHz Nortek AWAC	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Not required, though was collected using YSI Model 6600	Tide (depth), non-directional waves, water temperature, electrical conductivity, PAR (Photosynthetically Available Radiation)
Site 2 145.8040, -16.8089	15/02/2013 – 22/08/2013	MSI Trawl resistant bed mounted frame	NA	600 kHz Nortek AWAC	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Not required, though was collected via YSI Model 6600	Tide (depth), water temperature, electrical conductivity.
Outer Channel Beacon C7 145.8162,-168561	20/02/2013 – 15/04/2014	Ocean Sciences Sea Spider bed mounted frame. CTD deployed from floating Sealite Model 600 marker buoy.	NA	600 kHz Nortek AWAC	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Teldyne RD Instruments Citadel CTD deployed from floating buoy	Tide (depth), water temperature, conductivity
Outer Channel Beacon C11 145.8078,-16.8706	20/02/2013 – 24/08/2013	Ocean Sciences Sea Spider bed mounted frame. CTD deployed from floating Sealite Model 600 marker buoy.	NA	1200 kHz Teledyne RD Instruments Workhorse Sentinel	YSI Model 6600 EDS water quality instrument fitted with turbidity sensor	Teldyne RD Instruments Citadel CTD deployed from floating buoy	Tide (depth), water temperature, conductivity
Beacons C2, C11 and C20. 145.8316,-16.8335 145.8088,-16.8692 145.7869,-16.9106	15/02/2013 – 15/04/2014[1]	Fixed to Beacons C2, C11 and C20	NA	NA	NA	NA	Environdata Model Maestro Weather Station (wind, rain, relative humidity, atmospheric pressure, solar radiation)

[1] Approximate deployment period for weather stations

3.2 Calibration Period Characteristics

The study area experiences a tropical climate. The mean annual rainfall for the Cairns region is 2013mm, with the vast majority of rainfall occurring during the north-west monsoon influenced “wet season” months from November to April. The “dry season” period typically occurs from May to October where the synoptic meteorological pattern is strongly influenced by the Coral Sea trade winds.

The model calibration simulation period was from March to June 2013 and therefore includes late wet season and early dry season months. The representativeness of this period relative to wind, rainfall and wave climate long term averages is discussed below.

3.2.1 Wind

Wind roses for the simulation period and the long term average of the simulation period months (i.e. February to June inclusive) are compared in Figure 3-3 (offshore location) and Figure 3-4 (Cairns Aero). Note that at the offshore location the simulation period wind rose is based on recorded data from Arlington Reef (consistent with the constructed wind field described in Section 2.1.3.2) while the long term average is based on recordings from nearby Green Island (approximately 15km to the south west) where a longer data record was available. The simulation period wind characteristics are as follows:

- The offshore wind roses show the predominance of south to south-easterly trade winds. The offshore directional spread of winds for the simulation period appears consistent with the long term average however the 10-minute wind speed exceeds 14m/s (approximately 27knots) on slightly fewer occasions than average.
- There are significant orographic influences within the nearshore regions of the study area and this is reflected in the Cairns Aero wind roses which are distinctly different to the more exposed locations within the GBR lagoon. The Cairns Aero wind directional spread is predominantly south-south-west to south-easterly. The roses also reveal a subtle land breeze/sea breeze cycle which occurs along the coastal margin of the study area. The Cairns Aero simulation period wind rose is considered consistent with the long term average.

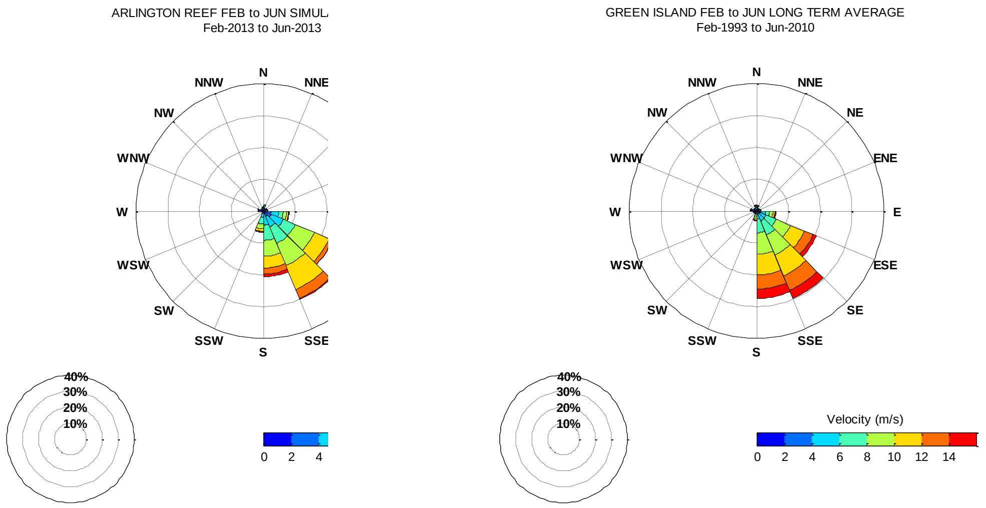


Figure 3-3 Offshore Wind Roses – February to June 2013 Simulation Period (top) and February to June Long Term Average (bottom)

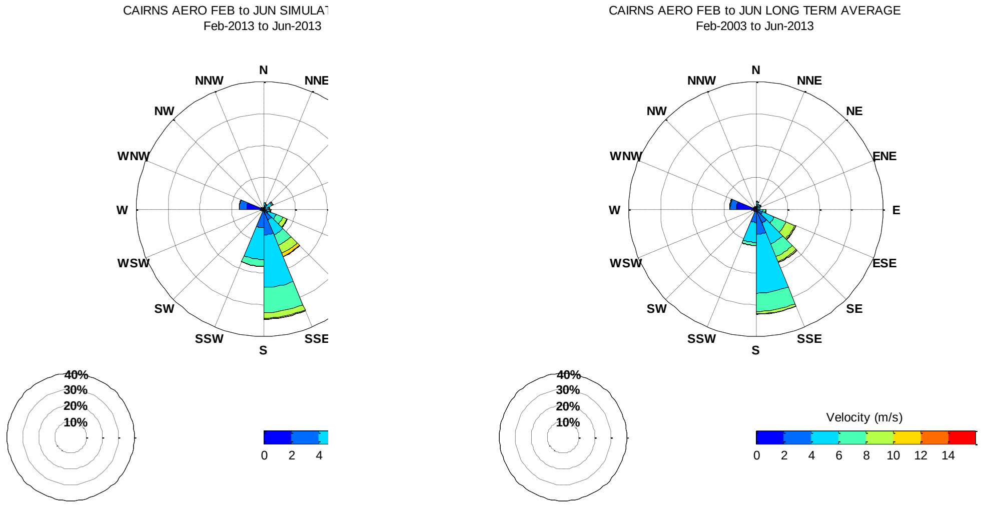


Figure 3-4 Cairns Aero Wind Rose – February to June 2013 Simulation Period (top) and February to June Long Term Average (bottom)

3.2.2 Fluvial Discharge

The Barron River catchment discharges directly into Trinity Bay and is characterised by frequent flooding (approximately annually) associated with wet season rainfall, in particular due to monsoon trough and/or tropical cyclone influences.

Fluvial discharge and sediment loads from the Barron River are inputs to the hydrodynamic model. Relatively low flows were recorded during the simulation period. This is highlighted in Table 3-2 which compares Barron River daily mean flows for the 2013 simulation period with the long term averages obtained from the DNRM Watershed data service. It is noted that the 2013 wet season monthly (February, March and April) flows are low compared to the long term averages and therefore the calibration period was not significantly influenced by fluvial inputs. Barron River discharge during a wet season with higher than average flows is considered in Section 5.

Table 3-2 Simulation Period and Long Term Average Barron River Flow Summary

Month	Simulation Period Daily Mean (ML)	Long Term Average Daily Mean (ML)
February	490	6119
March	2259	6360
April	741	1935
May	458	1141
June	381	753

3.2.3 Waves

On a regional scale, the Great Barrier Reef partially shelters the North Queensland coastline from the deep ocean waves propagating westward from the Coral Sea. Gaps in the offshore in reef network (such as Trinity Opening to the north-east of Cairns) allow some swell to penetrate into the GBR lagoon, albeit with significantly attenuated energy.

On a more local scale, Cape Grafton shelters Trinity Bay and Cairns beaches from the south-easterly sea waves generated within the GBR lagoon. Fetches within the GBR lagoon are generally limited to 30-50km by the large mid shelf reef complexes. Non-cyclonic winds rarely exceed 13m/s (approximately 25knots) and locally generated sea wave heights recorded at the Cairns Waverider buoy are typically less than 1.4m and have a 3-5 second period (BPA, 1984).

A simulation period wave rose at the Cairns Waverider buoy location is presented in Figure 3-5. The wave rose is based on model output since the Cairns buoy recordings are non-directional and therefore provide no information regarding wave direction. Considering the limited swell energy entering the study area and the good representativeness of the simulation period wind conditions (refer Section 3.2.1) it is likely based on the wind-climate assessment that the simulation period wave climate (dominated by locally generated wind waves) is likewise representative of prevailing conditions. The largest significant wave height at the Cairns buoy for the simulation period was approximately 1.4m with a mean significant wave height close to 0.6m. A summary of peak wave heights recorded at the Cairns buoy is provided in Table 3-3. Historical peak wave conditions occur during the wet season months and are typically associated with tropical cyclone events. Additional recorded wave data from various locations throughout the study area is presented in Section 3.4.2.

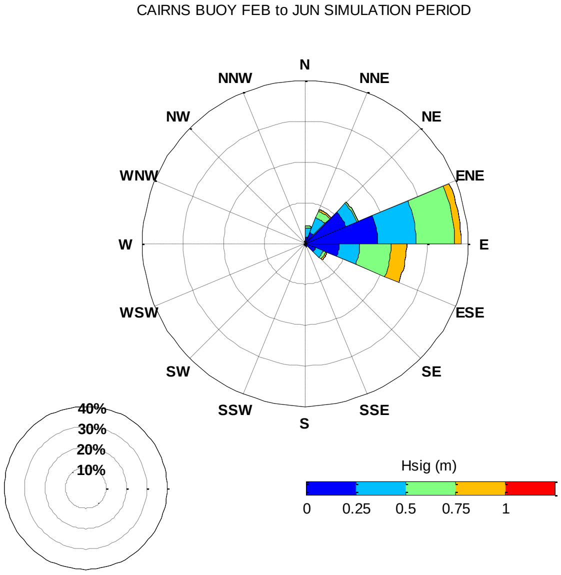


Figure 3-5 Cairns Buoy Wave Rose – February to June 2013 Simulation Period

Table 3-3 Top 10 Significant Wave Heights Recorded at the Cairns Buoy prior to the 2012/2013 Wet Season (data provided by DSITIA)

Rank	Date/Time	Significant Wave Height (m)
1	27/02/2000 21:30	2.8
2	11/02/1999 21:00	2.5
3	03/02/2011 04:30	2.4
4	23/12/1990 20:54	2.2
5	19/03/1990 08:42	1.9
6	31/01/1977 09:00	1.9
7	12/01/2009 07:00	1.9
8	03/01/1979 03:00	1.8
9	11/02/2004 06:00	1.6
10	27/04/2000 04:00	1.6

3.3 Hydrodynamic Model Calibration

3.3.1 Hydrodynamic Model Parameterisation

The TUFLOW FV model calibration was undertaken in 3D baroclinic mode using a hybrid sigma/z-coordinate layer scheme. Between the model surface and -3mAHD four sigma layers were applied and able to vary in vertical thickness depending on the tidally dominated changes in water surface elevation. Below -2mAHD a z-coordinate scheme was applied with vertical layer thicknesses of 1-2m in shallow water (between depths of -2mAHD and -25mAHD) increasing in deeper offshore areas beyond the edge of the continental shelf. A maximum of 30 z-layers were resolved in the deeper sections of the model domain. This high degree of vertical resolution in the top 25m of the water column was necessary in order to simulate vertical stratification within the water column. This also allows for detailed representation of the vertical distribution of dredge plume suspended sediment.

Salinity and temperature were simulated within the model as density-coupled scalar constituents in order to incorporate baroclinic density gradient forcing and more importantly the effect of vertical density stratification on the water column turbulent mixing. The turbulence model (GOTM – www.gotm.net) was coupled with the hydrodynamic model for the purposes of deriving vertical turbulent mixing parameters.

The TUFLOW FV model configurations and parameterisations are summarised in Table 3-4, including the bottom roughness length scales for the four generic bed surfaces represented throughout the model domain. It is noted that variation of the bottom roughness length scale across the shallow, offshore reefs was the key focus of the model calibration process. The adopted model parameters are typically “default” values and/or within the range of accepted literature values. An example TUFLOW FV simulation control file is provided in Appendix B.

Table 3-4 Summary of TUFLOW FV Model Configuration and Parameterisations

Model Configuration Description	Model/Value
Momentum mixing model	Smagorinsky
Scalar mixing model	Smagorinsky
Bottom drag model	Derived from application of the “log-law”
Bottom roughness length scales: Default (offshore areas) Shallow reefs (less than 20m depth) Reef passes Mangroves and fringing reefs	 0.05m 1.00m 0.10m 0.50m
GOTM turbulence model	2-equation k-omega with default parameters

3.3.2 Hydrodynamic Model Calibration Results

The hydrodynamic model calibration period was from 1st March 2013 to 29th June 2013. This period incorporated representative spring and neap tide conditions, a range of meteorological conditions and offshore EAC forcing. This enabled assessment of the models ability to adequately represent a range of conditions and its suitability for use in impact assessments. For illustrative purposes, examples of predicted current patterns at times of peak flood and ebb tide conditions are shown in Figure 3-6.

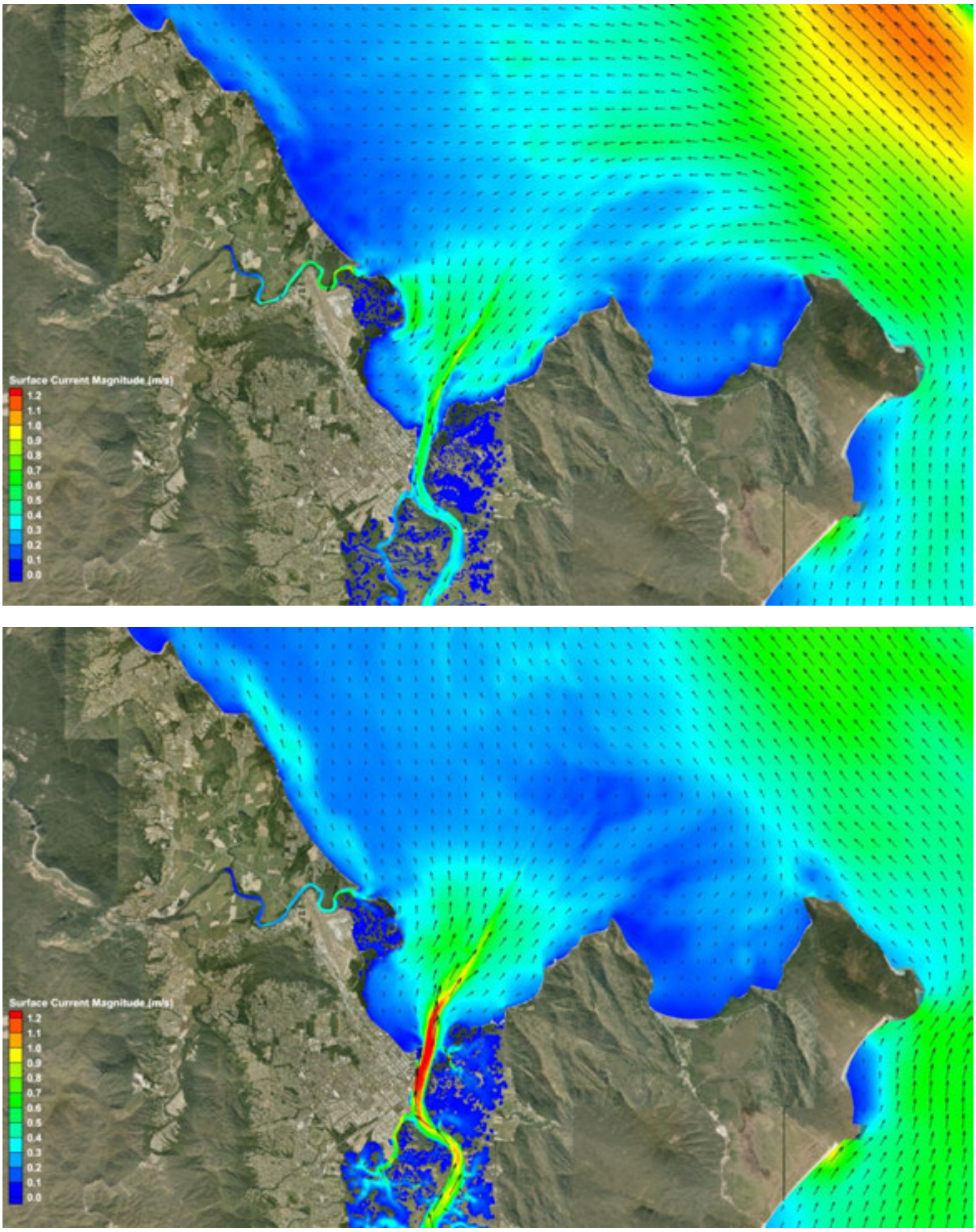


Figure 3-6 Predicted Peak Flood (top) and Peak Ebb (bottom) Surface Current Patterns

In the following sections calibration plots at each continuous data recording location are presented, including:

- Water level and depth-average current time series (six day period);
- Top, middle and bottom third of water column current velocity and direction (six day period);
- Depth-average current polar plots (entire calibration period); and
- Near-bed water temperature time series (entire calibration period).

The presentation of time series data over a six day period is provided to allow clear visualisation of the model/data comparison. The selected six day period includes a significant south easterly wind event between 11/04/2013 and 14/04/2013 and the times series plots show the associated hydrodynamic response.

In addition to the above, Appendix C, Appendix D and Appendix E provide further model calibration results for the entire calibration period:

- Appendix C: top and bottom half of water column current velocity and direction time series (entire calibration period);
- Appendix D: top and bottom half of water column current polar plots (entire calibration period); and
- Appendix E: Current velocity Quantile-Quantile (Q-Q) plots (entire calibration period).

3.3.2.1 Site 1 DMPA

Model calibration results at the DMPA continuous data recording location show the following:

- Figure 3-7 (top plot) suggests variations in water level amplitude at the DMPA are accurately predicted by the model during both spring and neap tides. Tidal phasing is also appropriately represented however the model appears to slightly the lag the recordings (in the order of minutes). This minor discrepancy is likely to be due the limited set of tidal constituents used to force the regional-scale Coral Sea model (which provides tidal boundary conditions to the 3D model) and/or the complicated flow patterns and flow resistance between the networks of offshore reefs not being precisely represented by the model.
- The current speed at the DMPA is also predicted well by the model. The depth-average current velocity (Figure 3-7, middle plot) and current velocity layer (Figure 3-8) time series plots show an increase in current magnitude between 11/04/2013 and 13/04/2013. This period corresponds to a south-easterly wind event and the hydrodynamic response to this meteorological forcing is clearly reproduced by the model throughout the water column.
- The recorded data presented in Figure 3-8 show a slightly stratified water column with regard to current magnitude. This generally behaviour is well predicted by the model.
- Figure 3-7 (bottom plot) and Figure 3-9 suggest current direction is predicted well by the model. Figure 3-9 also shows a relatively uniform current direction throughout the water column for the period shown.

- Predicted and recorded distributions of depth-average current magnitude and direction at the DMPA are presented as polar plots in Figure 3-10. The polar plots are based on the entire calibration period and show good overall consistency. These plots also identify a current residual at the DMPA to the northwest for the calibration period.

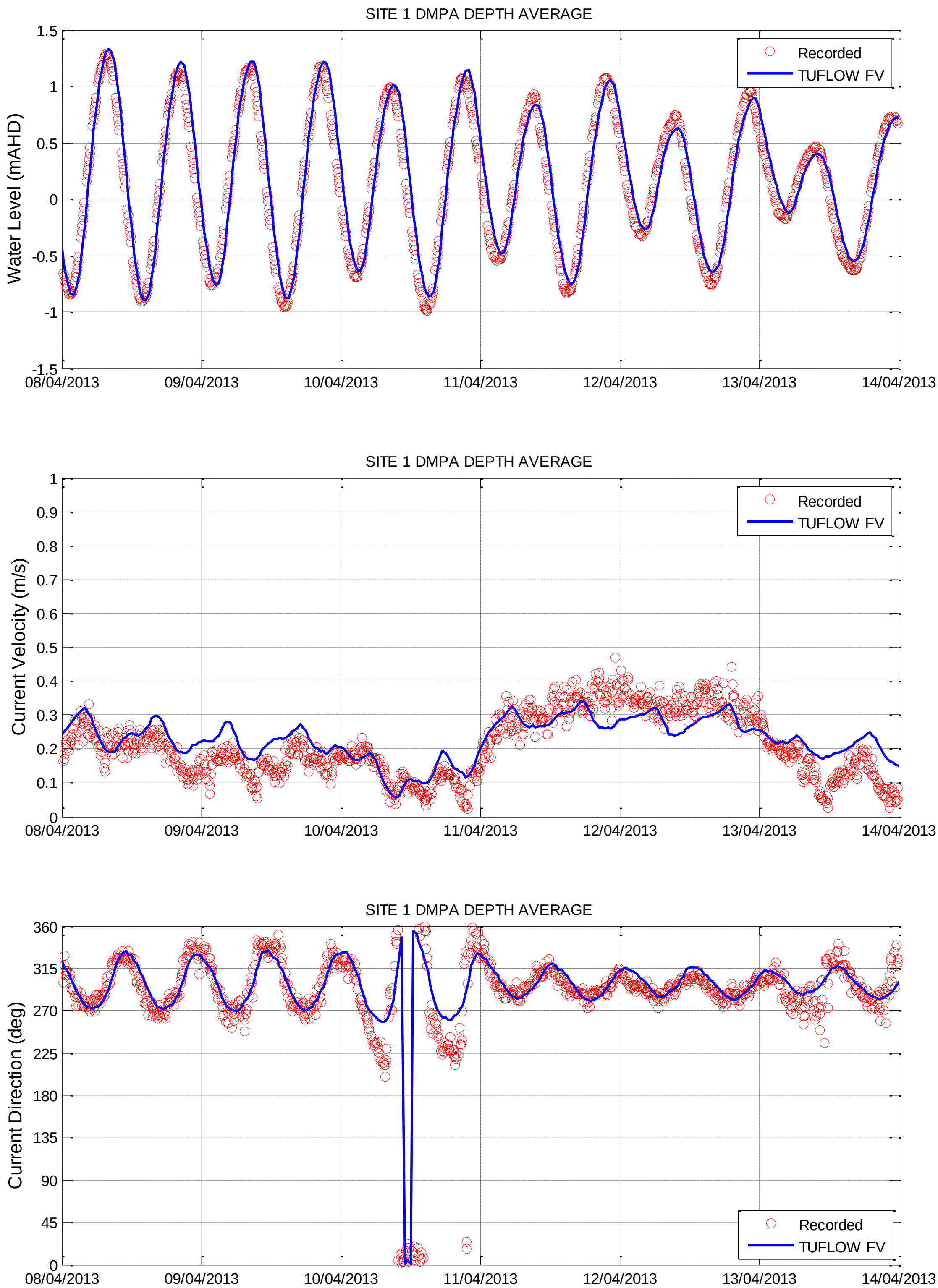


Figure 3-7 Hydrodynamic Model Calibration 3D Depth Average – Site 1 DMPA

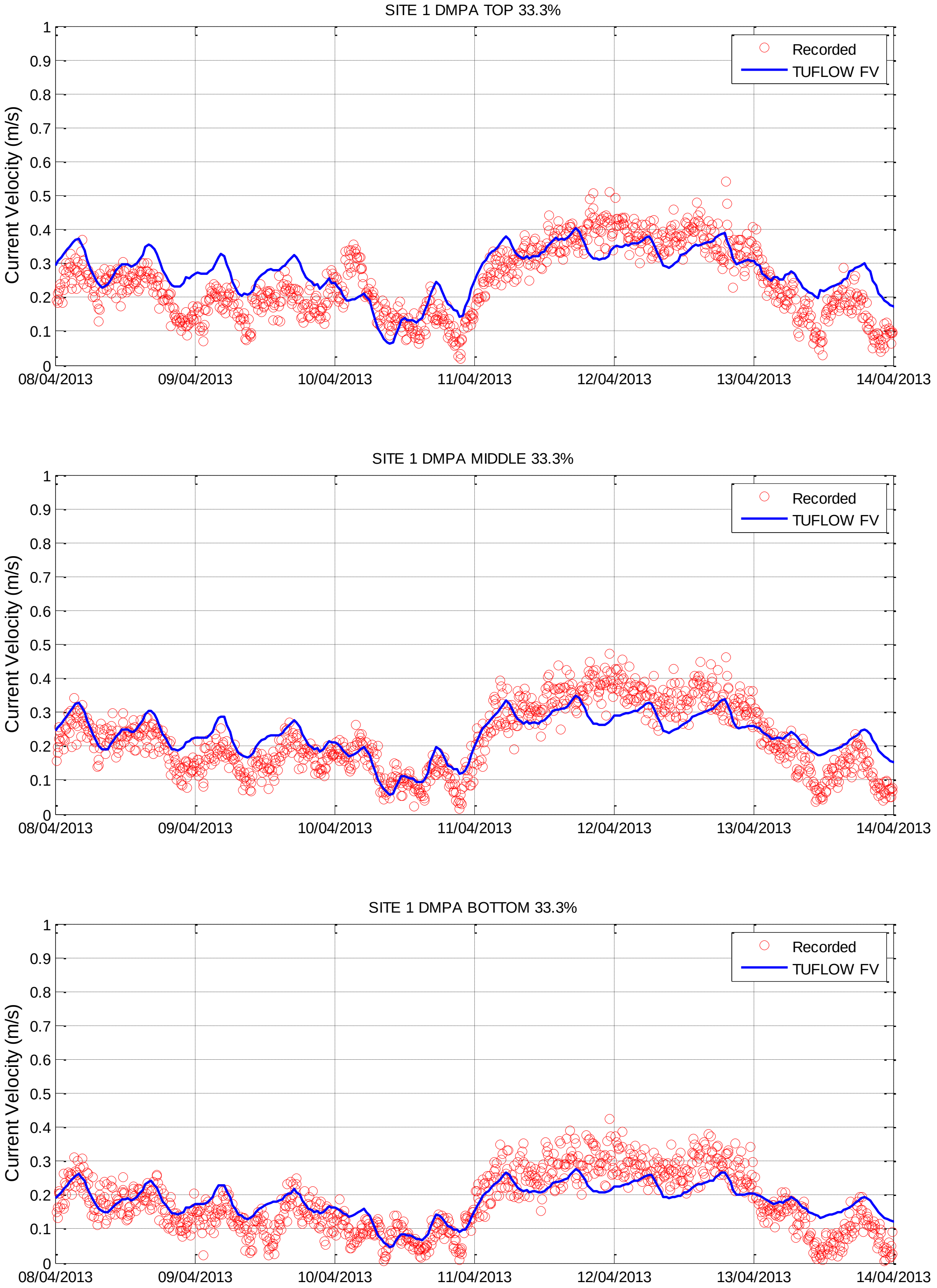


Figure 3-8 Hydrodynamic Model Calibration Current Velocity Layers – Site 1 DMPA

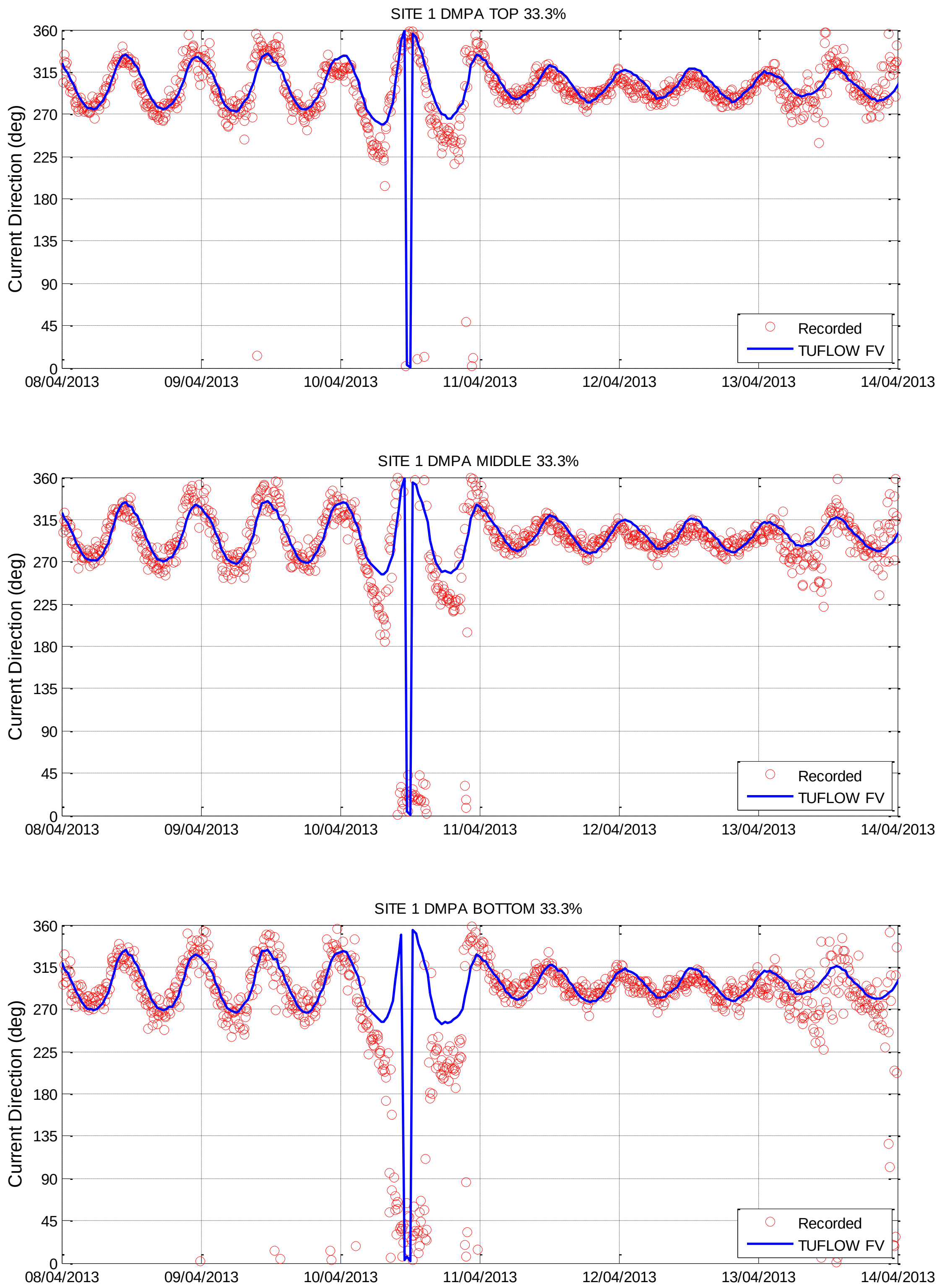


Figure 3-9 Hydrodynamic Model Calibration Current Direction Layers – Site 1 DMPA

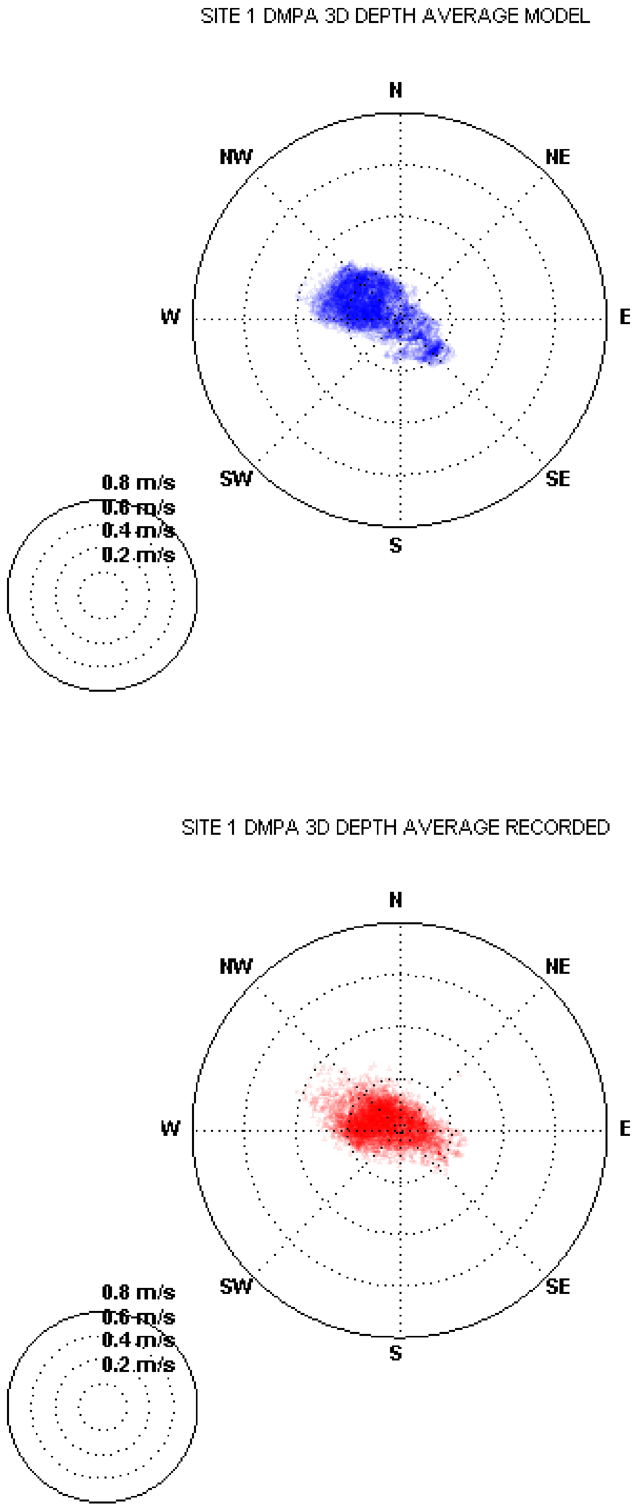


Figure 3-10 Current Polar Plot Validation – Site 1 DMPA

3.3.2.2 Site 2

Model calibration results at the Site 2 continuous data recording location show the following:

- Figure 3-11 (top plot) suggests variations in water level amplitude at Site 2 are accurately predicted by the model during both spring and neap tides. Similar to the DMPA site, the model appears to slightly the lag the recordings (in the order of minutes) with regarding to phasing.
- An increase in current magnitude between 11/04/2013 and 13/04/2013 associated with south easterly winds was also recorded at Site 2 and is generally reproduced by the model. The depth-average current velocity (Figure 3-11, middle plot) and current velocities throughout the water column (Figure 3-12) during the wind event are slightly smaller in magnitude compared to the recordings. Furthermore, Figure 3-12 suggests slightly greater current magnitude stratification is predicted.
- Figure 3-11 (bottom plot) and Figure 3-13 suggest current direction is generally predicted well by the model. During the final day of the period shown, Figure 3-13 suggests some inconsistency between the recorded and predicted current direction. This corresponds to a neap tide period and therefore a time when tidal forcing is low and meteorological forcing dominates the hydrodynamic conditions. The inaccurate current direction prediction is most likely due to inaccuracies with the constructed wind field in the vicinity of Site 2.
- Predicted and recorded distributions of depth-average current magnitude and direction at Site 2 are presented as polar plots in Figure 3-14. Despite the short periods of current direction discrepancy described above, the model and recordings show good overall consistency in current distribution over the entire calibration period. Similar to the DMPA location, Site 2 shows a current residual towards the northwest.

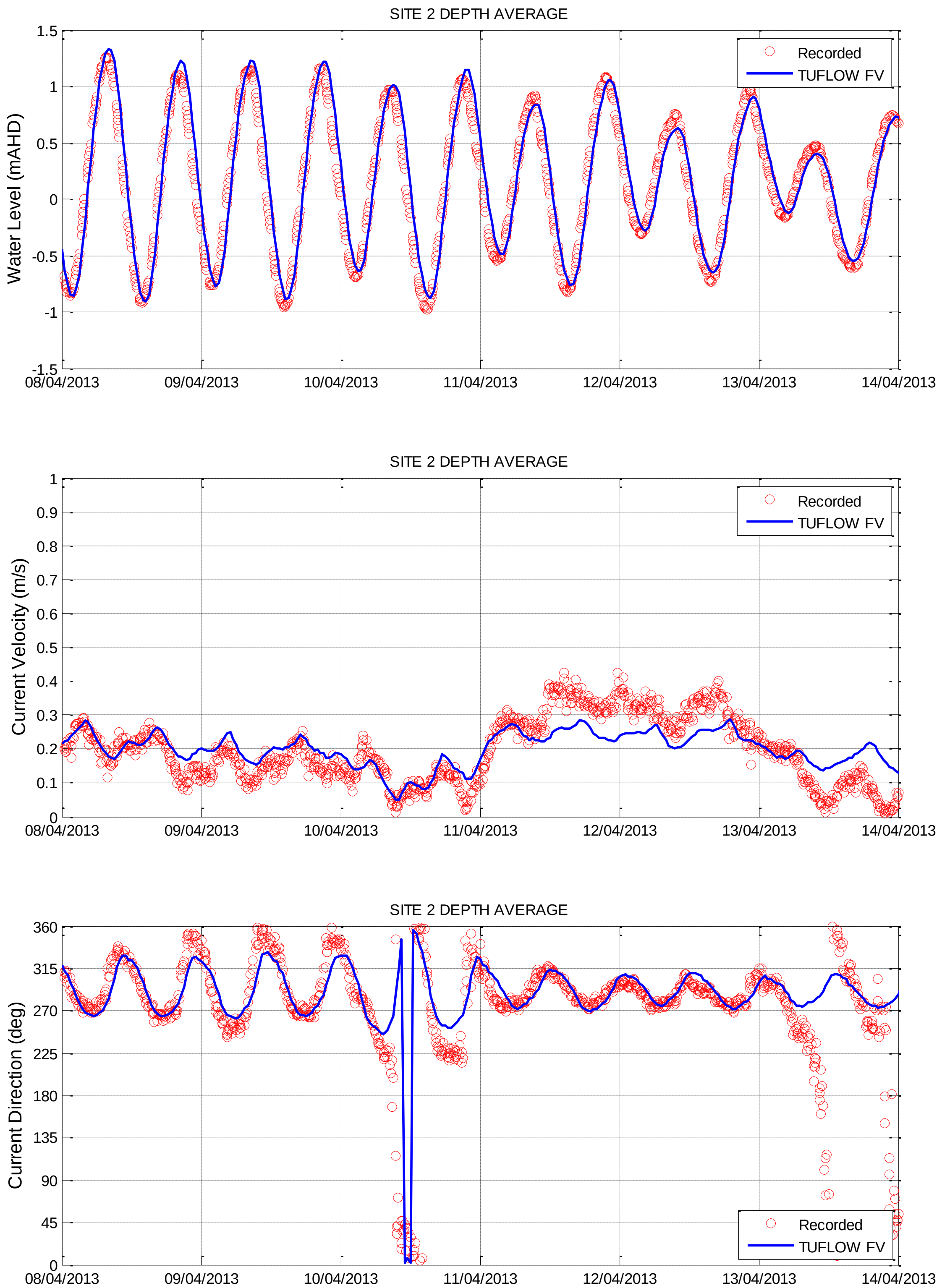


Figure 3-11 Hydrodynamic Model Calibration 3D Depth Average – Site 2

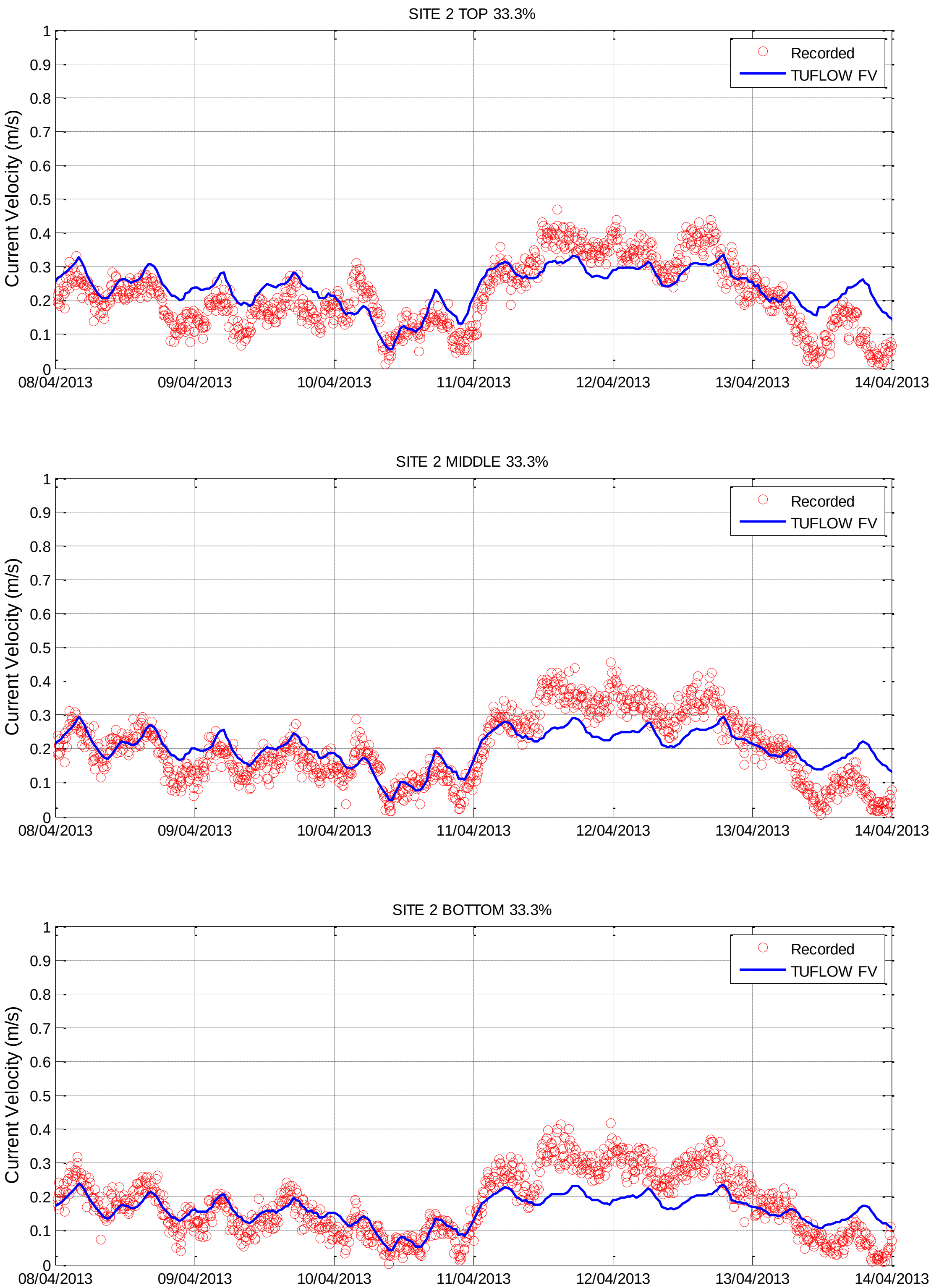
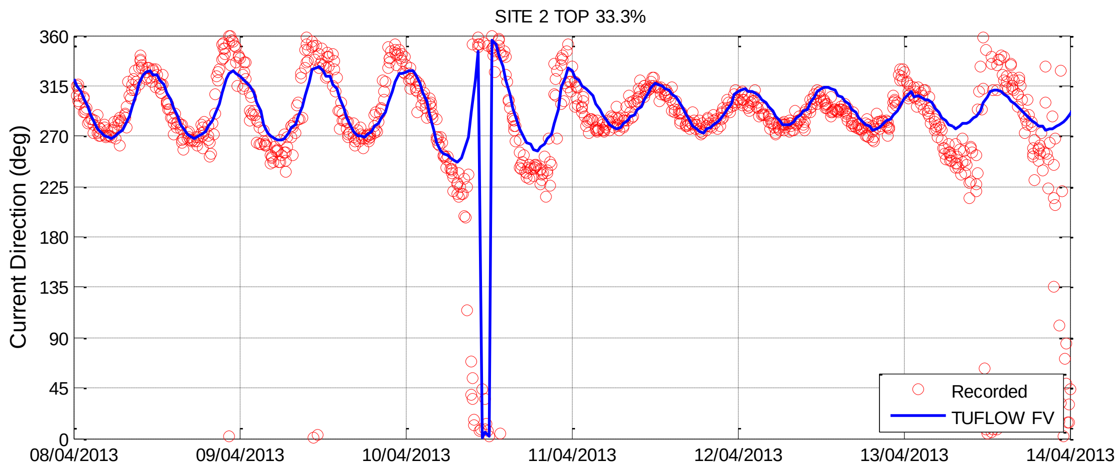
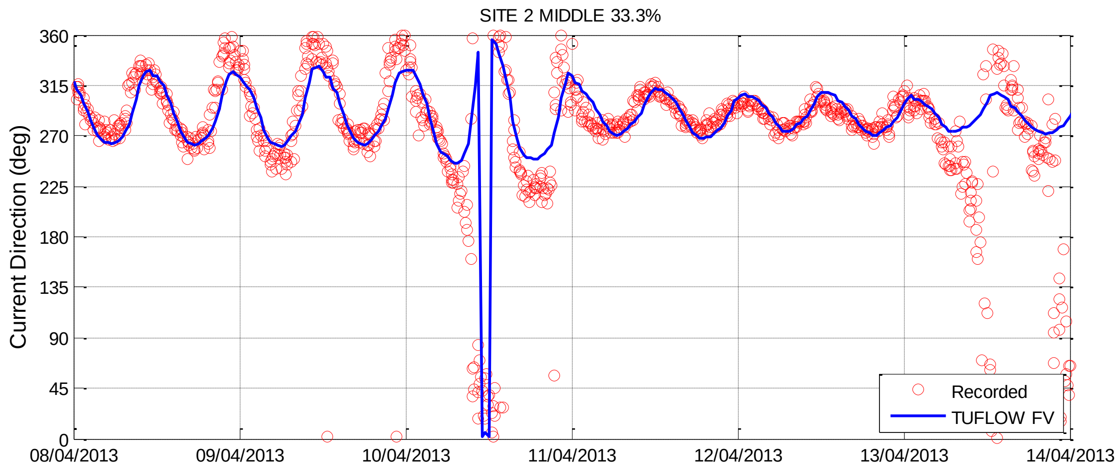


Figure 3-12 Hydrodynamic Model Calibration Current Velocity Layers – Site 2





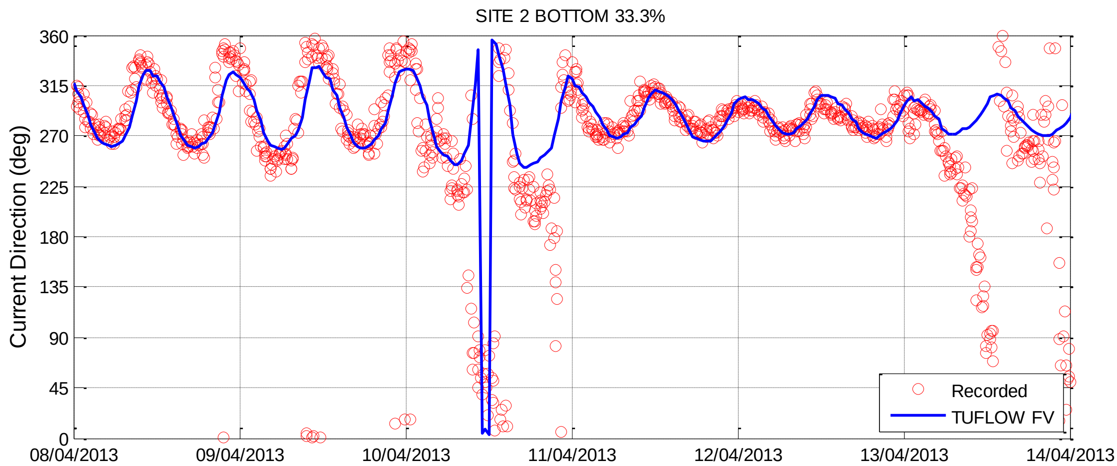


Figure 3-13 Hydrodynamic Model Calibration Current Direction Layers – Site 2

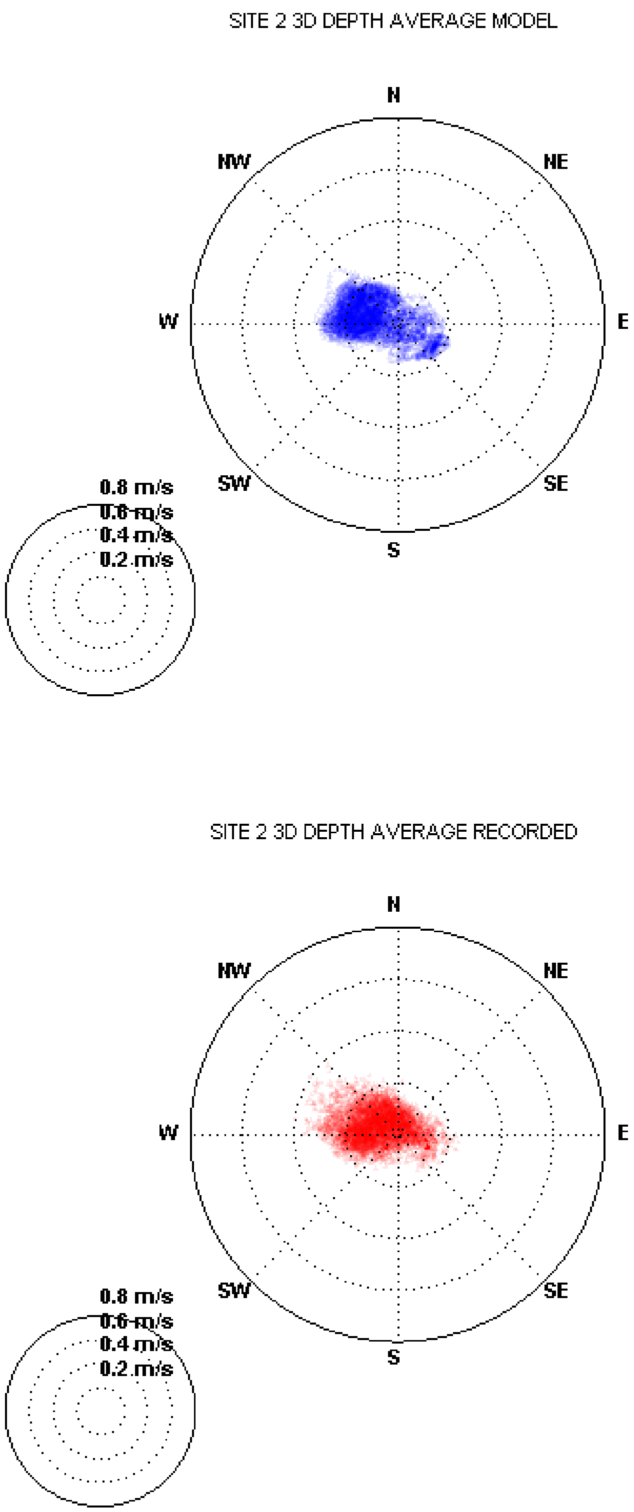


Figure 3-14 Current Polar Plot Validation – Site 2

3.3.2.3 Site 3 Beacon C7

Model calibration results at the Beacon C7 continuous data recording location show the following:

- Figure 3-15 (top plot) suggests variations in water level amplitude at Beacon C7 are accurately predicted by the model during both spring and neap tides. The slight phase discrepancy evident at offshore data recording locations is also apparent at Beacon C7.
- Current data from Beacon C7 shows a strong tidal signal which is only slightly less dominant during the south easterly wind event between 11/04/2013 and 13/04/2013. The depth-average current velocity (Figure 3-15, middle plot) and current velocity layer (Figure 3-16) time series calibration plots suggest good model predictive skill.
- Some discrepancy between recorded and predicted current direction is evident in Figure 3-15 (bottom plot) and Figure 3-17 during and after the south easterly wind event between 11/04/2013 and 13/04/2013. It is assumed this is due to the inaccuracies in the constructed wind field which is not expected to capture all the orographic effects around the hills to the east of the shipping channel.
- Predicted and recorded distributions of depth-average current magnitude and direction at Beacon C7 are presented as polar plots in Figure 3-18. Despite some current direction discrepancy described above, the model and recordings show good overall consistency in current distribution over the entire calibration period.

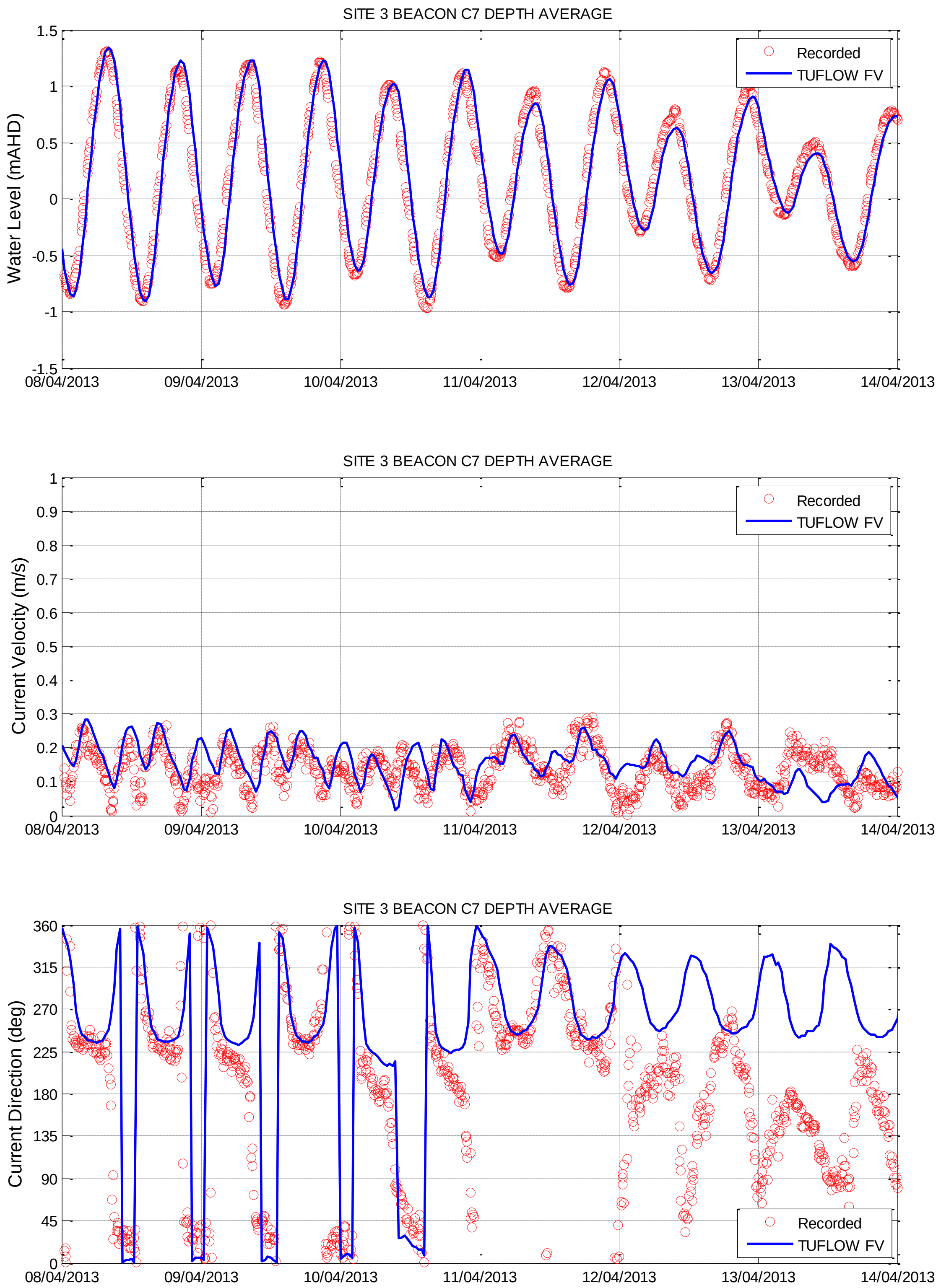


Figure 3-15 Hydrodynamic Model Calibration 3D Depth Average – Site 3 Beacon C7

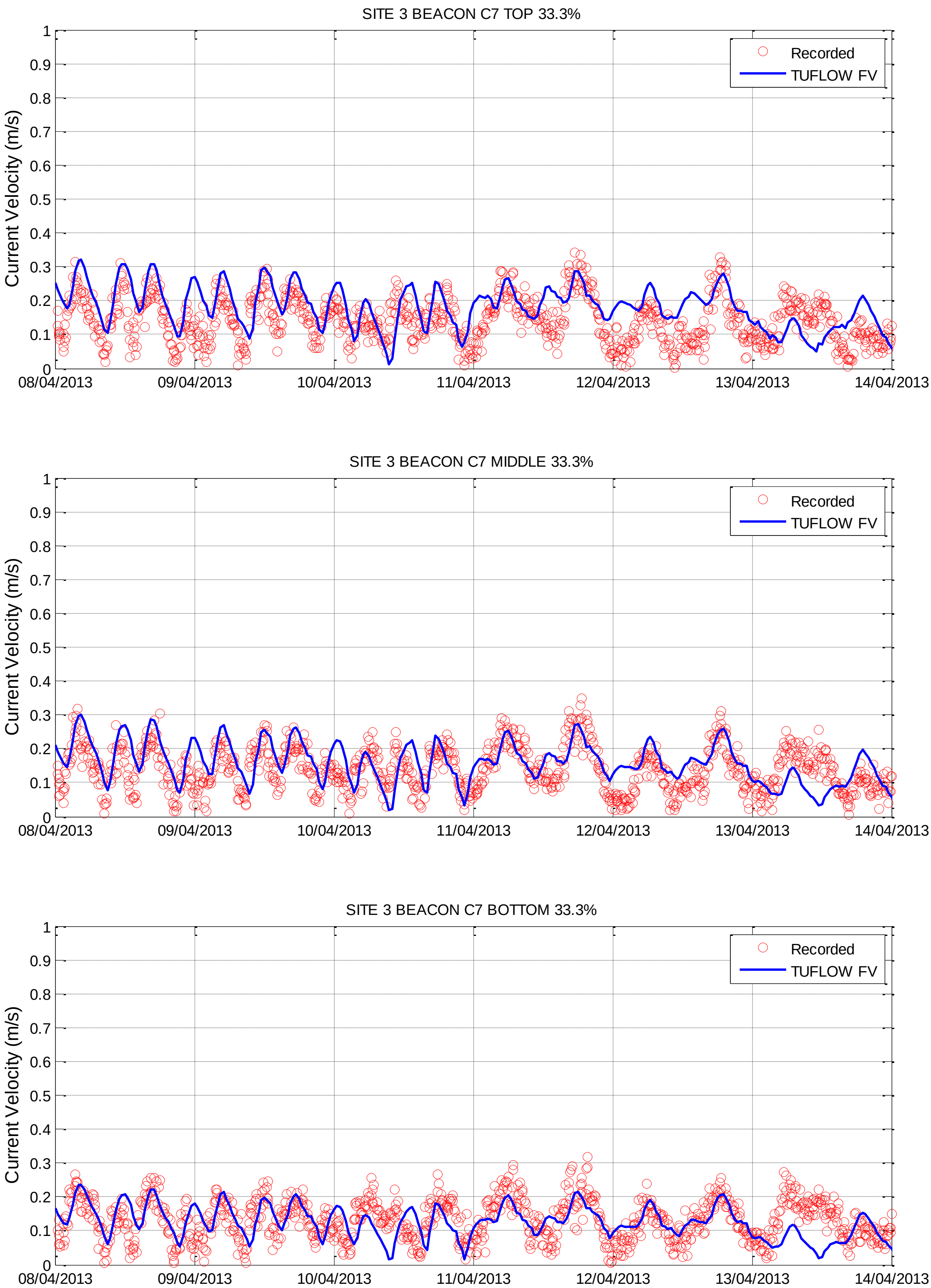


Figure 3-16 Hydrodynamic Model Calibration Current Velocity Layers – Site 3 Beacon C7

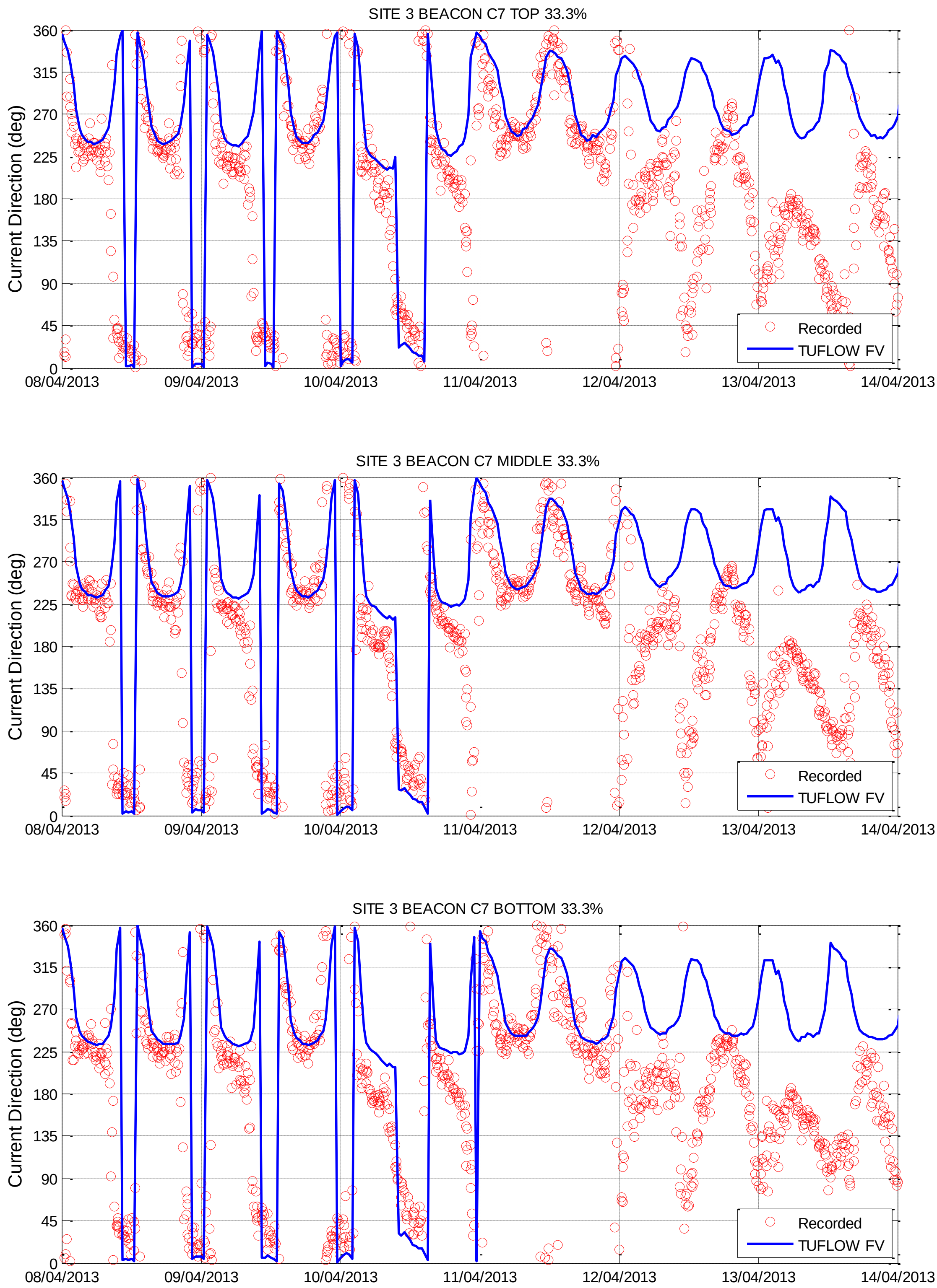
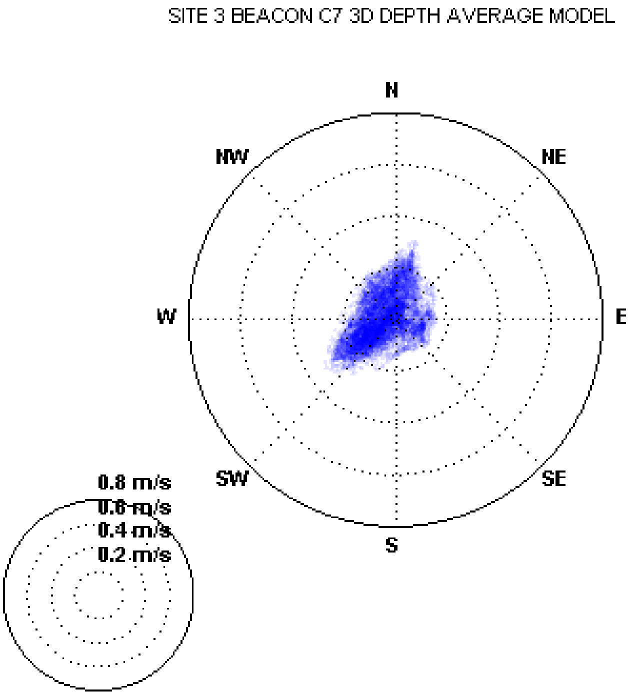


Figure 3-17 Hydrodynamic Model Calibration Current Direction Layers – Site 3 Beacon C7



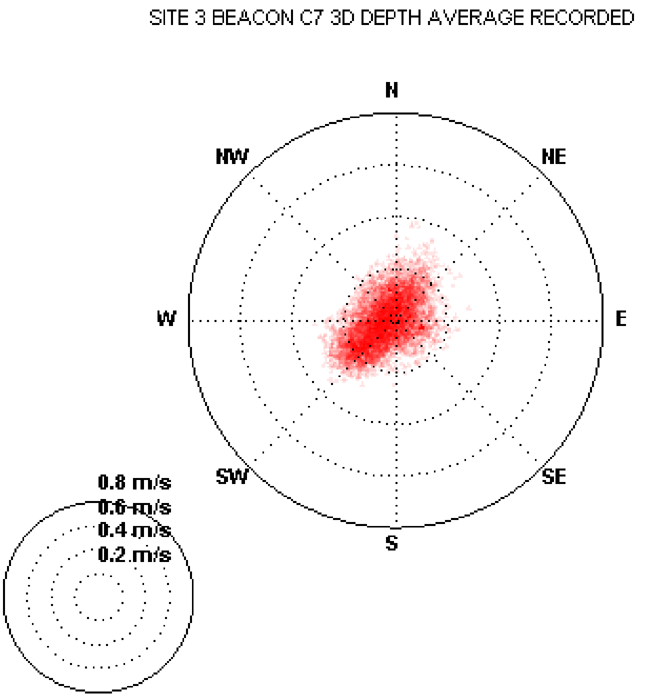


Figure 3-18 Current Polar Plot Validation – Site 3 Beacon C7

3.3.2.4 Site 4 Beacon C11

Model calibration results at the Beacon C11 continuous data recording location show the following:

- Figure 3-15 (top plot) suggests variations in water level amplitude at Beacon C11 are accurately predicted by the model during both spring and neap tides.
- Current data from Beacon C11 shows a strong tidal signal with a higher peak velocity (occasionally exceeding 0.6m/s) during the ebb tide phase. A minor over-prediction bias in peak velocity is evident during the flood tide phase. Better model predictive skill is observed during the more dominant ebbing tides.
- The flood and ebb current direction interchanges between approximately 205 degrees during flood tides and 15 degrees during ebb tides. This behaviour is generally well predicted by the model. Some minor discrepancy between recorded and predicted current direction is evident in Figure 3-19 (bottom plot) and Figure 3-21 during the south easterly wind event between 11/04/2013 and 13/04/2013. Compared to Beacon C7, the current direction discrepancy is less evident at Beacon C11 and the currents appear to remain dominated by tidal forcing.
- Predicted and recorded distributions of depth-average current magnitude and direction at Beacon C11 are presented as polar plots in Figure 3-22. The predicted current distribution shows less directional spreading compared to the recordings. Nevertheless, good overall consistency over the entire calibration period has been achieved.

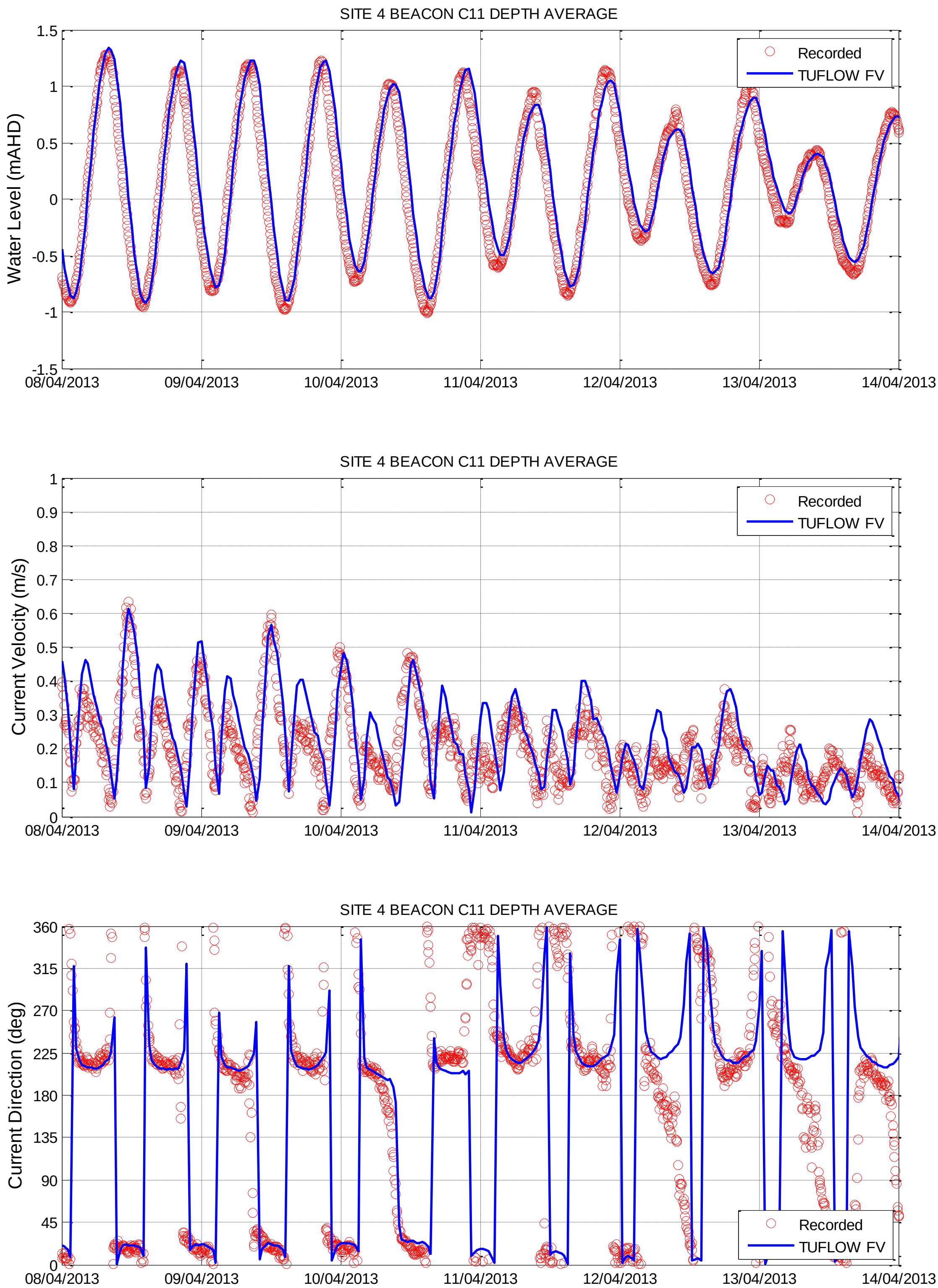


Figure 3-19 Hydrodynamic Model Calibration 3D Depth Average – Site 4 Beacon C11

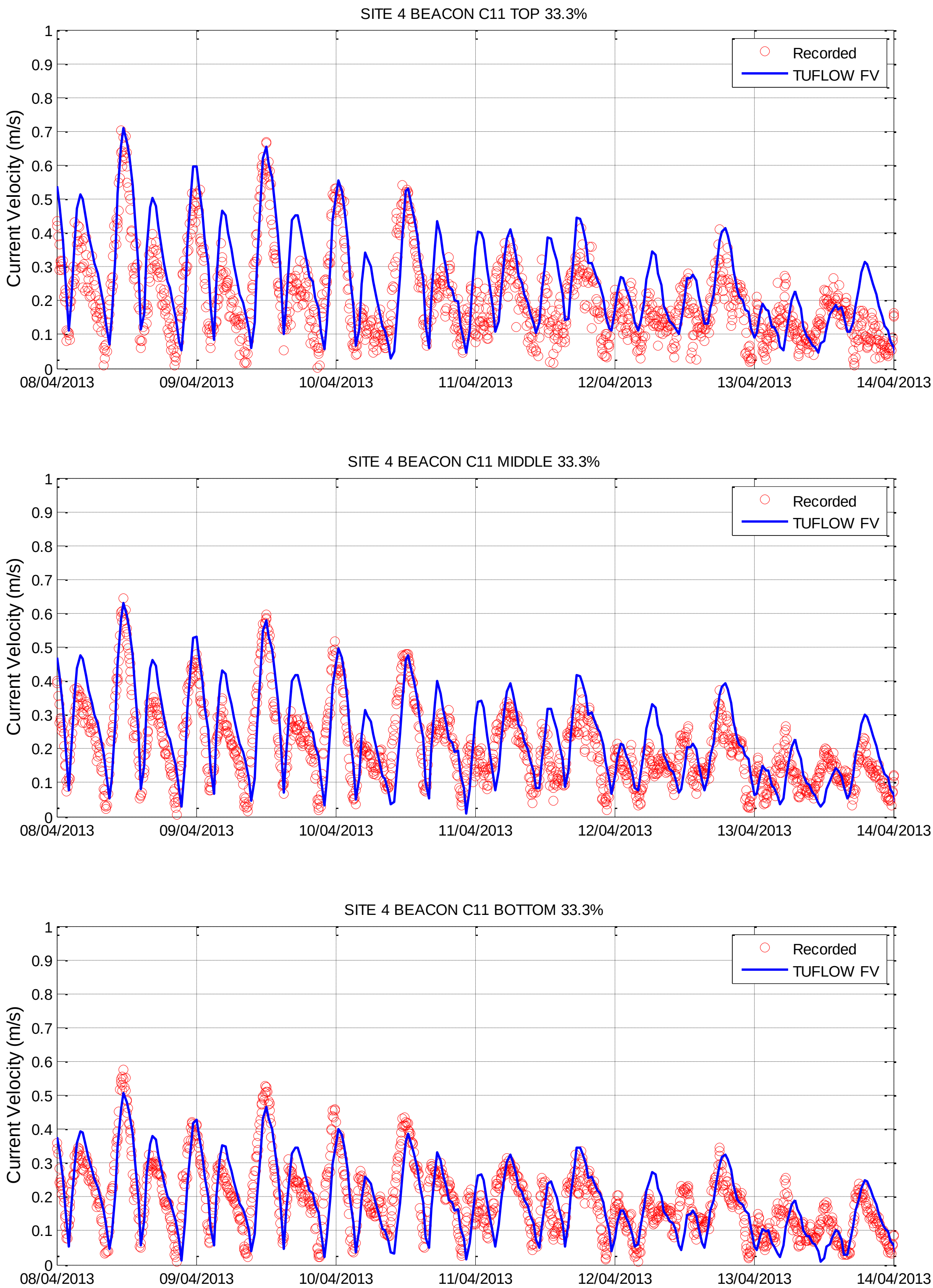


Figure 3-20 Hydrodynamic Model Calibration Current Velocity Layers – Site 4 Beacon C11

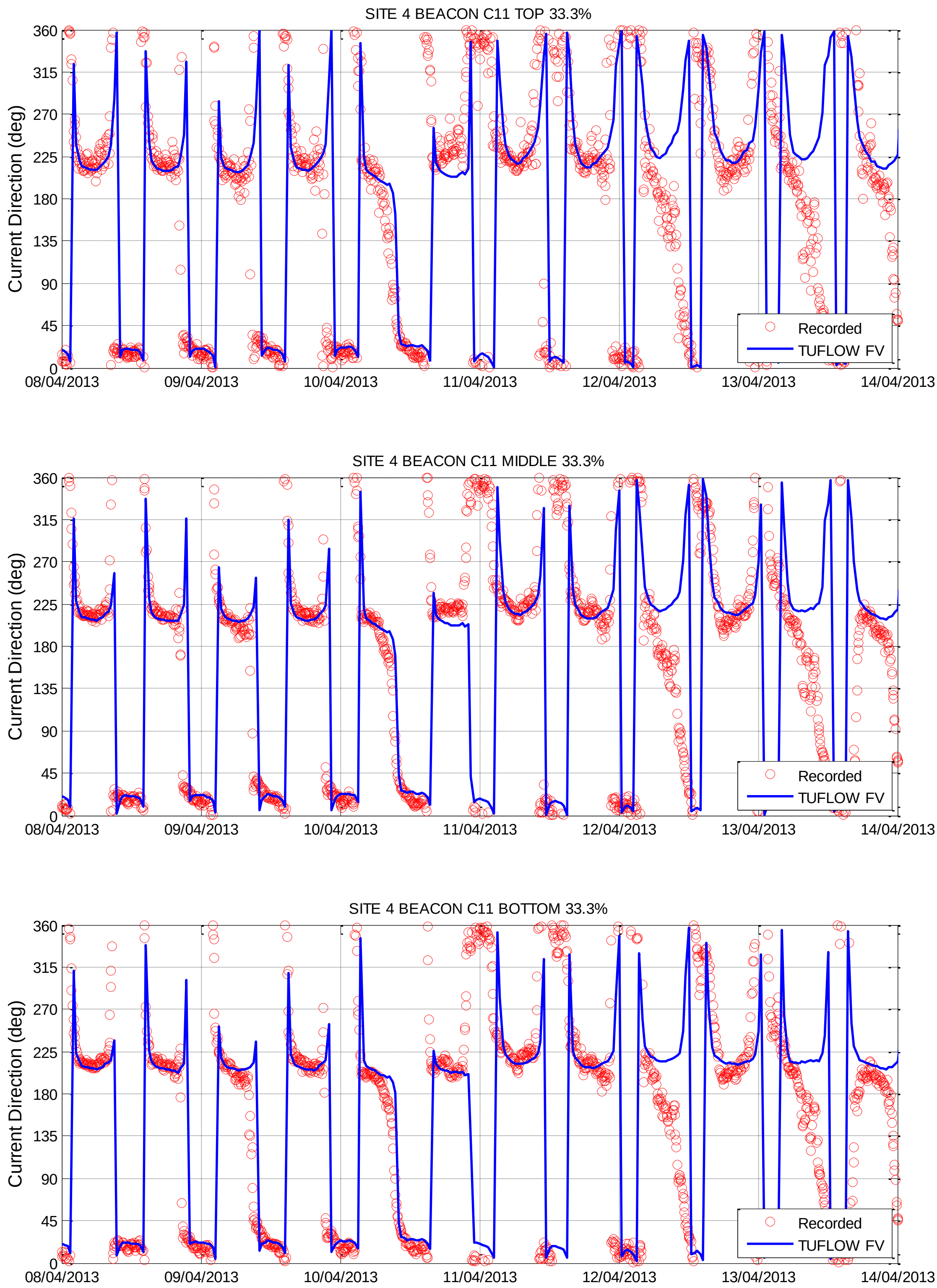


Figure 3-21 Hydrodynamic Model Calibration Current Direction Layers – Site 4 Beacon C11

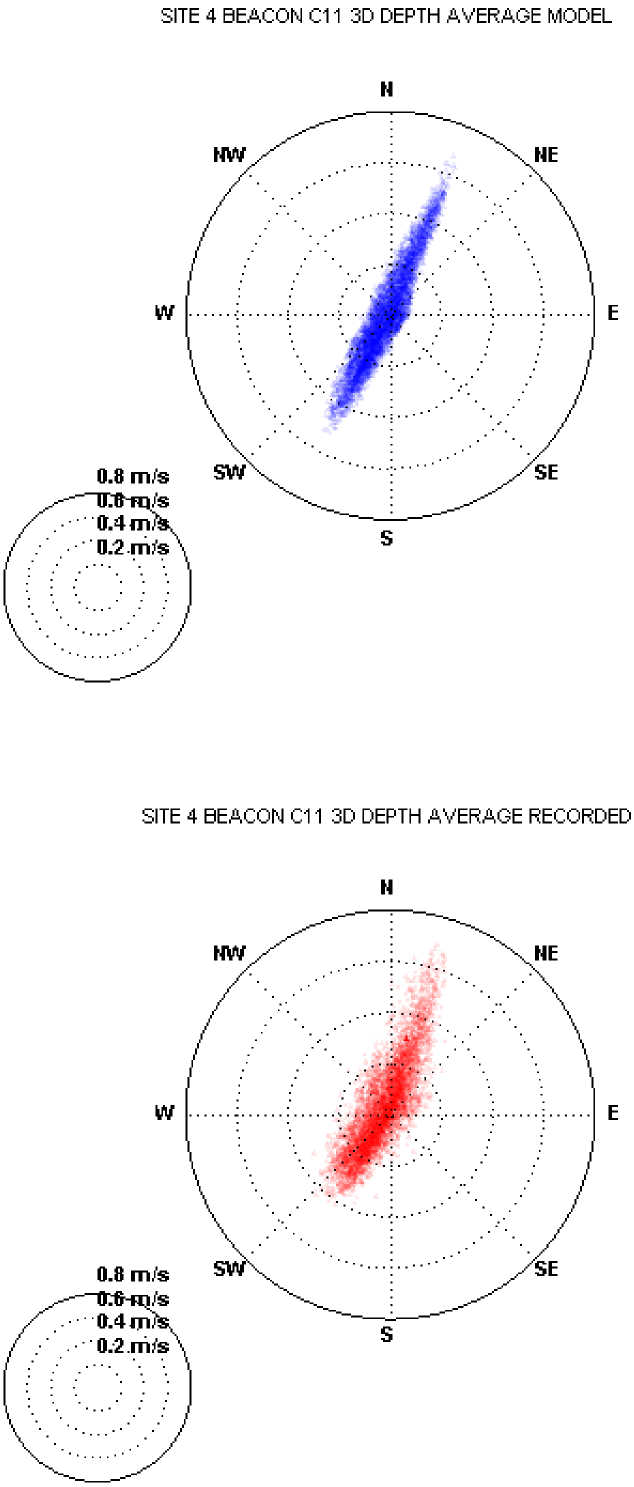


Figure 3-22 Current Polar Plot Validation – Site 4 Beacon C11

3.3.3 Water Temperature Calibration

Comparisons of the modelled near-bed water temperature with continuous measurements obtained using YSI Model 6600 EDS nephelometers (co-located with the ADCP instruments) are shown in Figure 3-23 to Figure 3-26. The model accurately simulates the gradual cooling trend observed during the calibration period.

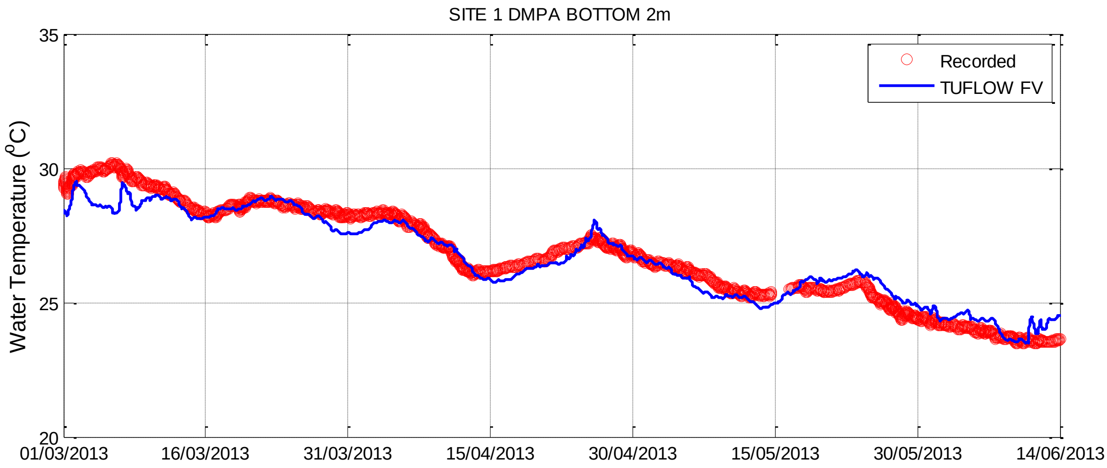


Figure 3-23 Hydrodynamic Model Calibration Near Bed Temperature – Site 1 DMPA

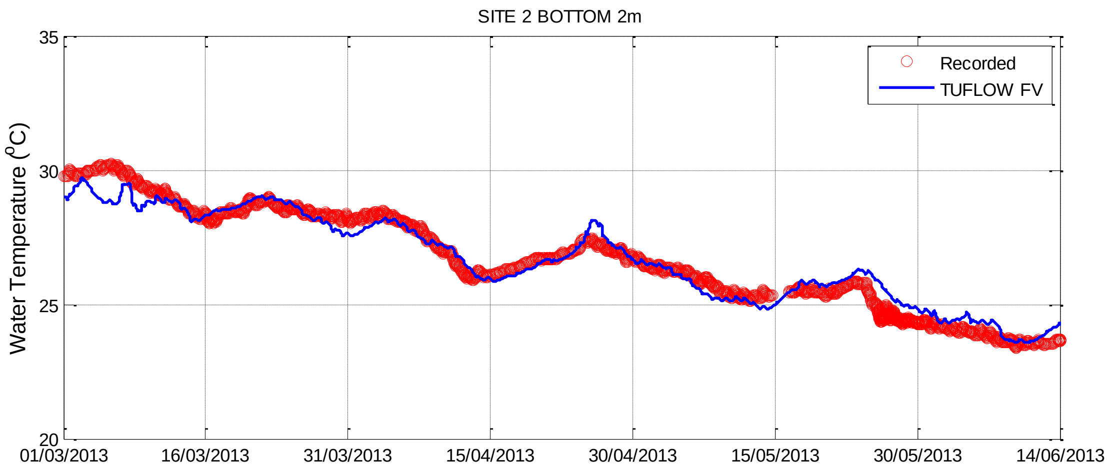


Figure 3-24 Hydrodynamic Model Calibration Near Bed Temperature – Site 2

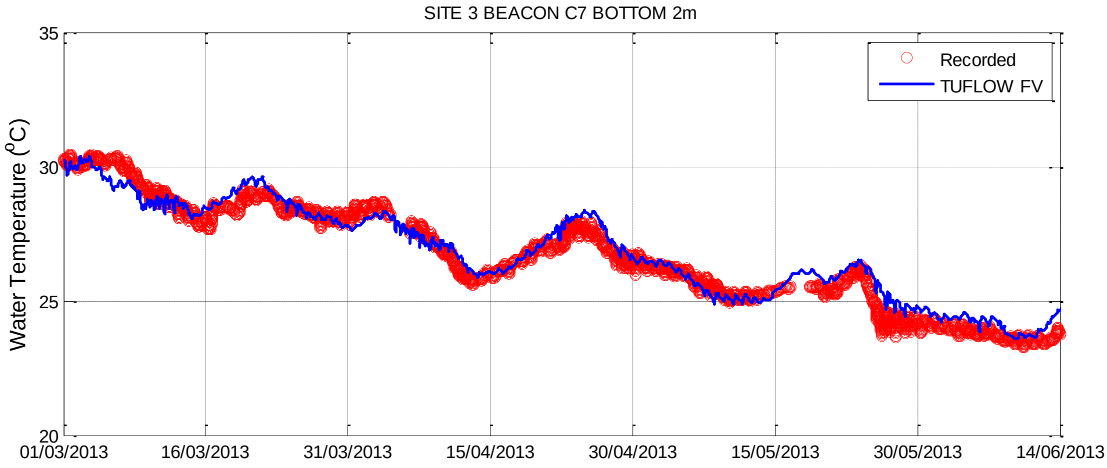


Figure 3-25 Hydrodynamic Model Calibration Near Bed Temperature – Site 3 Beacon C7

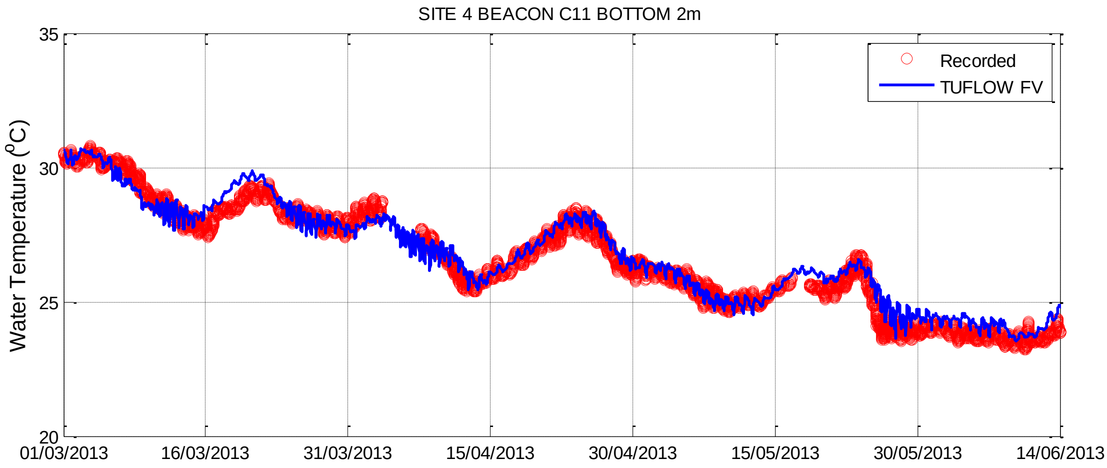


Figure 3-26 Hydrodynamic Model Calibration Near Bed Temperature – Site 4 Beacon C11

3.4 Wave Model Calibration

3.4.1 Wave Model Parameterisation

The SWAN wave model computations were undertaken in third-generation mode which considers various physical processes that add/withdraw wave energy to/from the wave field. Physical processes activated and considered important to the study area include:

- Linear wind growth (Cavaleri and Malanotte-Rizzoli, 1981).
- Exponential wind growth (Komen et al., 1984).
- Bottom friction (Collins, 1972).

- Depth-induced wave breaking (Battjes and Janssen, 1978).
- Whitecapping (Komen et al., 1984).
- Wave-wave interactions (Hasselmann et al., 1985).

With the exception of friction, the default values for the model coefficients as described in Delft University of Technology (2006) were adopted. Friction coefficients were adjusted as part of the calibration process. Table 3-5 summarises the SWAN model configuration and parameterisations.

Table 3-5 Summary of SWAN Model Configuration and Parameterisations

Model Configuration Description	Model/Value
Offshore boundary (500m grid only)	Wavewatch III with 30deg directional spreading
Generation mode	GEN3 with default parameters
Bottom friction model	Collins (1972)
Bottom friction coefficients: Default (offshore areas) Reef passes	 0.025 0.1
Computational mode	Non-stationary two-dimensional

3.4.2 Wave Model Calibration Results

Continuous time series of recorded significant wave height, peak wave period and wave direction were available at the following locations indicated in Figure 3-2:

- Cairns Wave Buoy operated by DEHP (significant wave height and peak wave period only);
- DMPA;
- Site 2;
- Beacon C7; and
- Beacon C11.

With the exception of the Cairns Wave Buoy, wave recording instruments were deployed specifically for the CSDP and data is presented for the period 01/03/2013 to 30/06/2013.

The recorded peak period data at all locations shows the wave conditions varying between dominant "swell" and dominant locally generated "sea" states. The amount of Coral Sea swell energy reaching the recording locations is limited by the Great Barrier Reef. Swell state conditions dominate the peak energy parameters only when the local wind conditions are particularly mild. The Swell wave train component is characterised by longer peak wave periods (>6s) and generally small significant wave heights.

Sea state wave conditions are characterised by shorter wave periods (typically 3-5s) and are generated by local winds acting on the sea surface within the Great Barrier Reef lagoon. Due to the complex arrangement of reef passes, fetch lengths and local bathymetry, the wave climate in the study area can at times be multi-modal, meaning that it is made up of multiple component wave trains with distinct wave periods and directions.

Figure 3-27 uses 2D wave energy spectrum model output to illustrate typical wave conditions for the Cairns region. The left spectral plot shows a time when the wave climate is dominated low frequency (longer period) swell wave energy entering the Great Barrier Reef lagoon from the north-easterly directional sector. In contrast, the spectral plot on the right shows a time when a sea state generated by south-easterly winds is dominant. The locally generated wind waves are of high frequency (shorter period) compared to the swell wave energy wave field which has an independent direction and period.

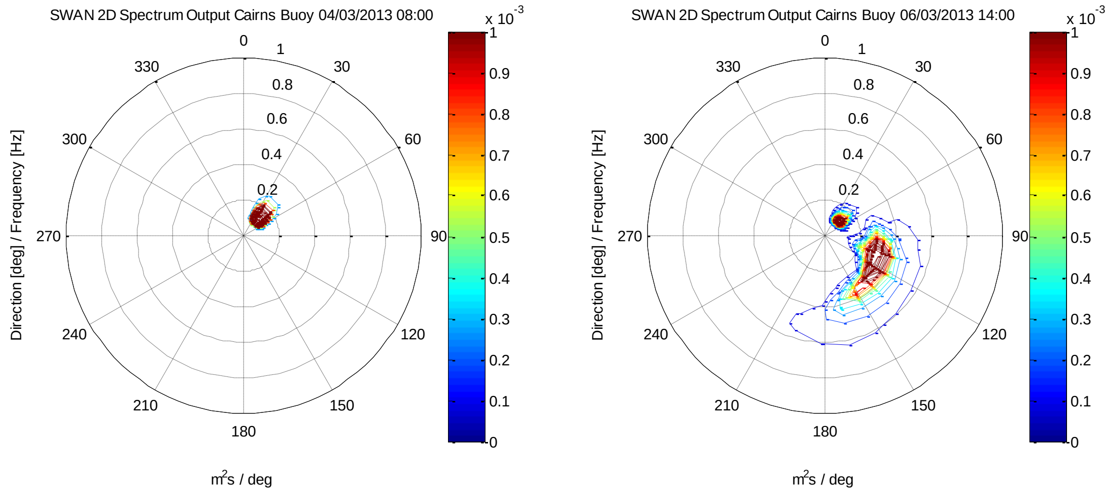


Figure 3-27 Example Wave Energy Spectrum showing Dominant Swell (left) and Wind Generated Sea (right) States

3.4.2.1 Cairns Wave Buoy

Non-directional wave recordings were provided by DEHP for the period 01/01/2011 to 28/02/2013. The results of the local model (100m grid resolution) calibration to a selected period of this data set is provided in Figure 3-28. The significant wave height prediction is generally good, particularly during the event associated with ex-Tropical Cyclone Oswald (23-24 January 2013) with a peak significant wave height close to 2.4m. At other times the recorded data and model predictions show mild wave conditions with significant wave heights typically less than 1m.

The peak wave period at the Cairns Buoy is also represented well by the model with times of dominant swell and sea states reproduced. At times, the peak wave period is over predicted and represents times when slightly too much swell energy reaches the buoy location. This typically occurs during periods of low wind-driven wave energy. The consequence of too much long period (swell) wave energy in terms of the CSDP dredging assessments is a slight over prediction of sediment suspension.

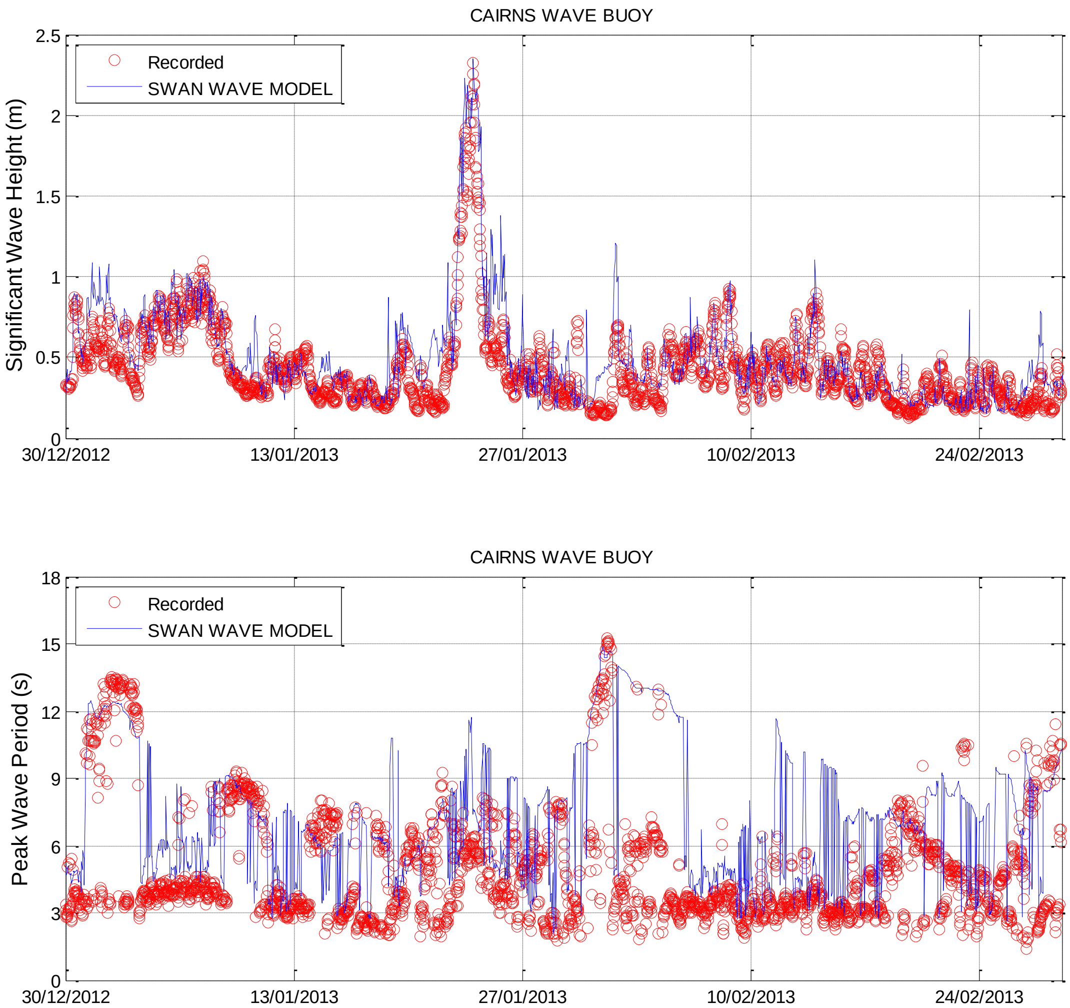


Figure 3-28 SWAN Wave Model Calibration – Cairns Wave Buoy

3.4.2.2 Targeted Wave Recordings

Predicted wave parameters (significant wave height, peak wave period and wave direction) are compared to continuous time series data in Figure 3-29 to Figure 3-32. Recorded and predicted 2D wave energy spectral plots are compared in Figure 3-33 and Figure 3-34. The wave model predictive skill is satisfactory and considered appropriate for assessing the potential impacts associated with the CSDP. Key features of the wave calibration results include:

- Significant wave height at Site 1 and Site 2 is predicted well. The dominant wave direction (from the east to south east) at these locations is generally represented by the model.
- A slight significant wave height over-prediction is evident at the Beacon C7 and Beacon C11 where the south-easterly fetch length is particularly limited. The over prediction in wave height is probably attributable to the effects of wind drag over land, and the transition from over land to over sea winds, not being precisely resolved by the constructed wind field. The consequence of this minor inaccuracy in terms of the CSDP dredging assessments is a slight over prediction of wave-driven sediment suspension.

- The wave model predicts periods of dominant sea and swell states at each location and this is reflected in comparisons with the peak wave period recordings. As observed at the Cairns Wave Buoy location, occasionally the peak wave period is over-predicted and represents times when slightly too much offshore swell energy is propagated into Great Barrier Reef lagoon.
- Due to wave refraction processes, the dominant wave direction of the longer period swell waves at Beacon C7 and Beacon C11 is progressively east to north-easterly. This general pattern is represented by the model.
- The energy spectrum comparisons correspond to a 20 minute time-averaged period when swell state (Figure 3-33) and sea state (Figure 3-34) wave conditions dominant. Despite relative robust predictions of wave parameters, the spectral comparison suggest the predicted directional spread of wave energy is somewhat narrower than recorded.

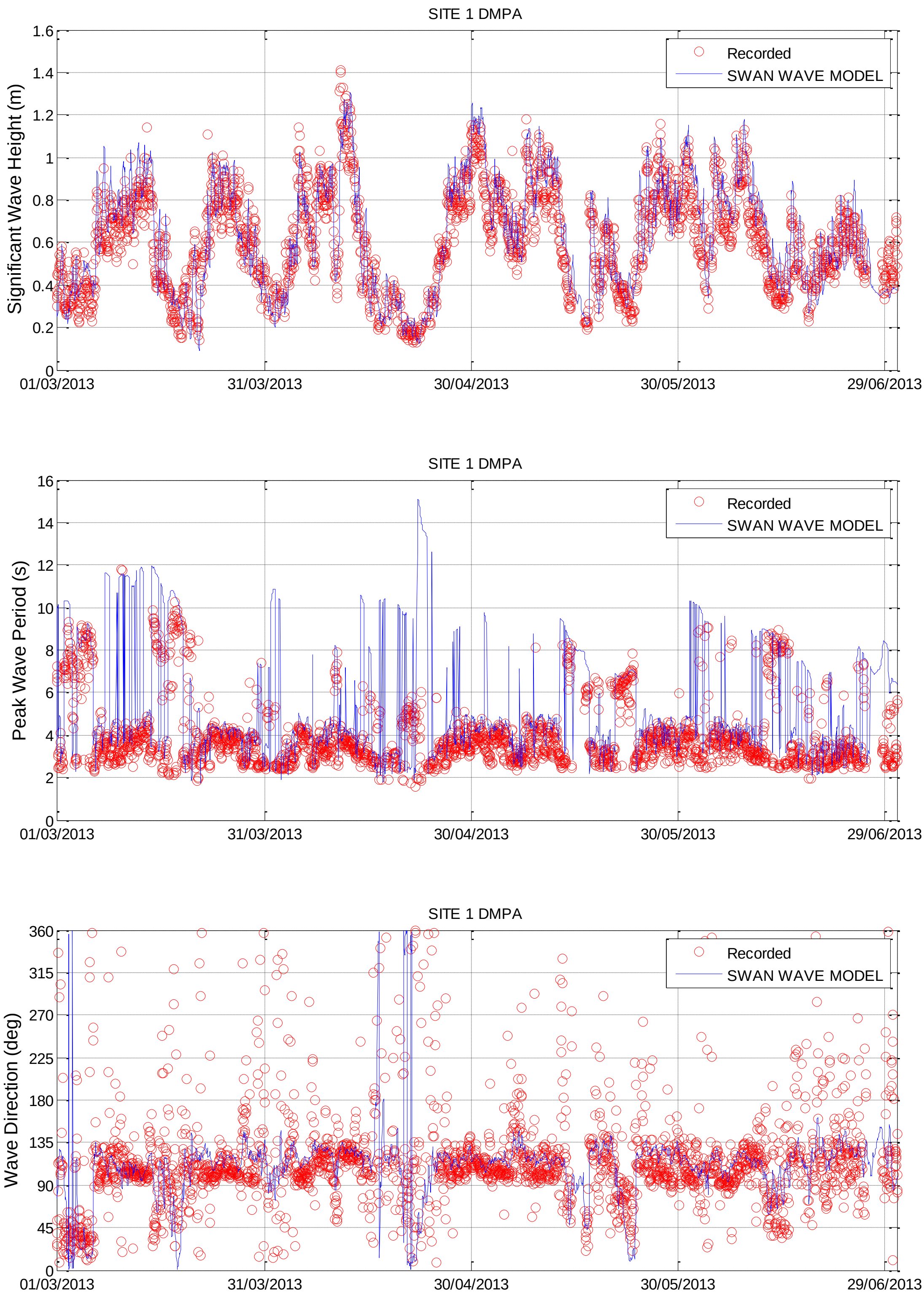


Figure 3-29 SWAN Wave Model Calibration – Site 1 DMPA

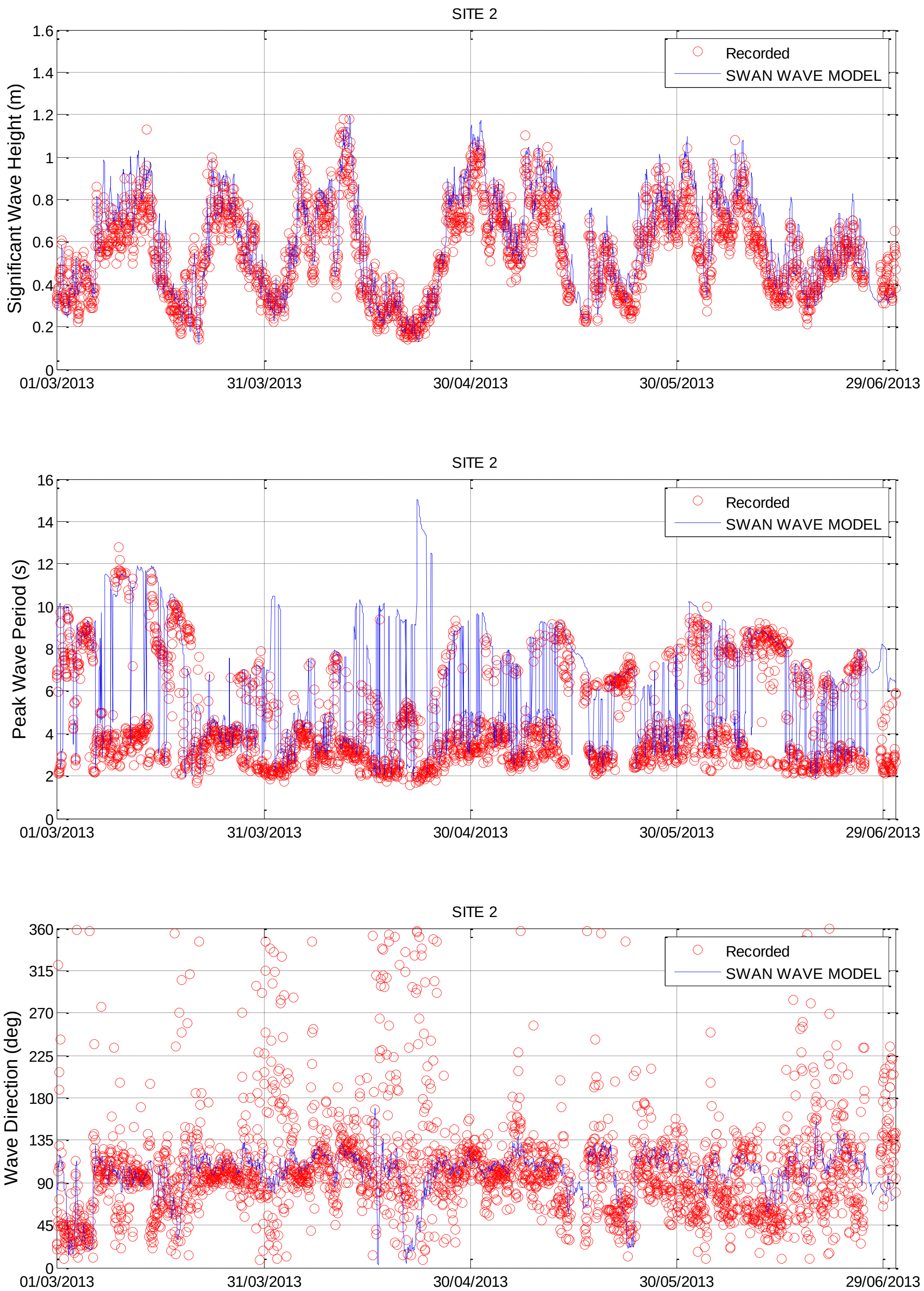


Figure 3-30 SWAN Wave Model Calibration – Site 2

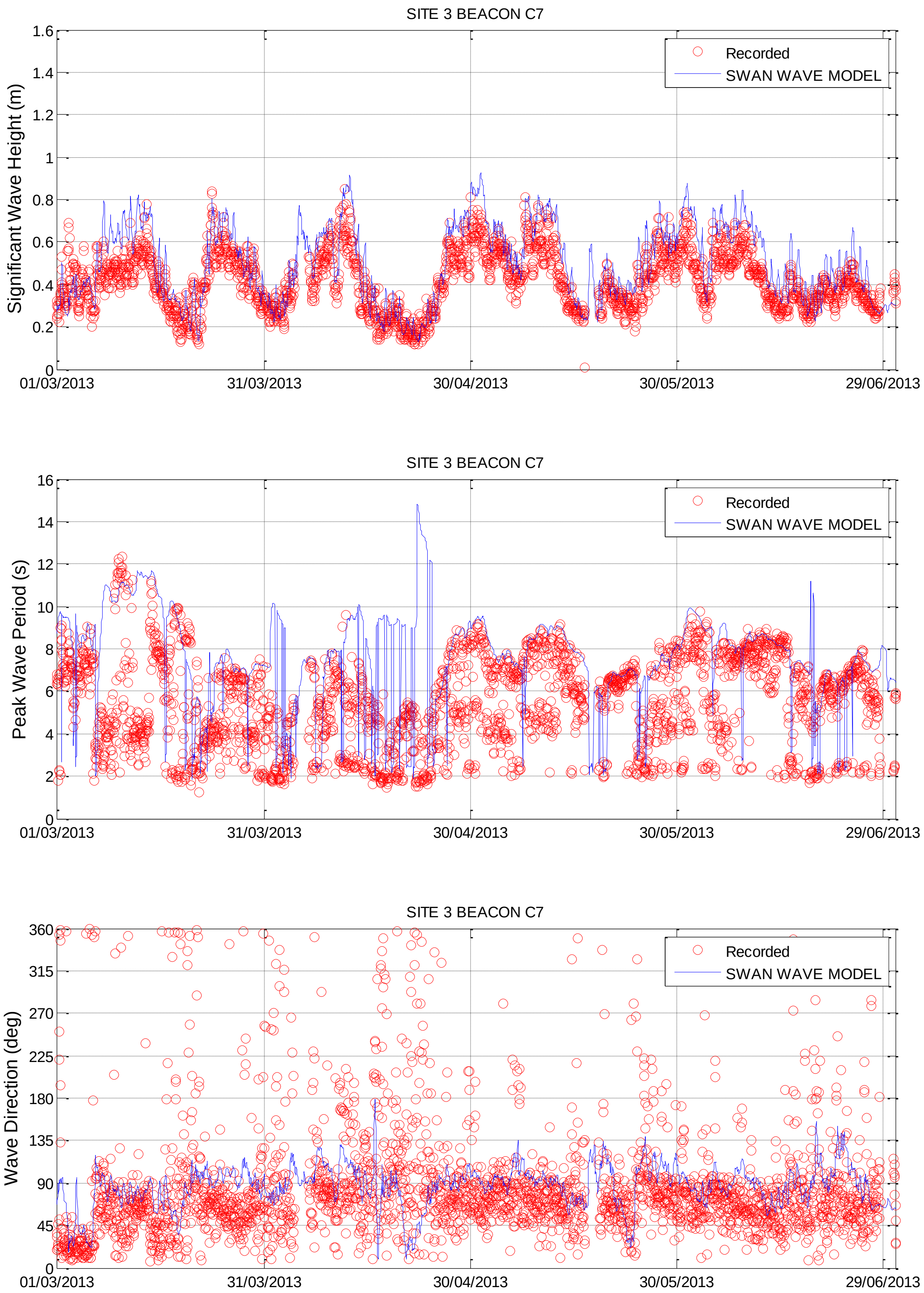


Figure 3-31 SWAN Wave Model Calibration – Site 3 Beacon C7

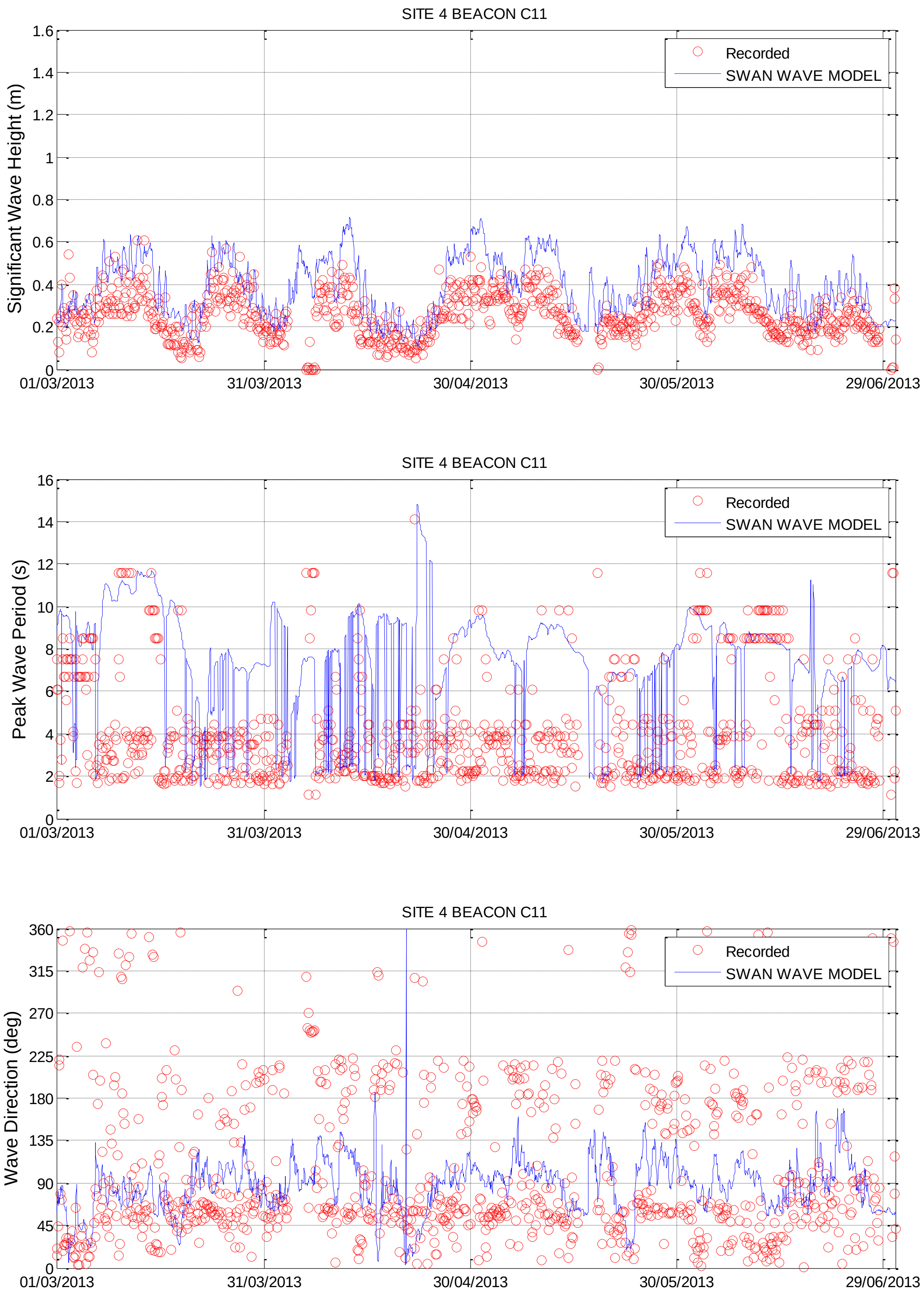


Figure 3-32 SWAN Wave Model Calibration – Site 4 Beacon C11

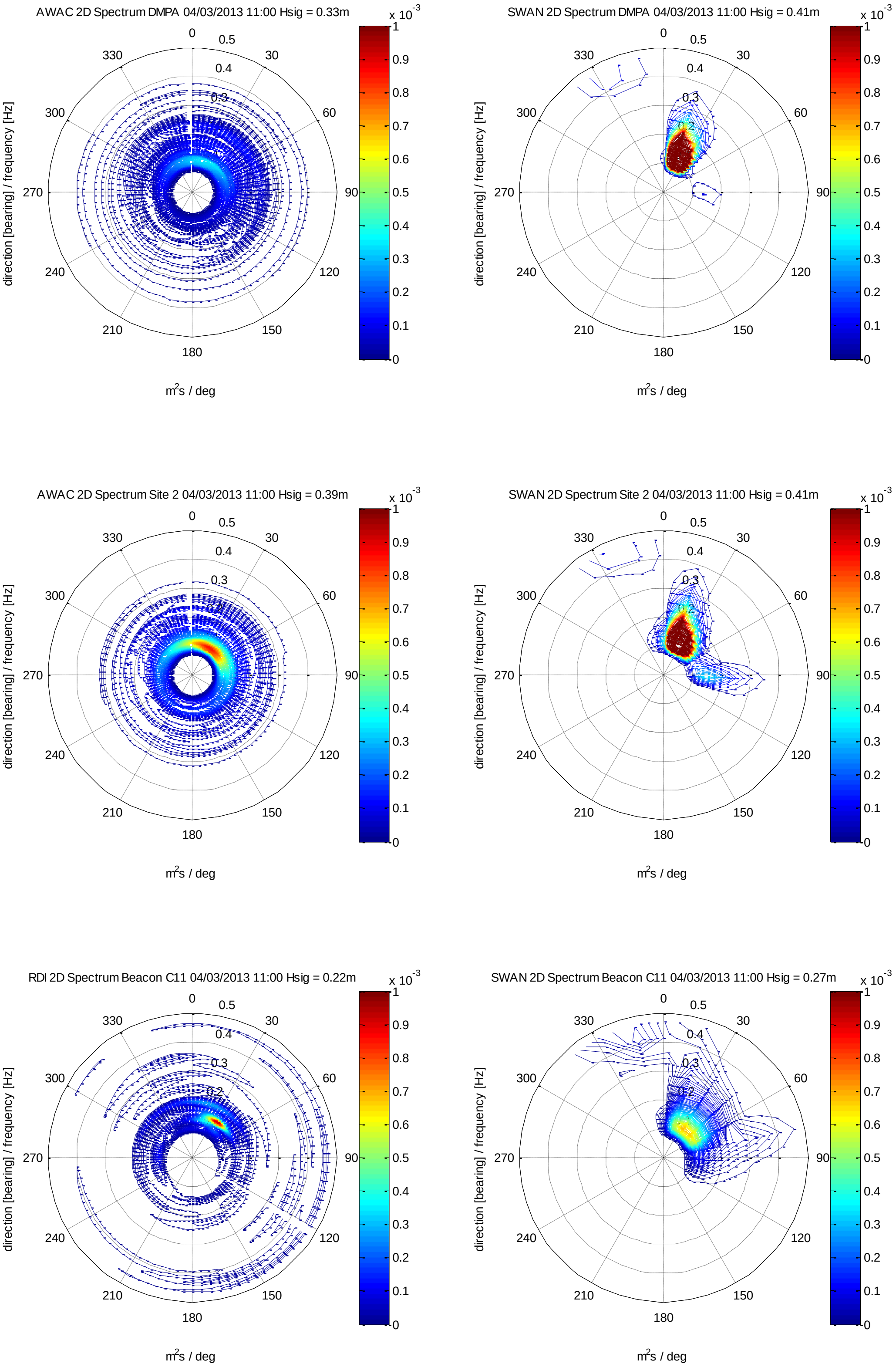


Figure 3-33 Recorded (left) and Predicted (right) 2D Wave Energy Spectrum: Dominant Swell State

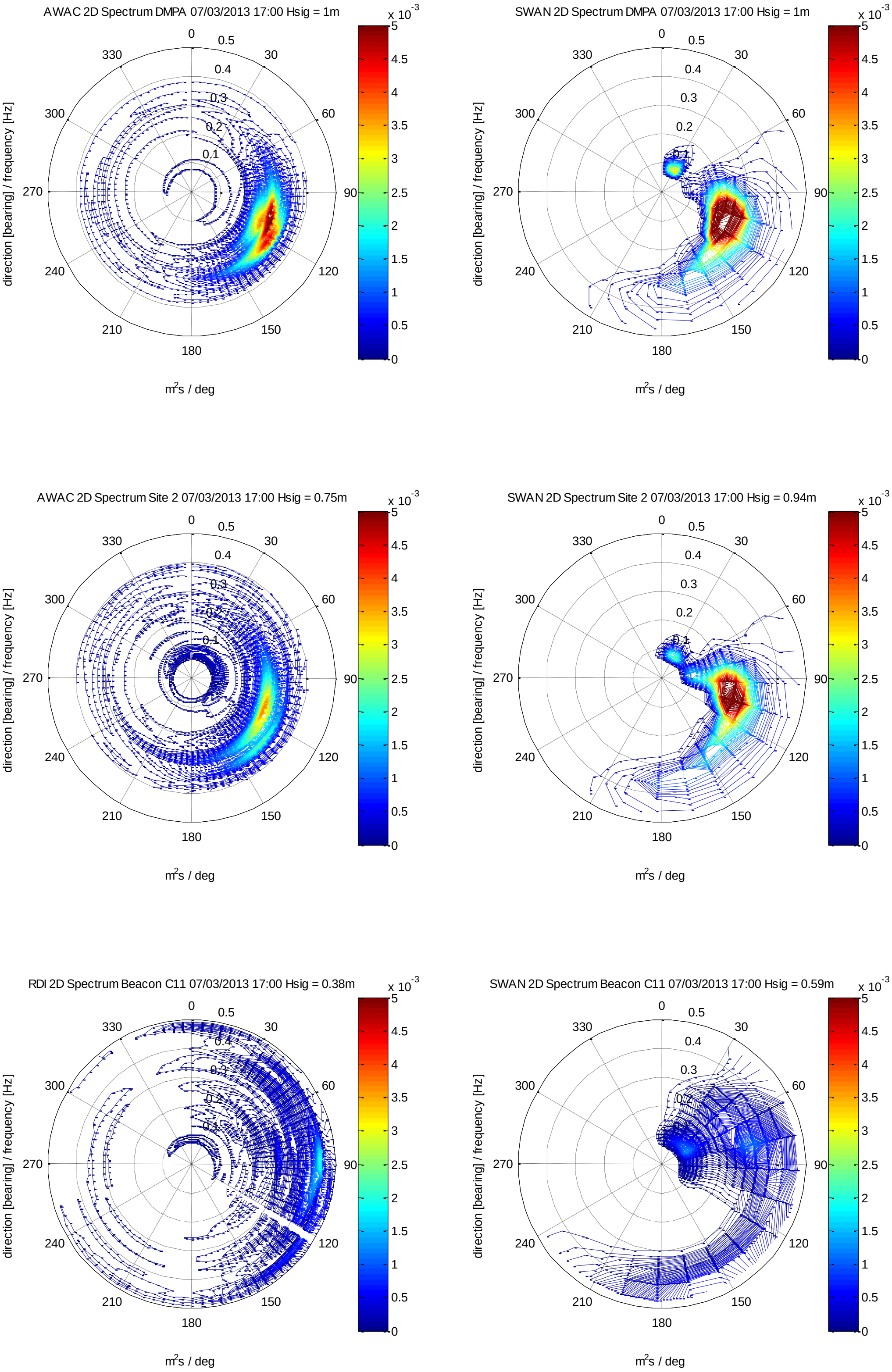


Figure 3-34 Recorded (left) and Predicted (right) 2D Wave Energy Spectrum: Dominant Sea State

3.5 Sediment Re-suspension Model Calibration

3.5.1 Sediment Re-suspension Model Parameterisation

The re-suspension, dispersion and settling of the natural bed sediments throughout the study area was estimated using the TUFLOW FV ST module coupled with the calibrated wave and hydrodynamic models. Simulated ambient TSS concentration was calibrated to continuous recordings of near-bed turbidity converted to TSS using the site specific NTU-TSS relationship shown in Figure 3-1. Estimates of the average annual channel sedimentation derived from hydrographic survey measurements provided by Ports North were also used to further validate the model's predictive skill.

The sediments existing in the natural bed were represented using four sediment classes. The TUFLOW FV cohesive sediment module simulates the exchange of sediments between the bed and the water column. The effective clear water sediment settling velocity of each sediment fraction is directly specified and is assumed to have no dependence on suspended sediment concentration. A distinction between the siliceous and carbonaceous sands has been made because the typical shape of the particles result in markedly different settling velocities. The erosion and settling characteristics of each sediment class is summarised in Table 3-6.

Table 3-6 Characteristics of Simulated Sediment Classes

	Siliceous Sand	*Silt*	*Clay*	*Carbonaceous Sand*
Still Water Fall Velocity, W_s (m/s)	3 x10^{-2}	1 x10^{-3}	1 x10^{-4}	1 x10^{-2}
Critical Shear Stress Erosion, T_{ce} *(Pa)*	0.2	0.2	0.2	0.2
Critical Shear Stress Deposition, T_{cd} *(Pa)*	0.2	0.18	0.18	0.2
Erosion Rate Constant, E (g/m^2/s)	0.1	0.1	0.1	0.1
Sediment Particle Density, ρ_s (Kg/m^3)	2650	2650	2650	2650

The composition of the natural bed relates to the proximity of sediment sources and the bed shear stress climate (due to currents and waves) that causes redistribution of the sediment. The inner shelf (from the coastline to approximately 20m depth) is dominated by terrigenous sediments, reflective of fluvial sources and the limited cross shelf mixing. The relative carbonate content within the seabed generally increases with distance from the coastline where it usually forms the dominant sediment class beyond the 20m depth contour (the beginning of the middle shelf between 20-40m depth). The carbonaceous grains are predominantly sand and gravel sized particles.

Within Trinity Bay, there is a strong correlation between the local bed shear stress climate and the proportion of siliceous sand within the sea bed as described in BPA (1984), Carter et al. (2002), Mathews et al. (2007) and observed in sediment samples collected for the CSDP. The wave component of the bed shear stress increases towards the coastline and so too does the sand content within the natural bed. Sands will also form the dominant sediment fraction in areas where the current component of the bed shear stress is conducive to the erosion of finer sediments.

The composition of the natural bed and the bed shear stress climate were considered using a two-staged approach to develop a representative “initial condition” distribution of bed sediments. To account for the sediment sources, the relative proportions of the four sediment classes in the “pre-warm up” bed were assigned based on existing information (e.g. BPA, 1984; Carter et al., 2002 and Mathews et al., 2007) and depending on the proximity to the coastline:

- Between the coastline and the 15m depth contour the initial bed comprised of:
  - 4.5 % siliceous sand;
  - 75 % silt;
  - 20 % clay; and
  - 0.5 % carbonaceous sand.
- Beyond the 15m depth contour the initial bed comprised of:
  - 3.75 % siliceous sand;
  - 25 % silt;
  - 1.25 % clay; and
  - 70 % carbonaceous sand.

Consideration was given to the bed shear stress climate by undertaking an initial “warm up” simulation which included a large wave event and representative tide and regional current forcing. This process allowed the composition of the “pre-warm up” bed to redistribute toward a quasi-equilibrium assumed to be representative of the natural bed. The warm up simulation also provided a means to smoothen the transition from terrigenous sediments that dominant the nearshore to the predominantly carbonaceous sediments found offshore. The “pre-warm up” and “post-warm up” bed sediment distributions are presented in Figure 3-35.

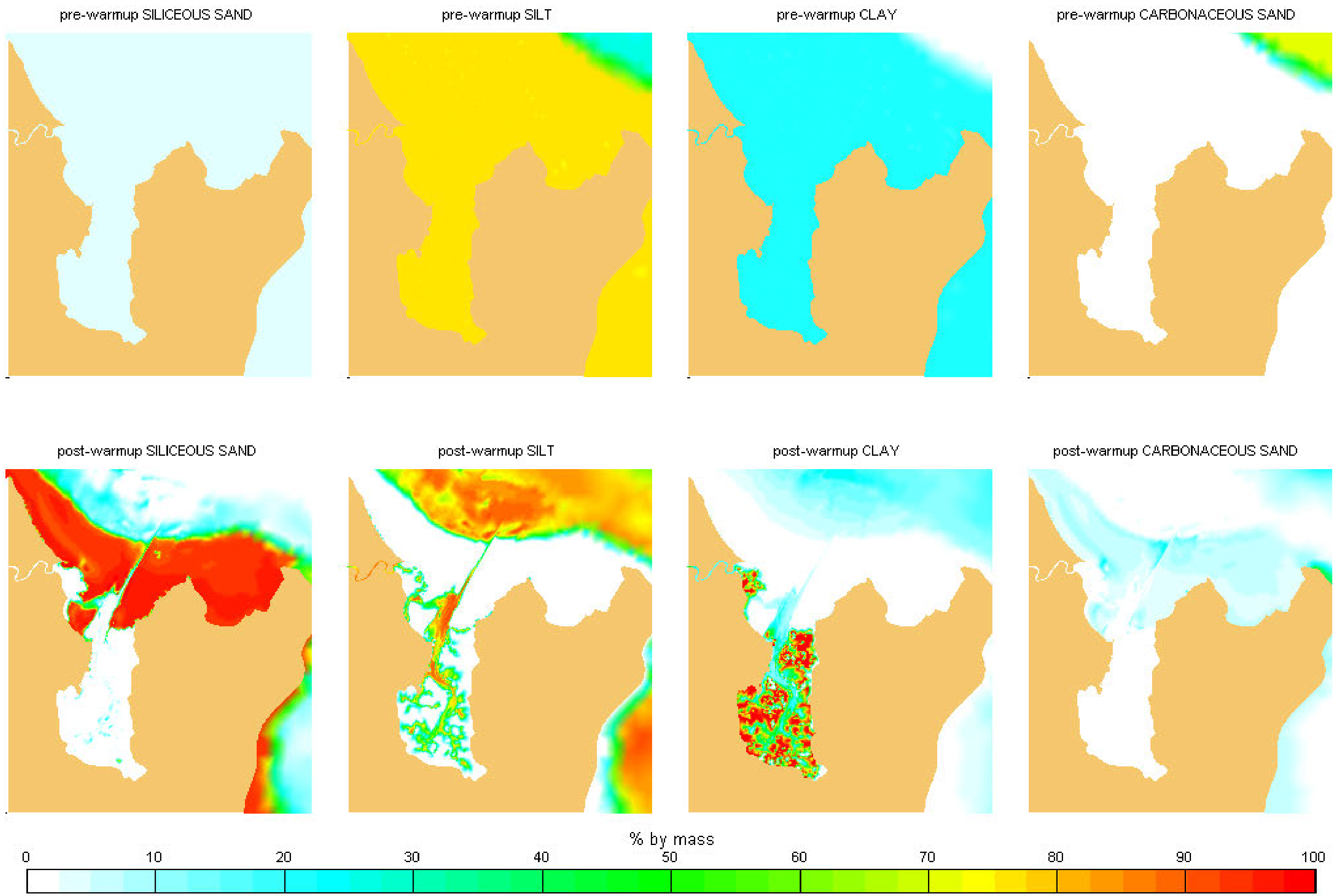


Figure 3-35 "Pre-Warm Up" and "Post-Warm Up" Bed Sediment Distributions

3.5.2 Sediment Re-suspension Model Calibration Results

The calibration period described in Section 3.2 was used for sediment module calibration. This period incorporated several wave events and multiple spring-neap tidal cycles and therefore represents a typical range of conditions.

In Section 3.5.2.1 the ambient TSS calibration plots at each continuous data recording location (DMPA, Site 2, Beacon C7 and Beacon C11) are presented. In addition, the mass of sediment that settled in the dredged channel during the calibration period has been used to derive an annual siltation depth. This is compared long term annual siltation records in Section 3.5.2.2.

3.5.2.1 Targeted Turbidity Recordings

Active offshore disposal activities associated with dredging at Wharf 12 and the Marlin Marina were being undertaken during the calibration period (Ports North 2013, pers. comm. 14 October). There are a number of short periods of elevated TSS recorded at the DMPA due to these activities, most notably during early April when a peak TSS concentration close to 500mg/L was observed for a short period. No attempt was made to simulate these disposal activities as the focus of the initial sediment module calibration was the re-suspension of natural bed sediments. Detailed calibration of the model to dredging and disposal activities is described in Section 4.

Sediment module calibration results at the continuous data recording locations are presented in Figure 3-36 to Figure 3-39 and demonstrate the following:

- The near bed, background ambient TSS concentration (approximately 25mg/L) is under predicted by the model. This behaviour has been observed by BMT WBM in previous North Queensland Port assessments (e.g. Port of Townsville) and the recorded background ambient TSS during calm conditions is understood to be due in part to non-sediment based biological sources such as planktonic algae. A better representation of lower TSS levels could be achieved by adopting a more complex NTU-TSS relationship that does not intercept zero when converting the measured nephelometer data.
- The response in the natural TSS signal due to wind-driven wave and current events between 11-14 April and in early May is particularly well represented in the model with respect to both magnitude and timing at the offshore locations (DMPA and Site 2).
- The recorded TSS concentration at Beacon C7 and Beacon C11 exhibits a tidal signal. Close inspection suggests that a phase lag between peak tidal currents and peak TSS concentration is present, suggesting that plumes of suspended sediment are sourced from beyond the immediate surrounds of the nepholometer and advected with the tides over the instrument.
- Generally, ambient TSS concentration prediction throughout the calibration period is considered adequate, particularly at offshore locations. It is noted that short peaks in TSS concentration along the inner channel are at times under predicted. In terms of the CSDP assessments, an under prediction in ambient TSS will lead to conservative dredging impact predictions.

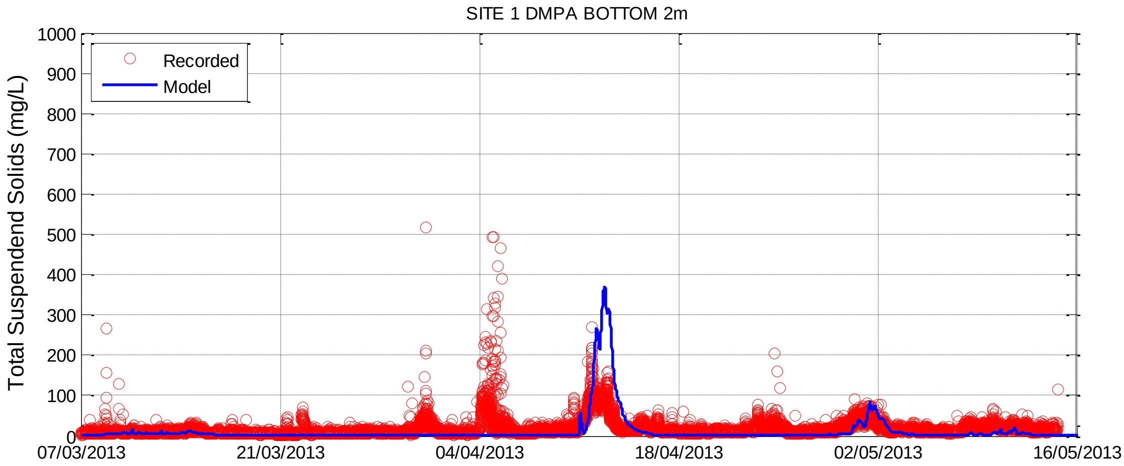


Figure 3-36 Sediment Re-suspension Calibration – DMPA

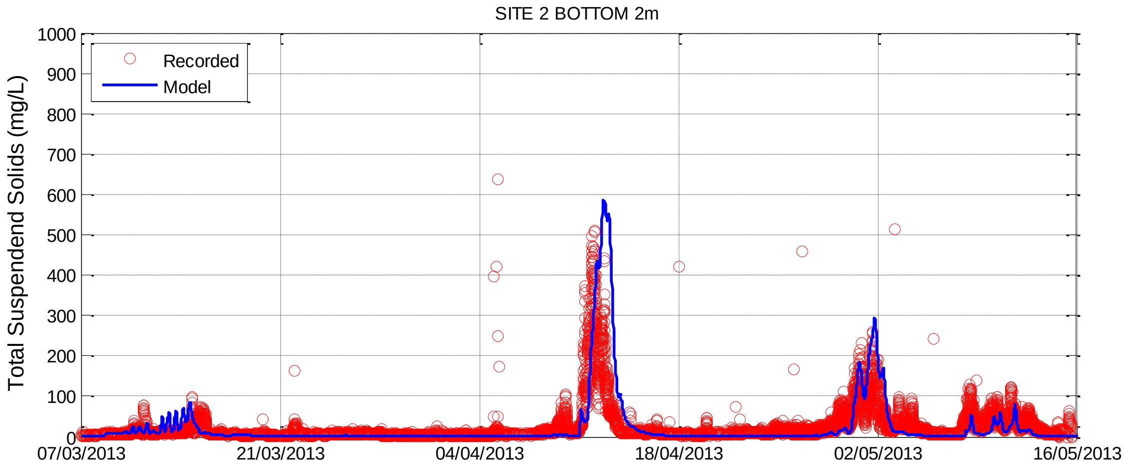


Figure 3-37 Sediment Re-suspension Calibration – Site 2

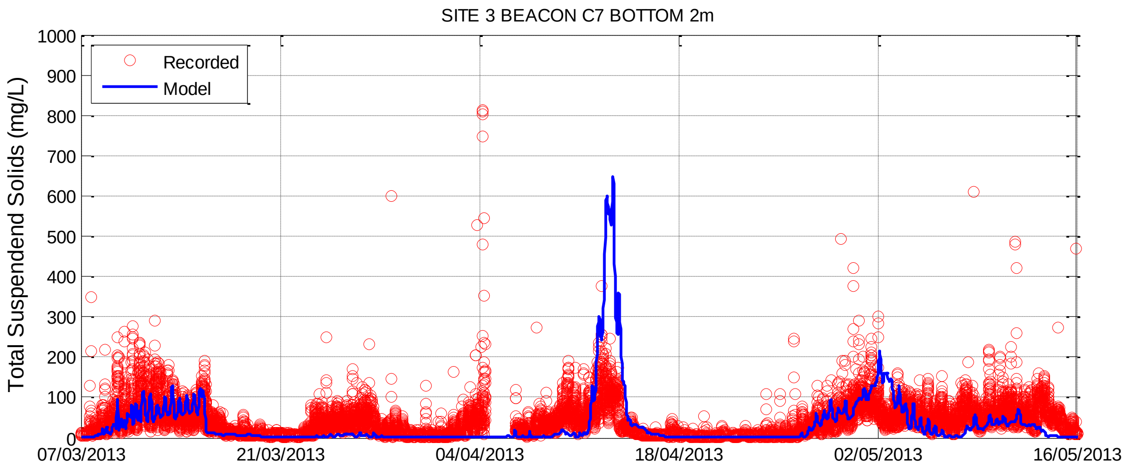


Figure 3-38 Sediment Re-suspension Calibration – Beacon C7

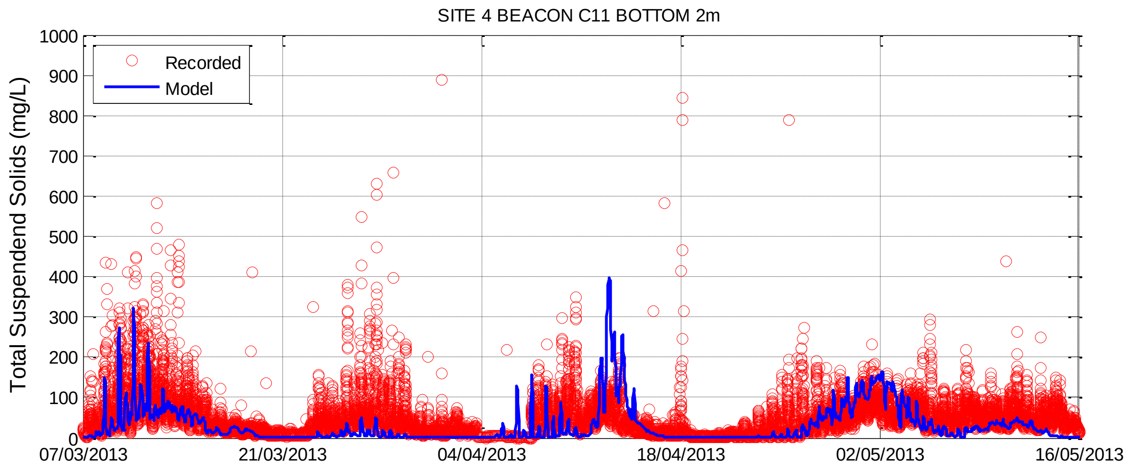


Figure 3-39 Sediment Re-suspension Calibration – Beacon C11

3.5.2.2 Channel Sedimentation Calibration

The mass of sediment which settled in the dredged channel during the calibration period was used to derive an annual siltation depth. As a validation of the sediment transport model performance this estimate was compared with the measured sedimentation provided by Ports North and presented in Figure 3-40. The conditions which resulted in the re-suspension and deposition of sediments in the study area during the calibration period were reasonably representative of longer term conditions (as detailed in Section 3.2).

The measured localised peaks in siltation close to Beacon C11 and C18 are represented by the model. The derived annual siltation volume of approximately 480,000m^3 (from Berth 1 to Beacon C1) is larger than the long-term average (for years 1990-2010) provided by Ports North however less than the maximum (approximately 760,000m^3) for the reported period. The predicted siltation rates and total volume are therefore considered to be towards the upper end of the historical limit. It should be noted that when undertaking impact assessments the predictive model is used to determine relative changes compared with the modelled baseline conditions, for instance to determine a percentage change in channel siltation. Some bias in the baseline predictions (within reasonable limits) should not significantly affect the ability of the model to determine the relative impacts of the proposed development.

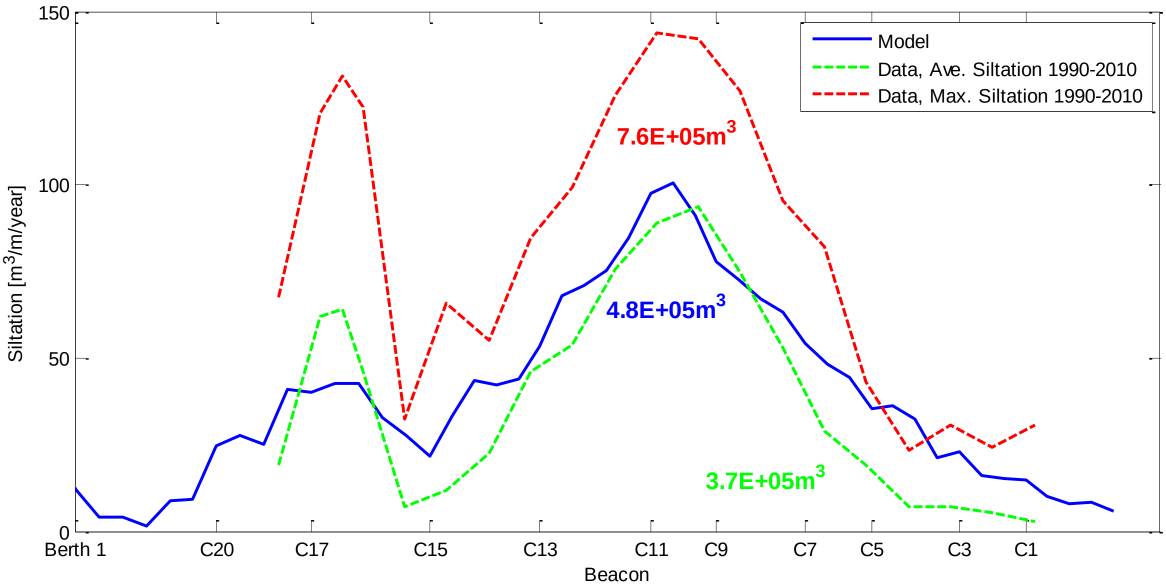


Figure 3-40 Estimated and Measured Annual Siltation of Shipping Channel

4 Dredge Plume Advection-Dispersion Calibration

4.1 Targeted Plume Monitoring Program

In 2010 a Long Term Management Plan (LTMP) for Dredging and Disposal 2010-2020 (Worley Parsons, 2010) was developed for the Port of Cairns and approved by the Great Barrier Reef Marine Park Authority (GBRMPA). An environmental monitoring program within the LTMP requires verification of the “typical” extents of plumes of suspended sediment generated during maintenance dredging operations. Information gathered from the monitoring program is intended to assist in the management of future dredging operations.

Maintenance dredging of the Port and entrance channel was undertaken in August 2011 by the trailing arm suction hopper dredger (TSHD) *Brisbane*, operated by the Port of Brisbane Pty Ltd. BMT WBM was commissioned by Ports North to monitor the extent of turbid plume development during maintenance dredging operations by TSHD *Brisbane* in accordance with the LTMP and their environmental management system.

Dredge plume monitoring was conducted by BMT WBM in the nearshore and offshore areas of the Port of Cairns from 28th – 30th August 2011. These measurements have been used in the CSDP to assist in the validation of the advection-dispersion model and to guide the adoption of specific sediment loading rates for the proposed dredging activities.

Monitoring of the extents of dredging and placement plumes within the Port of Cairns occurred over 3 days between the Sunday 28th and the Tuesday 30th August 2011 using the research support vessel *Viking* as a platform for all measurements.

DMPA plume measurements were completed during light winds and generally calm seas on Sunday 28th August 2011. Three dumping events were monitored on this day, consisting of one ebb tide event beginning in the late morning and two flood tide events in the afternoon.

Dredge plume monitoring about the shipping channel coincided with periods of moderate south-easterly trade winds on the 29th and 30th August 2011, with wind strengths typically ranging between 15 and 20 knots with occasional rain squalls. The windy conditions together with strong spring tide currents generated significant natural re-suspension of muddy seabed sediments in the shallow Port waters during the monitoring.

4.1.1 Data Processing

Measurements of turbidity in Nephelometric Turbidity Units (NTU) and Total Suspended Solids (TSS) results from the laboratory were compared in order to establish the TSS – NTU relationship shown in Figure 4-1. The turbidity measurements (converted into TSS) and the water sample TSS results were then used as the basis for converting the ADCP backscatter measurements to TSS concentrations.

It is noted that the TSS-NTU relationship for Cairns has been further developed using additional measurements and water samples collected as part of the CSDP. The relationship adopted for the EIS assessments has been previously presented in Figure 3-1 and differs slightly to the relationship derived in 2011 and used for maintenance dredging model validation.

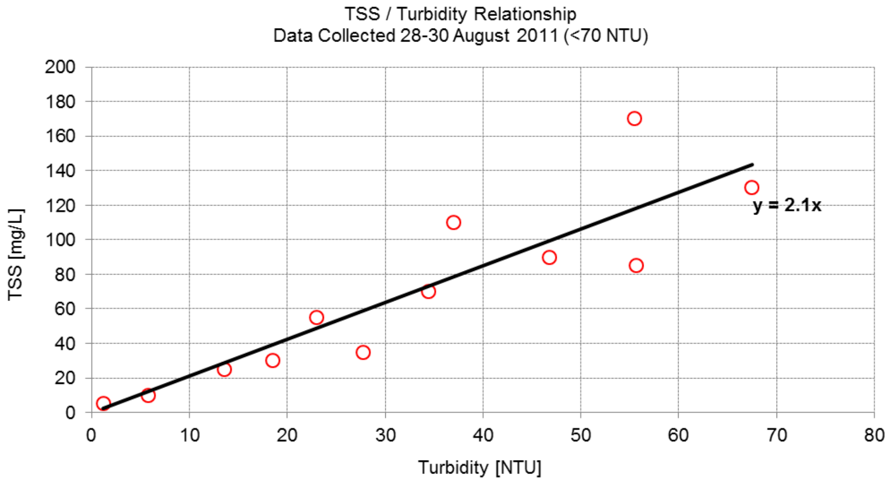


Figure 4-1 TSS-NTU Relationship August 2011 Dredge Plume Monitoring

4.2 Model Parameters

Dredging works cause the generation of plumes of suspended sediment through a number of potential sources/mechanisms. The major sources considered for the modelling of the *TSHD Brisbane* were:

- Sediment entrainment at the draghead during dredging;
- Overflow of sediment from the hopper; and
- Placement of material at the DMPA by hopper release.

The measured 3D TSS concentrations from the January 2011 ADCP transects were compared to simulations of plume dispersion using the TUFLOW FV cohesive sediment module coupled with the calibrated hydrodynamic models in order to calibrate the dredge plume source parameters.

The dredging logs were obtained and used to locate the dredge and also to determine the mode of operation (i.e. dredging, dredging with overflow or dumping).

Prediction of dredge plume impacts involves a number of components, namely:

- Source rate definition (i.e. mass load and characteristics of sediment entrained by the dredging activities);
- Prediction of plume advection/dispersion; and
- Prediction of plume settling.

The first of these is the most variable, and depends intimately on the type of dredging activities and equipment as well as the material being excavated. As such, this component of the dredge plume modelling is also the most subject to variation. Initially, the source parameters were chosen based on experience on similar projects and literature values. These parameters were then modified during the calibration process on the basis of comparisons with the measured data. The source terms adopted after model calibration are summarised below:

- Total source while overflow dredging in the channel: 250 kg/s.
- Dumping source: 200 kg/s.

The material released during dredging was assumed to be composed of 30% clay, 65% silt and 5% fine sand with assumed settling velocities of 1×10^{-4} m/s, 5×10^{-4} m/s and 1×10^{-2} m/s respectively. It is noted that the adopted description of the maintenance dredge material is not expected to be representative of the capital material considered in the CSDP EIS assessments. The sediment fraction breakdown used to describe the CSDP capital dredge material follows Golder (2013) and is presented in Section 6.2.3 of this report.

The dredge plume boundary condition was applied as a depth-averaged source into the model as there was no consistent indication in the near-field ADCP data that the source was particularly concentrated in any one part of the water column during either dredging or dumping.

Examples of the results of the plume model validation exercise are illustrated in Figure 4-2 to Figure 4-6 for channel dredging and Figure 4-7 to Figure 4-10 for DMPA placement. The upper panels in each figure show transects through the dredge plume, with contour plots of TSS measured by the ADCP (on the left) and modelled (on the right). The lower panels show a plan view of depth-averaged TSS, with the model results in the background and the ADCP-measured TSS shown as a black-bordered line along the transect. A red cross marks the start point of the transect (0m chainage in the upper panel). The channel dredging figures represent five individual transects during a 36 minute period and are presented in chronological order. The DMPA placement figures represent four individual transects during a 55 minute period following a single hopper release. The first figure in each series is annotated to aid interpretation.

The plume advection-dispersion validation results generally indicate that the model is accurately reproducing the pattern of suspended sediment distribution associated with dredge plumes. The accuracy of the ADCP data in the near field is sometimes uncertain due to bubbles and turbulence generated by the dredge propeller wash (as noted on Figure 4-7 and Figure 4-10). Given the complexity of data collection campaign and the modelling task, the highly three-dimensional nature of plumes and the temporal variation in the actual dredge discharge, a high degree of predictive skill is demonstrated.

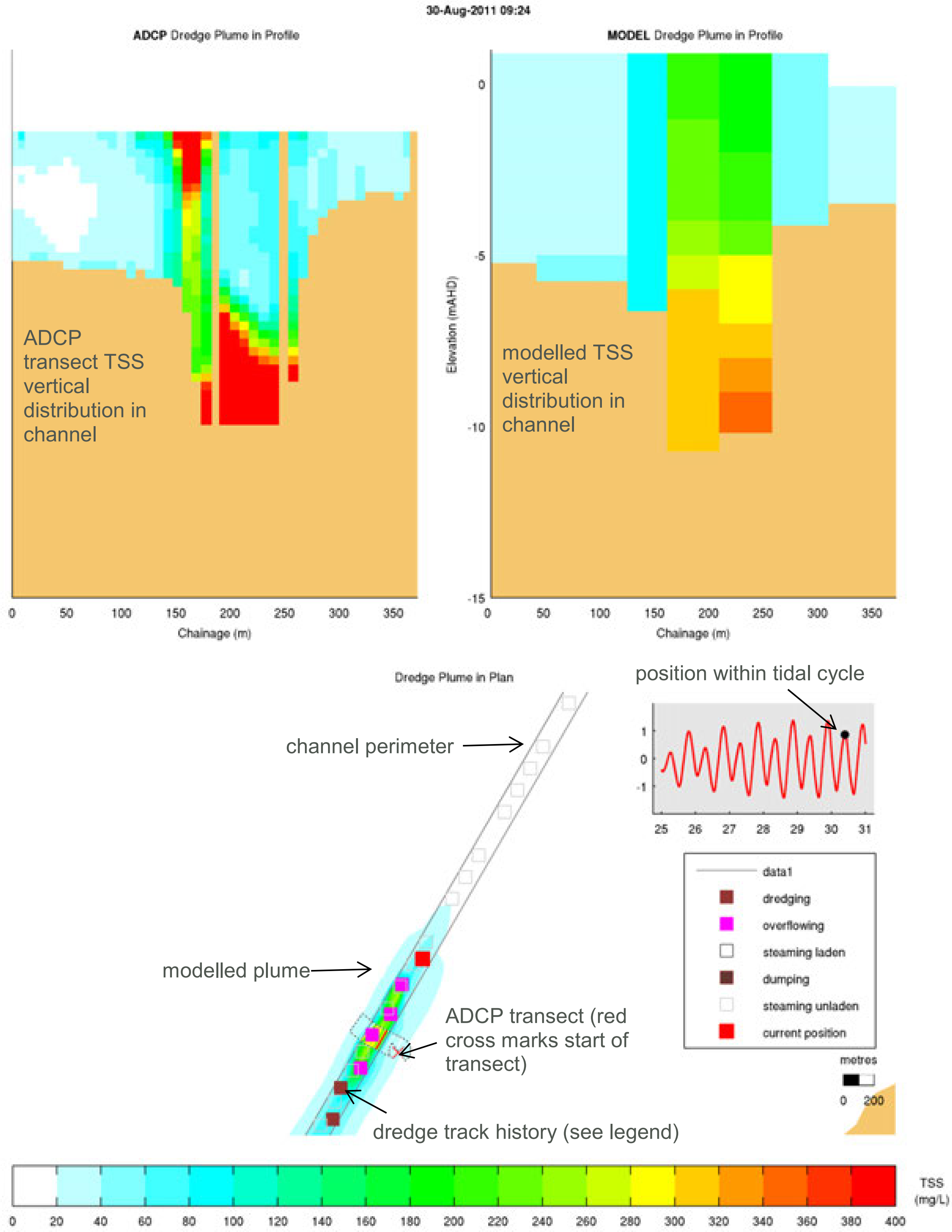


Figure 4-2 Maintenance Dredging Plume Validation, 30/08/2011 09:24: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

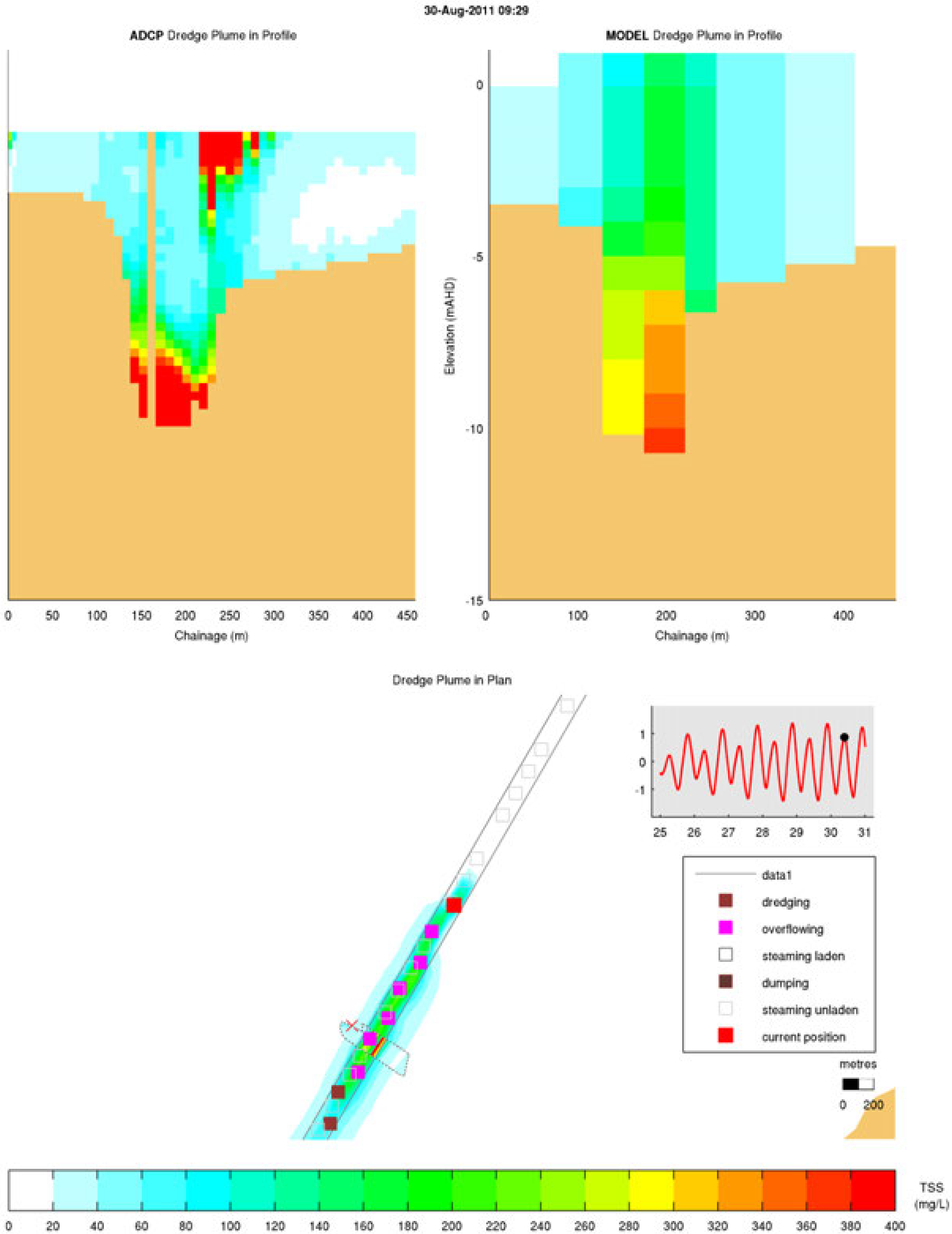


Figure 4-3 Maintenance Dredging Plume Validation, 30/08/2011 09:29: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

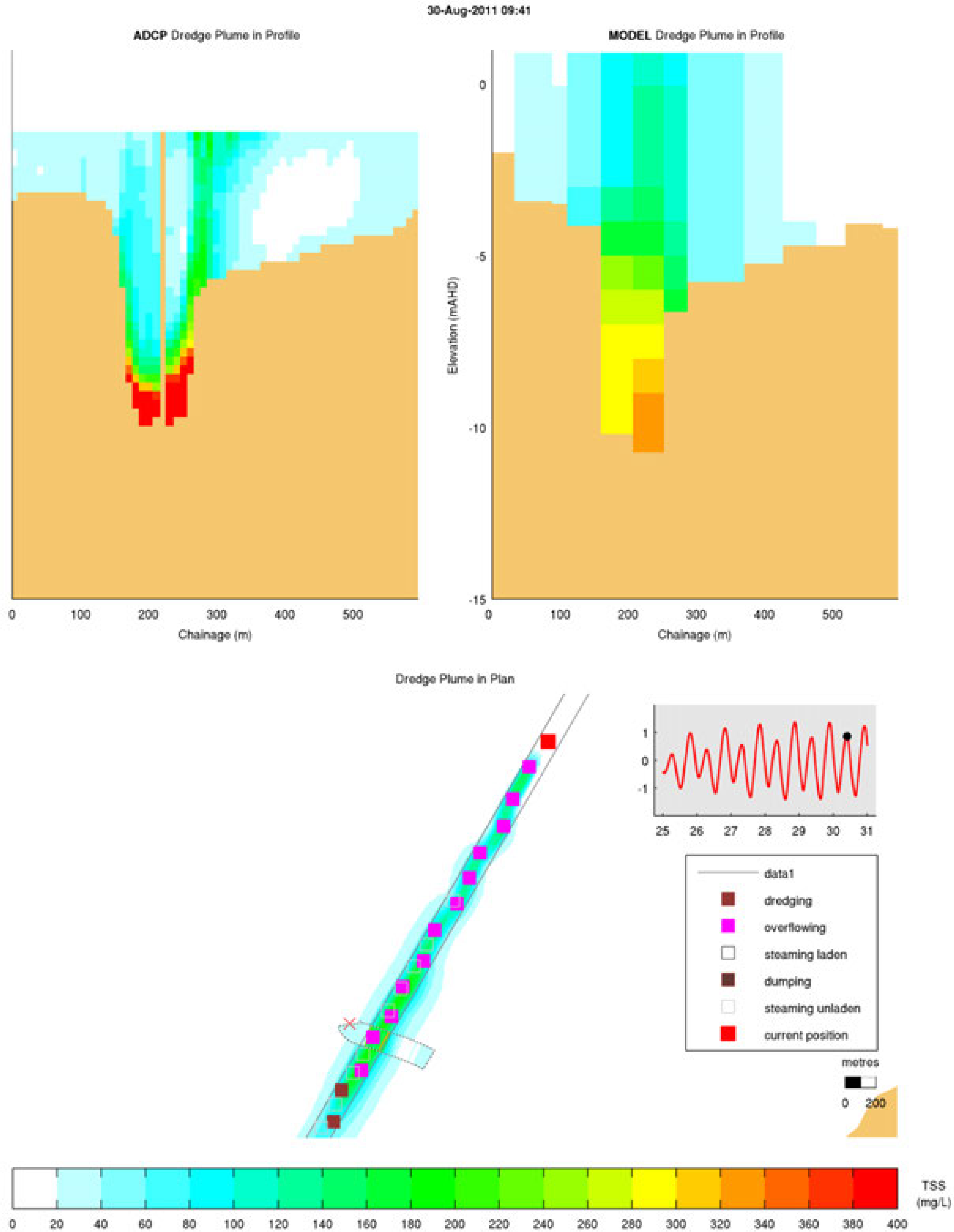


Figure 4-4 Maintenance Dredging Plume Validation, 30/08/2011 09:41: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

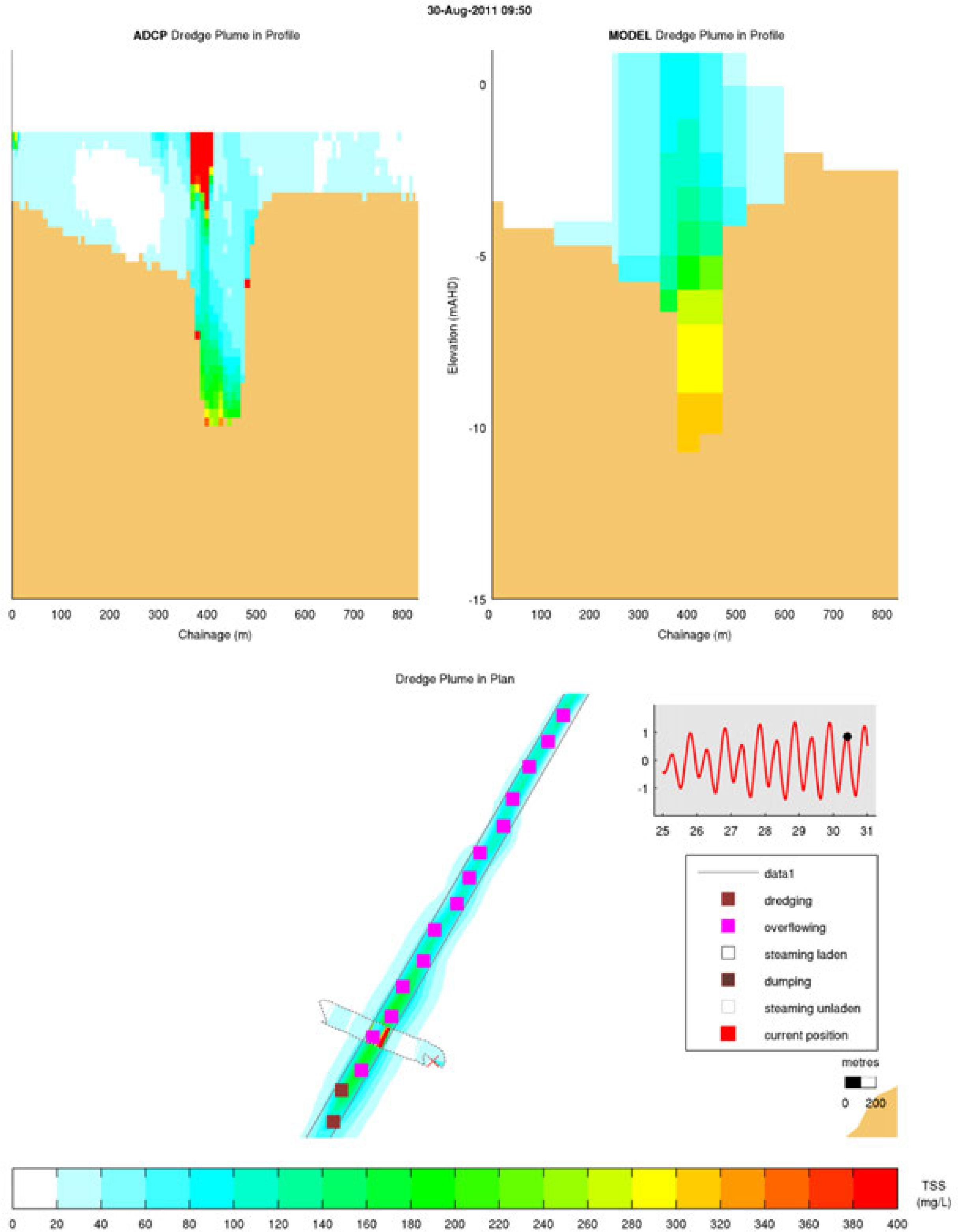


Figure 4-5 Maintenance Dredging Plume Validation, 30/08/2011 09:50: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

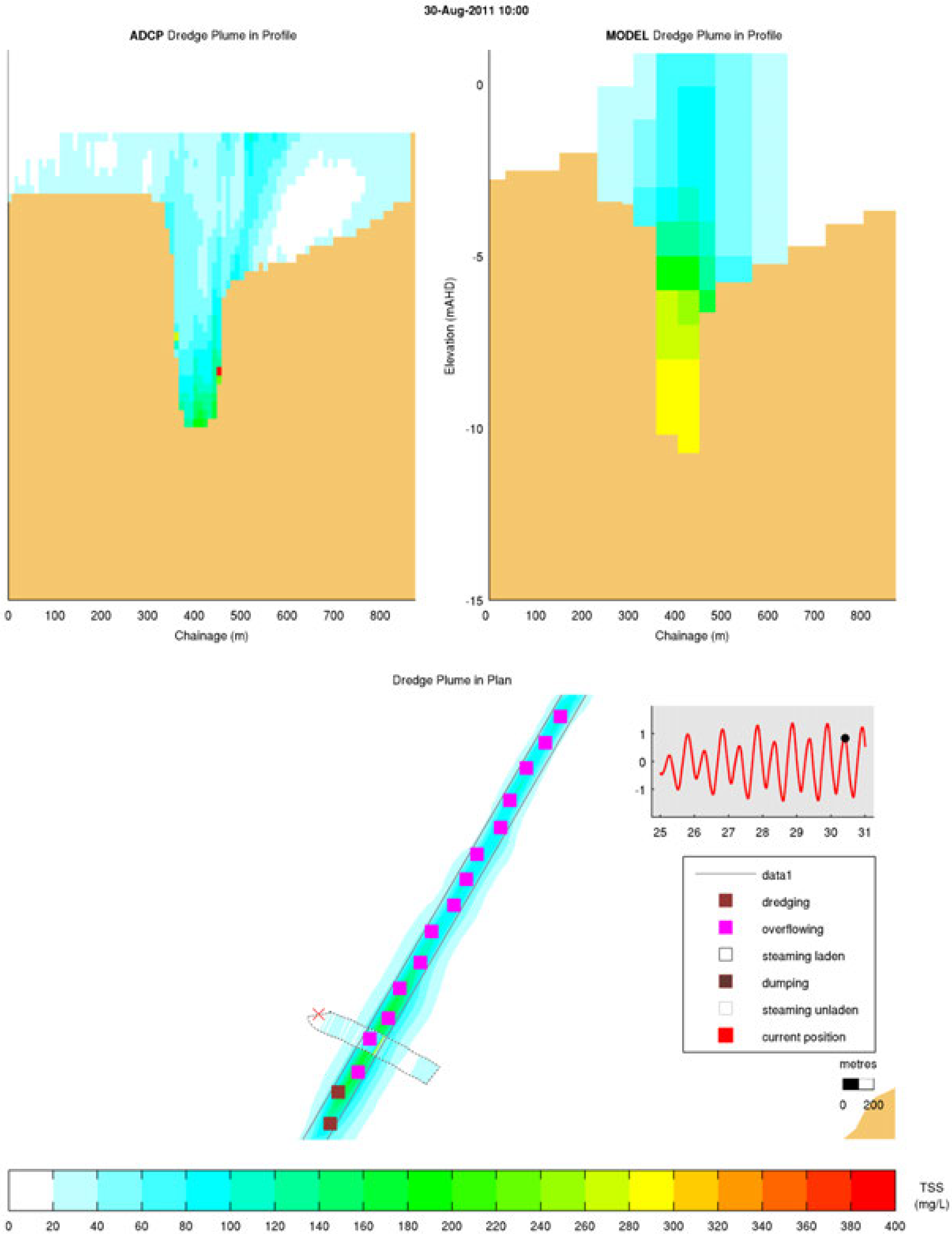


Figure 4-6 Maintenance Dredging Plume Validation, 30/08/2011 10:10: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

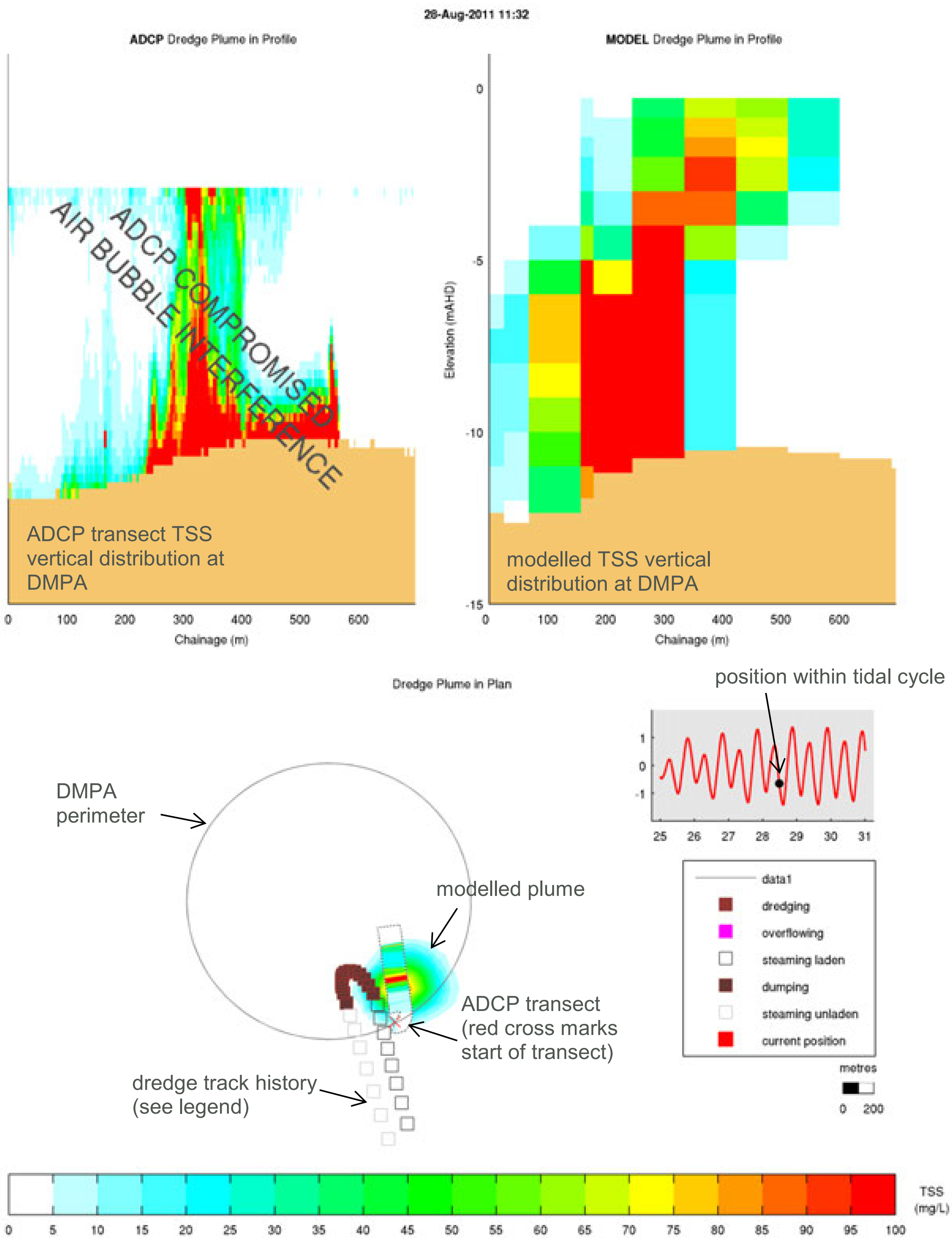


Figure 4-7 DMPA Plume Validation, 28/08/2011 11:32: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

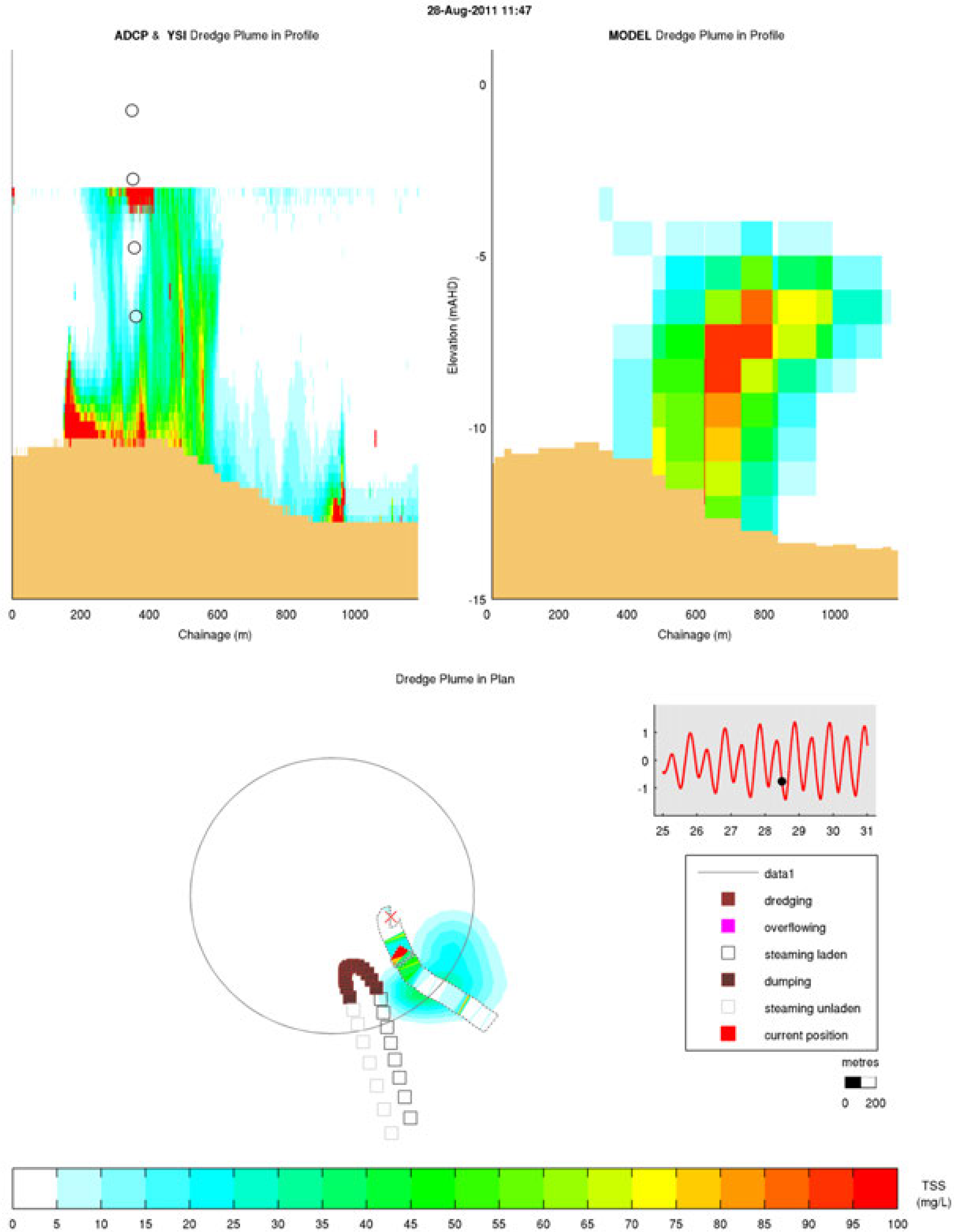


Figure 4-8 DMPA Plume Validation, 28/08/2011 11:47: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

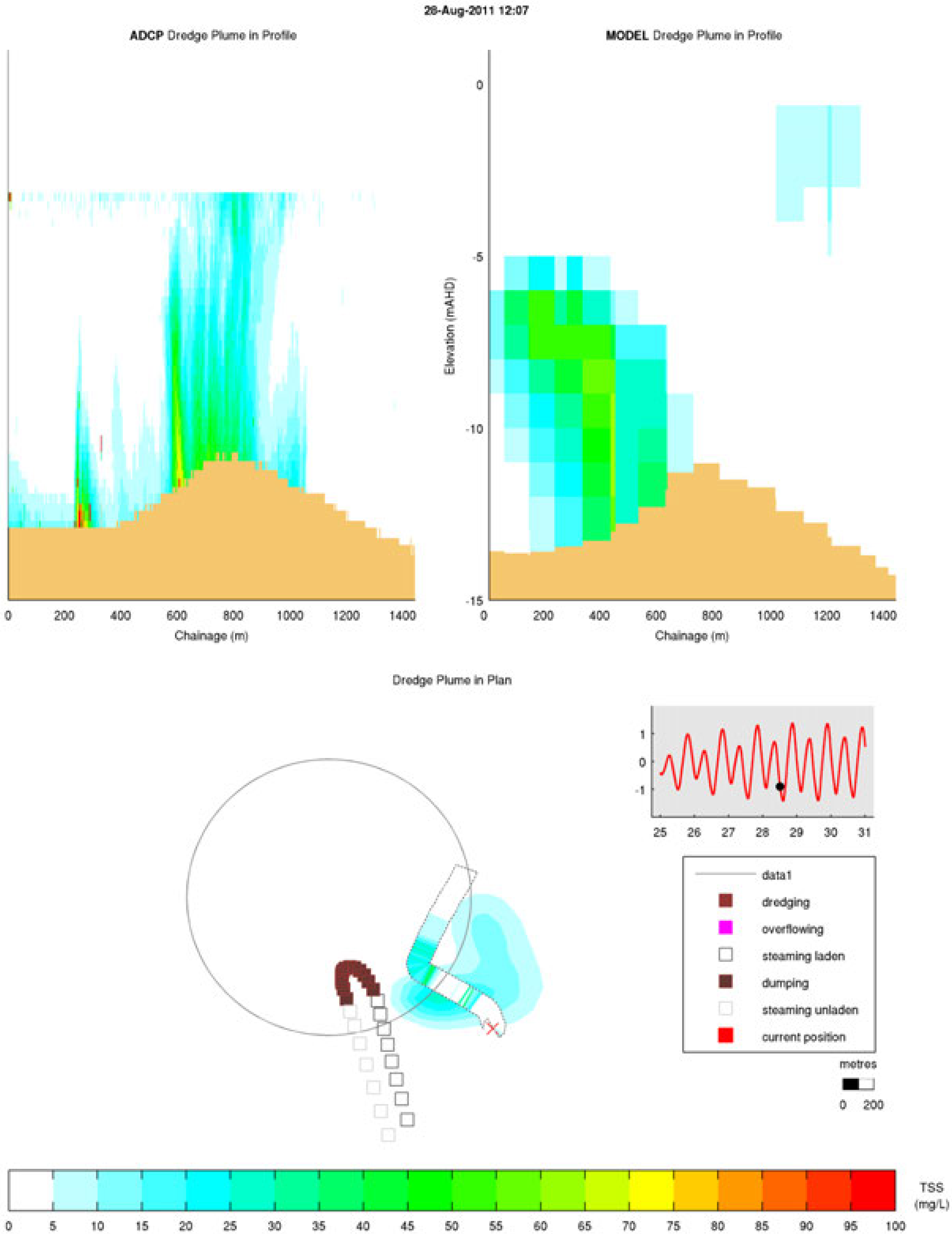


Figure 4-9 DMPA Plume Validation, 28/08/2011 12:07: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

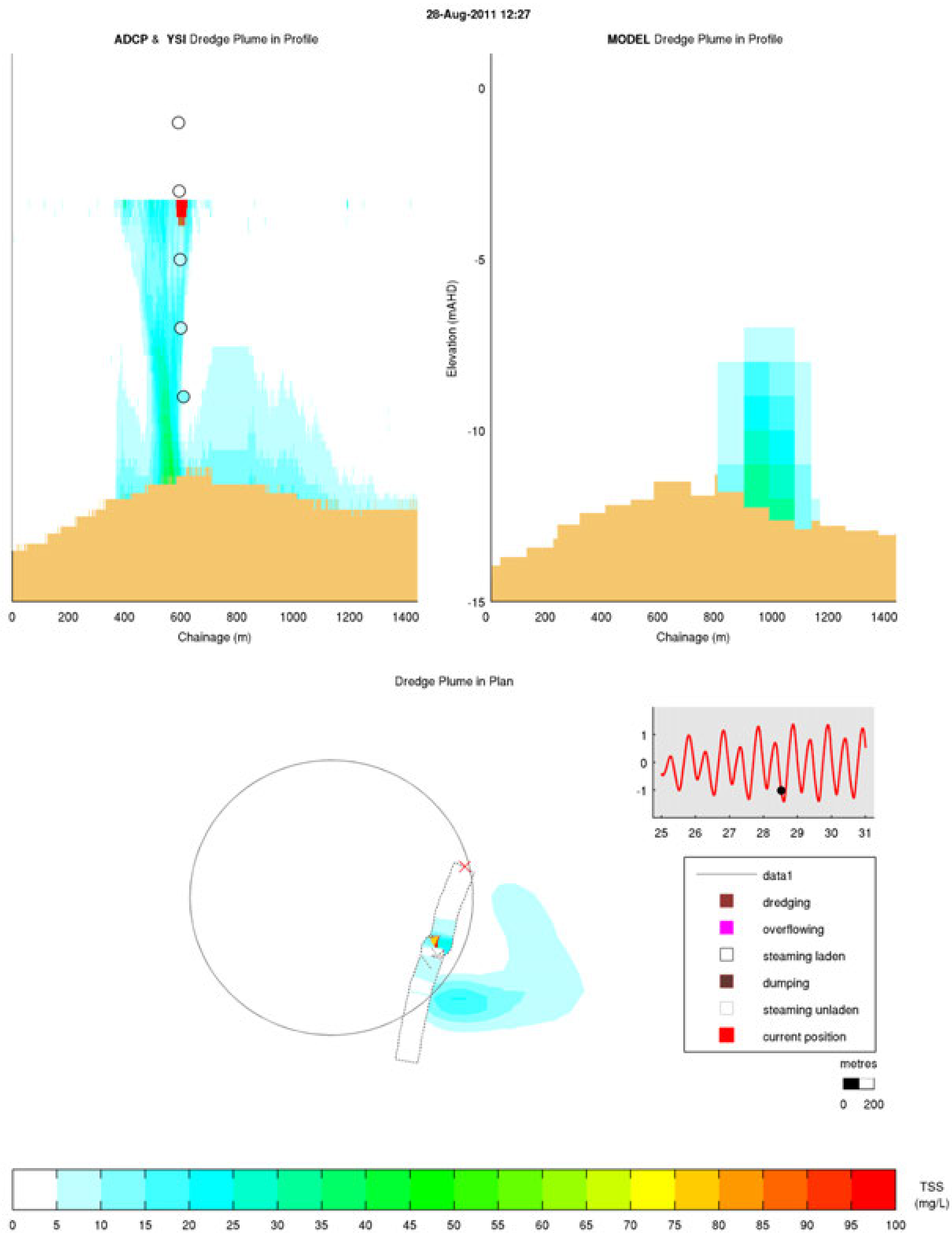


Figure 4-10 DMPA Plume Validation, 28/08/2011 12:27: Recorded Plume (top left) and Modelled Plume (top right) Vertical Distribution; Recorded and Modelled Plume Plan View (bottom)

5 Model Validation

5.1 Baseline Validation Data

The baseline validation data was obtained as part of the wider CSDP data collection campaign. Relevant information regarding this campaign has been previously provided in Section 3.1.

5.2 Validation Period Characteristics

As described in Section 3.2, the study area experiences a tropical climate. The “dry season” period typically occurs from May to October where the synoptic meteorological pattern is strongly influenced by the Coral Sea trade winds.

The model calibration simulation period was from July to October 2013 and therefore dominated by dry season months. The representativeness of this period relative to the wind and wave climate long term averages is discussed below.

5.2.1 Wind

Wind roses for the validation period and the long term average of the simulation period months (i.e. June to October inclusive) are compared in Figure 5-1 (offshore location) and Figure 5-2 (Cairns Aero). Note that at the offshore location the simulation period wind rose is based on recorded data from Arlington Reef (consistent with the constructed wind field described in Section 2.1.3.2) while the long term average is based on recordings from nearby Green Island (approximately 15km to the south west) where a longer data record was available. The validation period wind characteristics are as follows:

- The offshore wind roses show the predominance of south to south-easterly trade winds. The offshore directional spread of winds for the simulation period appears consistent with the long term average however the 10-minute wind speed exceeds 14m/s (approximately 27knots) on fewer occasions than average. This is consistent with the calibration period/long term average assessment and the slight difference in wind magnitude may be influenced by the comparison being across two different weather station locations.
- As described in Section 3.2.1, there are significant orographic influences within the nearshore regions of the study area and this is reflected in the Cairns Aero wind roses which are distinctly different to the more exposed locations within the GBR lagoon. The Cairns Aero wind directional spread is predominantly south-south-west to south-easterly. The roses also reveal a subtle land breeze/sea breeze cycle which occurs along the coastal margin of the study area. The Cairns Aero validation period wind rose is considered consistent with the long term average.

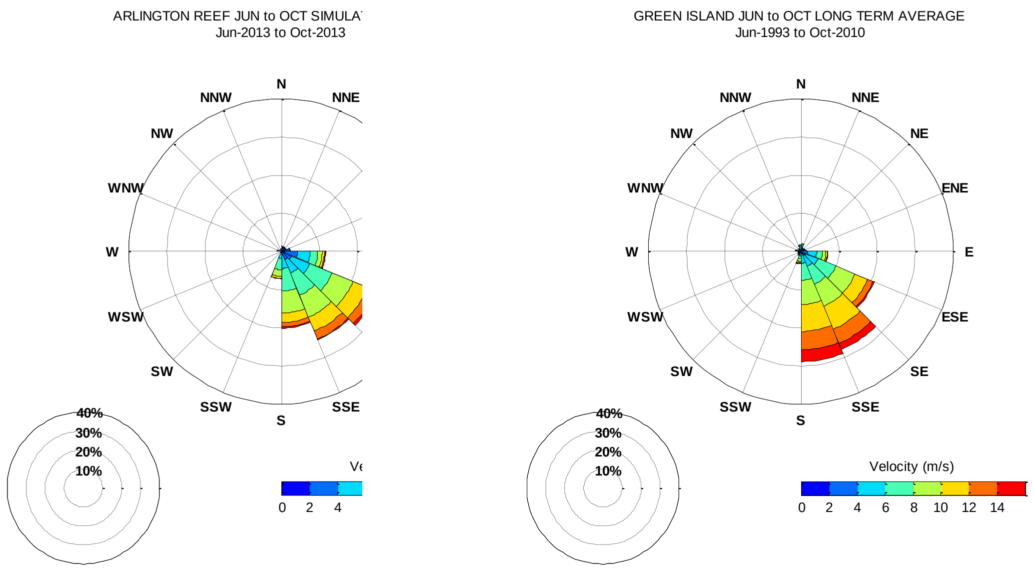


Figure 5-1 Offshore Wind Roses – June to November 2013 Simulation Period (top) and June to November Long Term Average (bottom)

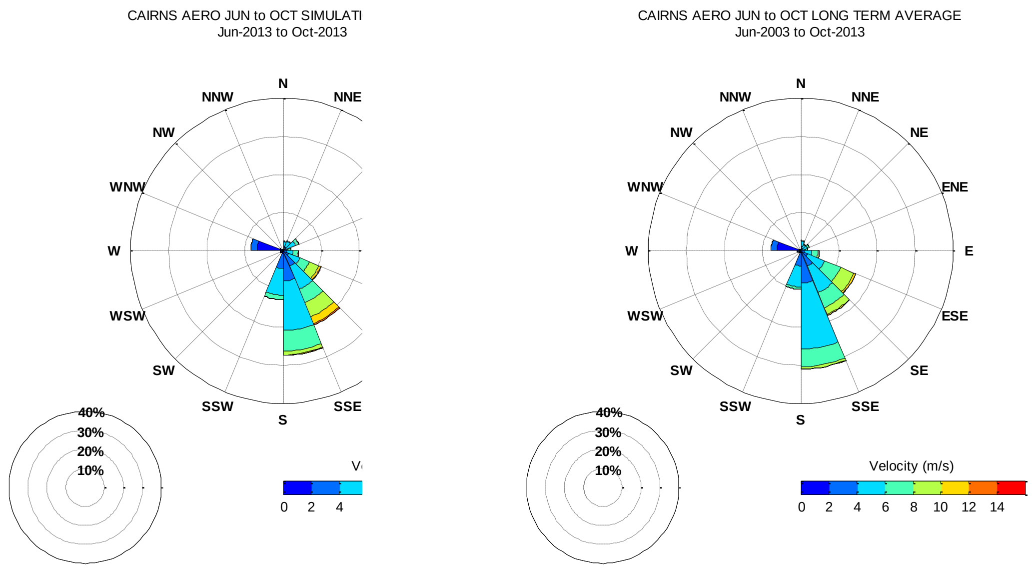


Figure 5-2 Cairns Aero Wind Roses – June to November 2013 Simulation Period (top) and June to November Long Term Average (bottom)

5.2.2 Waves

A validation period wave rose at the Cairns Waverider buoy location is presented in Figure 5-3. As discussed previously in Section 3.2.3, study area is dominated by locally generated wind waves. The largest significant wave height at the Cairns buoy for the validation period was approximately 1.7m with a mean significant wave height close to 0.7m. The validation period includes a number of wave events with significant wave heights above 1m, driven by the strong Coral Sea trade winds.

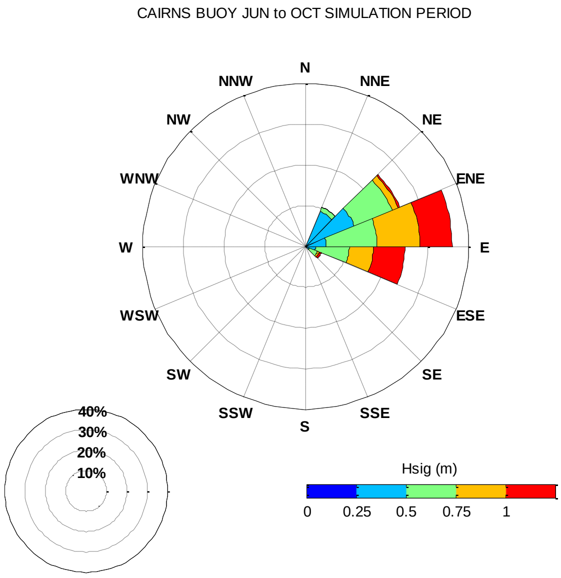


Figure 5-3 Cairns Buoy Wave Rose –June to October 2013 Simulation Period

5.3 Hydrodynamic Model Validation

The hydrodynamic model validation period was from July 2013 to October 2013. The validation simulation was completed using the model parameters adopted for the final calibration simulation (refer Section 3.3 and Appendix B). The simulation period incorporated representative spring and neap tide conditions, a range of meteorological conditions and offshore EAC forcing. In contrast to the calibration period (March to June), the validation period includes "dry season" months typically characterised by strong Coral Sea trade winds. Considering both the calibration and validation periods enabled assessment of the model's predictive skill for a range of conditions and its suitability for use in long term (years) impact assessments required by the CSDP EIS.

In the following sections model validation plots at the DMPA and Beacon C7 are presented. The presentation generally follows the format in Section 3 and includes:

- Water level and depth-average current time series (six day period);
- Top, middle and bottom third of water column current velocity and direction (six day period);
- Depth-average current polar plots (entire calibration period);
- Near-bed water temperature time series (entire calibration period); and
- Cairns Port and Trinity Inlet (Swallows Landing) water level time series (two week period).

The six day period selected for clear visualisation of the time series comparison includes large spring tides and relatively light wind conditions.

In addition to the above, Appendix F, Appendix G and Appendix H provide further model validation results for the entire validation period:

- Appendix F: top and bottom half of water column current velocity and direction time series (entire validation period);
- Appendix G: top and bottom half of water column current polar plots (entire validation period); and
- Appendix H: Current velocity Quantile-Quantile (Q-Q) plots (entire validation period).

5.3.1 Hydrodynamic Model Validation Results

Generally, the model validation results indicated a predictive skill consistent with the calibration results. The validation results confirm that the adopted model parameters are appropriate for the range of seasonal hydrodynamic conditions typically encountered at Cairns. The validation results are briefly described below.

5.3.1.1 Site 1 DMPA

Model validation results at the DMPA continuous data recording location show the following:

- Figure 5-4 (top plot) suggests variations in water level amplitude at the DMPA are accurately predicted by the model during both spring and neap tides. Tidal phasing is also appropriately represented.
- The current speed at the DMPA is also predicted well by the model. The depth-average current velocity (Figure 5-4, middle plot) and current velocity layer (Figure 5-5) time series plots indicate a very small offshore current magnitude with little variation over depth for the six day period shown.
- Figure 5-4 (bottom plot) and Figure 5-6 suggest current direction is predicted well by the model, with the general flood and ebb tide patterns clearly represented. The top plot in Figure 5-6 shows some minor scatter in the data associated with light winds influencing the currents in the surface layer.
- Predicted and recorded distributions of depth-average current magnitude and direction at the DMPA are presented as polar plots in Figure 5-7. The polar plots are based on the entire validation period and show good overall consistency.

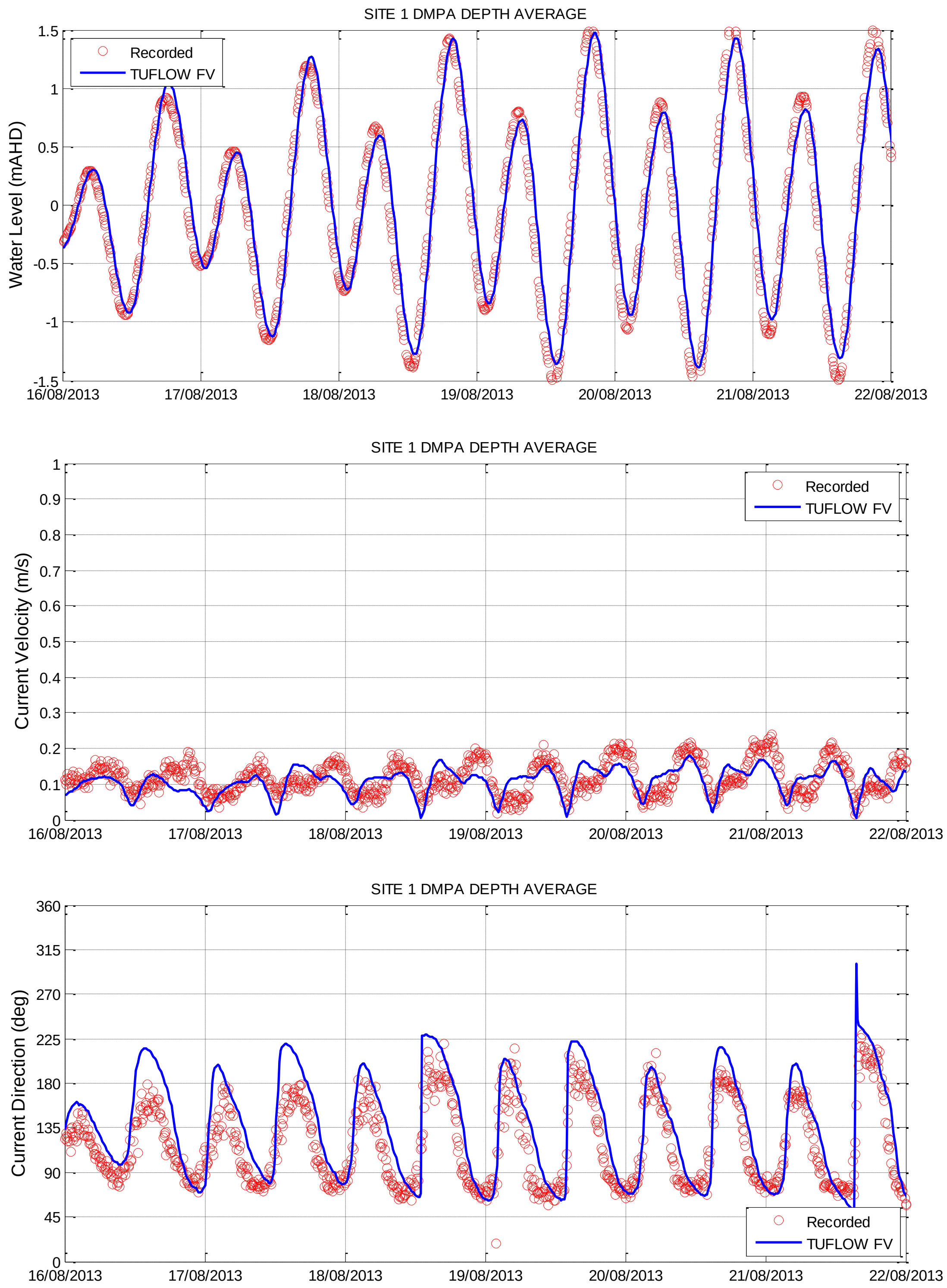


Figure 5-4 Hydrodynamic Model Validation 3D Depth Average – Site 1 DMPA

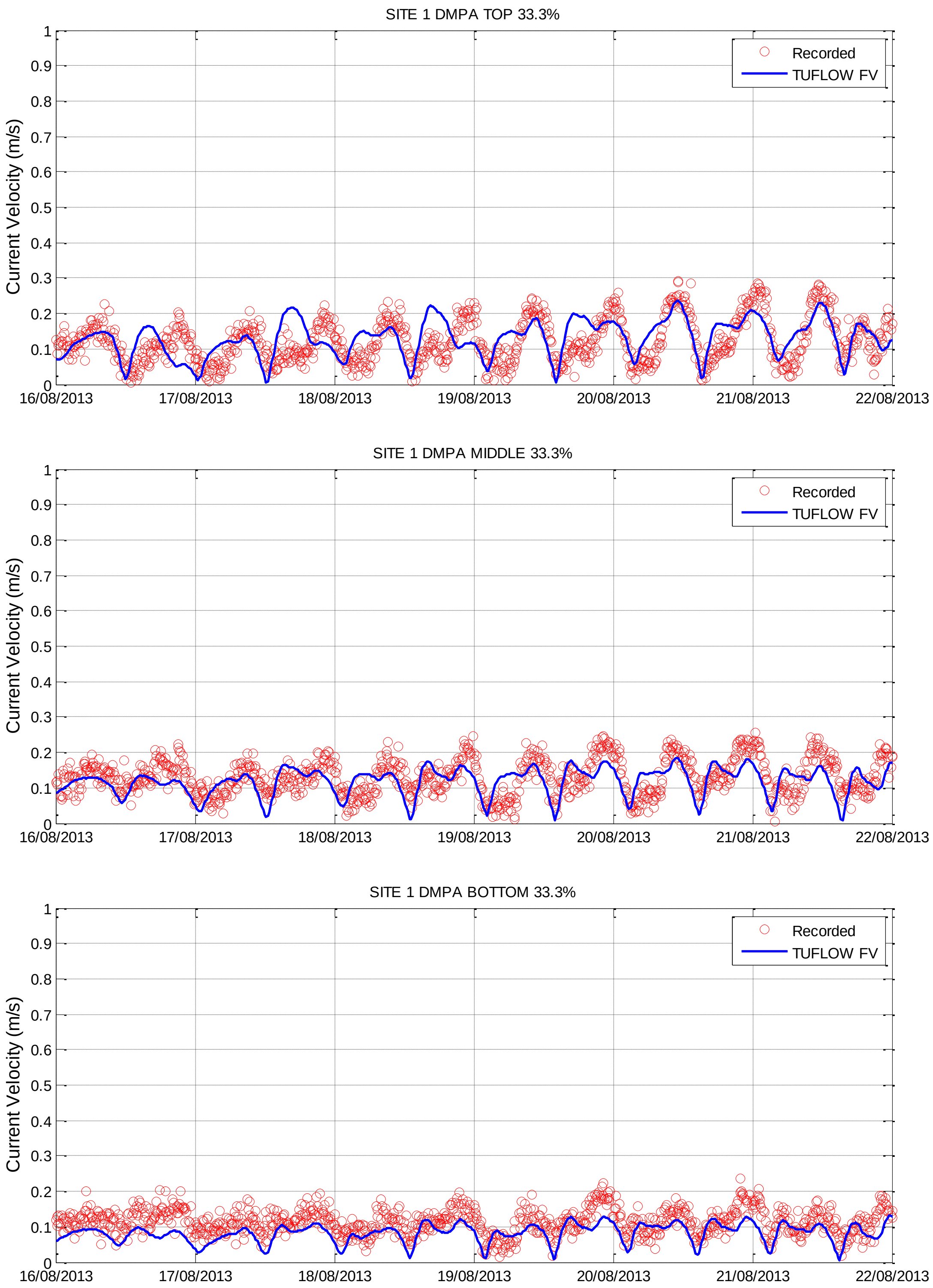


Figure 5-5 Hydrodynamic Model Validation Current Velocity Layers – Site 1 DMPA

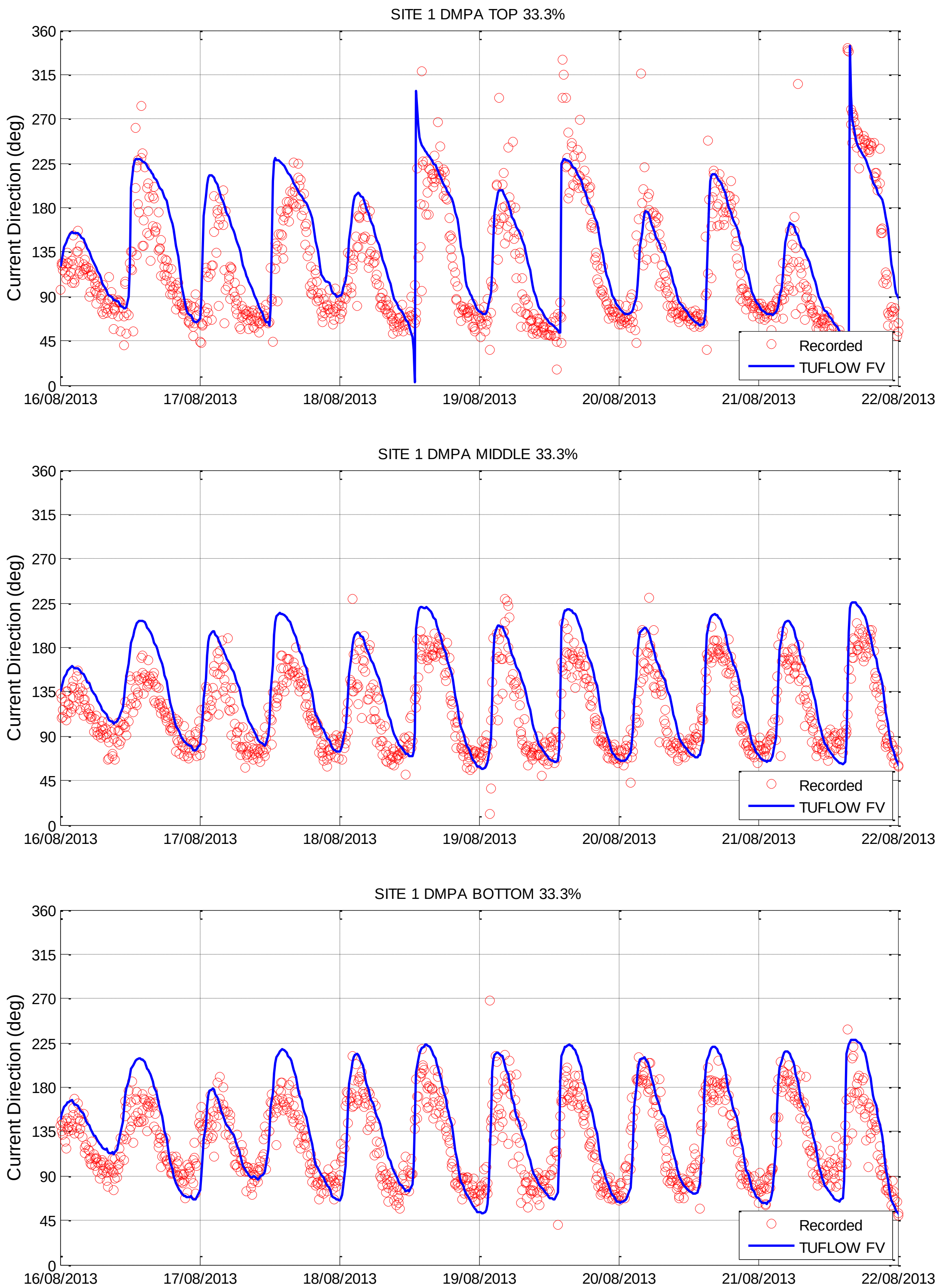


Figure 5-6 Hydrodynamic Model Validation Current Direction Layers – Site 1 DMPA

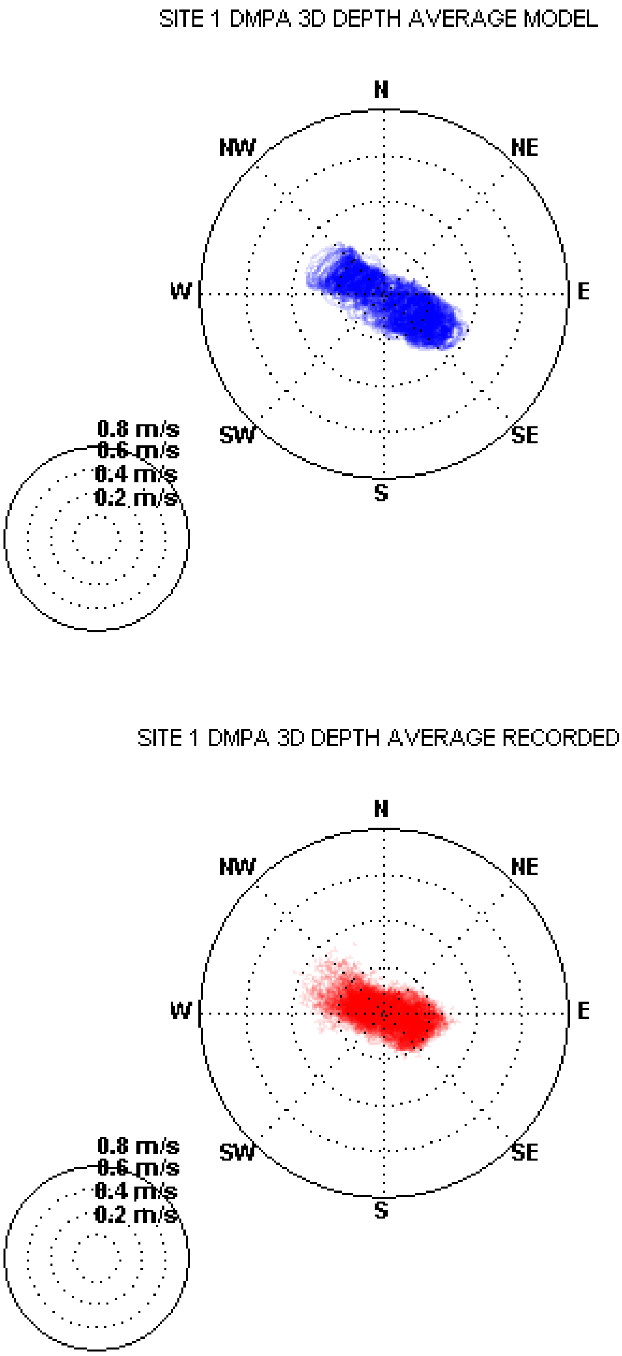


Figure 5-7 Current Polar Plot Validation – Site 1 DMPA

5.3.1.2 Site 3 Beacon C7

Model validation results at the Beacon C7 continuous data recording location show the following:

- Figure 5-8 (top plot) suggests variations in water level amplitude at Beacon C7 are accurately predicted by the model during both spring and neap tides.
- In contrast to the DMPA location further offshore, the Beacon C7 current velocity plots show a clear increase in tidal magnitude during the spring tides. The depth-average current velocity (Figure 5-8, middle plot) and current velocity layer (Figure 5-9) time series calibration plots suggest good model predictive skill, occasionally slightly under predicting the peak ebb currents.
- Figure 5-8 and Figure 5-10 suggest current direction is generally well predicted at Beacon C7 over the six day period shown.
- Predicted and recorded distributions of depth-average current magnitude and direction at Beacon C7 are presented as polar plots in Figure 5-11. The polar plots are based on the entire validation period and show good overall consistency.

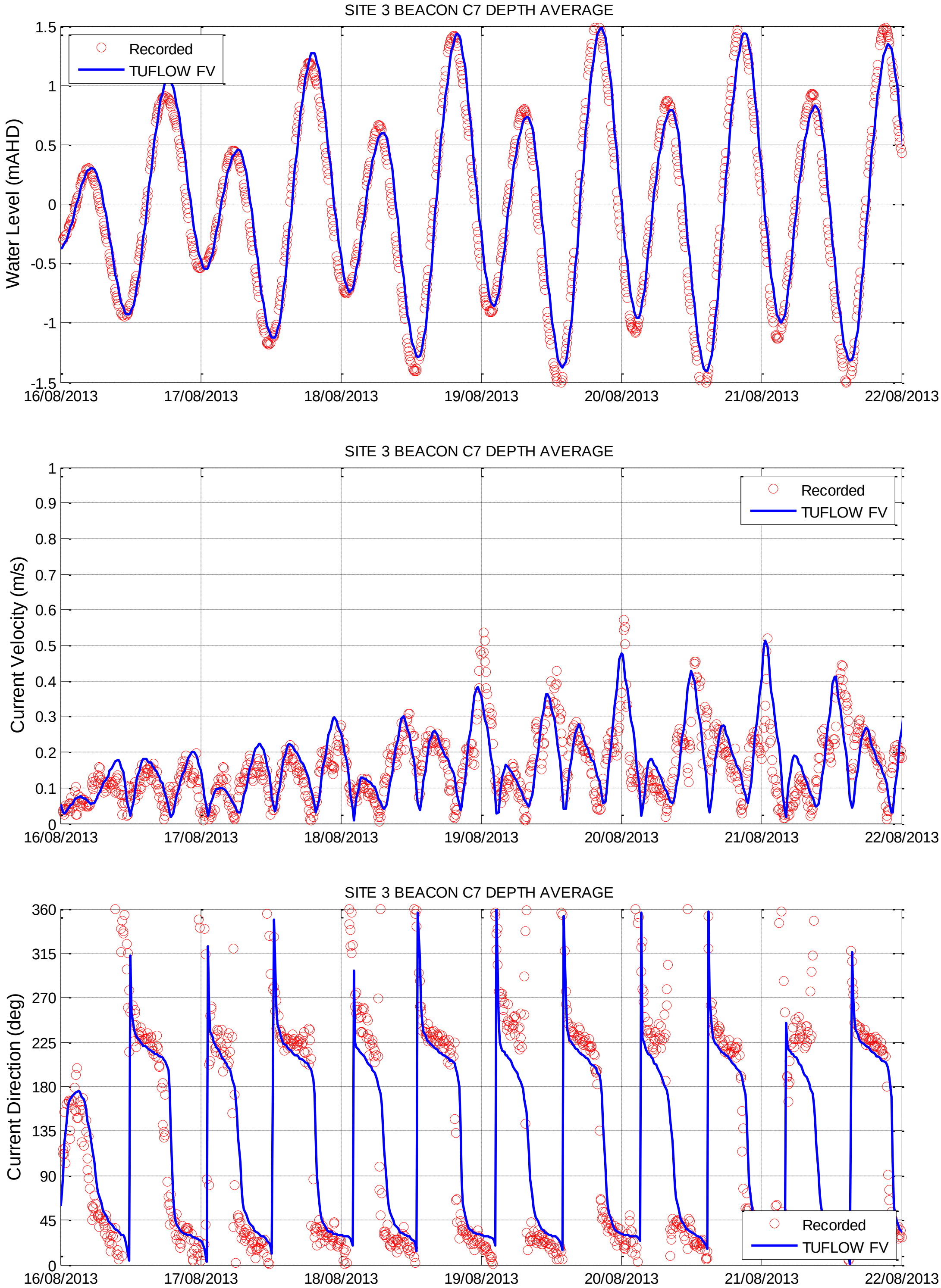


Figure 5-8 Hydrodynamic Model Validation 3D Depth Average – Beacon C7

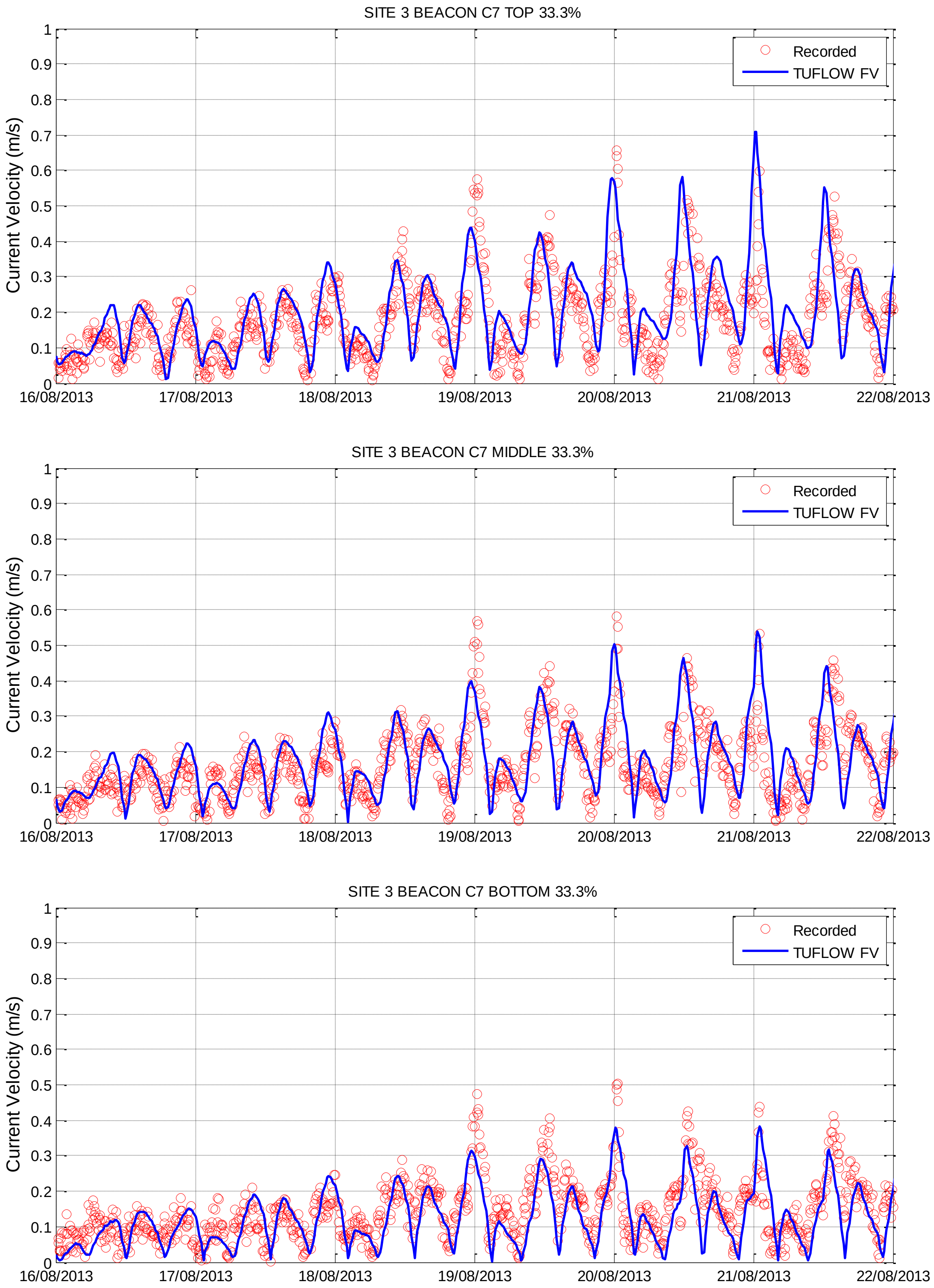


Figure 5-9 Hydrodynamic Model Validation Current Velocity Layers – Beacon C7

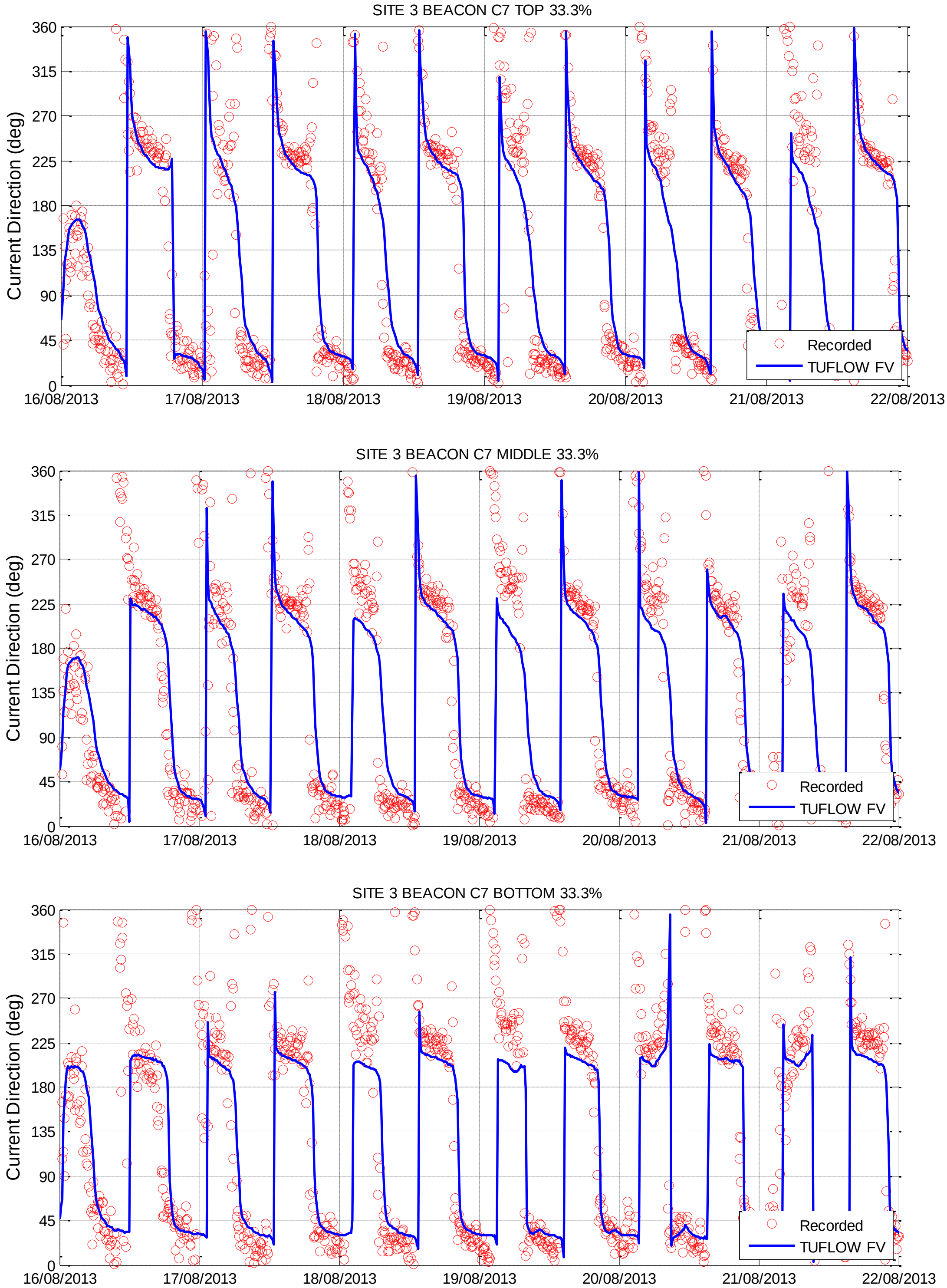


Figure 5-10 Hydrodynamic Model Validation Current Direction Layers – Beacon C7

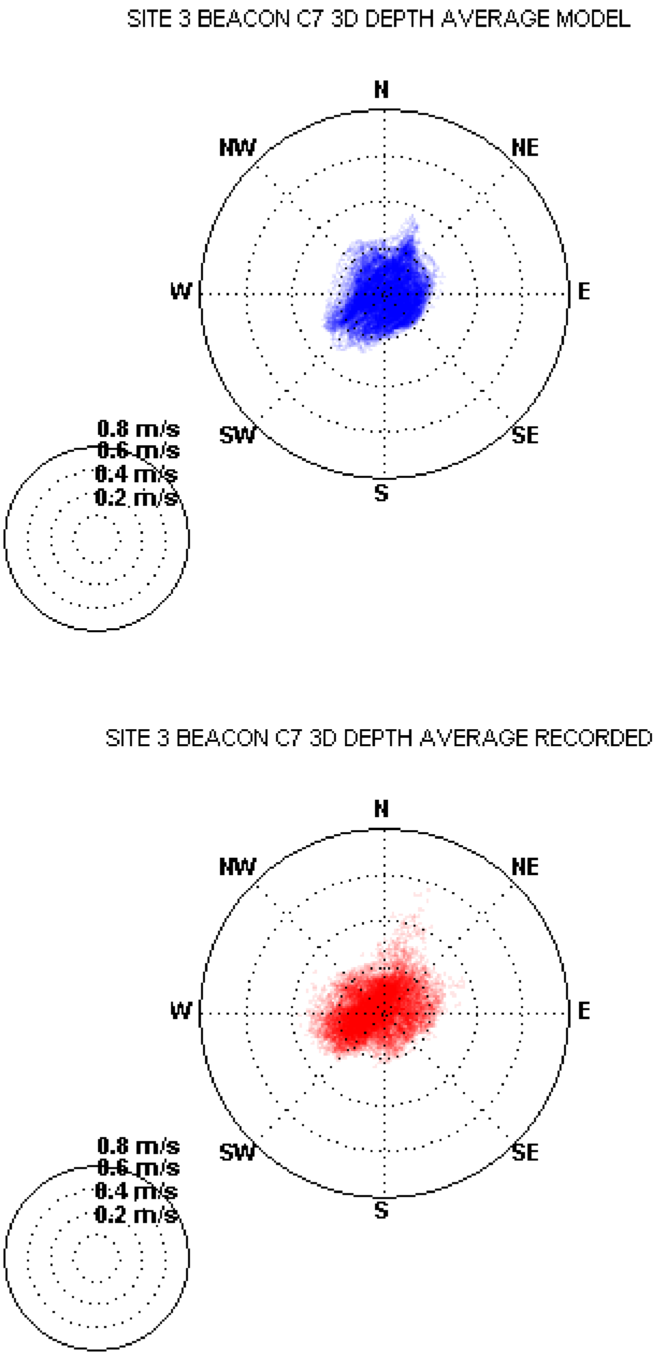


Figure 5-11 Current Polar Plot Validation – Site 3 Beacon C7

5.3.1.3 Cairns Port Gauge and Swallows Landing

Additional continuous water level data was obtained from the Cairns Standard Port Gauge (provided by MSQ) and a pressure transducer deployed near Swallows Landing (southern Trinity Inlet, refer Figure 3-2). These datasets were obtained to further validate the hydrodynamic model performance within the inner port and Trinity Inlet. Figure 5-12 and Figure 5-13 demonstrate satisfactory water level prediction at the Port Gauge and near Swallows Landing.

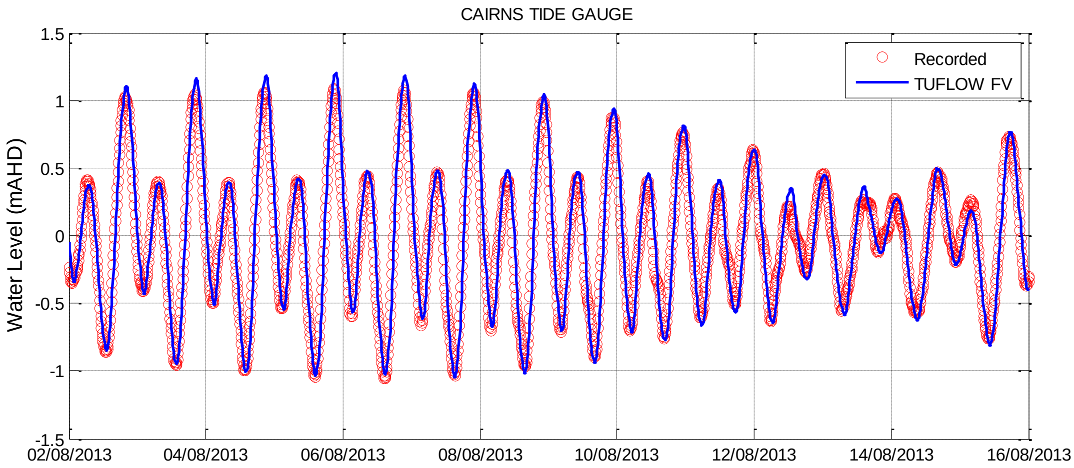


Figure 5-12 Hydrodynamic Model Validation Water Level – Cairns Port Gauge

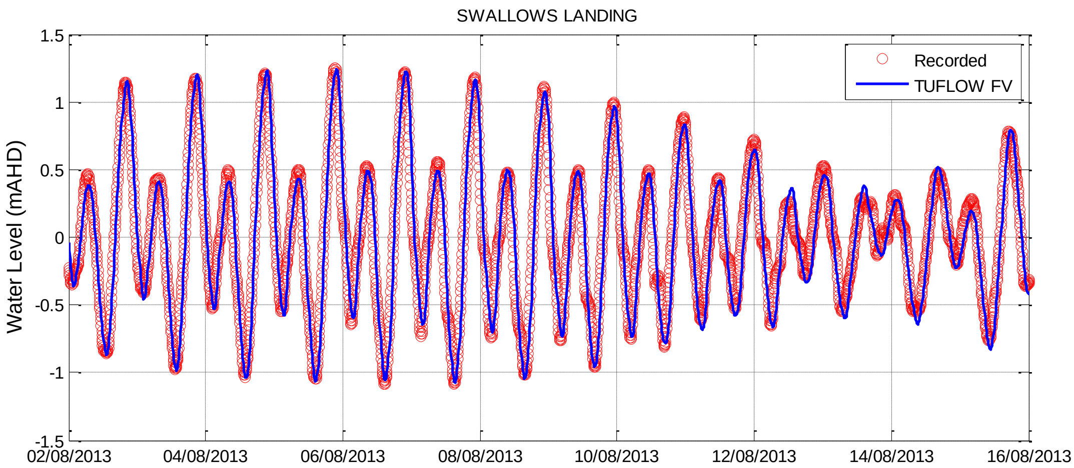


Figure 5-13 Hydrodynamic Model Validation Water Level – Swallows Landing

5.3.2 Temperature and Salinity Validation

Comparisons of the modelled near-bed water temperature with continuous measurements obtained using YSI Model 6600 EDS nephelometers (co-located with the ADCP instruments at the DMPA and Beacon C7) are shown in Figure 5-14 and Figure 5-15. The model represents the gradual warming trend during the validation period; however, the rate of warming is slightly over predicted from late-July to mid-August.

Surface salinity data recorded using a Teldyne RD Instruments Citadel CTD deployed from floating buoy at Beacon C7 is compared to the predicted salinity in Figure 5-16. Salinity is shown to be relatively constant and slightly over predicted by the model. It is noted that the recovery of reliable salinity data collected as part of CSDP was limited due to rapid bio-fouling of the instrument sensors after each deployment.

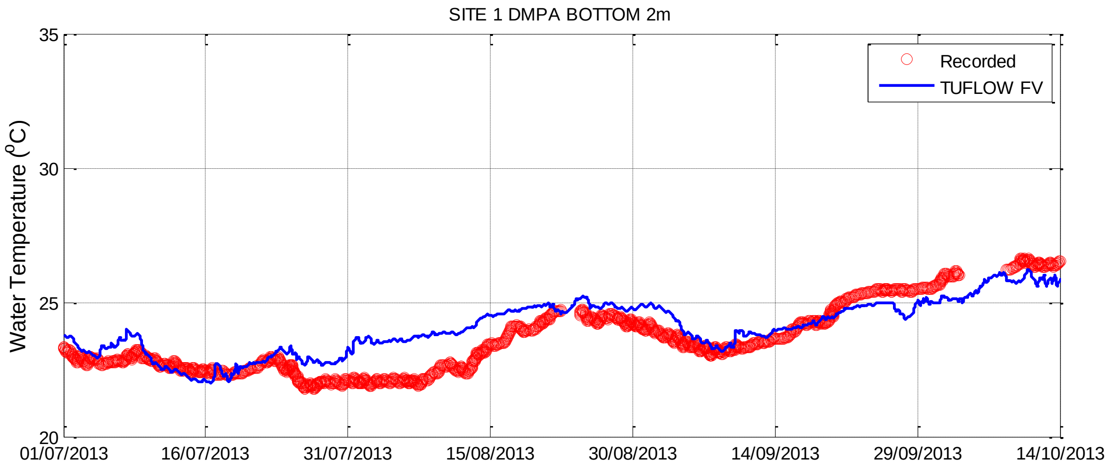


Figure 5-14 Hydrodynamic Model Validation Near Bed Temperature – Site 1 DMPA

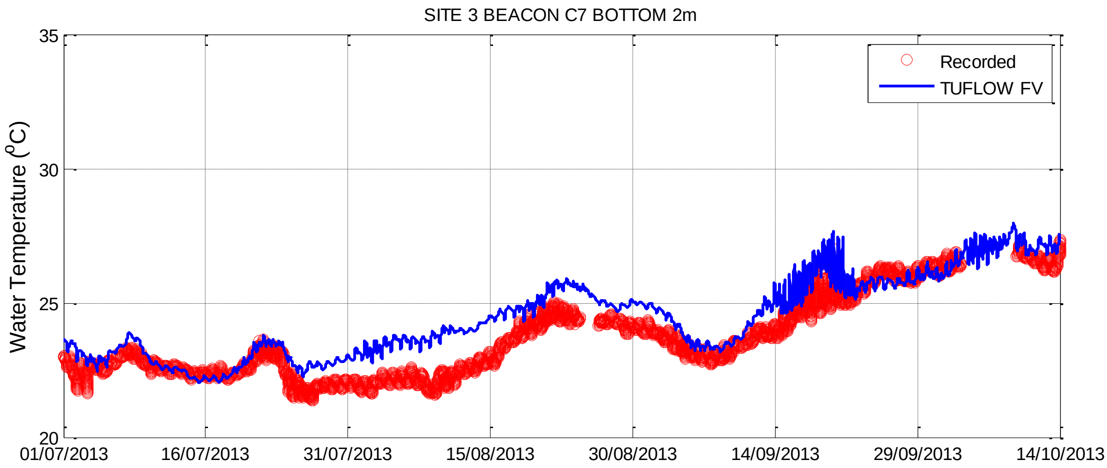


Figure 5-15 Hydrodynamic Model Validation Near Bed Temperature – Site 3 Beacon C7

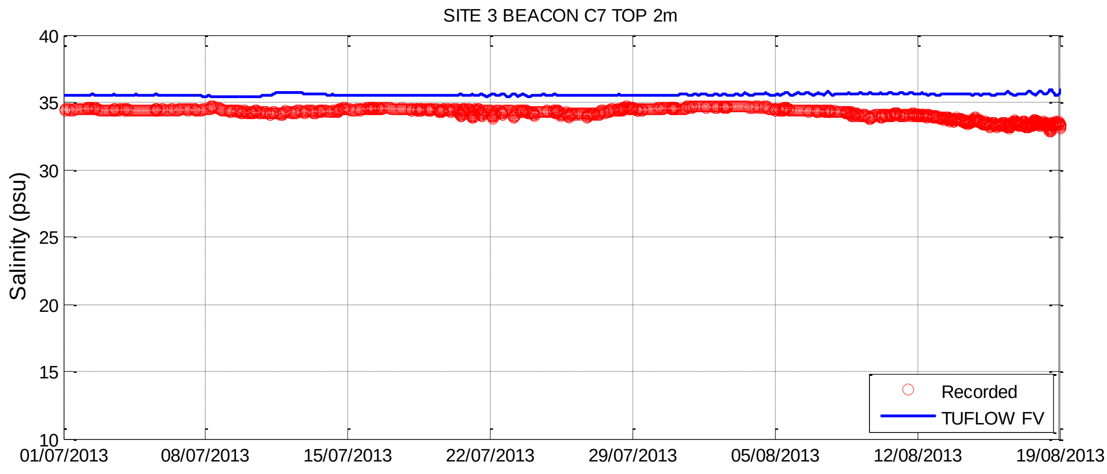


Figure 5-16 Hydrodynamic Model Validation Surface Salinity – Site 3 Beacon C7

5.4 Wave Model Validation

Wave model validation was based on recorded significant wave height, peak wave period and wave direction data from ADCP instruments deployed at the DMPA and Beacon C7. Predicted and recorded wave parameters are presented for the period 01/06/2013 to 30/10/2013.

5.4.1 Wave Model Validation Results

Predicted wave parameters are compared to continuous time series data at the DMPA and Beacon C7 in Figure 5-17 and Figure 5-18. The wave model validation satisfactory and considered appropriate for assessing the potential impacts associated with the CSDP. Key features of the wave calibration results include:

- Significant wave height validation is acceptable with a slight over prediction at Beacon C7 (consistent with the calibration results). As discussed in Section 3.4.2, over-prediction in wave height is probably attributable to the effects of wind drag over land, and the transition from over land to over sea winds, not being precisely resolved by the constructed wind field. In the context of the CSDP EIS assessments, this is likely to cause an over prediction of sediment re-suspension and is therefore considered a conservative result.
- The wave model predicts periods of dominant sea and swell states at each location and this is reflected in comparisons with the peak wave period recordings. At times, the peak wave period is over-predicted at the DMPA and represents periods when slightly too much offshore swell energy is propagated into Great Barrier Reef lagoon. Again, this will cause a slight over prediction in sediment re-suspension and is therefore a conservative result.
- The dominant wave direction of the at the DMPA and Beacon C7 is generally from the east to south easterly sector throughout the validation period. This general pattern is represented by the model.

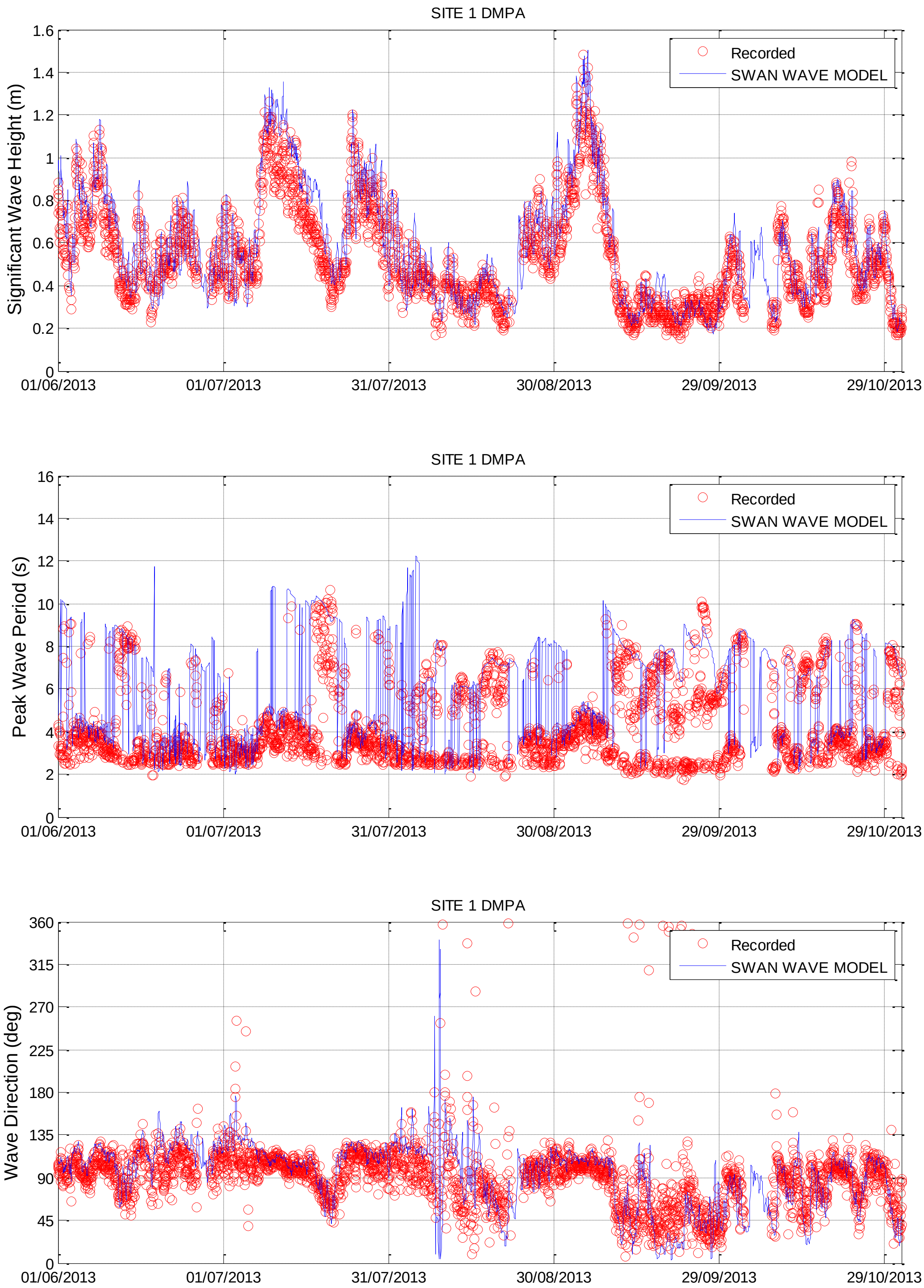


Figure 5-17 SWAN Wave Model Validation – Site 1 DMPA

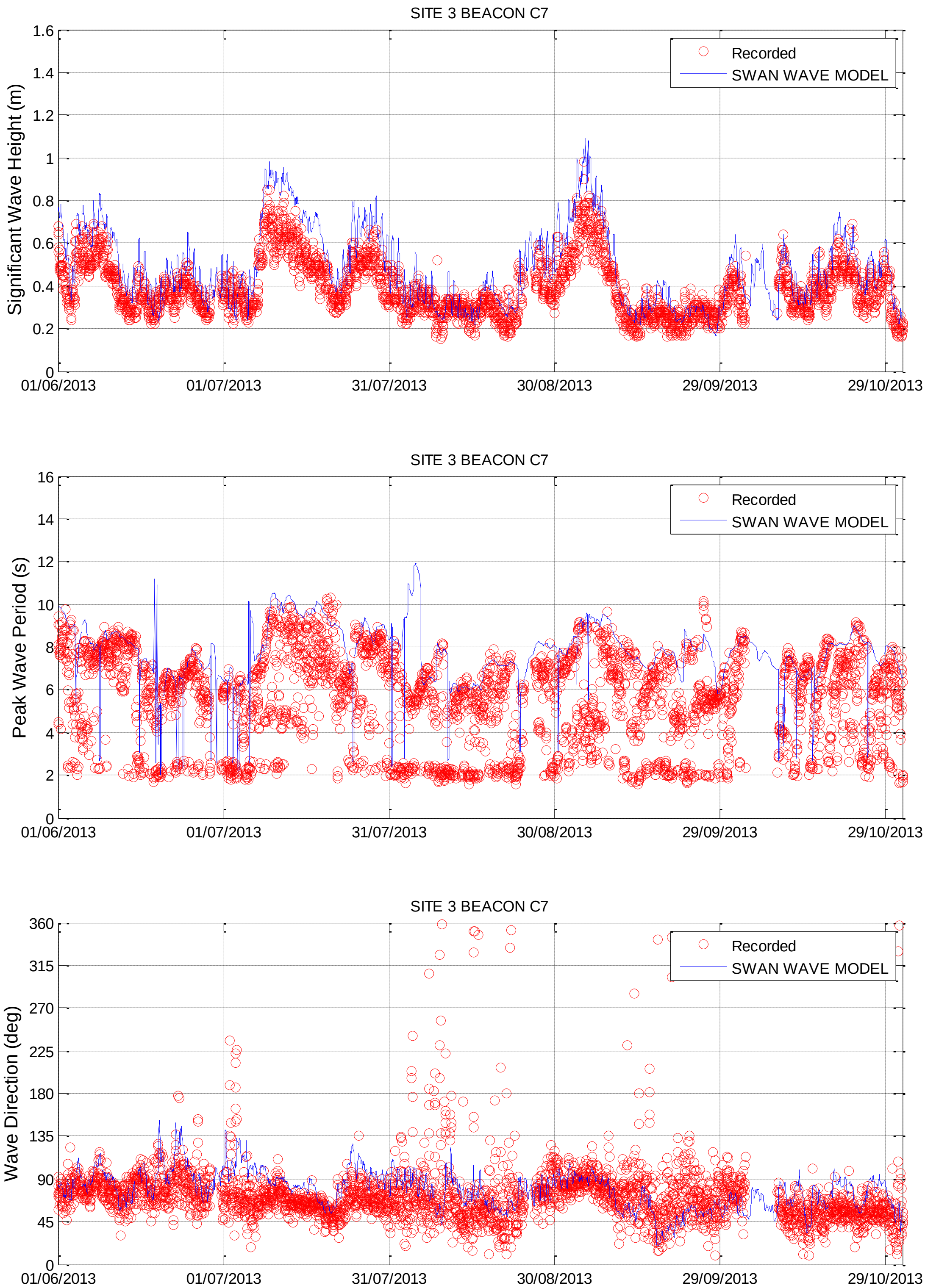


Figure 5-18 SWAN Wave Model Validation – Site 3 Beacon C7

5.5 Sediment Re-suspension Model Validation

5.5.1 Sediment Re-suspension Model Validation Results

Baseline turbidity data collected for the CSDP was used to further validate the sediment transport module. The natural sediment re-suspension validation simulation adopted the calibrated model parameters described in Section 3.5.1.

5.5.2 Targeted Turbidity Recordings

Ambient TSS validation plots at four baseline data recording locations (Trinity Bay, Yorkeys Knob and Palm Beach, indicated in Figure 3-2) are presented in Figure 5-19 to Figure 5-21 and demonstrate the following:

- Given the complexities of modelling the re-suspension of natural bed sediments, the ambient TSS concentration prediction throughout the validation period is considered adequate. Together with the TSS calibration results presented in Section 3.5.2.1, the model demonstrates a relatively high degree of predictive skill both temporally and spatially.
- Natural re-suspension in Trinity Bay is reasonably well predicted with the short periods of elevated TSS associated with spring tide periods being represented by the model.
- There is a lag in predicted elevated TSS at Yorkeys Knob and Palm Beach during early September. Nevertheless, the magnitude and duration of natural turbidity event is represented by the model.

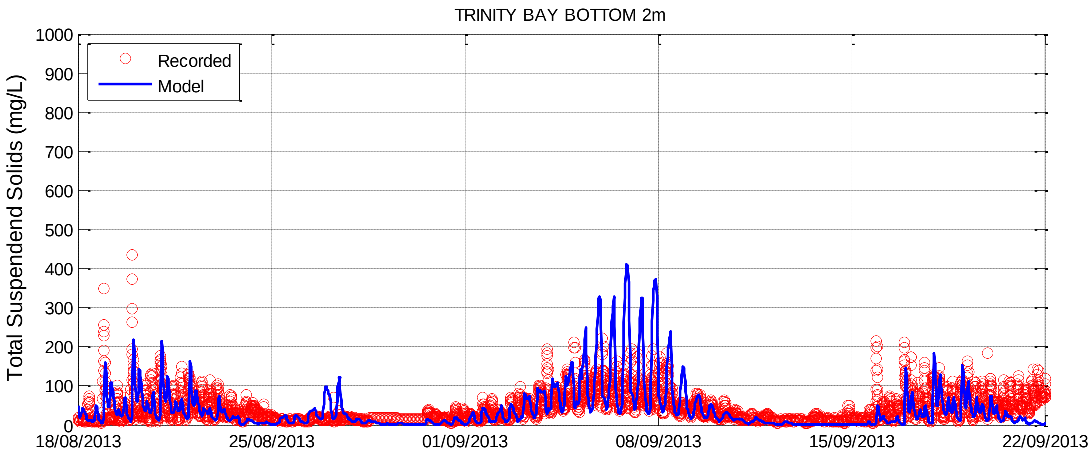


Figure 5-19 Sediment Re-suspension Validation – Trinity Bay

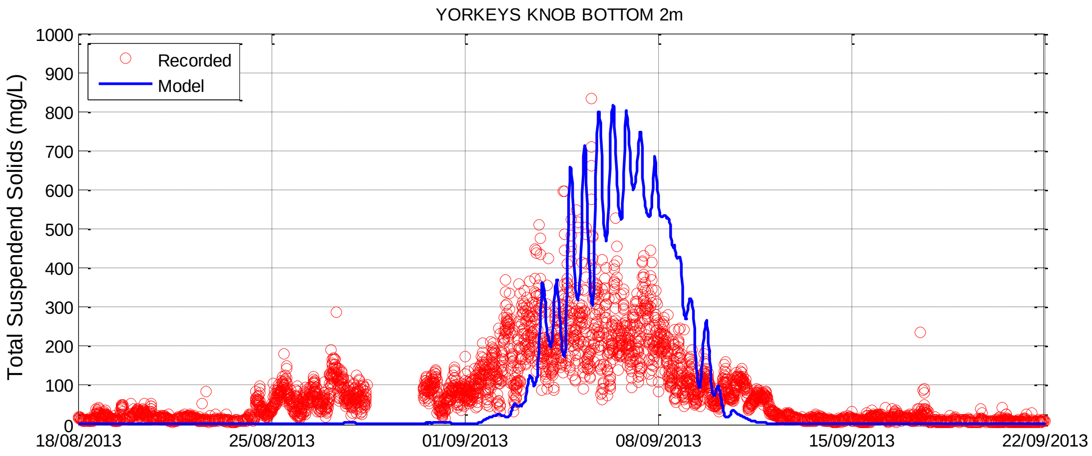


Figure 5-20 Sediment Re-suspension Validation – Yorkeys Knob

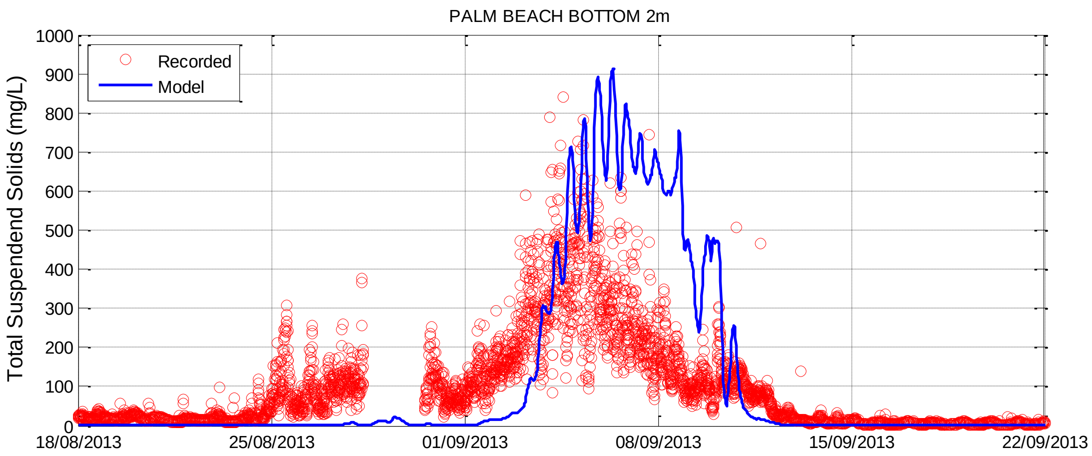


Figure 5-21 Sediment Re-suspension Validation – Palm Beach

5.6 Barron River Plume 2011 Hindcasting

5.6.1 Overview

The Barron River is the major source of sediment input to Trinity Bay, determining the characteristics of most of the coastal and Trinity Inlet sediments. The mineral composition of the material that resists abrasion during fluvial transport to the coast includes quartz, feldspar and mica, which occur in substantial proportions within the sand fraction of the sediment load of the Barron River catchment streams (BPA, 1984). There is a high discharge of fine (muddy) wash load from the catchment to the sea where it forms a substantial proportion of the seabed sediment material.

Discharges of Barron River catchment loads are typically associated with floods caused by tropical cyclone rainfall events. The resultant plumes deliver sediment, nutrients and pollutants to the GBR lagoon and reefs. In the Wet Tropics region (including the Barron River catchment), increased dissolved nutrients from fertilised agricultural runoff is the dominant pollutant delivered to Trinity Bay (e.g. Delvin et al., 2012a). The discharge of fluvial sediments may also contribute to channel siltation and therefore understanding this process is important when assessing maintenance dredging requirements associated with the proposed shipping channel development.

Delvin and Schaffelke (2009) grouped GBR flood plumes into three types based on generic characteristics relevant to this modelling assessment:

- Primary plume: typically nearshore, high TSS concentration and low salinity waters (0-10ppt).
- Secondary plume: reduced TSS concentration and sediment load due to rapid deposition of heavier sediment fractions.
- Tertiary plume: the far-field extent of the flood plume and the transition of riverine effected to ambient marine waters. Salinity levels are higher than the secondary plume however remaining lower than the ambient marine waters (approximately 35ppt).

Using in-situ water quality measurements throughout the 2010/11 wet season, Delvin et al. (2012b) assigned TSS concentrations to the plume types described above. The mean TSS concentrations for the Wet Tropics region are shown in Figure 5-22 and summarised below:

- Primary plume: 23mg/L;
- Secondary plume: 14mg/L; and
- Tertiary plume: 8mg/L.

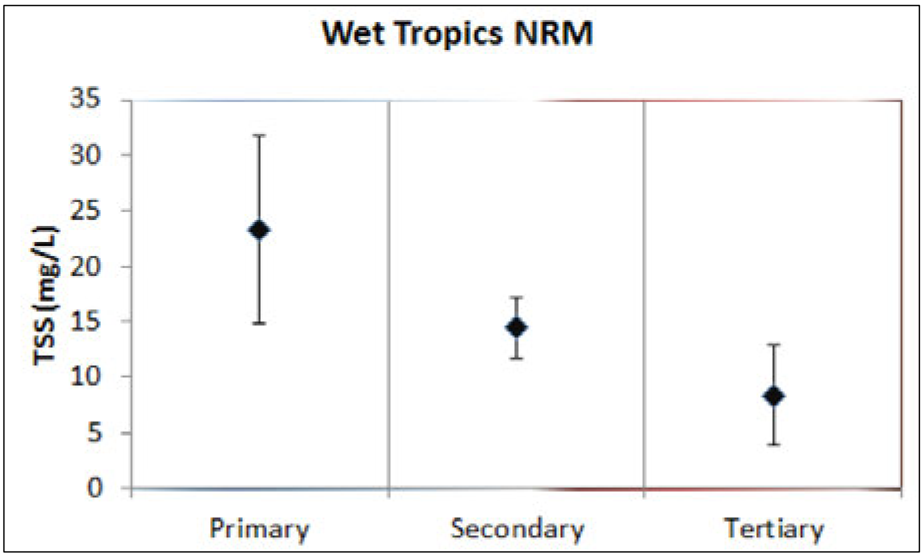


Figure 5-22 Wet Tropics Plume Type Mean TSS Concentrations (from: Delvin et al., 2012b)

5.6.2 Fluvial Inputs and Model Parameterisation

Barron River fluvial discharge and sediment loads for the 2010/11 wet season have been simulated using the modelling system described in this report. This period was selected due to the availability of the following data:

- Barron River TSS annual load estimates provided by RRRC; and
- Barron River daily flow and turbidity (NTU) recordings at Myola (station 110001D Barron River) obtained from the DNRM Watershed data service.

Table 3-1 summarises Barron River TSS annual loads provided by RRRC. The estimates are derived from fluid concentration measurements at Myola collected at monthly (minimum) intervals. For the period of available estimates, Table 3-1 suggests the 2010/11 TSS annual load was representative of above average conditions.

Table 5-1 Barron River TSS Annual Loads (data provided by RRRC[2])

	2006-07	2007-08	2008-09	2009-10	2010-2011
Barron River TSS annual load (tonne)	30,403	396,503	163,366	174,425	239,404

The 2010/11 TSS annual load, daily mean discharge and turbidity (NTU) recordings were used to establish a NTU-TSS relationship for the 2010/11 period. The derived Barron River mean TSS (mg/L) time series and discharge used as model inputs are shown in Figure 5-23.

[2] Estimated TSS loads may be updated following further analysis (RRRC 2013, pers. comm. 1 July)

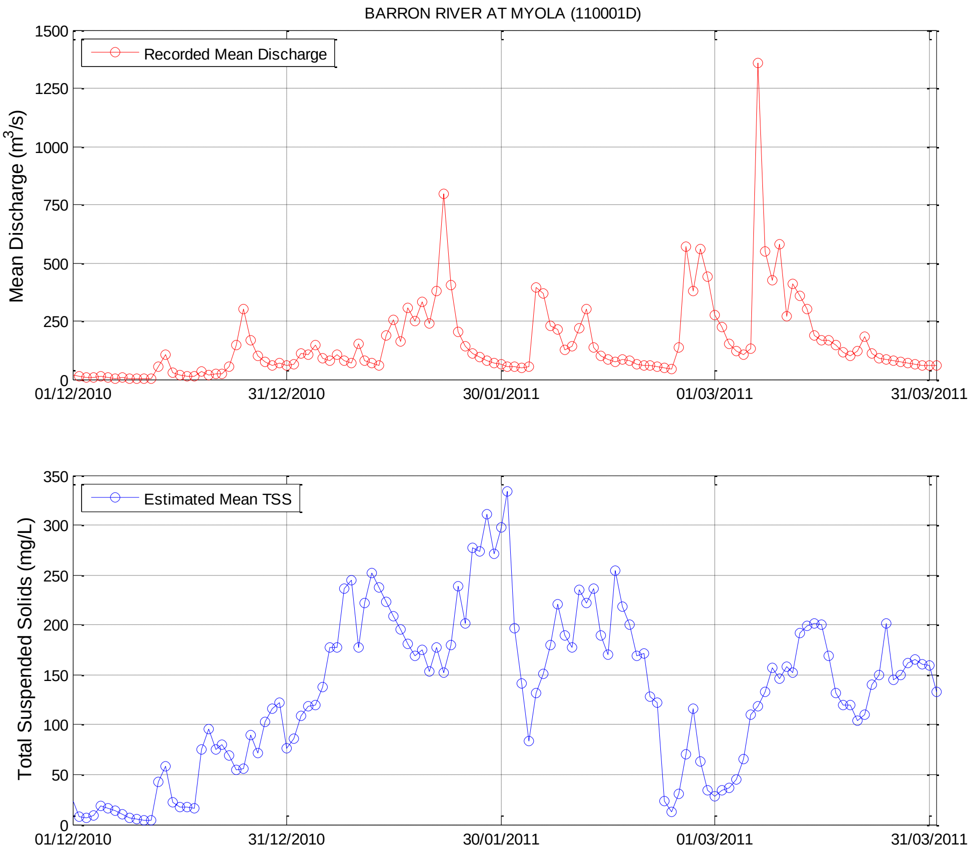


Figure 5-23 Barron River at Myola Recorded Daily Mean Discharge (top) and Estimated Mean TSS (bottom)

Specific detail of the fluvial sediment characteristics was not available however it was assumed the discharge contained siliceous sand (20%), silt (40%) and clay (40%) fractions. Each sediment class was assigned the characteristics previously presented in Table 3-6. The re-suspension of Trinity Bay bed sediments was not simulated in order to isolate the influence of the Barron River plume.

5.6.3 Barron River Plume Results

Figure 5-24 shows a surface TSS prediction from the TUFLOW FV model on 5 February 2011 together with the MODIS satellite image from the same date (http://oceancolor.gsfc.nasa.gov/). The date shown corresponds to Barron River flood flow due to rainfall associated with Tropical Cyclone Yasi, which made landfall south of the study area on 3 February 2011. The peak daily mean discharge in the Barron River associated with this event was approximately 400m^3/s. The model results show good qualitative agreement with the plume spatial distributions which are discernible from the MODIS satellite images.

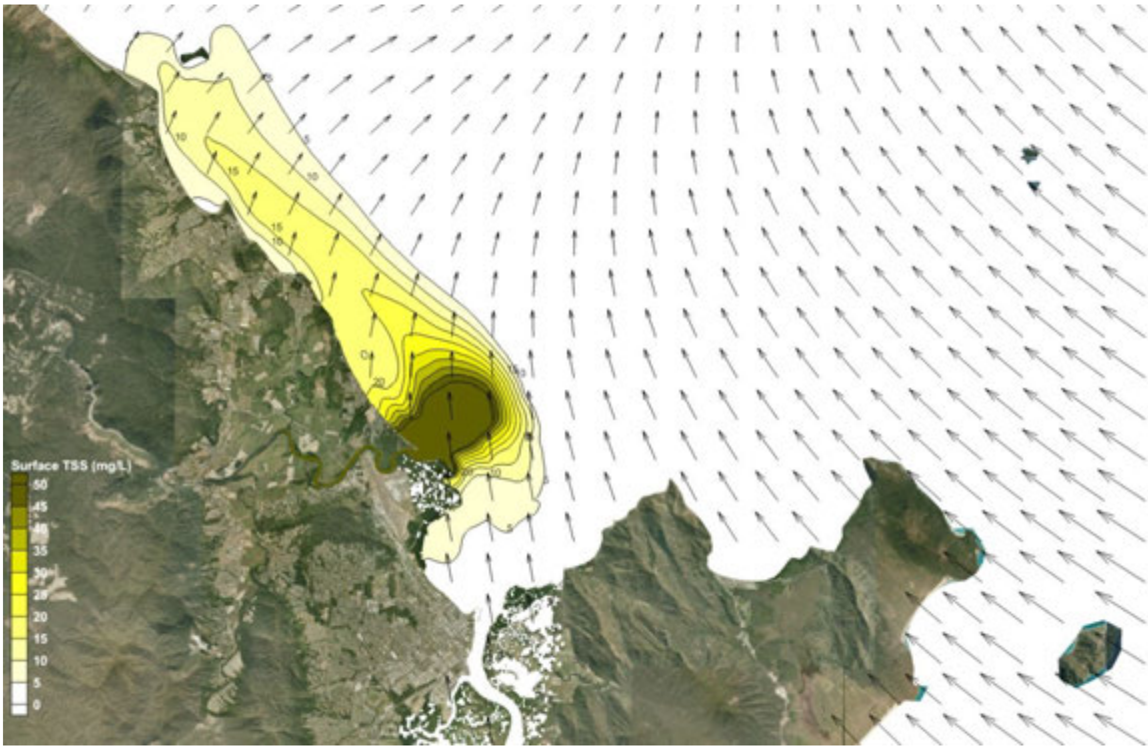


Figure 5-24 Barron River Flood Plume on 05/02/2011 - MODIS Satellite Image (top) and Predicted Surface TSS with Wind Vectors (bottom)

For illustrative purposes, surface salinity and surface TSS predictions are presented in Figure 5-25 and Figure 5-26. The model output corresponds to an early March 2011 Barron River flow event with a peak mean daily discharge close to 1400m^3/s. The instantaneous model output presented corresponds to times when the wind conditions significantly influence the extent of the surface plume. With reference to generic GBR flood plume types described in Section 5.6.1, the modelling results indicate the following:

- During the significant Barron River discharge and west south-westerly wind conditions, the spatial extent of the primary plume type (TSS < 23mg/L) extended approximately 15km offshore from the mouth of the Barron River. The secondary and tertiary plume types extend further offshore, with salinity approaching the ambient marine level near Green Island, location approximately 25km offshore from the mouth.
- During north-easterly wind conditions (Figure 5-26) the primary plume occurs parallel to the coastline and extends approximately 8km in a north-westerly direction. Secondary plume types continue along the coastline with the fluvial effected waters with salinity levels close to 25ppt reaching Double Island.

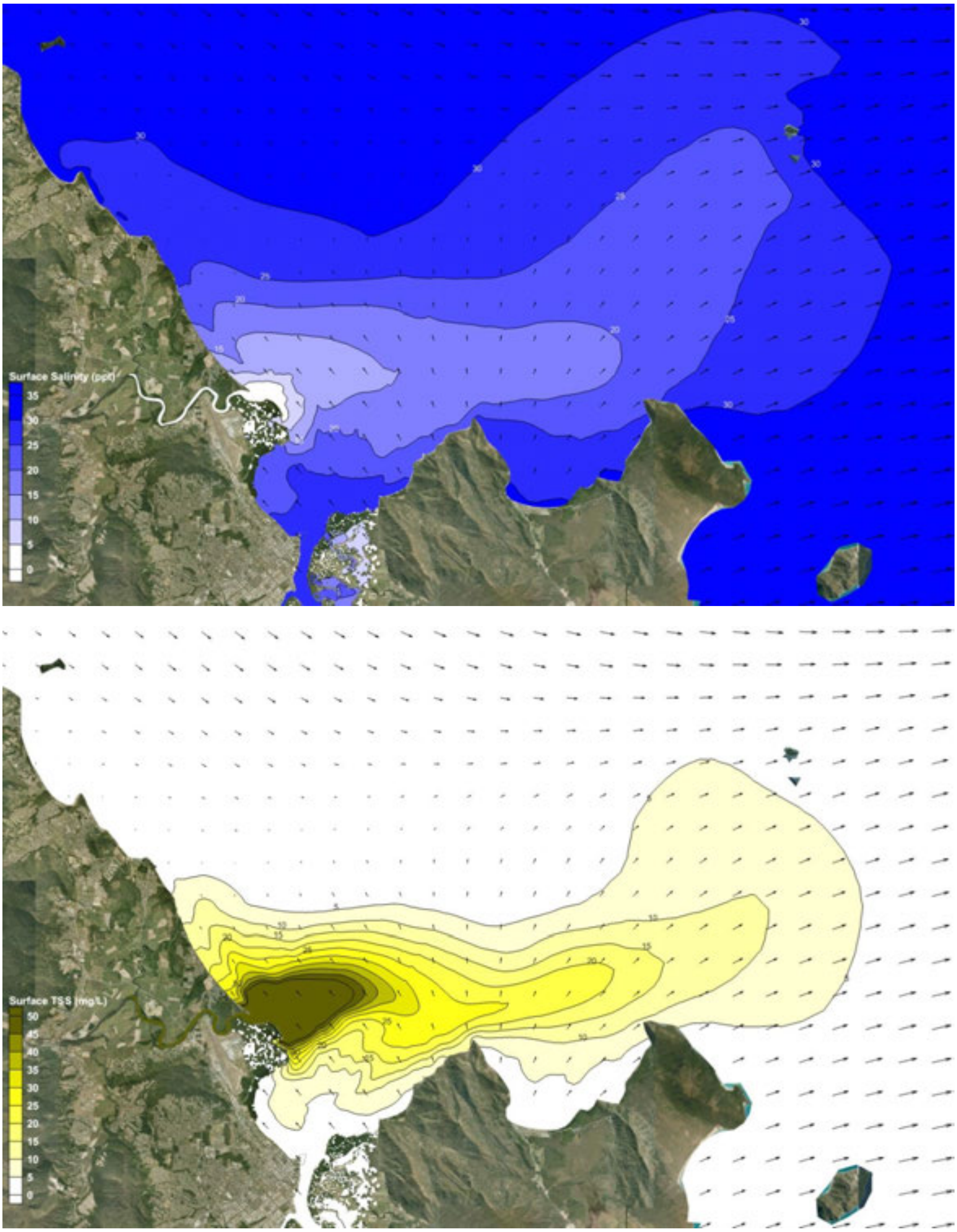


Figure 5-25 Barron River Flood Plume with West South-Westerly Winds - Surface Salinity (top) and Surface TSS (bottom)

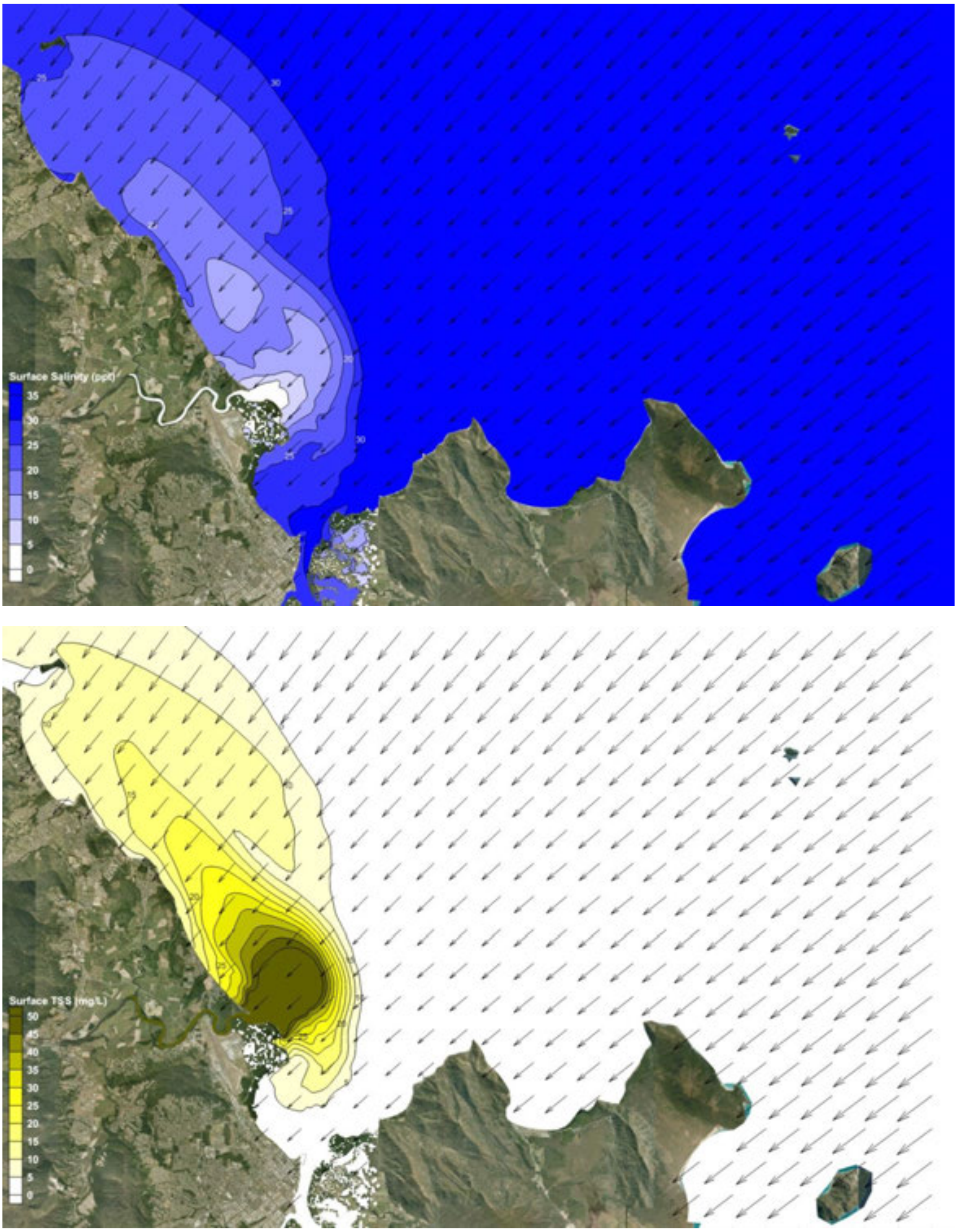


Figure 5-26 Barron River Flood Plume with North-Easterly Winds - Surface Salinity (top) and Surface TSS (bottom)

6 Dredging Impact Assessment

6.1 Introduction

The following section describes the methodology and results of numerical modelling assessment of the CSDP capital dredging and placement programme. The dredge plume modelling methodology is described in detail followed by the presentation of model results for the following impact assessments:

- Base Case Capital Program;
- Alternative Case Capital Program;
- “Worst Case” Soft Material Dredging;
- “Worst Case” Stiff Material Dredging;
- 12 month Re-suspension (following on from the Base Case Capital scenario; and
- “Worst Case” DMPA re-suspension.

The modelling outcomes provide a detailed and site specific assessment of possible dredge plume dispersion intended for CSDP impact assessment purposes.

6.2 Methodology

6.2.1 Modelled Sediment Fractions

In contrast to most other dredge plume dispersion assessments of dredge spoil dispersion within the Great Barrier Reef (GBR) Marine Park (e.g. SKM-APASA, 2012) the current assessment simulated the re-suspension of “ambient” surficial seabed material as well as the re-suspension of “dredged” material that had been placed at the DMPAs. The calibration and validation of the Sediment Transport model was detailed in Section 3.5.

As summarised in Table 6-1, eight (8) sediment fractions were simulated as part of the dredging impact assessments in order to track both the ambient and dredge material. Physical properties and model parameters were generally identical for corresponding size fractions of the ambient and dredge material, with the exception of the dredge material erosion rate constant which was increased by a factor of 1.5 over the calibrated ambient rate within the DMPA perimeter. This increase was undertaken in order to represent the potentially lower degree of consolidation of dredged material (at least initially after placement).

Table 6-1 Characteristics of Simulated Sediment Classes

Modelled Sediment Class	Still Water Fall Velocity, Ws (m/s)	Critical Shear Stress Erosion, Tce (Pa)	Critical Shear Stress Deposition, Tcd (Pa)	Erosion Rate Constant, E (g/m2/s)
Ambient Clay	1×10^{-4}	0.2	0.18	0.15
Ambient Silt	1×10^{-3}	0.2	0.18	0.15
Ambient Siliceous Sand	3×10^{-2}	0.2	N/A	0.15

Modelled Sediment Class	Still Water Fall Velocity, Ws (m/s)	Critical Shear Stress Erosion, Tce (Pa)	Critical Shear Stress Deposition, Tcd (Pa)	Erosion Rate Constant, E (g/m2/s)
Ambient Carbonaceous Sand	1×10^{-2}	0.2	N/A	0.15
Dredged Material Clay	1×10^{-4}	0.2	0.18	[0.225, 0.15]**
Dredged Material Silt	1×10^{-3}	0.2	0.18	[0.225, 0.15]**
Dredged Material Fine Sand	3×10^{-2}	0.2	N/A	[0.225, 0.15]**
Dredged Material Coarse Sand	5×10^{-3}	0.2	N/A	[0.225, 0.15]**

** The erosion rate constant, *E*, was increased above the calibrated ambient level within the DMPA perimeter only.

The inclusion of both ambient and dredged material within the dredge plume and dispersion modelling assessment allows for the process of mixing and assimilation of the dredged material with the ambient material through the processes of re-suspension, suspended sediment transport and deposition. The ambient sediment bed was "warmed up" as described in Section 3.5. Throughout the dredge plume and dispersion assessment simulation the surface seabed sediment layer experienced re-suspension and deposition of all of the modelled sediment classes, with the relative proportions within the surface layer being dependent on the relative quantities being deposited. In this way the surface sediment layer subsequently available for re-suspension was made up of a representative mix of ambient and dredged sediments, which is something that cannot be resolved in modelling assessments that only consider the dredged material fractions (e.g. SKM & APASA, 2013). Such assessments are analogous to depositing the dredged material onto a "concrete" substrate and have the potential to greatly overestimate the subsequent rates of re-suspension of the dredged material fractions (as these represent 100% of the material available for re-suspension).

6.2.2 Dredging Programme Schematisation

Numerical simulation of the CSDP capital dredging campaign required the development of representative dredge plume and DMPA placement boundary conditions for input into the hydrodynamic model. Simulations were developed to span the entirety of the capital dredging campaign as outlined in the Cairns EIS Dredging Technical Note Revision 5 (Pro-Dredging, 2014). This document provided preliminary dredging methods, productions and suspended sediment source loads for the purpose of informing the dredge plume impact modelling EIS tasks.

The volume of *in-situ* material to be dredged, dredge scheduling and production rates were calculated by Pro-Dredging based on four sediment classes: soft clay, firm clay, stiff clay and very-stiff clay. The vertical extents of these sediment classes within the dredge footprint were derived based on the Preliminary Geotechnical Investigation report (Golder, 2013), with eight dredge footprint sub-areas defined based on the eight boreholes presented in the Golder report. These sub-areas and the design depths (including an over-dredging allowance) are shown in Figure 6-1. The breakdown of each sediment class volume per sub-area is summarised in Table 6-2.

Table 6-2 Volumes of material to be removed per area and per soil classification (Pro-Dredging, 2014)

Area	Chainage (km)	Design Dredge depth (m LAT)	In situ Volume (m^3)			
			Total	Very soft – soft clay	Firm clay	Stiff Clay
1	10.25-14.39	9.7/8.3	764,074	338,806	105,355	319,913
2	9.00-10.25	11.1	470,215	470,215		
3	8.25-9.00	9.9	244,145	244,145		
4	6.75-8.25	10.1	699,348	699,348		
5	6.25-6.75	10.6	276,535	236,935	39,600	
6	4.25-6.25	11.1	1,168,409	873,609	294,800	
7	3.75-4.25	10.3	174,217	154,567	19,650	
8	0-3.75	9.9	552,673	552,673		
Totals			4,349,616	3,570,298	459,405	319,913

Note: the chainage system above was developed by Pro-Dredging for the purpose of soil classification and differs from the existing shipping channel reference system.

The assumed dry density of the various materials to be dredged are summarised below:

- Very soft and soft clays – 1,055 kg/m^3;
- Firm clay – 1,200 kg/m^3; and
- Stiff clay – 1,565 kg/m^3.

The preliminary dredging methods (Pro-Dredging, 2014) involved a combination of a TSHD (5,580m^3 type Marieke) generally operating in the channel and a BHD (730kW type Machiavelli) dredging stiff to very stiff clays in sub-areas 1, 2 and 3.

The dredge positions were dynamically updated throughout the simulation and were programmed to cover each sub-area with a sufficient number of cycles to remove the required volumes (refer Table 6-2) at the specified production rates (refer Table 6-3).

The TSHD was programmed to travel back and forwards along each area, with a turn at each end taking 10 minutes as suggested by Pro-Dredging (2014). The TSHD was positioned at the channel centreline throughout its manoeuvres, except for when it was undertaking trips to the DMPA. The location of placement at the DMPA was selected randomly with a uniform distribution over the entire site. The TSHD speed largely determined the position of the dredge at a given time, and the speed at which it could reach the DMPA and return to production. Speeds of dredging, as well as the maximum speed were taken from the Pro-Dredging document and Cairns Channel speed restrictions were also used between different beacons for the steaming rate of the dredge (Department of Main Roads and Transport, 2013). The TSHD was inactive 10% of the time to account for its expected operational efficiency (Pro-Dredging, 2014).

Table 6-3 Adopted TSHD production parameters (Pro-Dredging, 2014)

In-Situ Sediment Characterisation	TSHD Speed (knots)	In-Situ Production Rate (m^3/hr)
Soft Clay	1.5	6340
Firm Clay	2.0	4180
Stiff Clay	2.0	2090

The BHD was assumed to move slowly from one end to the other of its sub-areas over the course of its dredging and was assumed to operate with three hopper barges. The BHD was inactive 40% of the time to account for its expected operational efficiency (Pro-Dredging, 2014).

Table 6-4 Adopted BHD production parameters (Pro-Dredging, 2014)

In-Situ Sediment Characterisation	In-Situ Production Rate (m^3/hr)**
Soft Clay	350
Stiff Clay	230
Very-Stiff Clay	180

** When operational, i.e. 60% of the time

Title:

Channel Design and Sub Areas (mLAT)

Figure: 6-1

Rev: A

N

0 1.25 2.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_014_Dredge_Depths.wor

6.2.3 Dredge Plume Source Rates

Plume source rates were derived based on the Pro-Dredging (2014) technical note recommendations. In particular the following assumptions were used:

- During TSHD dredging the passive plume source rate due to draghead and propwash entrainment is 2% of the production rate;
- During TSHD overflow 80% of the fines entering the TSHD hopper exit via the overflow (note that not all modelled scenarios include overflow);
- Of the TSHD overflowing fines, 85% forms a dynamic plume to the seabed while 15% remains in the water column as a passive plume;
- At the DMPA during TSHD placement 8% of the material enters a “primary” passive plume that is evenly distributed in the water column and 7% enters a “secondary” passive plume concentrated just above the seabed;
- During BHD dredging the passive plume source rate is 3% of the production rate; and
- At the DMPA during BHD barge placement 7% of the material enters a “primary” passive plume that is evenly distributed in the water column.

Based on these assumptions source rates were derived for each stage of the various dredge cycles operating in each of the material classes, as summarised in Table 6-5. As the dynamic plume does not contribute to suspended sediment concentrations, except in the immediate vicinity of the dredge while it is operating, it is not explicitly considered as a source rate into the numerical plume model. That is the numerical model only resolves the “passive” plumes. However, the DMPA dynamic plume is input to the model as a source directly to the seabed sediment layer such that the placed material gradually accumulated within the model and was available for subsequent re-suspension.

Table 6-5 Adopted TSHD Plume Source Parameters (Pro-Dredging, 2014)

Material / Operational Mode	Draghead/ Propwash Passive Plume Source (kg/s)	Overflow Passive Plume Source (kg/s)**	DMPA Placement Passive Plume Source (t/cycle)	DMPA Placement Dynamic Plume Source to bed (t/cycle)
Soft Clay – no overflow	37.2	N/A	490	2390
Soft clay – 10 min overflow	37.2	210	534	2610
Firm Clay – no overflow	27.8	N/A	366	1790
Firm Clay – 10 min overflow	27.8	150	403	1970
Stiff Clay – 60 min overflow	18.1	60	513	2506

** Not all TSHD modelling scenarios included overflow.

Table 6-6 Adopted BHD Plume Source Parameters (Pro-Dredging, 2014)

Material	BHD Passive Plume Source (kg/s)	DMPA Placement Passive Plume Source (t/cycle)	DMPA Placement Dynamic Plume Source to bed (t/cycle)
Soft Clay	3.1	580	850
Firm Clay	3.0	809	1280
Stiff Clay	2.3	809	1280

The sediment size fraction composition of the plume and seabed source inputs was determined based on Golder (2013) and are summarised below in Table 6-7. All passive plumes are assumed to have a composition that is similar to the *in-situ* material, except for the TSHD overflow plume which is comprised entirely of fine (clay/silt) fractions. Where overflow TSHD dredging has occurred the DMPA placement plumes will tend to have a lower fines fraction, however this reduction has been conservatively ignored in the EIS assessments.

Table 6-7 Dredge Plume Sediment Fraction Breakdown (Golder, 2013)

Passive Plume Type/s	*In-situ* Material	Sediment Fraction %			
		Clay	Silt	Fine Sand	Coarse Sand
TSHD Drag/Prop Plume BHD Plume TSHD Placement Plume BHD Placement Plume	Soft Clay	49	47	4	0
	Firm Clay	41	51	6	2
	Stiff Clay	47	47	5	1
TSHD Overflow Plume	Soft Clay	51	49	0	0
	Firm Clay	45	55	0	0
	Stiff Clay	50	50	0	0

6.2.4 Simulation Periods

According to the preliminary schedule (Figure 6-4) the entire CSDP dredging program will run for approximately 48 weeks including plant mobilisation (approximately 34 weeks of dredging). The preferred dredging window is during the winter months and therefore a period between March and October has been selected for the "base case" and "alternative case" impact assessments. These assessments have simulated the entire dredge program as occurring between the 1st March 2011 to the 30th October 2011 (noting that the shorter alternative case occurs during April to September). As shown in Figure 6-2 this period in 2011 is reasonably representative of the long term average conditions for these months, and is therefore considered to be an appropriate basis for an "expected case" impact assessment.

The 12 month re-suspension assessment has been simulated for the historical period from the 30th October 2011 to the 1st November 2012. As shown in Figure 6-2 this 12 month period is reasonably representative of the long term average conditions for these months, and is therefore considered to be an appropriate basis for an "expected case" impact assessment. In addition a "worst case" re-suspension period based on the period between 10th January 2011 and 20th February 2011 that included the Category 5 Severe Tropical Cyclone Yasi has been simulated.

Worst case capital dredging assessments have been undertaken for a shorter 30 day period that coincides with the period of maximum impacts from the full 48 week base case assessment. While these worst case assessments have been undertaken for a period of relatively unfavourable climatic conditions, there main purpose is to assess the sensitivity of the expected case impacts to possible operational variations that may be encountered during the CSDP.

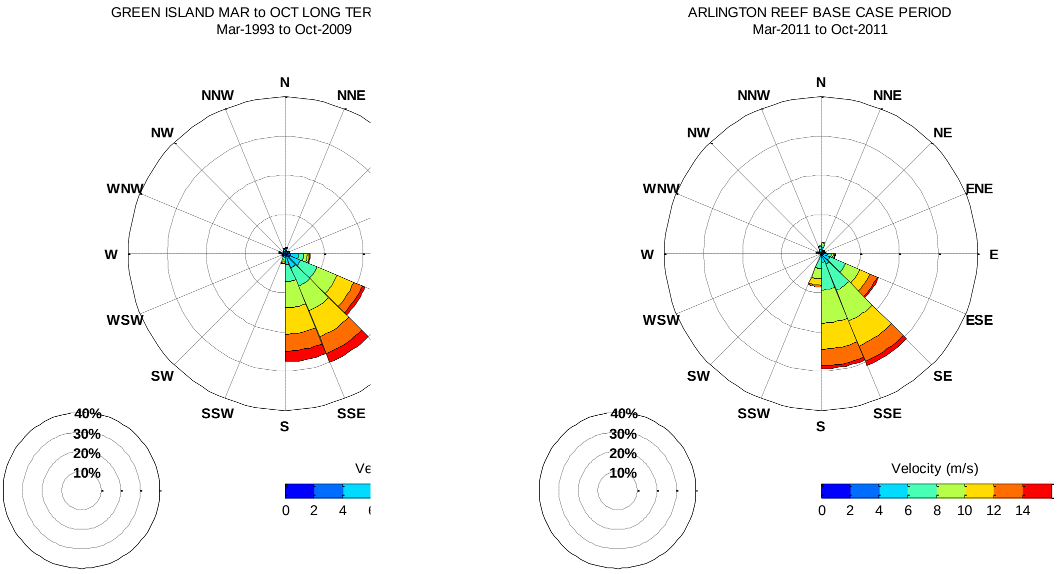


Figure 6-2 Base Case Capital Assessment period wind rose (right) compared with the long term average (left) for these months.

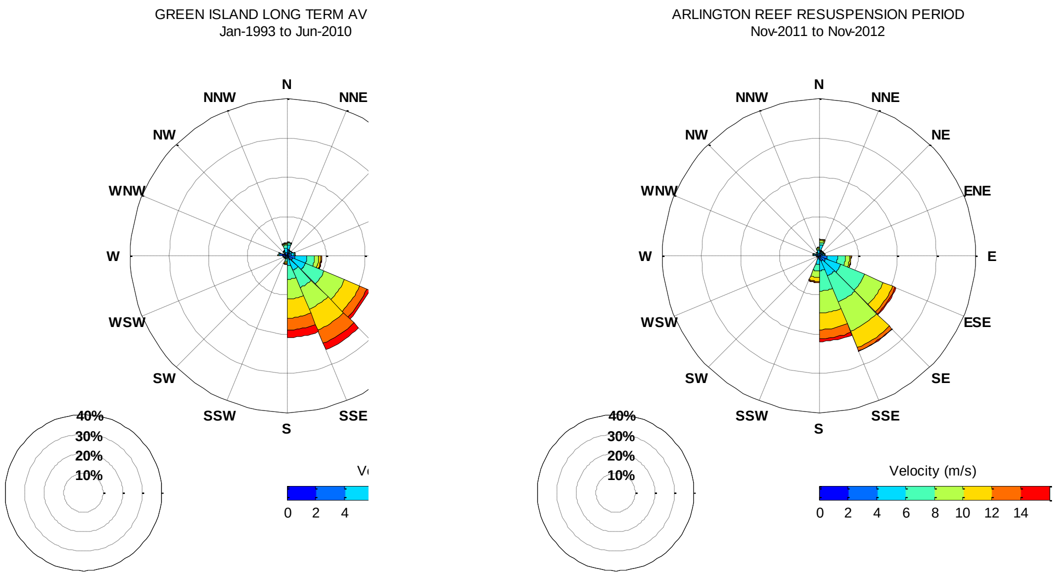


Figure 6-3 12 Month Re-suspension Assessment period wind rose (right) compared with the long term average (left).

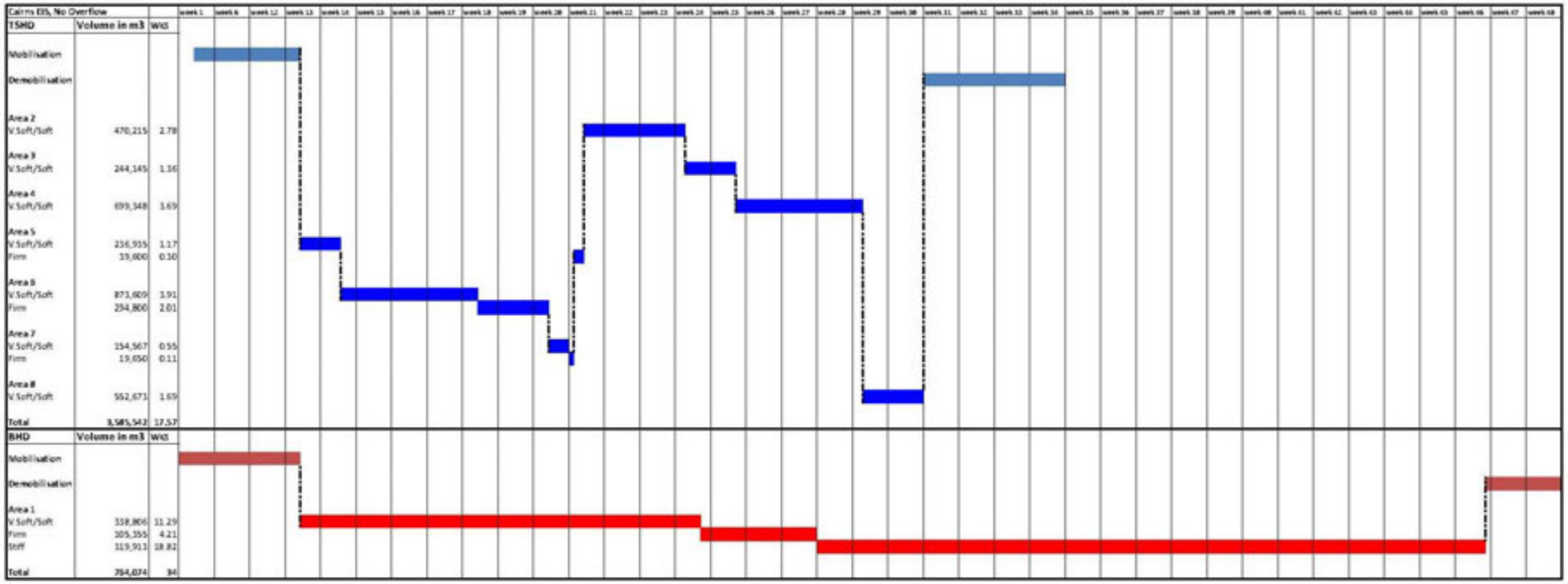


Figure 6-4 CSDP Base Case Schedule Assuming No Overflow (Pro-Dredging, 2014)

6.2.5 Assessment Methodology

The predicted effect of CSDP dredging was assessed based on modelled increases in suspended sediment concentration and sedimentation above natural or ambient levels. Both ambient and dredge related signals have been resolved in the predictive model, which allows for an understanding of how significant the dredge contribution is in relation to ambient conditions.

The water column turbidity impacts associated with dredging-related suspended sediment were derived by converting the modelled Total Suspended Solids (TSS) levels into an equivalent turbidity value using the relationship previously presented in Figure 3-1. In accordance with the GBRMPA guidelines both depth-averaged and near-bed turbidity values have been derived and used in the impact assessment. In general the depth-averaged turbidity values are more relevant to assessing ecological impacts due to the reduction in seabed Photosynthetically Active Radiation (PAR).

Sedimentation impacts were derived from the daily rate of change in bed sediment mass associated with the dredge fractions. The adopted sedimentation rate units are $mg/cm^2/day$.

The predicted effects of dredging have been assessed using two different presentation techniques:

- Timeseries at sensitive receptor sites; and
- Spatial plots based on percentile analysis.

The scope of this modelling report does not cover the entire impact assessment process, however it does supply (and describe) some of the impact assessment inputs that have been used in the Water Quality, Marine Ecology and Coastal Process impact assessment chapters.

6.2.5.1 Timeseries Analysis

Timeseries provide a simple way to present turbidity increases due to dredging at predetermined points of interest. Having simulated both dredging and ambient sediment, the timeseries show both these contributions to the total signal and in doing so provide important information on the relative magnitude of the dredging related signal. Turbidity timeseries plots for selected locations and each assessment scenario are provided in Appendix I.

6.2.5.2 Percentile Analysis

Spatial representations of the dredging impacts were based on percentile exceedance analysis of the model results and were derived by applying a moving 30 day analysis window over the entire simulation period. The 30 day window period is somewhat arbitrary but in a physical hydrodynamic context represents the approximate duration of two (2) consecutive spring-neap tidal cycles, while in an ecological context it is a meaningful timescale for assessing impacts to some key sensitive receptors in the area (e.g. dominant seagrass *Halolphila ovalis*). The moving window analysis was undertaken by moving the 30 day window by 10 day increments over the entire simulation period.

The percentile impact plots correspond to the predicted increase in turbidity/sedimentation over ambient conditions that are attributable to the dredging. Impacts at each percentile level were calculated for every 30-day window during the simulation, and the maximum increase at each location in the model domain is presented. Different locations within the model will have experienced their worst period at different times during the simulation and the different percentile statistics may also have occurred during different 30 day windows. It is important to note that the presented turbidity percentile plots do not represent the plume extent at any one particular instance in time.

Percentile values considered in this report are 95th, 80th, 50th and 20th which correspond to exceedance durations of 36hrs (5%), 6 days (20%), 15 days (50%) and 24 days (80%) respectively for the 30 day window. The highest percentiles correspond to relatively acute and short-lived increases in turbidity/sedimentation while the lower percentiles correspond to more chronic longer-term increases.

The spatial percentile exceedance dredging impact plots are presented in tandem with the equivalent modelled ambient percentile statistics, calculated as the average over all 30 day windows during the simulation period. This allows the increases in turbidity/sedimentation due to dredging to be seen relative to the modelled ambient conditions.

Key features of the moving window percentile analysis include:

- Consideration of a range of impact durations from acute to chronic;
- Can be applied to a long term programme and capture periods of high intensity versus low intensity impacts; and
- A similar analysis applied to the baseline data can quantify the ambient conditions including natural variability across different periods. This can be used to derive meaningful thresholds for the impacts.

Twelve months of baseline turbidity monitoring was undertaken for the CSDP which has allowed for the derivation of contour limits for the presentation of the percentile impact plots that are meaningful at specific sites. It should be noted that different thresholds (and therefore different contour limits) are appropriate for the different percentiles.

In order to illustrate this, the results of applying a moving 30 window analysis to the 12 month Trinity Bay baseline monitoring dataset, is shown in Figure 6-5. The x-axis represents the different percentile values extracted from the moving 30 day window analysis moving from frequently-exceeded on the left to rarely-exceeded on the right. The different curves are statistics representing the variability of the percentile analysis results across the different 30 day periods (making up the entire baseline monitoring period). The lower curve represents the least turbid conditions experienced across the monitoring period while the upper limit represents the most turbid conditions. The solid green line is the mean of all the different 30 day window conditions.

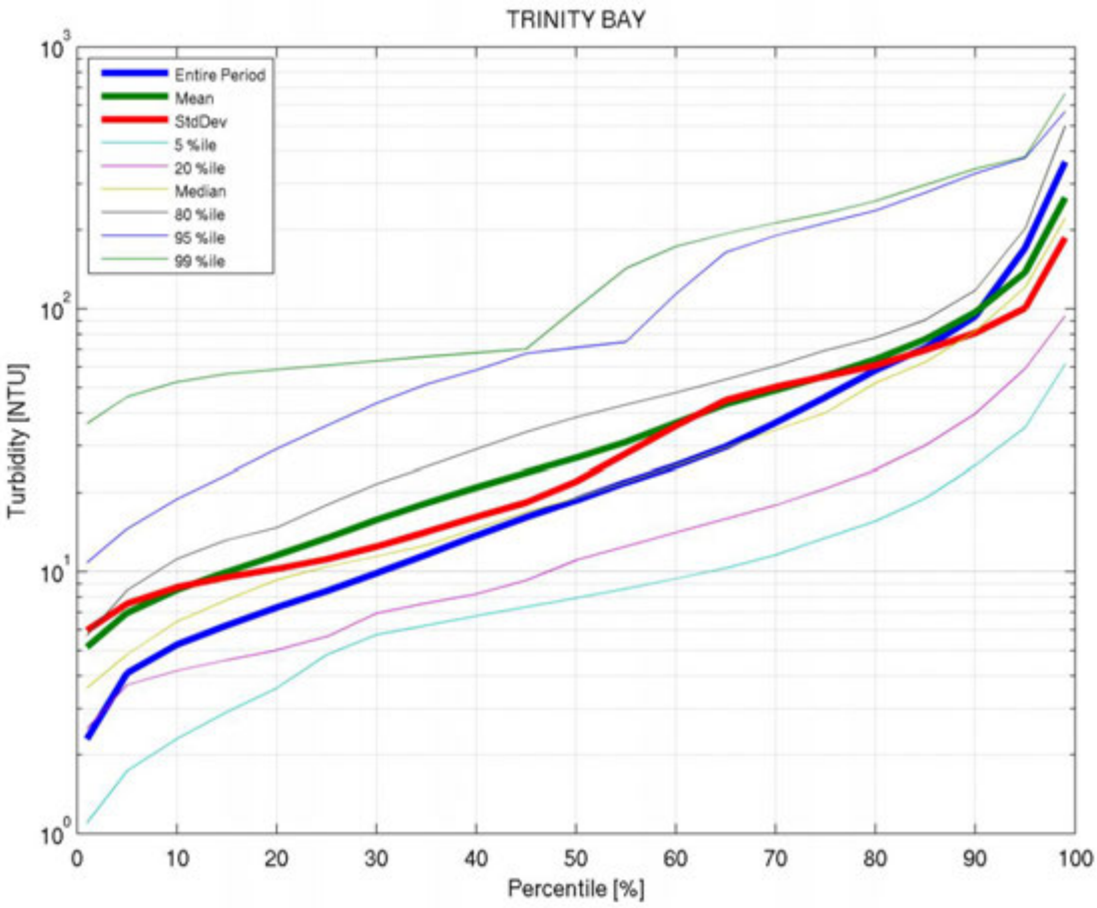


Figure 6-5 Trinity Bay Baseline Turbidity Statistics

After considering the baseline water quality statistics at the various monitoring sites (Refer to the Water Quality Chapter B7 for more detail), the following contouring limits in Table 6-8 have been adopted for presenting the water quality impact data. Notwithstanding substantial spatial variation, at most sites the lower contour limit is well below the lowest level experienced during the baseline data collection campaign (for that percentile) and the upper contour limit is generally also well below the highest experienced level. Therefore these contour limits are expected to fairly (if not conservatively) represent the significance of the increases in turbidity due to dredging.

Table 6-8 Turbidity percentile contour limits

Percentile	Lower Limit (NTU)	Upper Limit (NTU)
95th	10	200
80th	5	100
50th	2	40
20th	1	20

For the case of assessing sedimentation increases due to CSDP dredging activities, sufficient site-specific baseline sedimentation data was not available and therefore threshold values from literature (Sinclair Knight Merz, 2013) have been used to inform the contour selection, which is summarised in Table 6-9. For the same reason only the 95th percentile and 50th percentile sedimentation impacts were considered for the sedimentation impact assessment.

Table 6-9 Sedimentation percentile contour limits

Percentile	Lower Limit (mg/cm2/day)	Upper Limit (mg/cm2/day)
95th	5	100
50th	0.5	10

6.2.5.3 Zone of Influence Analysis

Another spatial and temporal analysis process was undertaken in order to determine the expected “Zone of Influence” of the CSDP dredging activity. The “Zone of Influence” was defined as the Probable Maximum Extent of detectable plumes due to the proposed CSDP dredging. The following criteria were adopted for determining this zone:

- Modelled dredging related turbidity exceeds 10% of the ambient turbidity level for more than 5% of the time.
- As 10% of ambient turbidity could result in very low turbidity values (especially in offshore waters), any value below 1 NTU was considered as being below detectable limits and disregarded from the output of the above analysis.

This assessment is undertaken for water quality and ecology impact assessment purposes and is presented in Chapter 5 and Chapter 7 of the CSDP EIS.

6.3 Base Case Capital Program

6.3.1 Description

The base case capital dredging scenario is based on TSHD (Type Marieke) dredging of all very soft, soft and firm clay material in areas 2 to 8 (refer Figure 6-1) and BHD (Type Machiavelli) dredging of all material in the inner harbour (area 1). The total *in-situ* volume removed by the TSHD in this scenario is 3,585,000 m^3, with the remaining 764,000 m^3 accounted for by the BHD. Referring to the program shown in Figure 6-4 the duration of TSHD dredging would be approximately 18 weeks (not including mobilisation and demobilisation) while the BHD component would actively dredge for around 34 weeks.

The base case capital dredging scenario assumes no TSHD overflow dredging. This assumption was based on the Pro Dredge (2014) advice that there is only a relatively small productivity increase achieved by TSHD overflow dredging in the Very soft – soft clay material, which is predominant in the CSDP dredge footprint. While the anticipated productivity benefits of overflow dredging are relatively small (for the overall program) it is still anticipated that limited overflow dredging will be required in certain operational circumstances. Accordingly, the worst case scenario assessments (Section 6.5 and Section) have been developed and undertaken in order to understand the additional impacts associated with limited overflow TSHD dredging.

As detailed in Section 6.2.4 the base case dredging scenario was simulated from the 1st March 2011 to the 30th October 2011. The simulation represented both ambient sediment dynamics and the additional contribution to turbidity and sedimentation due to dredging related plumes.

6.3.2 Results

The following results are presented below:

- The 95th percentile modelled average ambient turbidity – depth average (Figure 6-6 top)
- Impact of dredging on the 95th percentile turbidity – depth average (Figure 6-6 bottom)
- The 95th percentile modelled average ambient turbidity – bottom 1m (Figure 6-7 top)
- Impact of dredging on the 95th percentile turbidity – bottom 1m (Figure 6-7 bottom)
- The 50th percentile modelled average ambient turbidity – depth average (Figure 6-8 top)
- Impact of dredging on the 50th percentile turbidity – depth average (Figure 6-8 bottom)
- The 50th percentile modelled average ambient turbidity – bottom 1m (Figure 6-9 top)
- Impact of dredging on the 50th percentile turbidity – bottom 1m (Figure 6-9 bottom)
- Impact of dredging on the 95th percentile deposition rate (Figure 6-10 top)
- Impact of dredging on the 50th percentile deposition rate (Figure 6-10 bottom).

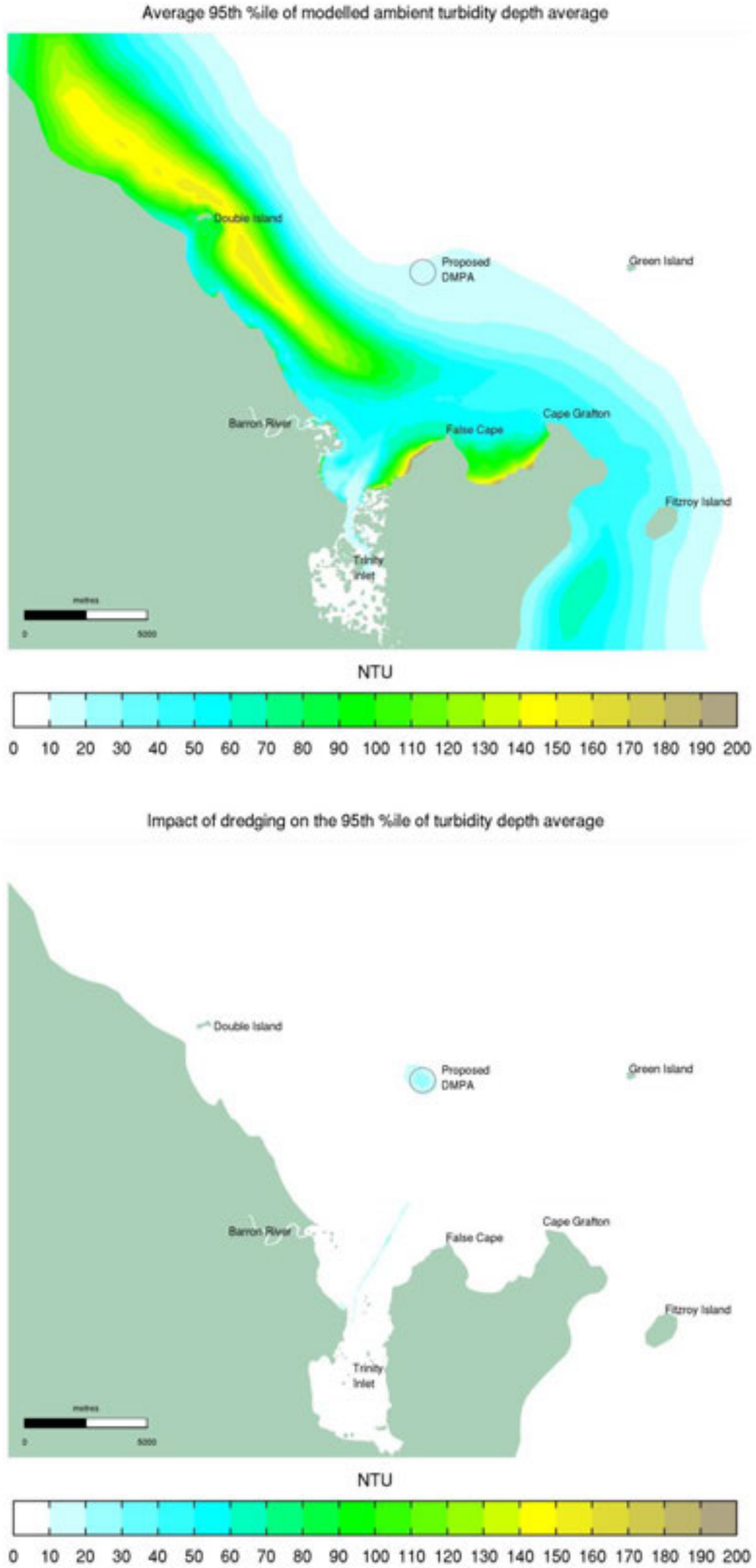
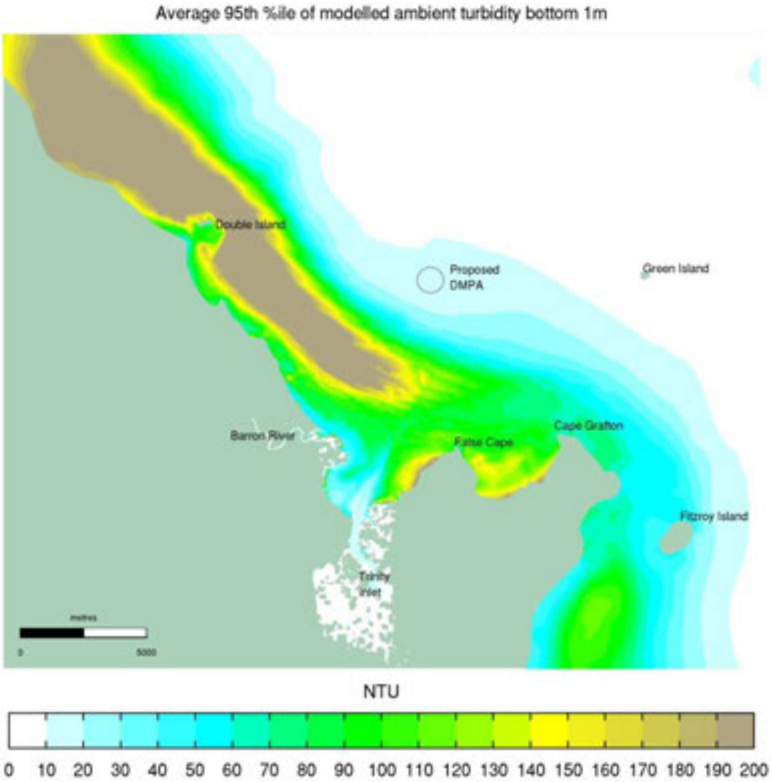


Figure 6-6 Base Case Capital Program 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



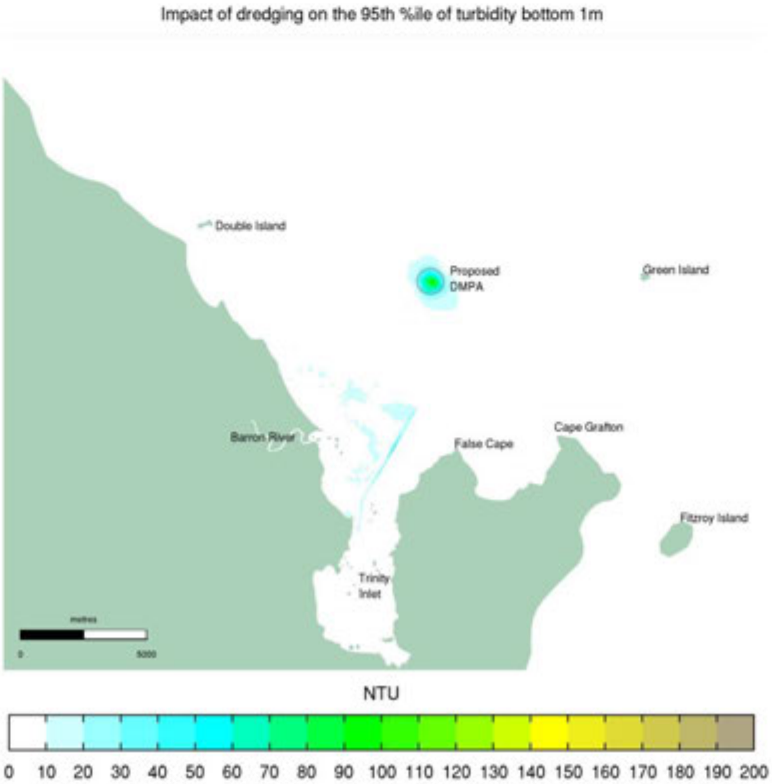


Figure 6-7 Base Case Capital Program 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

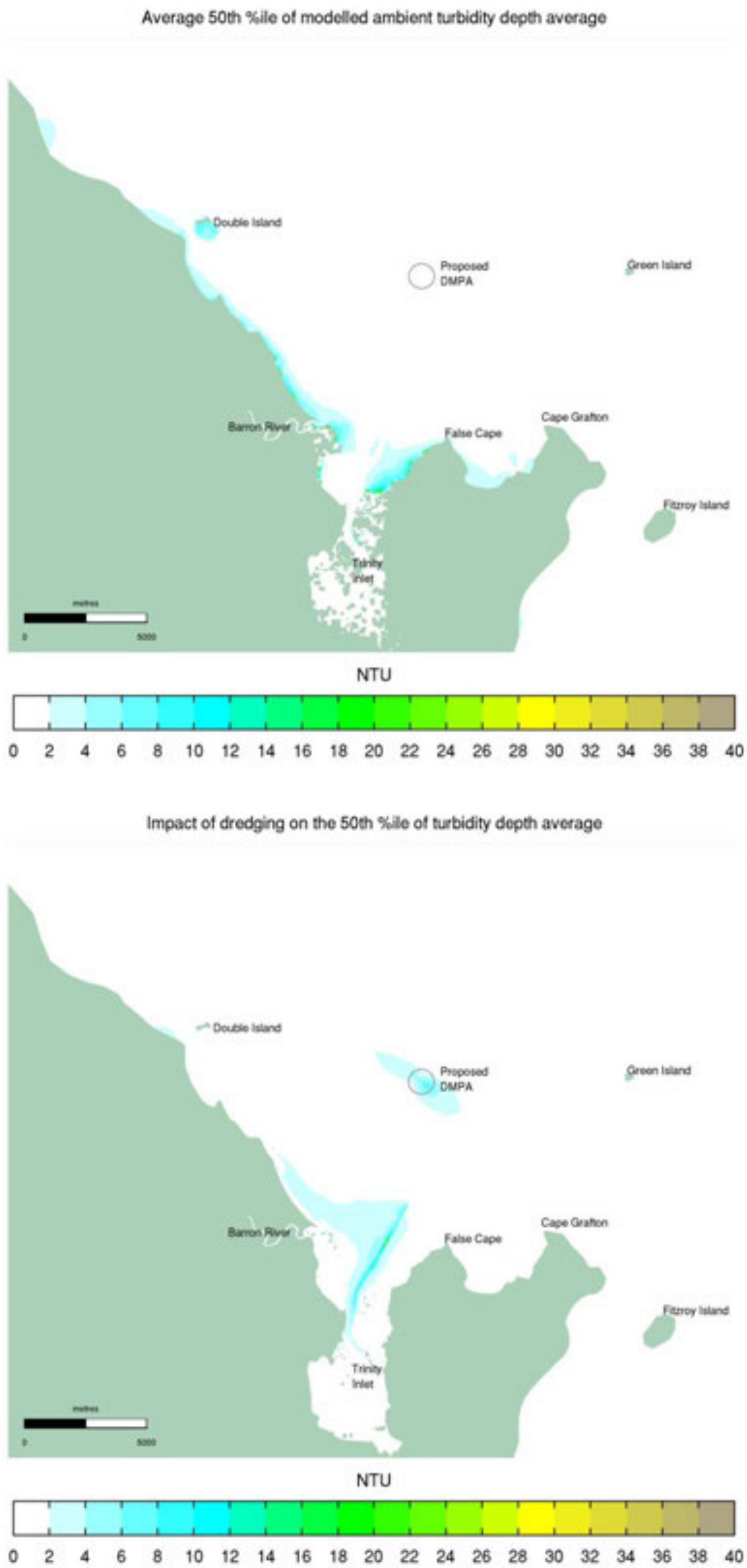


Figure 6-8 Base Case Capital Program 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

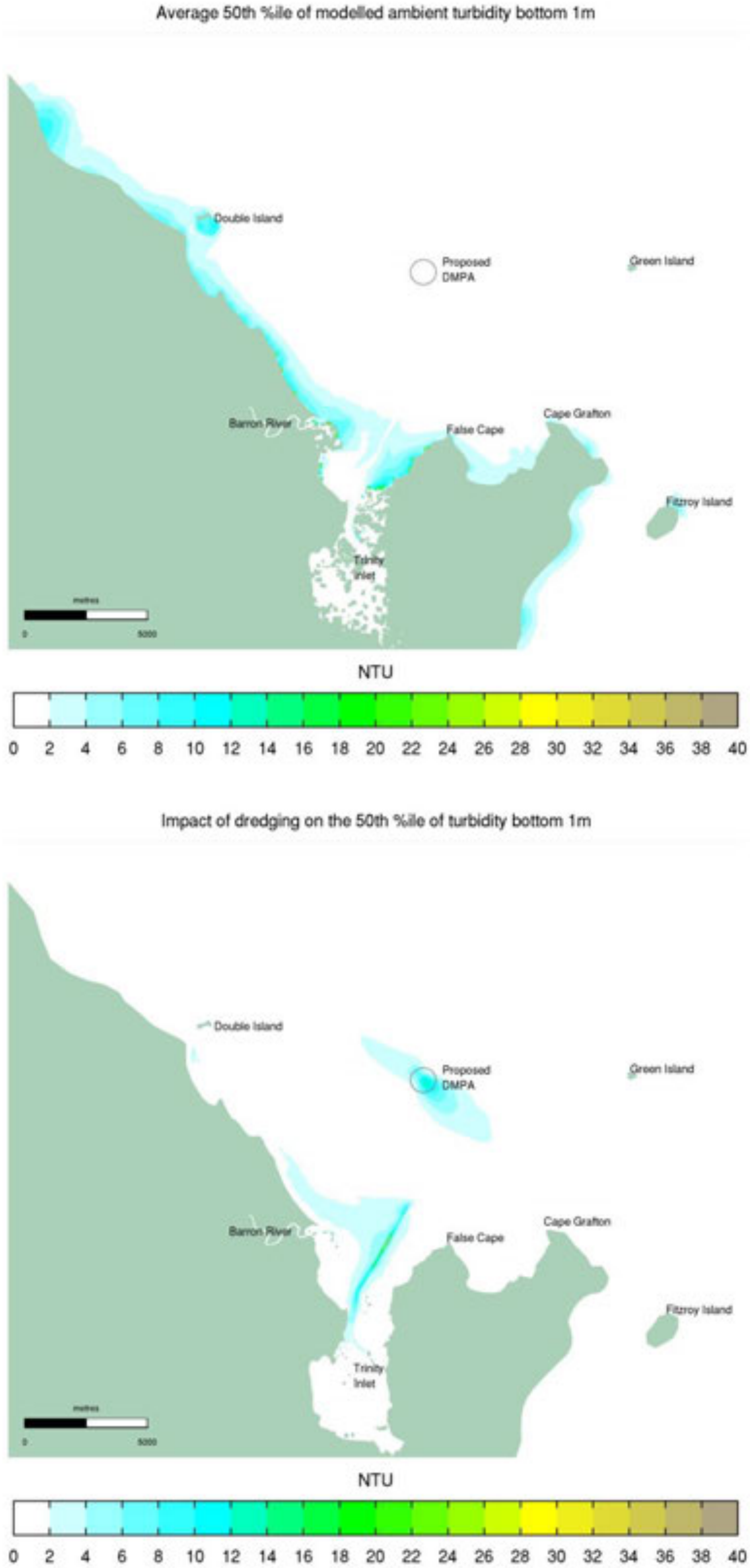


Figure 6-9 Base Case Capital Program 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

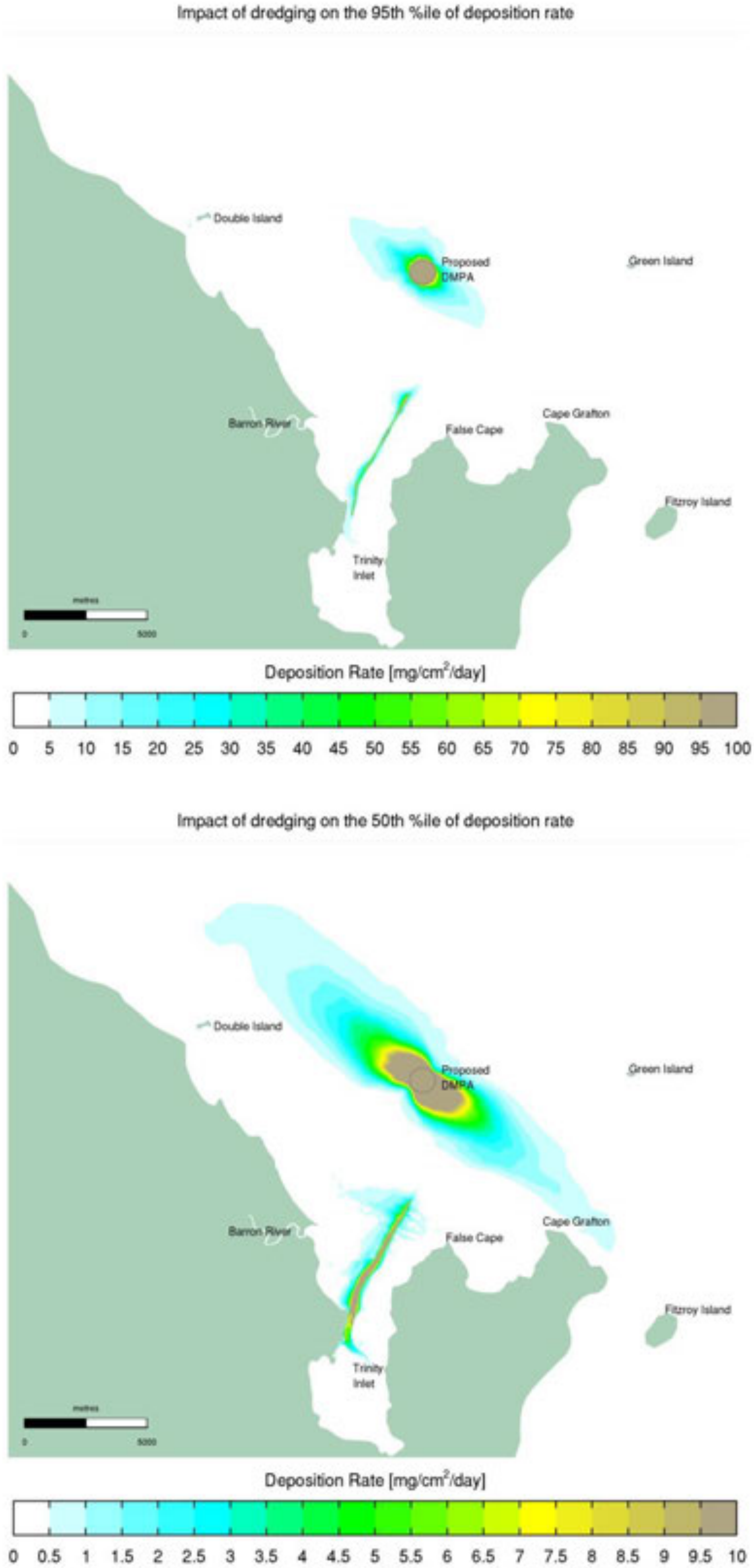


Figure 6-10 Base Case Capital Program Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom)

6.4 Alternative Case Capital Program

6.4.1 Description

The alternative case capital dredging scenario is based on TSHD (Type Marieke) dredging of all very soft, soft and firm clay material in areas 1 to 8 (refer Figure 6-1) and BHD (Type Machiavelli) dredging of the stiff material in the inner harbour (area 1). The total in-situ volume removed by the TSHD in this scenario is 4,030,000 m^3, with the remaining 319,000 m^3 of stiff clay accounted for by the BHD. The duration of TSHD dredging would be approximately 21 weeks (not including mobilisation and demobilisation) while the BHD component would actively dredge for approximately 19 weeks.

The alternative case assumption regarding no overflow dredging is the same as for the base case described in Section 6.3.

As detailed in Section 6.2.4 the alternative case dredging scenario was simulated from the 1st April 2011 to the 4th September 2011. The simulation represented both ambient sediment dynamics and the additional contribution to turbidity and sedimentation due to dredging related plumes.

6.4.2 Results

The following results are presented below:

- The 95th percentile modelled average ambient turbidity – depth average (Figure 6-11 top)
- Impact of dredging on the 95th percentile turbidity – depth average (Figure 6-11 bottom)
- The 95th percentile modelled average ambient turbidity – bottom 1m (Figure 6-12 top)
- Impact of dredging on the 95th percentile turbidity – bottom 1m (Figure 6-12 bottom)
- The 50th percentile modelled average ambient turbidity – depth average (Figure 6-13 top)
- Impact of dredging on the 50th percentile turbidity – depth average (Figure 6-13 bottom)
- The 50th percentile modelled average ambient turbidity – bottom 1m (Figure 6-14 top)
- Impact of dredging on the 50th percentile turbidity – bottom 1m (Figure 6-14 bottom)
- Impact of dredging on the 95th percentile deposition rate (Figure 6-15 top)
- Impact of dredging on the 50th percentile deposition rate (Figure 6-15 bottom).

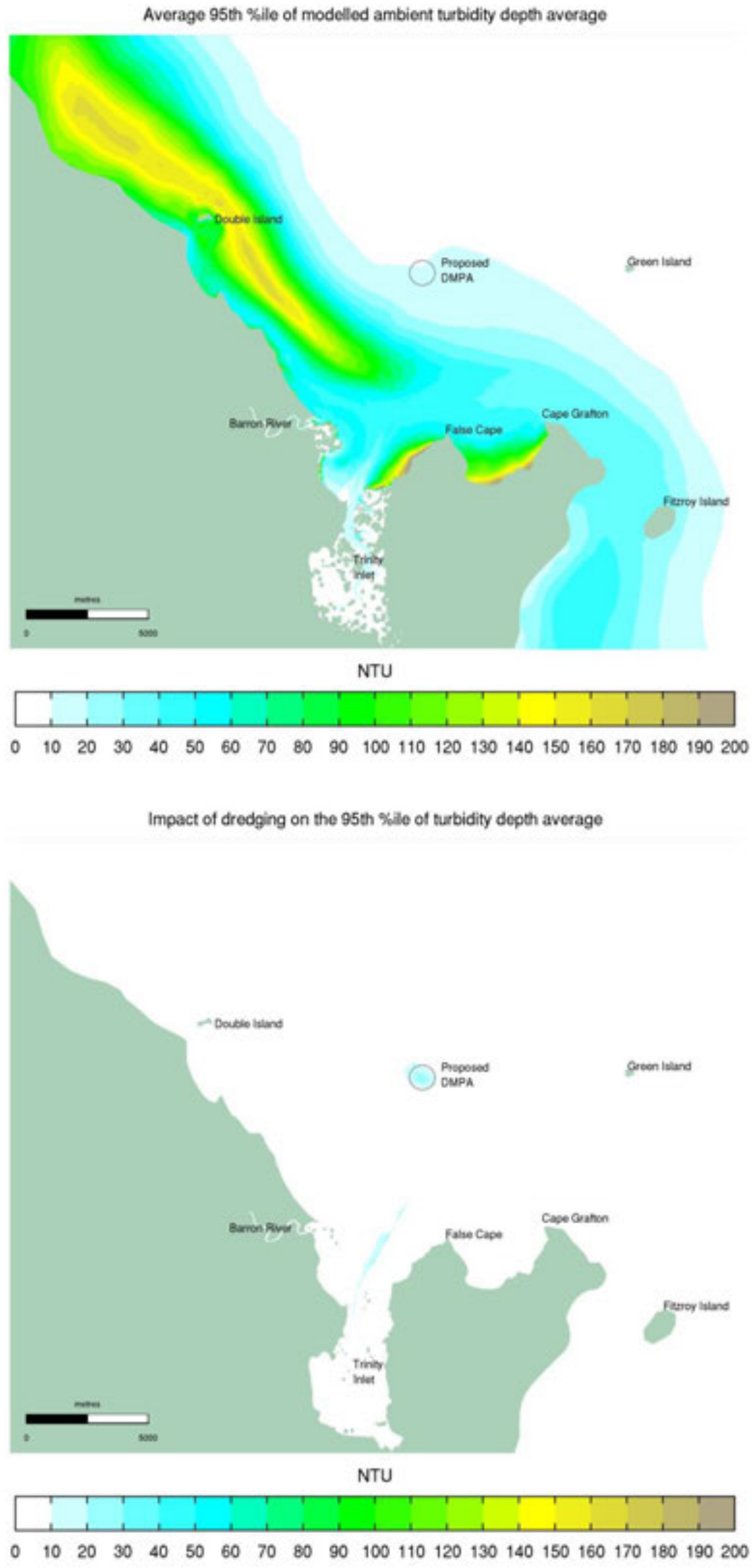


Figure 6-11 Alternative Case Capital Program 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

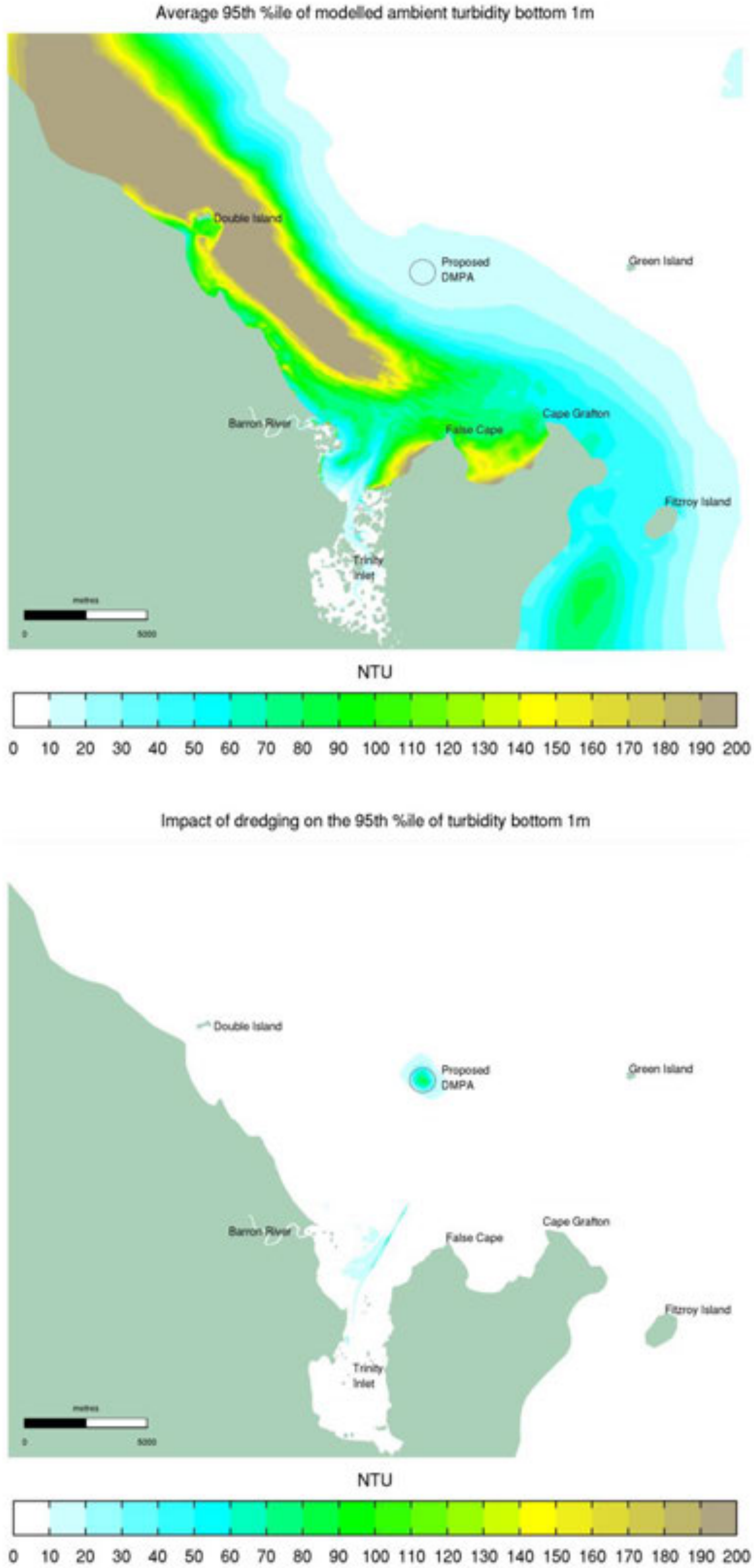


Figure 6-12 Alternative Case Capital Program 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

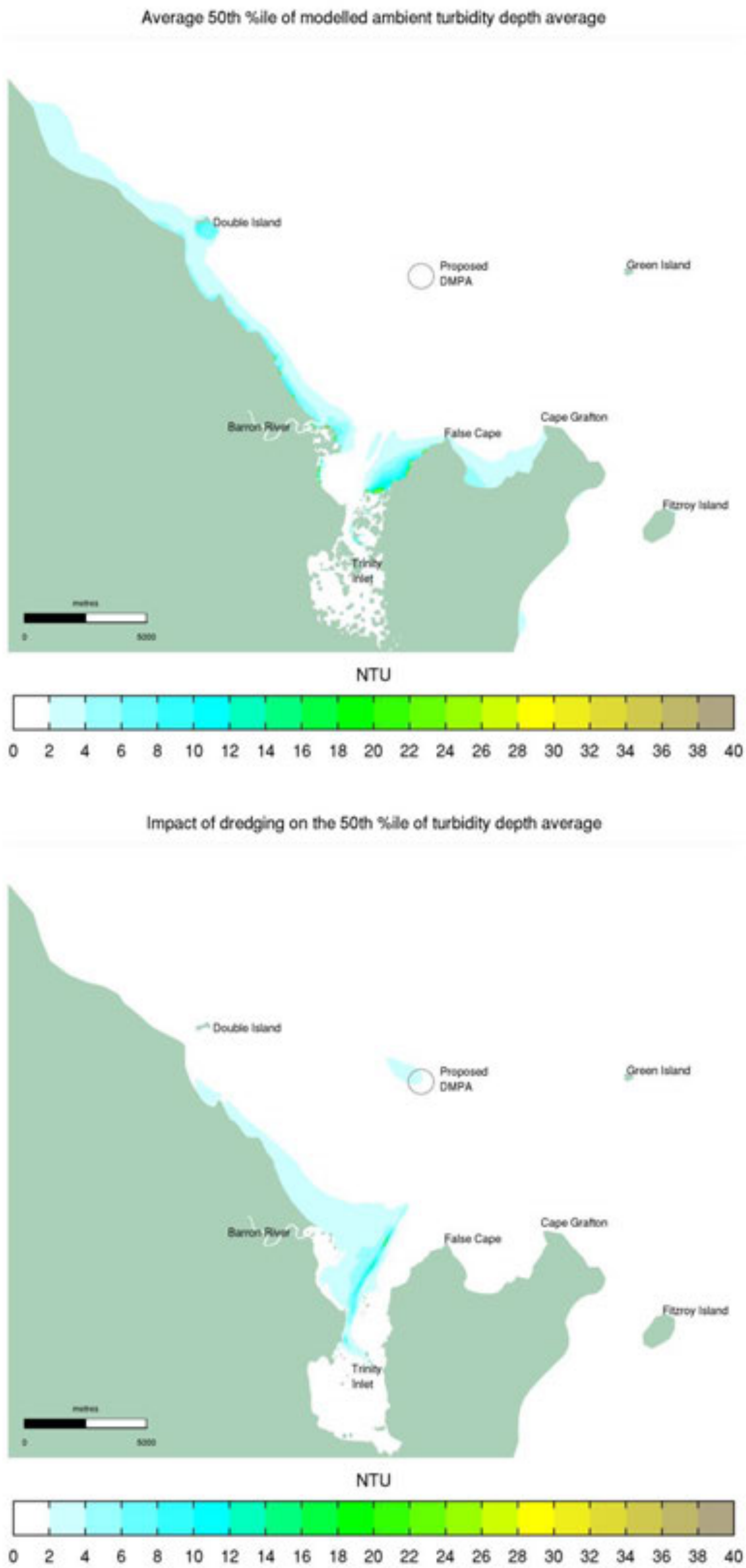


Figure 6-13 Alternative Case Capital Program 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

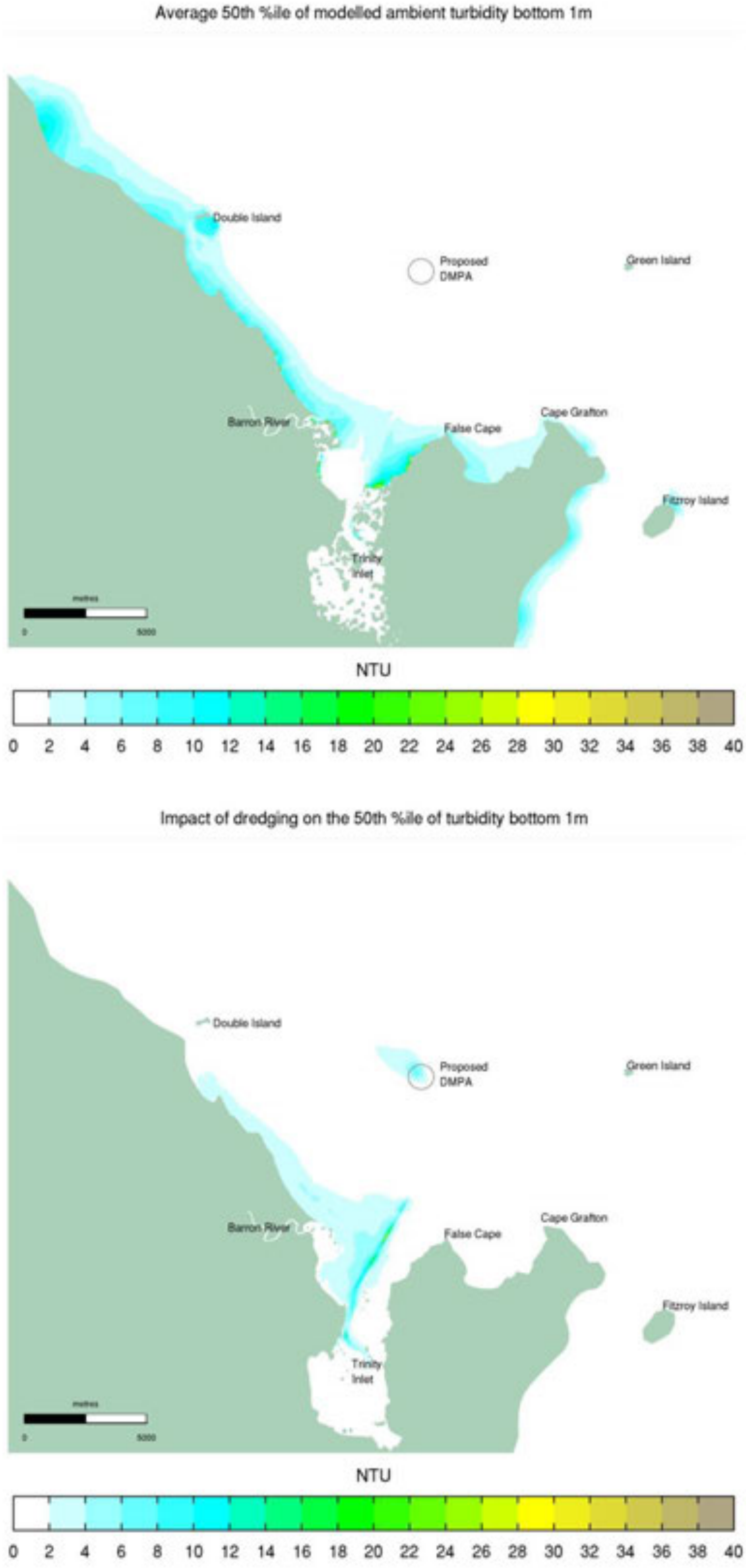


Figure 6-14 Alternative Case Capital Program 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

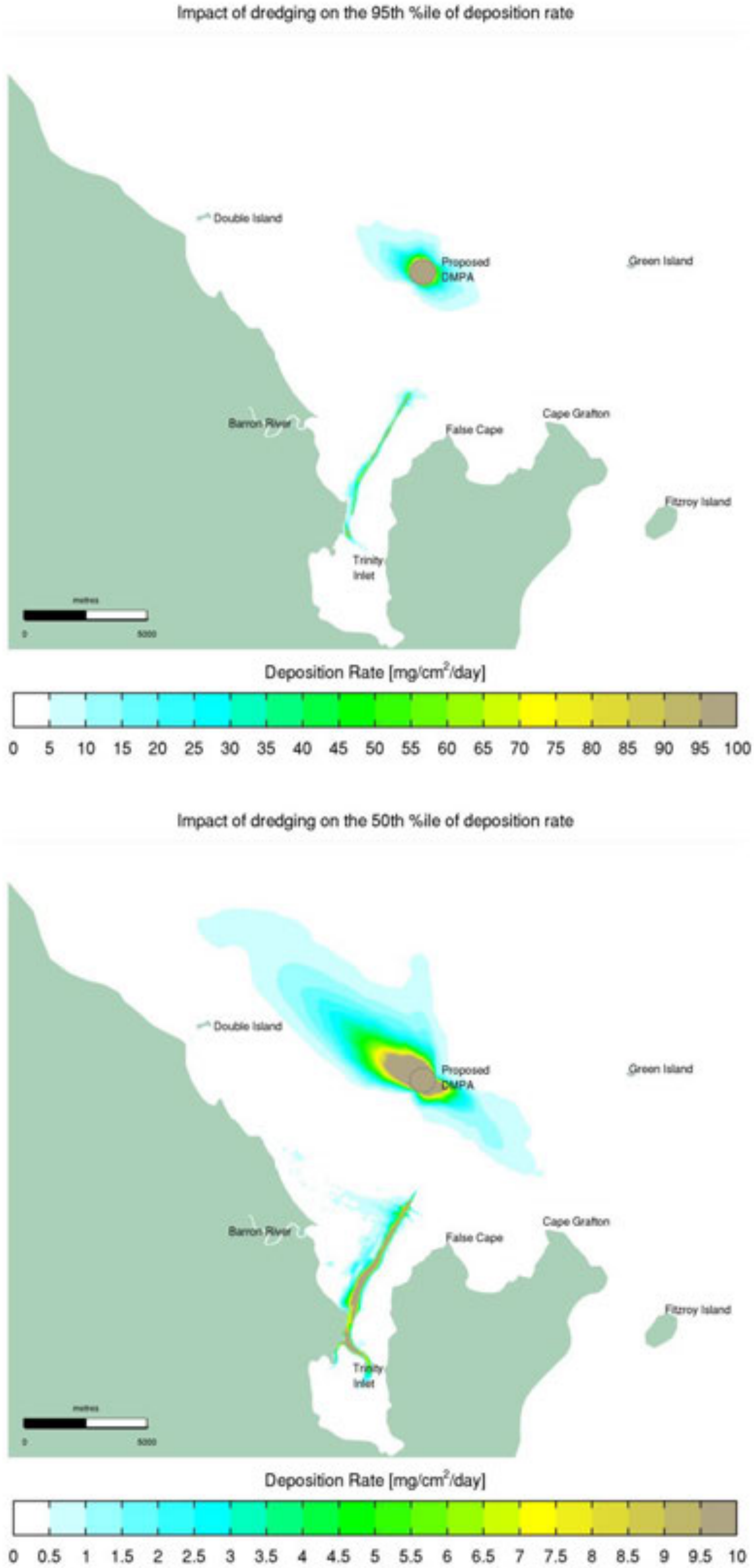


Figure 6-15 Alternative Case Capital Program Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom)

6.5 "Worst Case" Soft Material Dredging

6.5.1 Description

The base case assessment (Section 6.3) assumed that there was no overflow dredging undertaken in the program, based on the understanding that the productivity gains from overflow dredging in the soft clay material predominantly found in the CSDP footprint was relatively minor. However, it is considered likely that occasional limited overflow dredging may be required due to various operational factors. It was therefore considered prudent as a "worst case" scenario to consider a likely upper bound proportion of overflow dredging within the TSHD program.

The first "worst case" scenario included 10 minutes of overflow dredging during 50% of TSHD cycles in the predominant soft clay material.

The "worst case" scenarios were carried out for a single 30 day period that coincided with the most extensive dredge plumes generated during the base case capital assessment. It is therefore expected that this scenario will be representative of a "worst case" taking into consideration both climatic and operational factors.

An alternative "worst case" scenario which considers the possibility of encountering stiffer than expected material within the channel is detailed in Section 6.2.4.

The worst case dredging scenarios were simulated for the 30 day period from the 10th June 2011 to the 12th July 2011. The simulation represented both ambient sediment dynamics and the additional contribution to turbidity and sedimentation due to dredging related plumes.

6.5.2 Results

The following results are presented below:

- The 95th percentile modelled average ambient turbidity – depth average (Figure 6-16 top)
- Impact of dredging on the 95th percentile turbidity – depth average (Figure 6-16 bottom)
- The 95th percentile modelled average ambient turbidity – bottom 1m (Figure 6-17 top)
- Impact of dredging on the 95th percentile turbidity – bottom 1m (Figure 6-17 bottom)
- The 50th percentile modelled average ambient turbidity – depth average (Figure 6-18 top)
- Impact of dredging on the 50th percentile turbidity – depth average (Figure 6-18 bottom)
- The 50th percentile modelled average ambient turbidity – bottom 1m (Figure 6-19 top)
- Impact of dredging on the 50th percentile turbidity – bottom 1m (Figure 6-19 bottom)
- Impact of dredging on the 95th percentile deposition rate (Figure 6-20 top)
- Impact of dredging on the 50th percentile deposition rate (Figure 6-20 bottom).

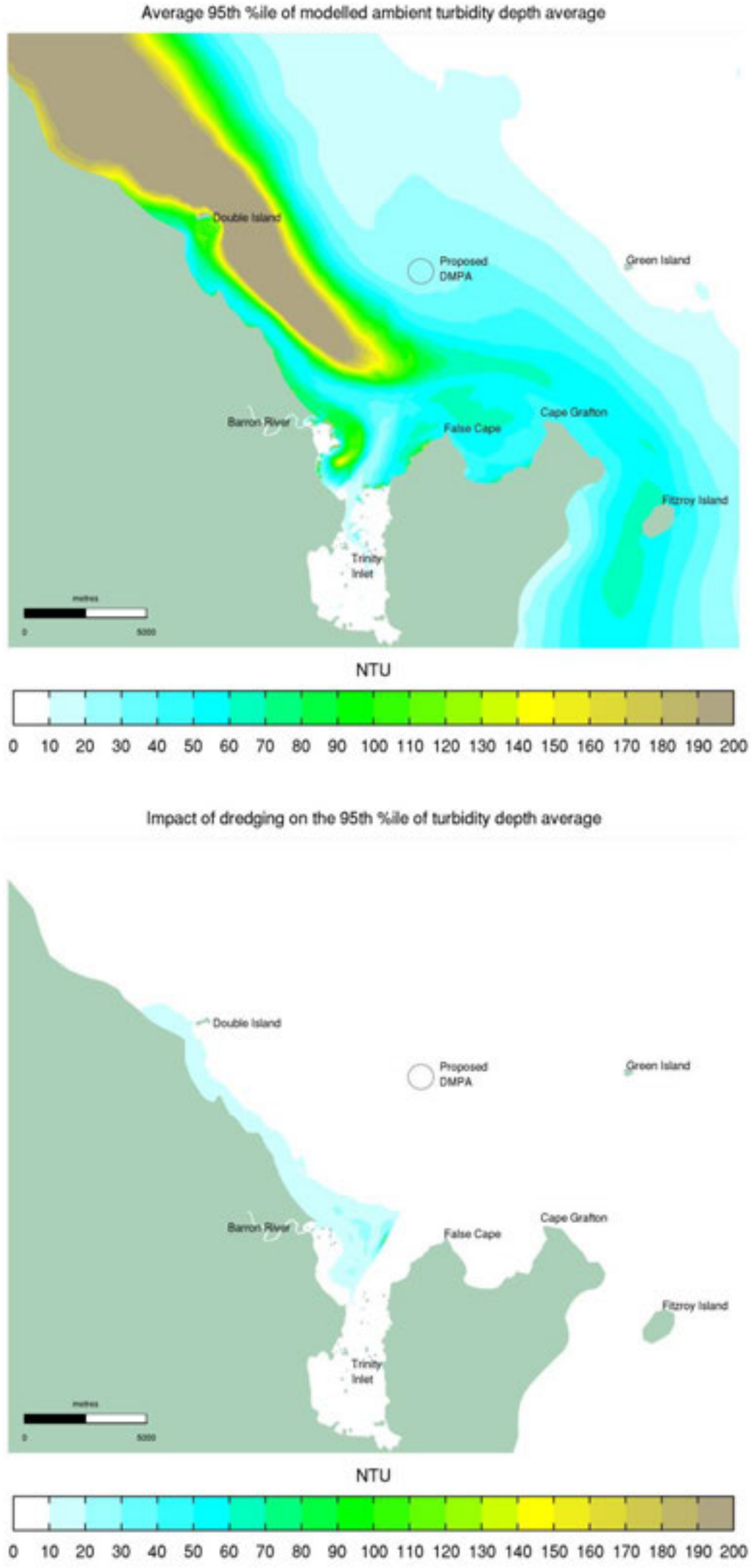


Figure 6-16 "Worst Case" Soft Material Dredging 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

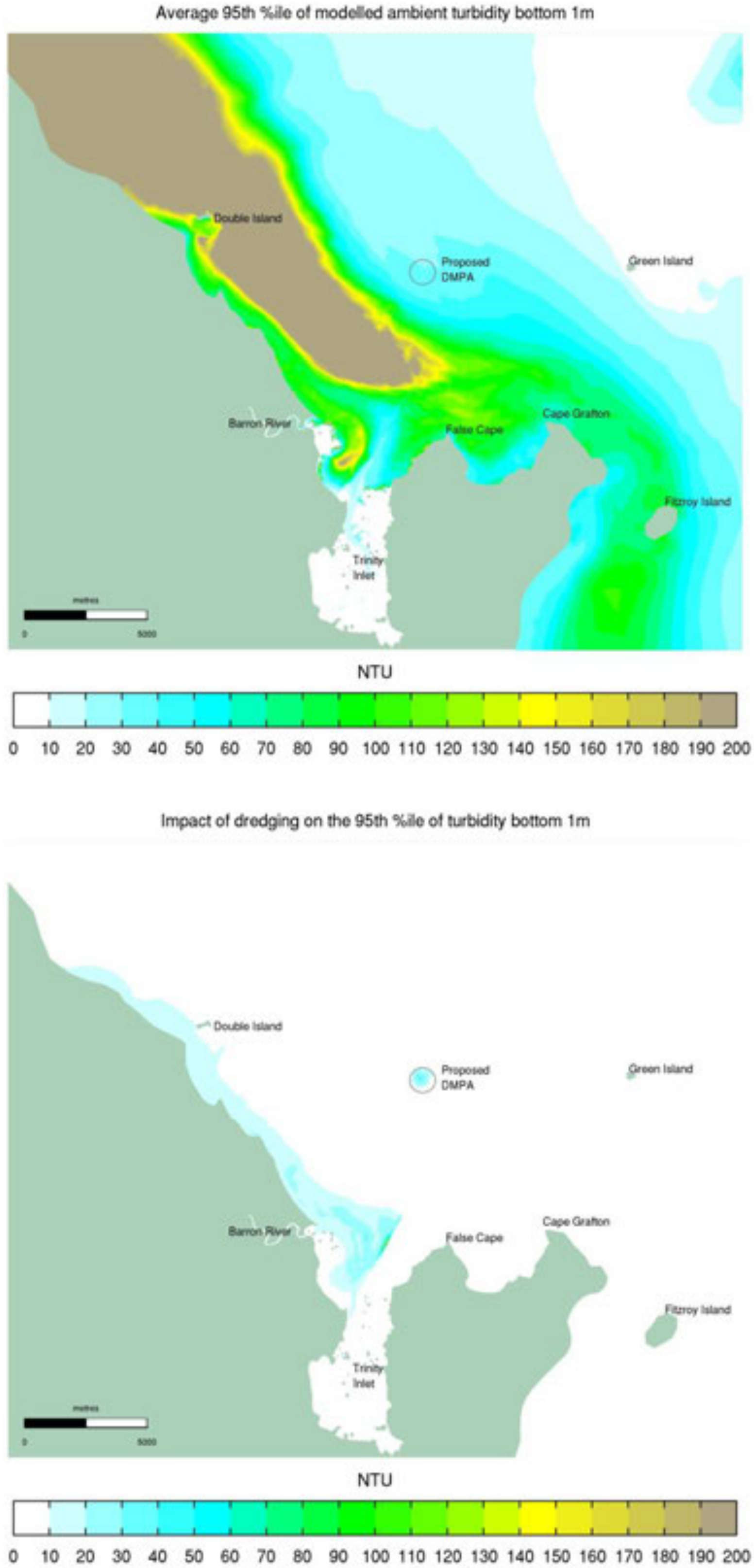


Figure 6-17 "Worst Case" Soft Material Dredging 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

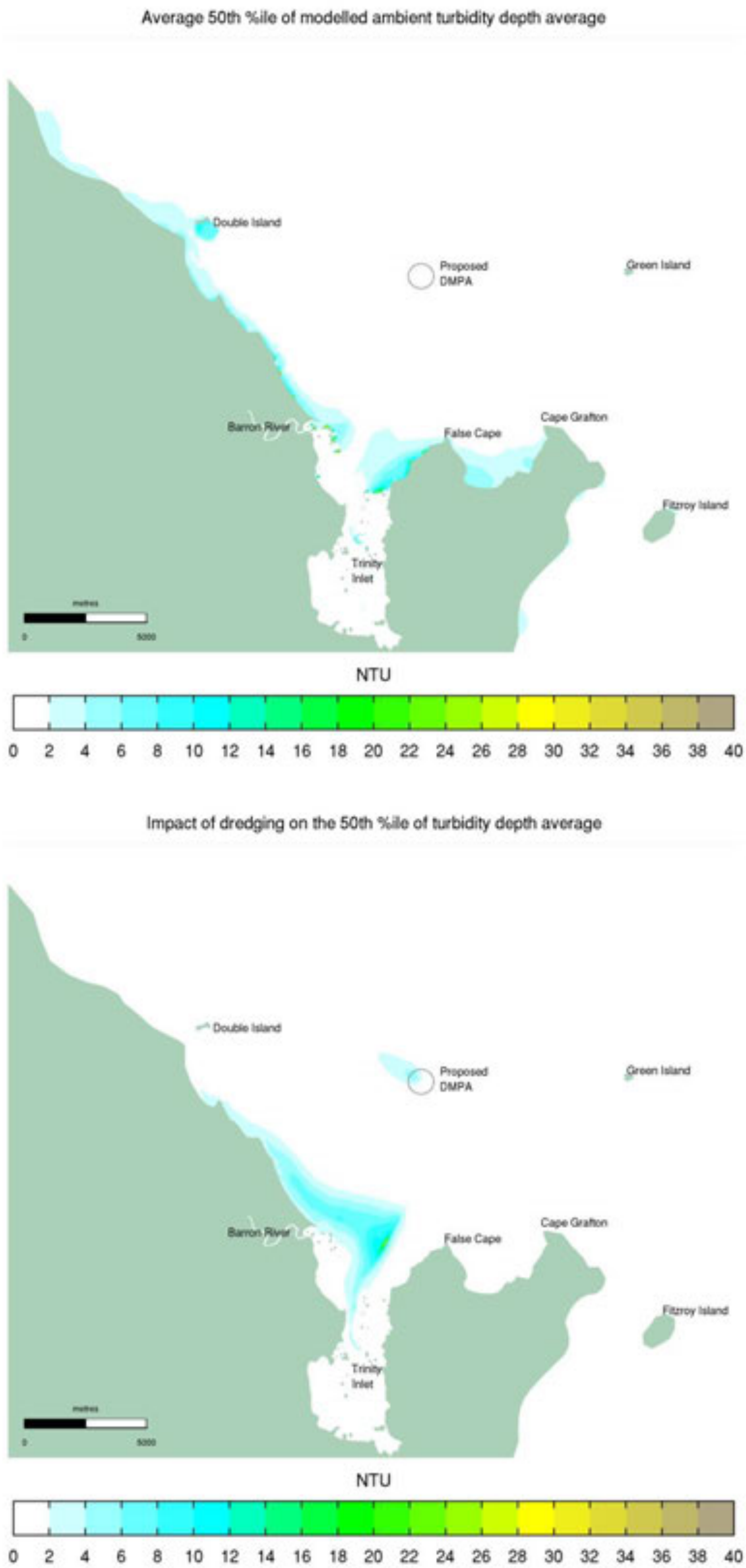


Figure 6-18 “Worst Case” Soft Material Dredging 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

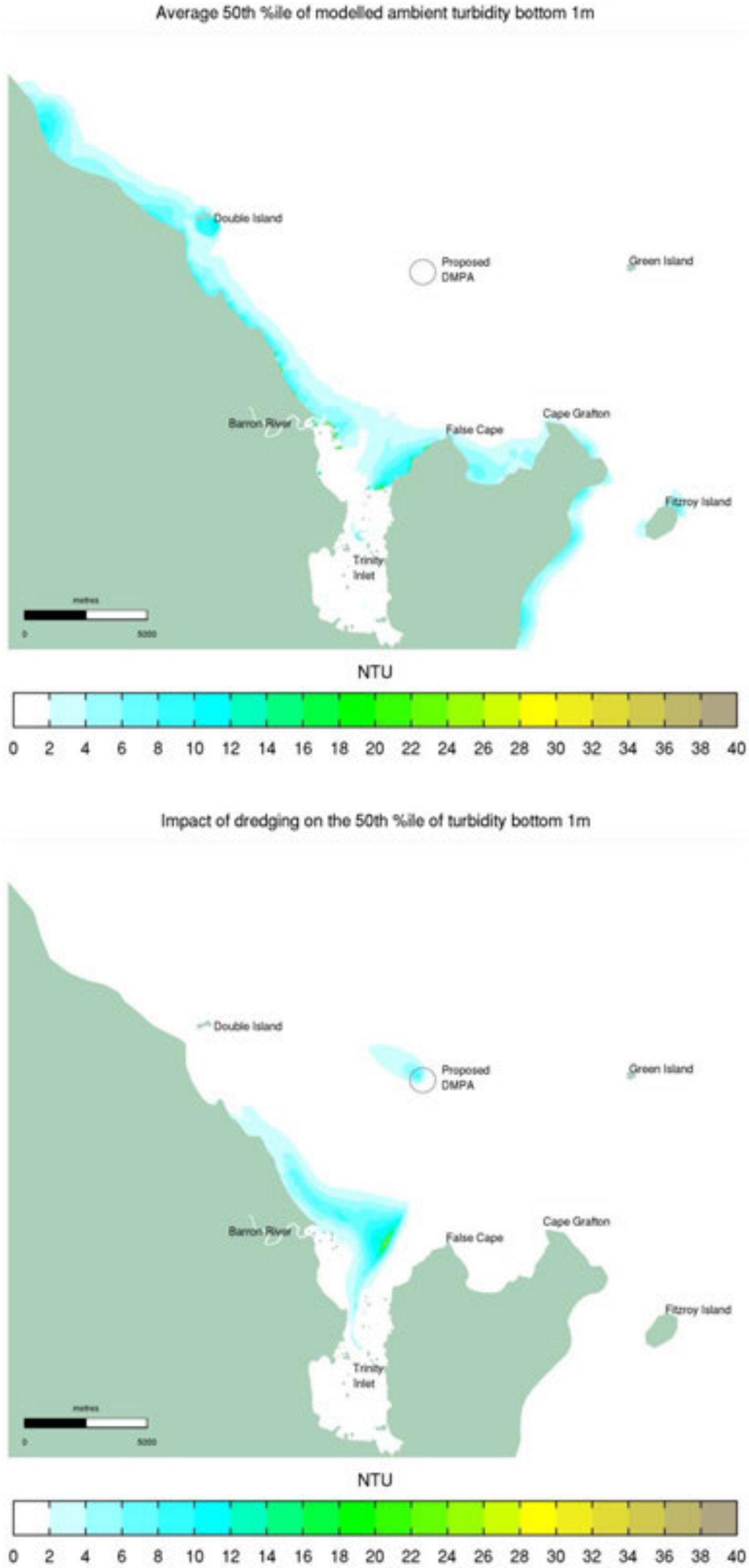


Figure 6-19 "Worst Case" Soft Material Dredging 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

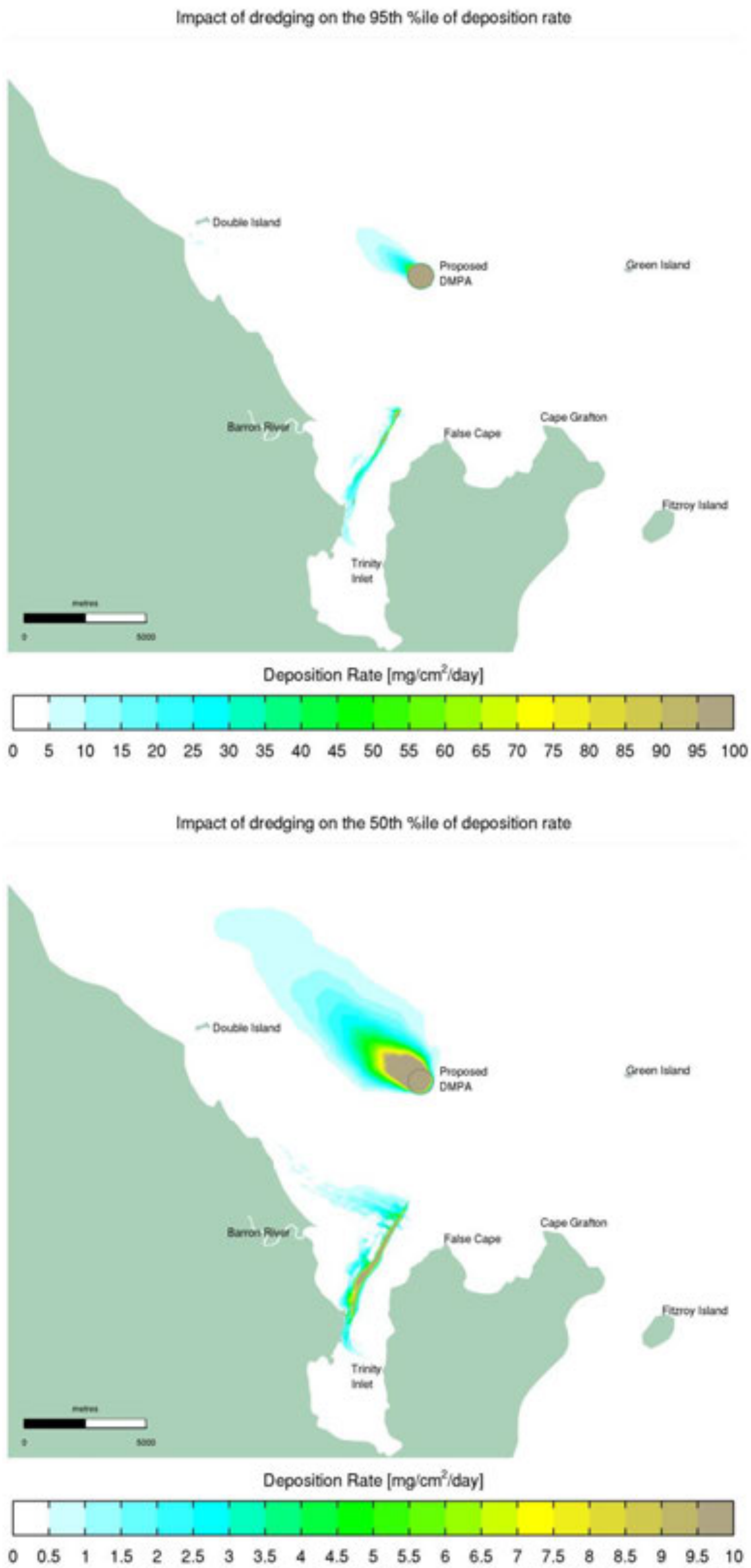


Figure 6-20 “Worst Case” Soft Material Dredging Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom)

6.6 "Worst Case" Stiff Material Dredging

6.6.1 Description

The base case assessment (Section 6.3) assumed that there was no overflow dredging undertaken in the program, based on the understanding that the productivity gains from overflow dredging in the soft clay material predominantly found in the CSDP footprint was relatively minor. However, it is considered likely that occasional limited overflow dredging may be required due to various operational factors. It was therefore considered prudent as a "worst case" scenario to consider a likely upper bound proportion of overflow dredging within the TSHD program.

The second "worst case" scenario considered the possibility of encountering stiffer than expected clay within the outer shipping channel. If encountered such material would require approximately 60 minutes of overflow dredging in order to achieve target productivity levels (Pro Dredge, 2014). An upper bound assumption regarding the total volume of stiff clay material was 350,000m^3, which would take around 3 weeks of dredging (including overflow). Therefore the "worst case" assumption was to continuously dredge the stiff clay material with overflow for 3 weeks within a 30 day simulation period.

The "worst case" scenarios were carried out for a single 30 day period that coincided with the most extensive dredge plumes generated during the base case capital assessment. It is therefore expected that this scenario will be representative of a "worst case" taking into consideration both climatic and operational factors.

An alternative "worst case" scenario which considers the possibility of limited overflow when dredging soft clay material is detailed in Section 6.5.

The worst case dredging scenarios were simulated for the 30 day period from the 10th June 2011 to the 12th July 2011. The simulation represented both ambient sediment dynamics and the additional contribution to turbidity and sedimentation due to dredging related plumes.

6.6.2 Results

The following results are presented below:

- The 95th percentile modelled average ambient turbidity – depth average (Figure 6-21 top)
- Impact of dredging on the 95th percentile turbidity – depth average (Figure 6-21 bottom)
- The 95th percentile modelled average ambient turbidity – bottom 1m (Figure 6-22 top)
- Impact of dredging on the 95th percentile turbidity – bottom 1m (Figure 6-22 bottom)
- The 50th percentile modelled average ambient turbidity – depth average (Figure 6-23 top)
- Impact of dredging on the 50th percentile turbidity – depth average (Figure 6-23 bottom)
- The 50th percentile modelled average ambient turbidity – bottom 1m (Figure 6-24 top)
- Impact of dredging on the 50th percentile turbidity – bottom 1m (Figure 6-24 bottom)
- Impact of dredging on the 95th percentile deposition rate (Figure 6-25 top)
- Impact of dredging on the 50th percentile deposition rate (Figure 6-25 bottom).

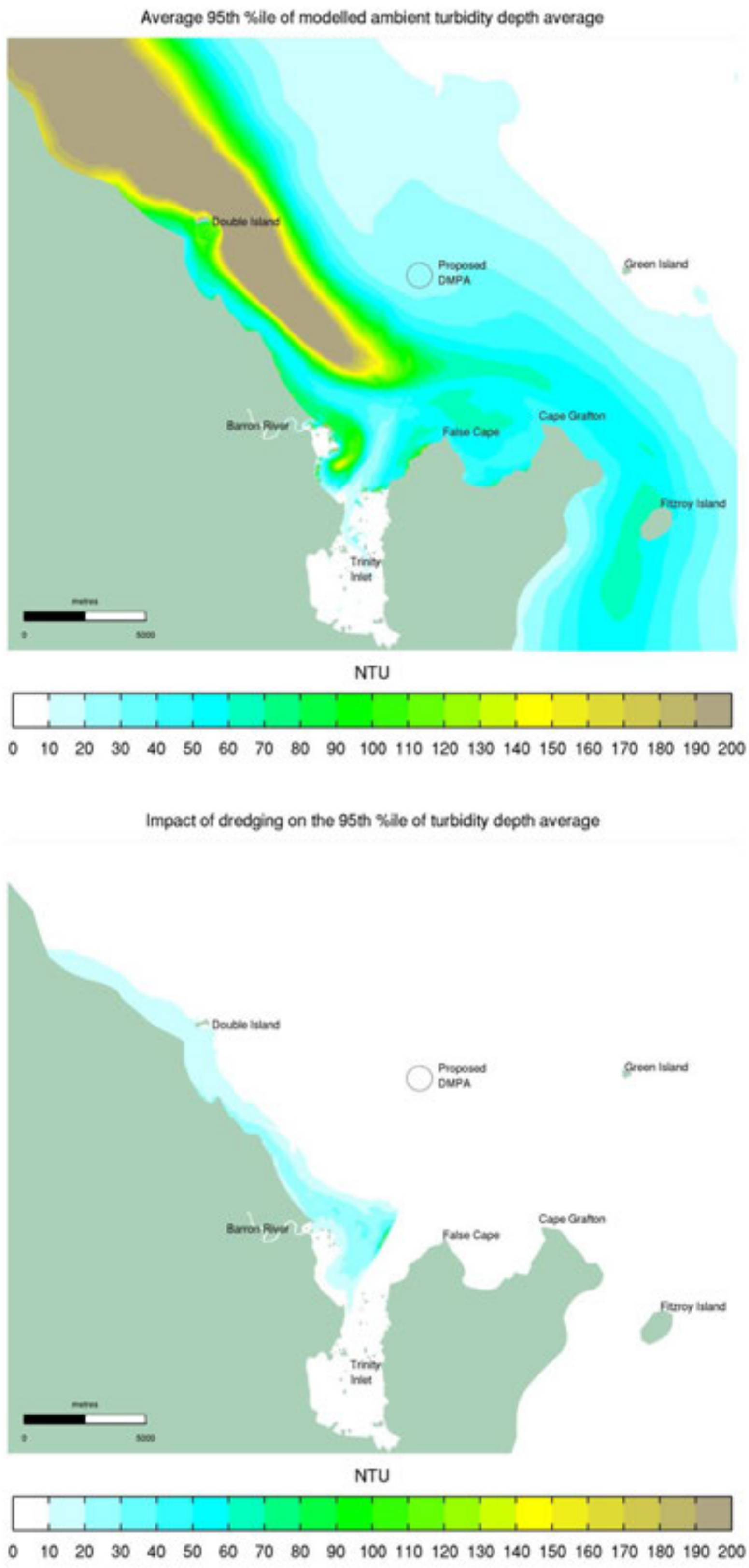


Figure 6-21 "Worst Case" Stiff Material Dredging 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

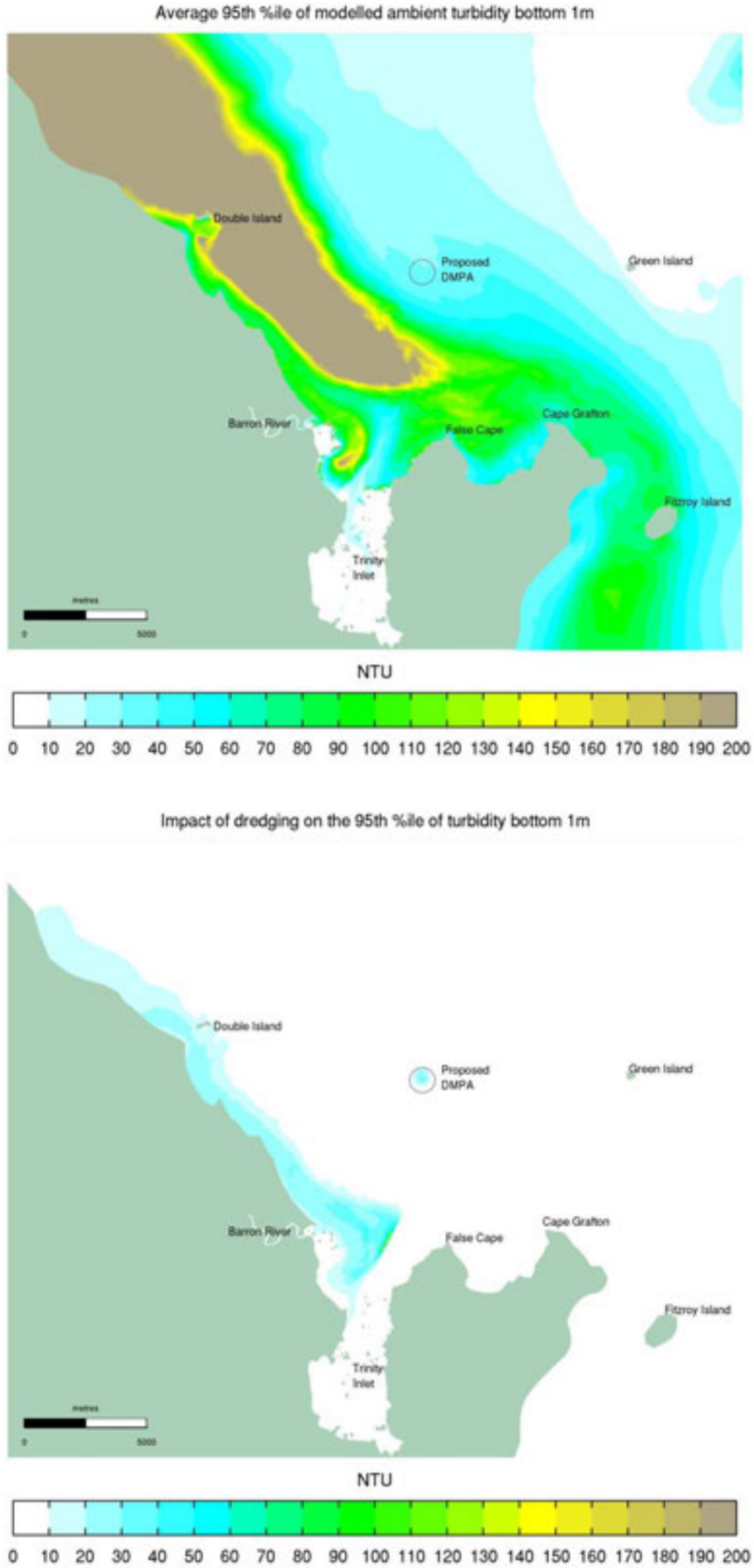


Figure 6-22 "Worst Case" Stiff Material Dredging 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

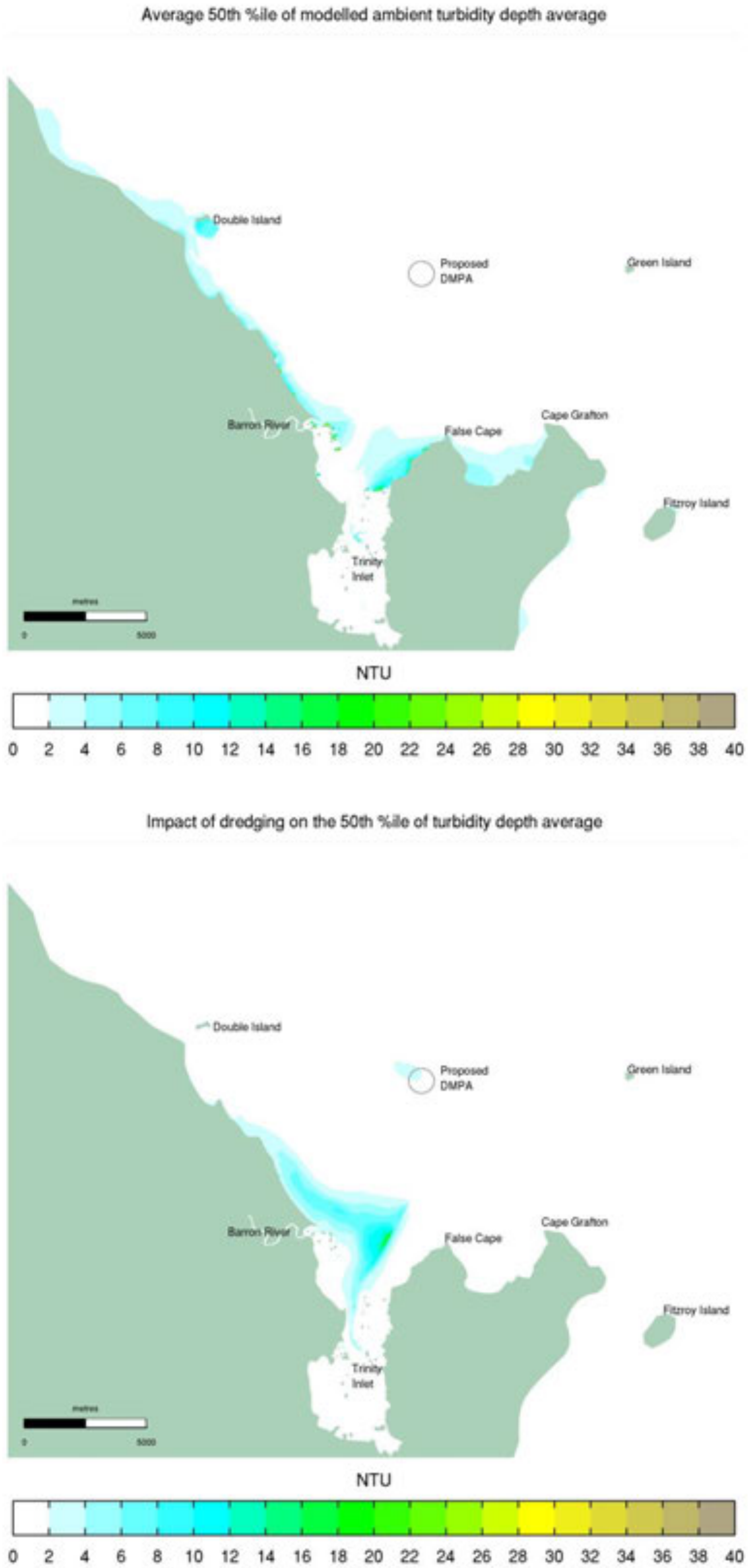


Figure 6-23 "Worst Case" Stiff Material Dredging 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

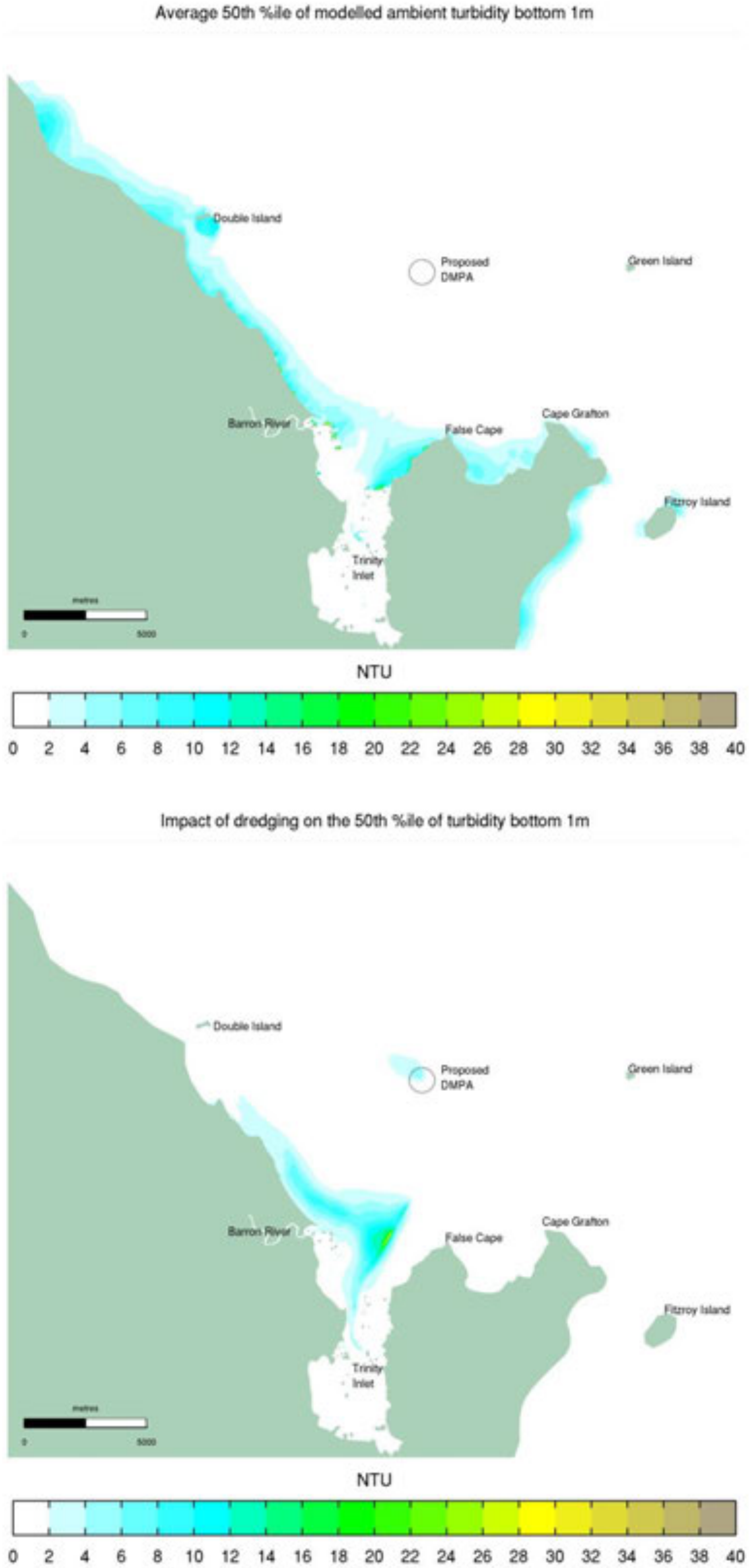


Figure 6-24 "Worst Case" Stiff Material Dredging 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

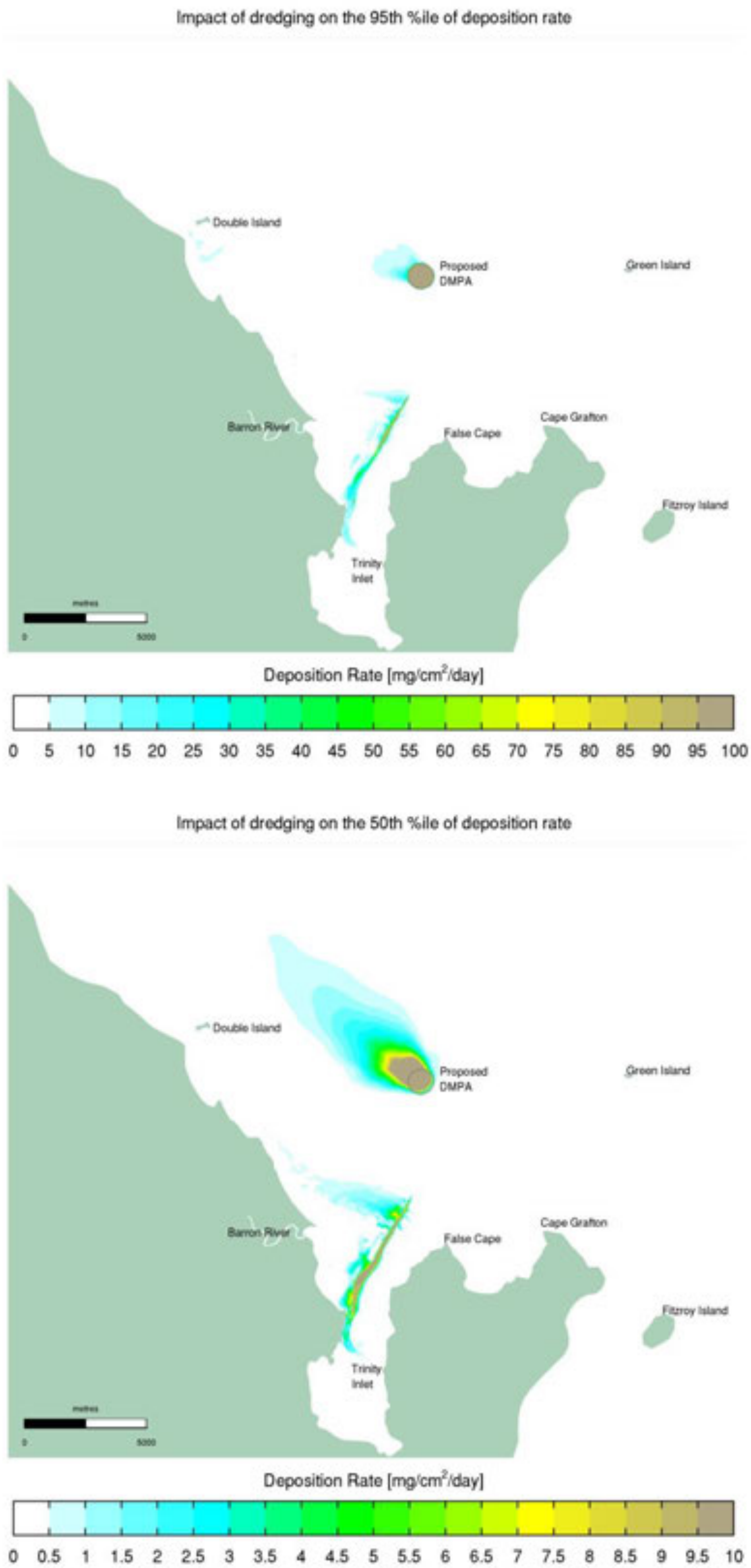


Figure 6-25 "Worst Case" Stiff Material Dredging Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom)

6.7 12 month Re-suspension Scenario

6.7.1 Description

The 12 month re-suspension scenario was undertaken to investigate the long term fate of dredged material following completion of the CSDP project. The assessment considered the potential re-mobilisation of:

- Sediment placed at the DMPA;
- Sediment spilt during dredging and placement operations; and
- Ambient sediment.

The initial condition for the 12 month re-suspension scenario was taken from the final state of the base case capital program assessment (Section 6.3). During the preceding capital program simulation, sediment contributing to the passive plume generated during dredging and placement operations was allowed to disperse, settle and re-suspend. In addition, the material transported to the DMPA was accumulated such that the entire volume of material removed from the CSDP dredging footprint was available for subsequent re-mobilisation. During the 12 month re-suspension assessment the entirety of this material continued to be differentiated and tracked as “dredged sediment”.

As detailed in Section 6.2.4 the 12 month re-suspension scenario was simulated from the 30th October 2011 to the 1st November 2012. The simulation represented both ambient sediment dynamics and the additional contribution to turbidity and sedimentation due to re-suspension of (formerly) dredged material.

6.7.2 Results

The following results are presented below:

- The 95th percentile modelled average ambient turbidity – depth average (Figure 6-26 top)
- Impact of dredging on the 95th percentile turbidity – depth average (Figure 6-26 bottom)
- The 95th percentile modelled average ambient turbidity – bottom 1m (Figure 6-27 top)
- Impact of dredging on the 95th percentile turbidity – bottom 1m (Figure 6-27 bottom)
- The 50th percentile modelled average ambient turbidity – depth average (Figure 6-28 top)
- Impact of dredging on the 50th percentile turbidity – depth average (Figure 6-28 bottom)
- The 50th percentile modelled average ambient turbidity – bottom 1m (Figure 6-29 top)
- Impact of dredging on the 50th percentile turbidity – bottom 1m (Figure 6-29 bottom)
- Impact of dredging on the 95th percentile deposition rate (Figure 6-30 top)
- Impact of dredging on the 50th percentile deposition rate (Figure 6-30 bottom).

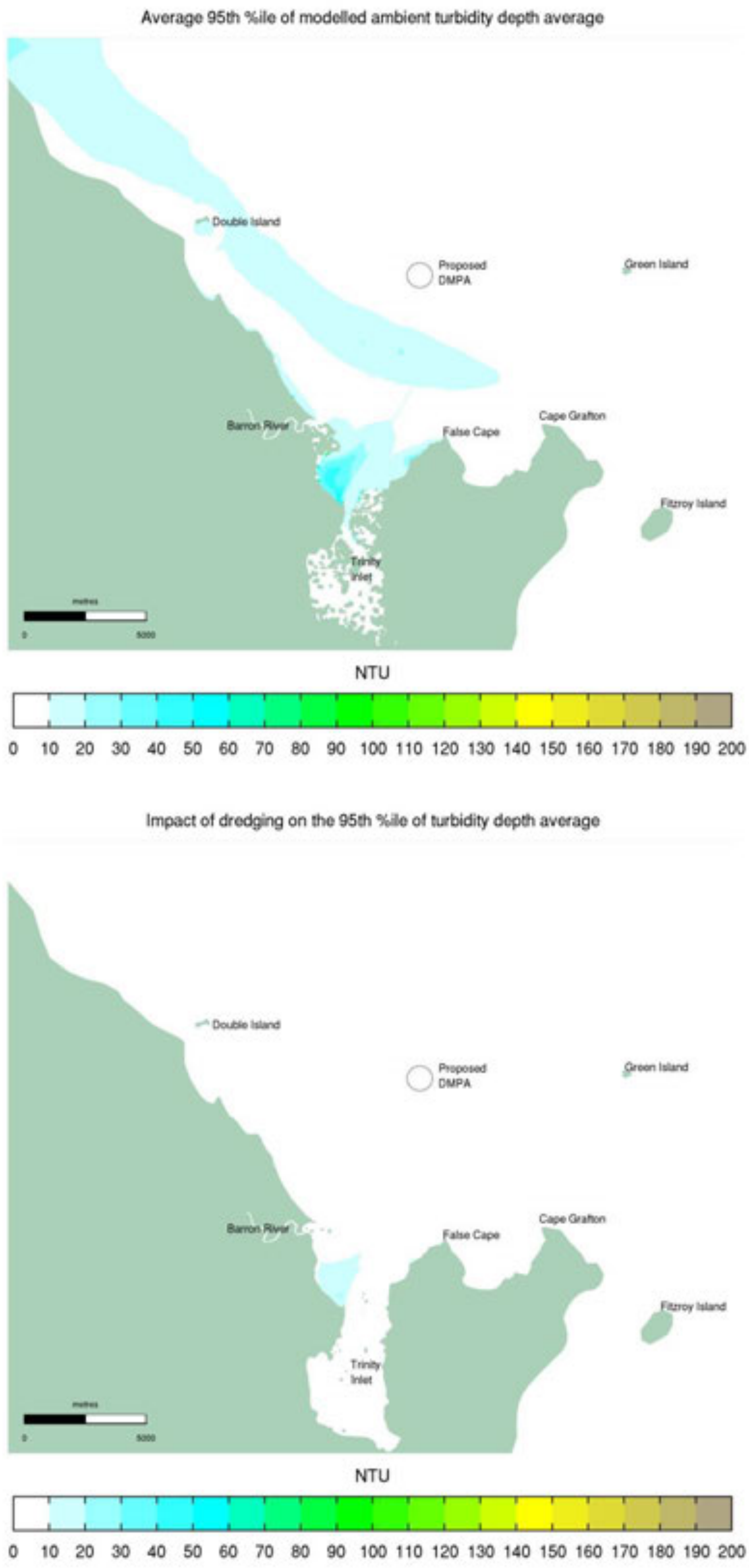
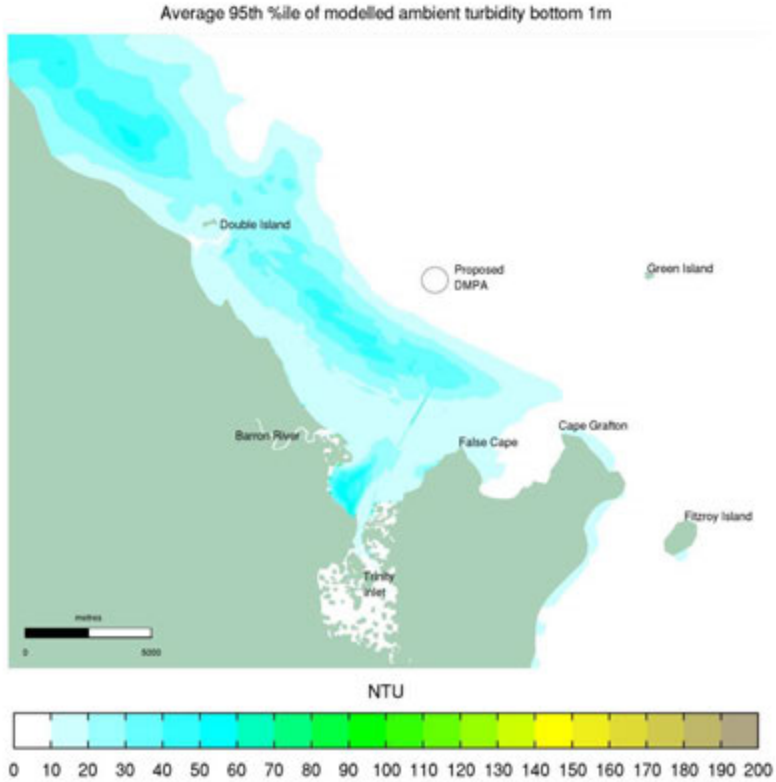


Figure 6-26 12mo Re-suspension Period 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



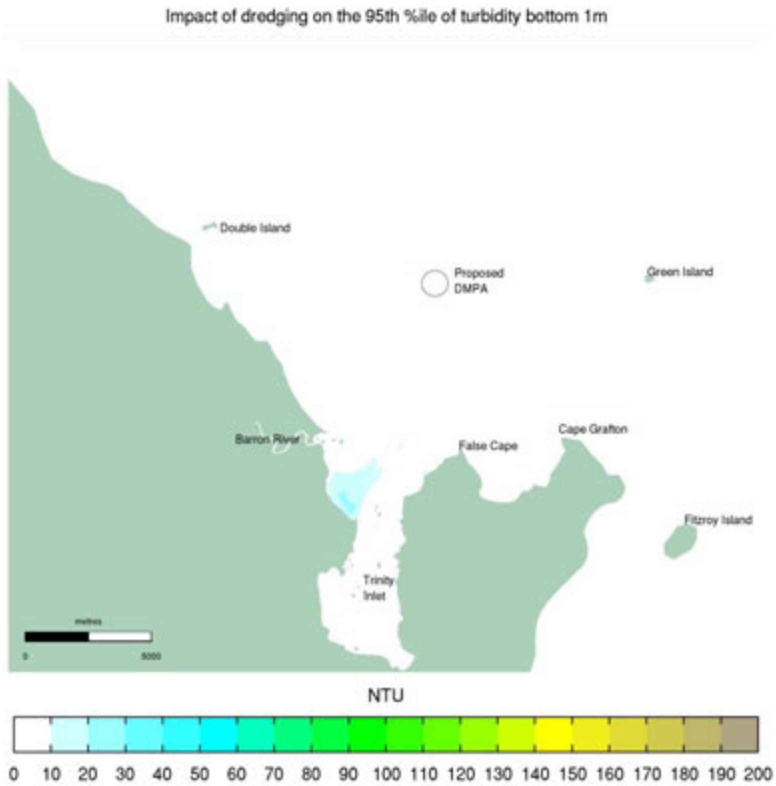


Figure 6-27 12mo Re-suspension Period 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

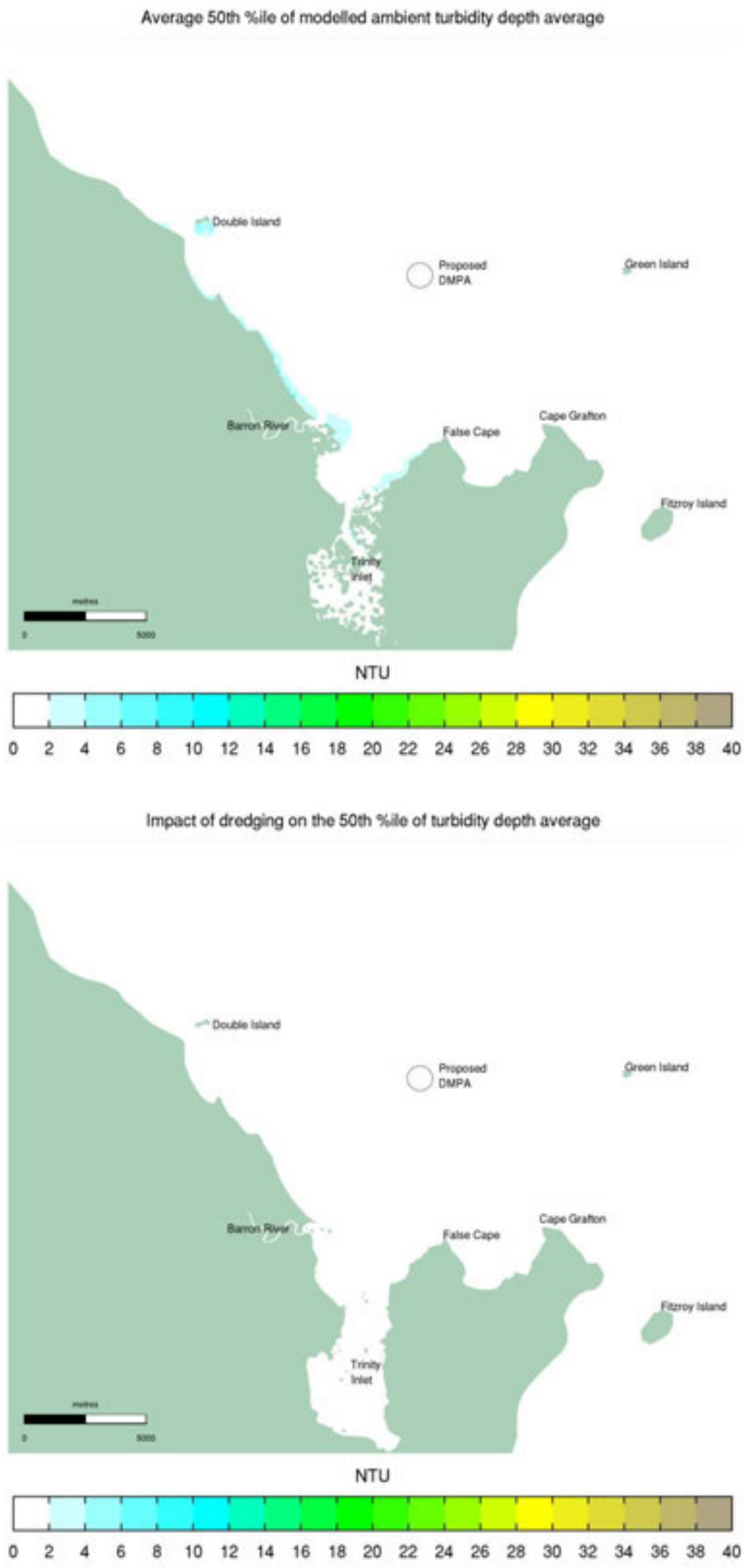


Figure 6-28 12mo Re-suspension Period 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

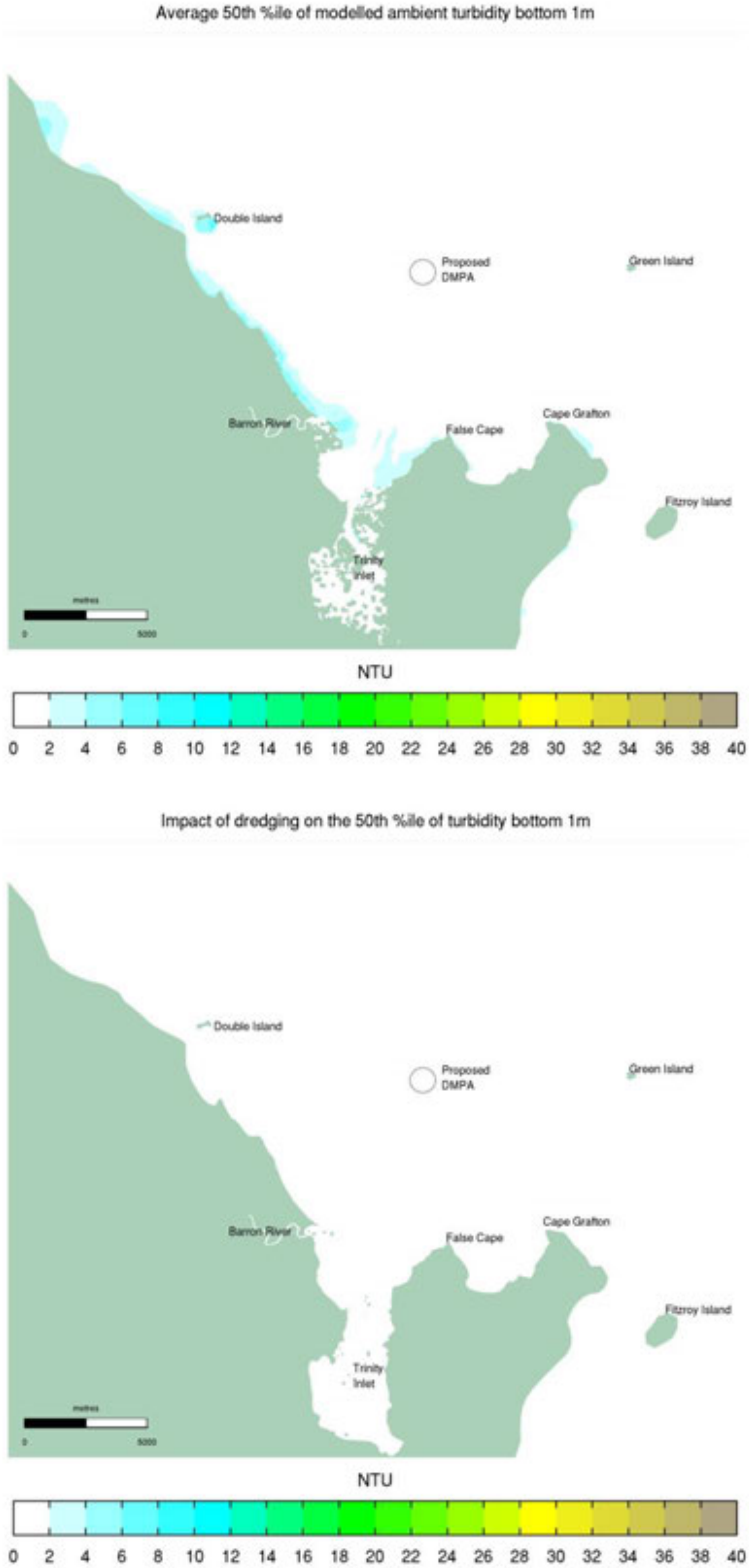
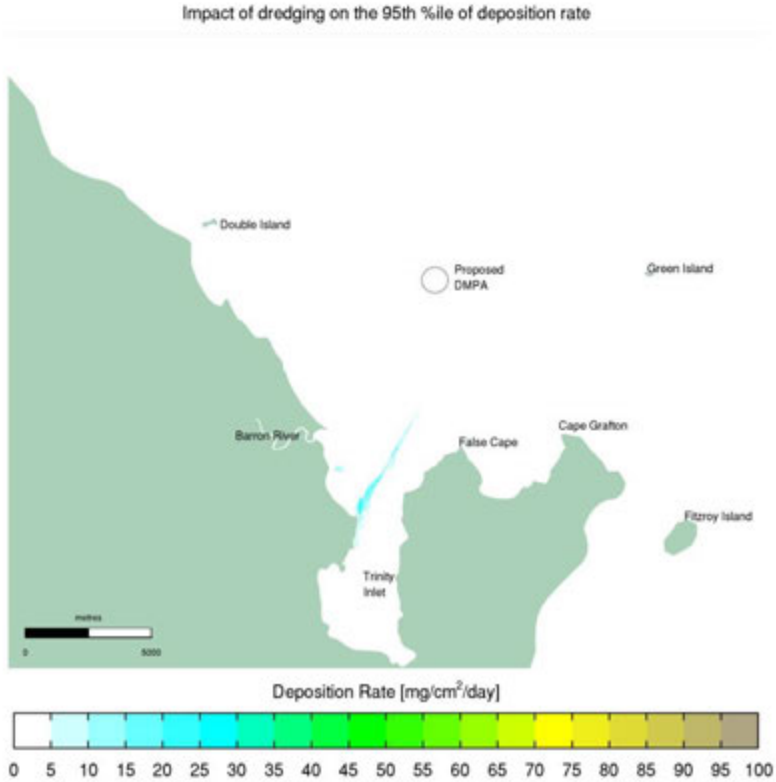


Figure 6-29 12mo Re-suspension Period 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



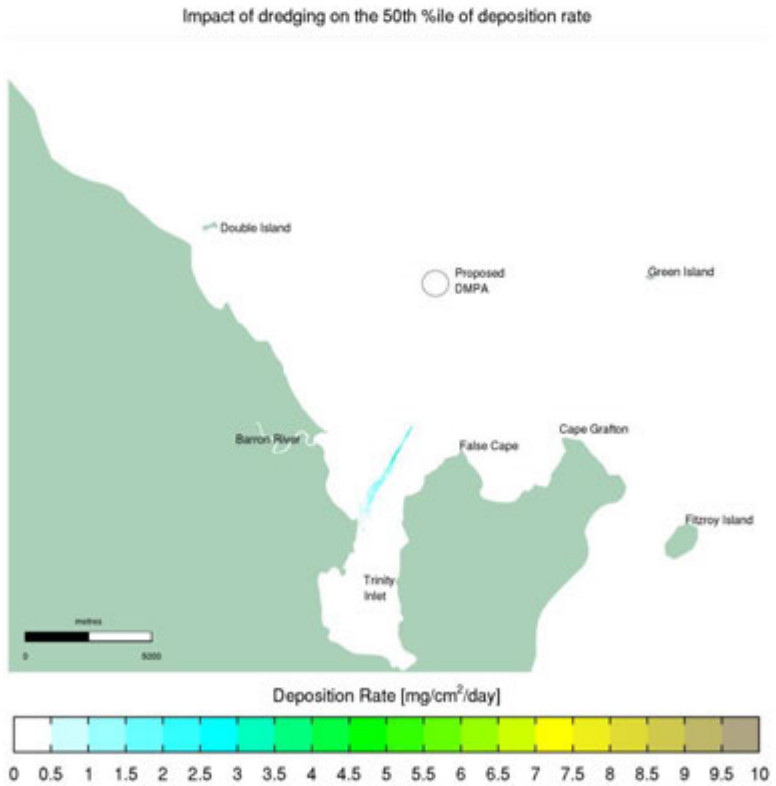


Figure 6-30 12mo Re-suspension Period Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom)

6.8 "Worst Case" Re-suspension Scenario

The "worst case" re-suspension scenario was undertaken to investigate the fate of dredged material due to with severe weather events. The assessment considered the potential re-mobilisation of:

- Sediment placed at the DMPA;
- Sediment spilt during dredging and placement operations; and
- Ambient sediment.

The initial condition for the "worst case" re-suspension scenario was taken from the final state of the base case capital program assessment (Section 6.3). During the preceding capital program simulation, sediment contributing to the passive plume generated during dredging and placement operations was allowed to disperse, settle and re-suspend. In addition, the material transported to the DMPA was accumulated such that the entire volume of material removed from the CSDP dredging footprint was available for subsequent re-mobilisation. During the "worst case" re-suspension assessment the entirety of this material continued to be differentiated and tracked as "dredged sediment".

As detailed in Section 6.2.4 the "worst case" re-suspension scenario was based on the period between 10^{th} January 2011 and 20^{th} February 2011 that included the Category 5 Severe Tropical Cyclone Yasi. The simulation represented both ambient sediment dynamics and the additional contribution to turbidity and sedimentation due to re-suspension of (formerly) dredged material.

6.8.1 Results

The following results are presented below:

- The 95^{th} percentile modelled average ambient turbidity – depth average (Figure 6-31 top)
- Impact of dredging on the 95^{th} percentile turbidity – depth average (Figure 6-31 bottom)
- The 95^{th} percentile modelled average ambient turbidity – bottom 1m (Figure 6-32 top)
- Impact of dredging on the 95^{th} percentile turbidity – bottom 1m (Figure 6-32 bottom)
- The 50^{th} percentile modelled average ambient turbidity – depth average (Figure 6-33 top)
- Impact of dredging on the 50^{th} percentile turbidity – depth average (Figure 6-33 bottom)
- The 50^{th} percentile modelled average ambient turbidity – bottom 1m (Figure 6-34 top)
- Impact of dredging on the 50^{th} percentile turbidity – bottom 1m (Figure 6-34 bottom)
- Impact of dredging on the 95^{th} percentile deposition rate (Figure 6-35 top)
- Impact of dredging on the 50^{th} percentile deposition rate (Figure 6-35 bottom).

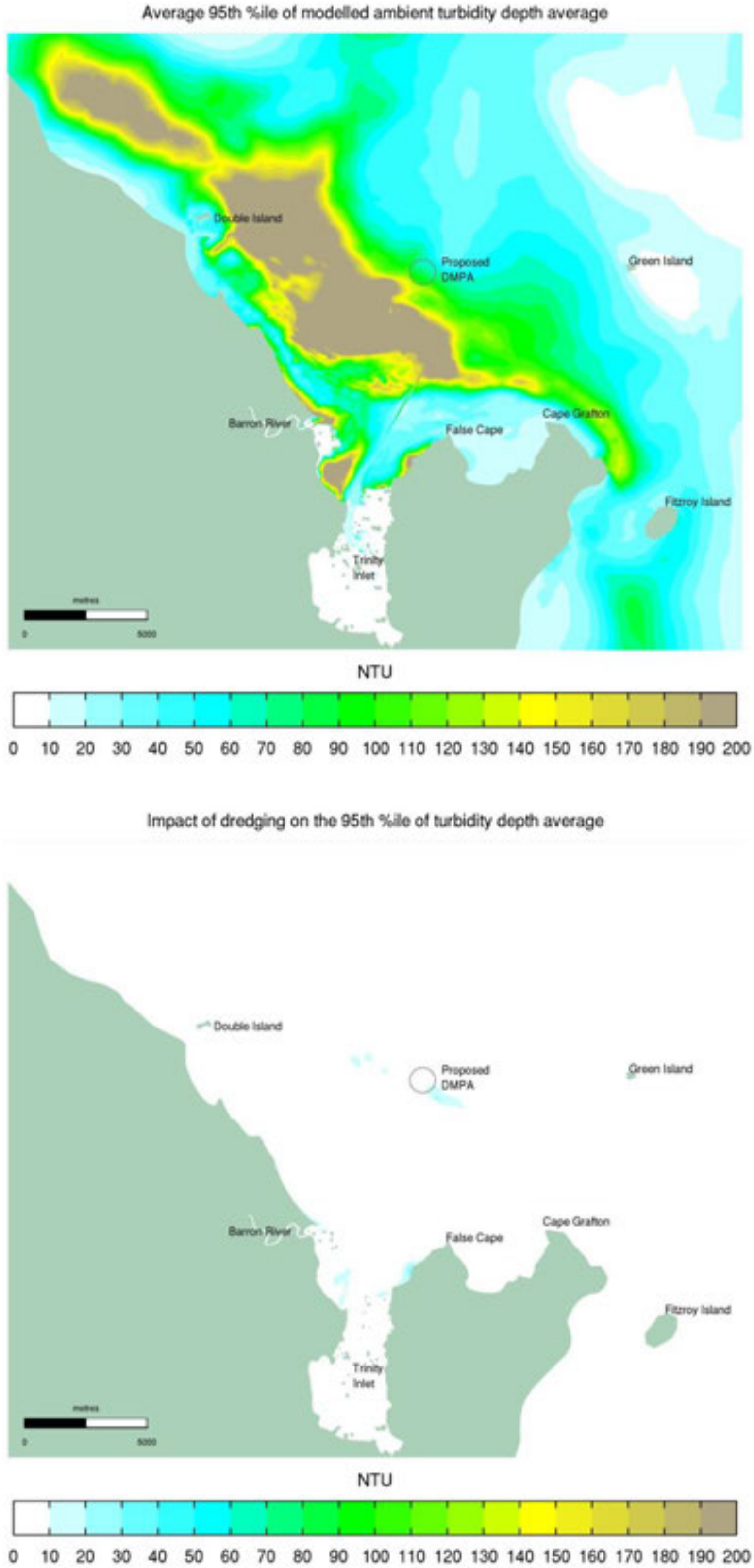


Figure 6-31 "Worst Case" Re-suspension Period 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

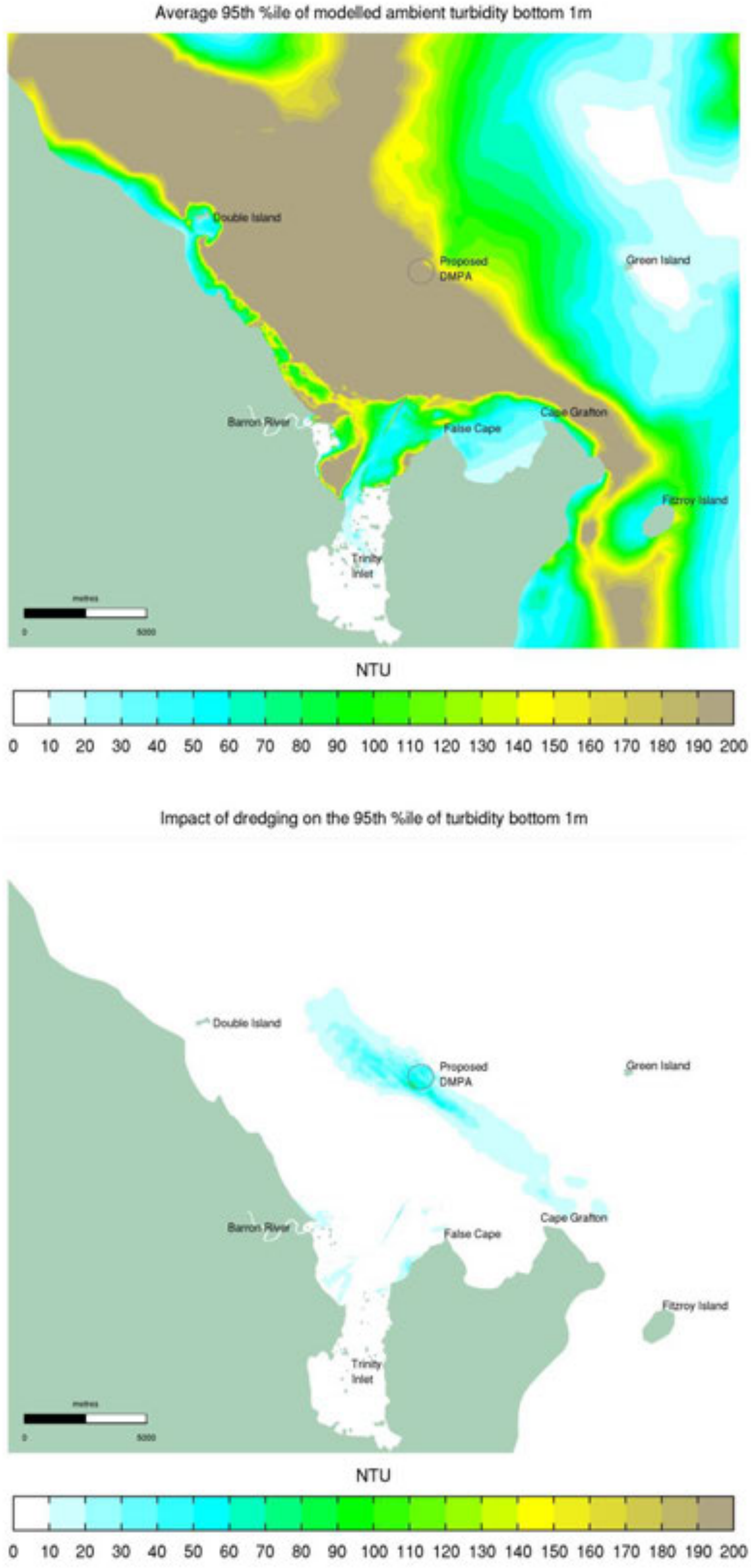


Figure 6-32 "Worst Case" Re-suspension Period 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

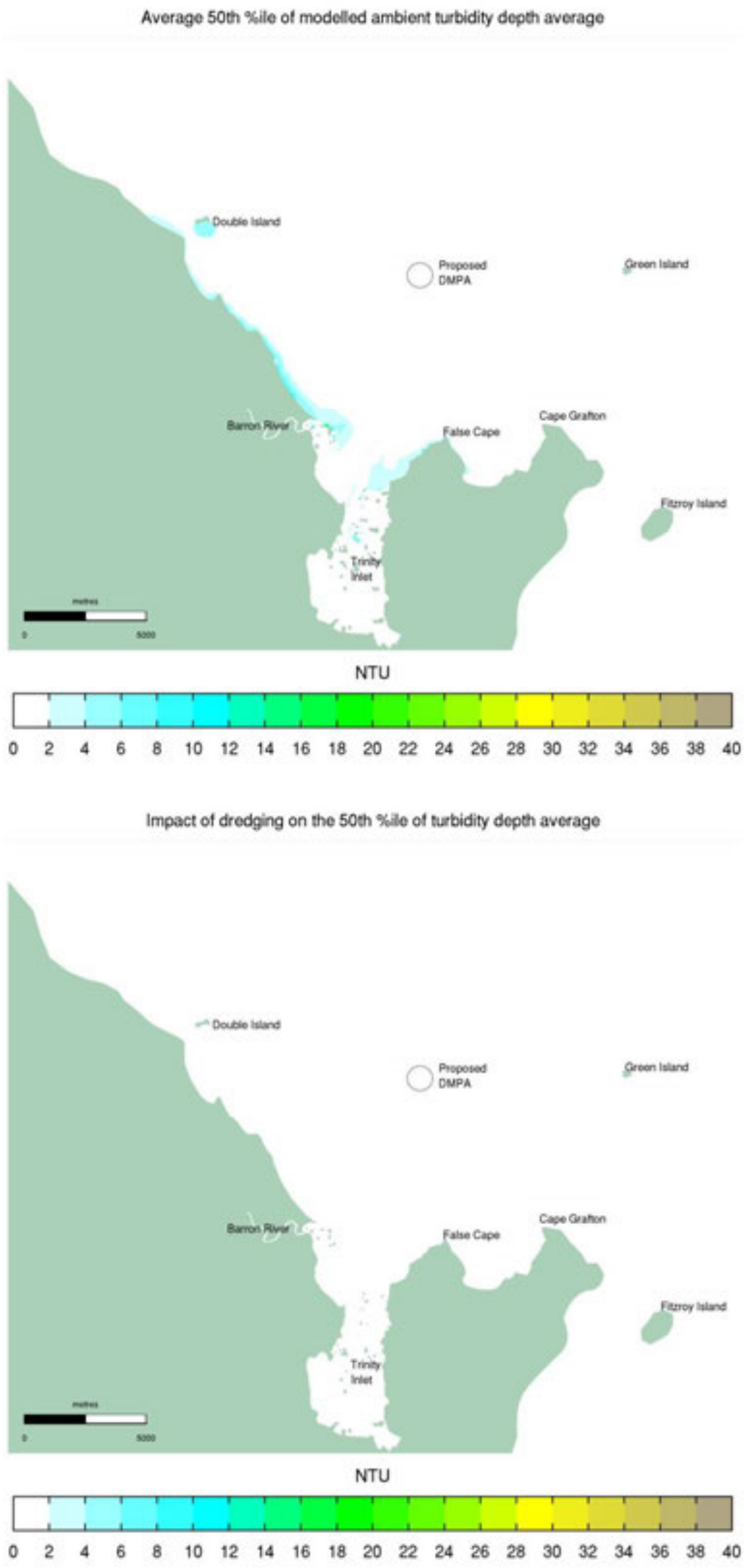


Figure 6-33 "Worst Case" Re-suspension Period 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

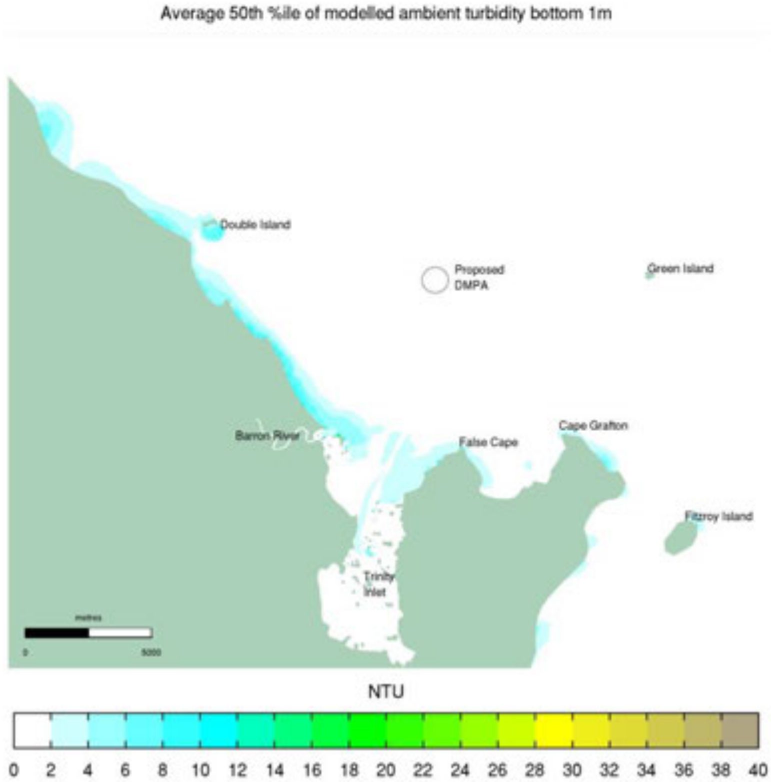


Figure 6-34 "Worst Case" Re-suspension Period 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

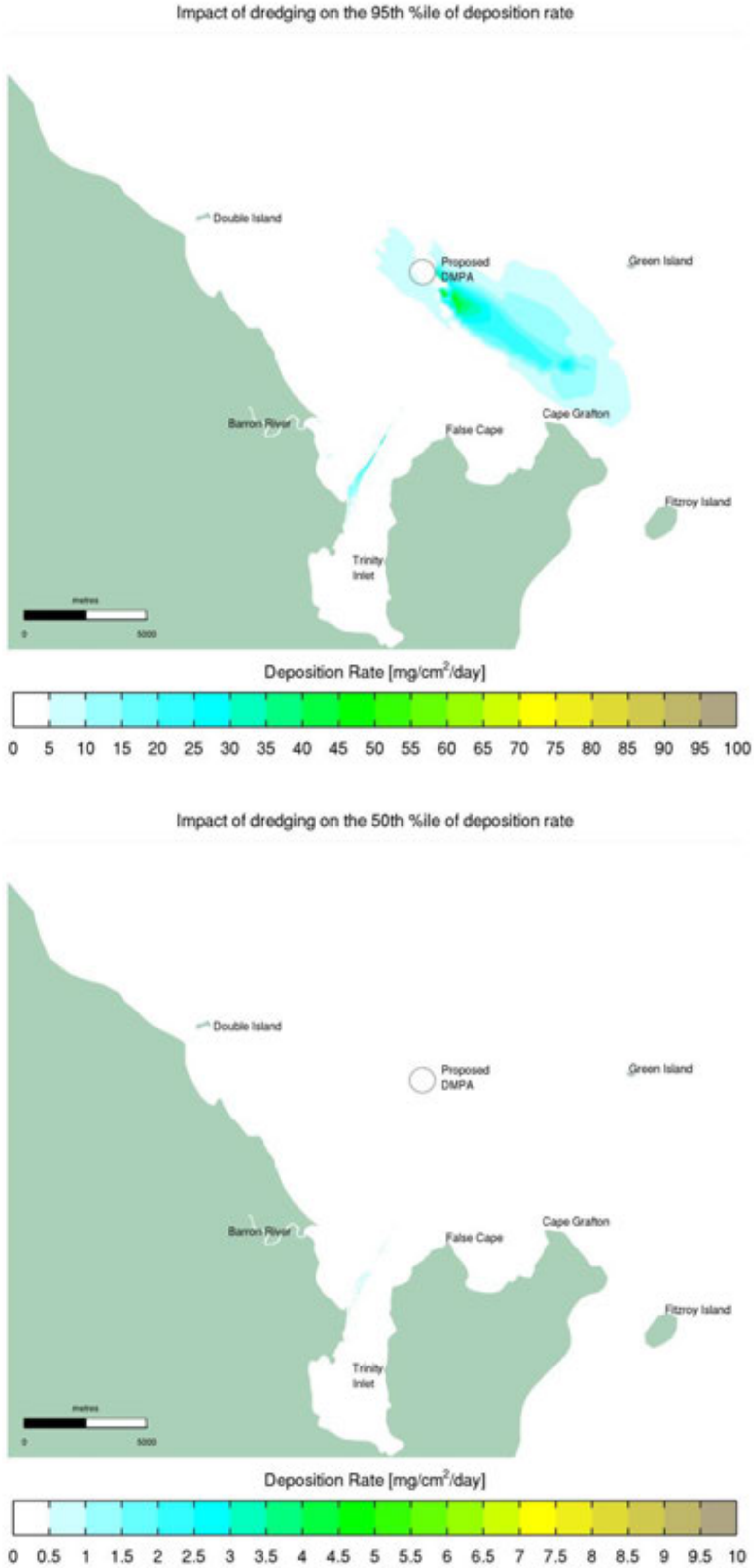


Figure 6-35 "Worst Case" Re-suspension Period Impact to Sediment Deposition Rate: 95th Percentile (top) and 50th Percentile (Bottom)

6.9 Discussion

A short discussion on the assessed dredging scenarios is provided below. This is simply intended to serve as a brief explanation of the model results and does not consider potential impacts to the receiving environment. Implications for marine ecology and water quality associated with the predicted increases to turbidity are described in Chapter B5 and B7 of the CSDP EIS.

6.9.1 Base Case Capital Program

In the context of ambient turbidity, acute (95th percentile) increases due to the base case capital dredging are predicted to be relatively low level and generally confined to the immediate project area (i.e. the dredge footprint and DMPA).

Chronic (50th percentile) increases in turbidity due to the base case capital dredging are predicted to be low to moderate level in the immediate project area and very low to low further afield. The predicted increase in turbidity outside of the immediate project area (typically 2-4 NTU) is likely to be insignificant in the context of ambient levels.

It is noted that the ambient re-suspension model tends to under predict residual turbidity/TSS levels during calm conditions. As discussed in Section 3.5.2.1, this is likely to be due to the influence of unresolved biological sources of turbidity. Turbidity impact colour scales have been selected in based on statistical analysis of the baseline monitoring data, such that the lowest visible colour levels relate to increases that are very small in the context of ambient turbidity.

Deposition of dredged sediments occurs in the vicinity of the channel and at the DMPA during the base case capital program. Outside of the DMPA perimeter, peak deposition rates are less than 80 mg/cm^2/day at the 95th percentile. This corresponds to deposition of less than 1mm/day during the infrequent periods of elevated sedimentation.

Typical sedimentation levels during the base case dredging campaign, represented by the 50th percentile, are generally less than 10 mg/cm^2/day, corresponding to less than 0.1 mm/day within the predicted deposition zone. At the DMPA, the deposition zone aligns with the prevailing currents in a north-easterly to south-easterly direction. The additional dredge sediment deposition is generally considered to be a negligible impact outside of the immediate project area in the context of the natural ambient material deposition rates.

6.9.2 Alternative Case Capital Program

The acute (95th percentile) increases in turbidity due to the alternative case capital dredging are generally consistent with the base case (i.e. relatively low level increases generally confined to the immediate project area).

Chronic (50th percentile) increases in turbidity due to the alternative case capital dredging are predicted to be low to moderate level in the immediate project area and very low to low further afield. Relative to the base case, the extent of increased turbidity is larger for the alternative case due to the additional dredging undertaken by the TSHD. Nevertheless, the far field increases are likely to be an undetectable change to ambient levels.

Alternative case deposition rates are of a similar magnitude to the base case capital program. At the acute level (95th percentile) deposition rates in areas outside of the project area are very low, corresponding to less than 1mm/day. At the chronic level (50^{th} percentile), rates of deposition are typically less than 10 mg/cm^2/day.

6.9.3 "Worst Case" Soft Material Dredging

In the context of ambient turbidity, acute (95^{th} percentile) increases due to the "worst case" soft material dredging are still expected to remain at low to moderate levels within the immediate project area. While the extent of the acute impacts is larger than for the base case, the levels of increased turbidity outside the project area remain in the very low to low range and are unlikely to be detectable above the ambient conditions.

Chronic (50^{th} percentile) increases due to the "worst case" soft material dredging are predicted to reach moderate levels within and immediately adjacent to the project area. Further afield, the increases are predicted to be low to moderate levels. It is anticipated that these increases could be maintained within the limits of natural variability through the application of dredge management procedures based on reactive monitoring.

Deposition rates during "worst case" soft material dredging increase slightly in comparison to the capital base case deposition rates, however, are still only predicted to reach low levels and are generally confined to the project area. Increases to deposition at far field locations are very low and likely to be undetectable.

6.9.4 "Worst Case" Stiff Material Dredging

The acute increases due to the "worst case" stiff material dredging are also predicted to remain low to moderate and likely to be undetectable relative to the 95^{th} percentile ambient conditions.

At the chronic level (50^{th} percentile), it is likely that turbidity increases due to "worst case" stiff material dredging can also be maintained within the limits of natural variability through the application of dredge management procedures based on reactive monitoring.

Deposition rates during "worst case" stiff material dredging are similar to the soft material case. The predicted increases to deposition are low to very low at the acute (95^{th} percentile) and chronic (50^{th} percentile) and are likely to be undetectable in the context of typical ambient conditions.

6.9.5 12 Month Re-suspension Scenario

During the 12 months following completion of the CSDP capital dredging, re-suspension leading to increases to turbidity and deposition of dredge material from the DMPA is undetectable for the percentiles and ranges presented. These results suggest a highly retentive DMPA for the typical range of conditions experienced over a 12 month period.

The redistribution and deposition of dredge related sediments is only evident within the immediate vicinity of the shipping channel. Deposition of dredge material from the DMPA is undetectable for the percentiles and ranges presented.

The quantity of material dispersed from the DMPA over a 12 month period following the completion of the capital dredge program was predicted using the model. The quantity of material outside of the DMPA perimeter at the end of the 12 month period is relatively low, corresponding to less than 0.1% of the initial DMPA mass. These results are summarised in Table 6-10 and suggest a highly retentive DMPA location.

Table 6-10 Predicted Dispersion from the DMPA over a 12-month Period

Initial DMPA Mass ($x10^6$ tonnes)	DMPA Mass after 12-months ($x10^6$ tonnes)	Percentage Dispersed (%)
4338	4336	<0.1%

6.9.6 "Worst Case" Re-suspension Scenario

The results of the "worst case" assessment suggest that minor re-suspension from the DMPA may occur during severe conditions associated with significant tropical cyclones. For the simulated period that included Tropical Cyclone Yasi, dredge related material was predicted to deposit southeast of the DMPA due to the north-easterly wind and wave conditions that occurred in Cairns after the cyclone made landfall near Cardwell.

At the "worst case" re-suspension 95th percentile, CSDP dredge sediment deposition rates of up to 40 mg/cm^2/day are predicted outside of the DMPA. Given the significant re-suspension and subsequent deposition of natural ambient sediment during extreme tropical cyclone events, the contribution of CSDP dredge sediments to the total deposition rate would be inconsequential.

Very minor deposition of CSDP dredge sediments within the vicinity of the shipping channel is shown at the "worst case" 95th and 50th percentiles. Again, this material would be undetectable within the context of ambient re-suspension during an extreme tropical cyclone event.

The quantity of material dispersed from the DMPA during "worst case" conditions was also predicted using the model. The quantity of material outside of the DMPA perimeter at the end of the "worst case" re-suspension assessment remains relatively low, corresponding to approximately 1.1% of the initial DMPA mass. These results are summarised in Table 6-11.

Table 6-11 Predicted Dispersion from the DMPA during Worst Case Conditions

Initial DMPA Mass ($x10^6$ tonnes)	DMPA Mass after 12-months ($x10^6$ tonnes)	Percentage Dispersed (%)
4338	4290	1.1%

7 Coastal Processes Impact Assessment

7.1 Introduction

In the context of coastal processes, the impacts associated with the CSDP are generally related to the proposed dredging works. These works entail widening the existing channel (to 130m in the outer channel), deepening to a declared depth of -9.4mLAT (plus overdredge allowances), which also involves extending the dredged channel by around 1km offshore. Additional dredging is also proposed for a cruise ship berthing facility and deepening of the Crystal and Smith's Creek swing basins. The total volume of sediment to be dredged as part of the CSDP capital development is 4.4Mm^3.

The difference in bed elevation between the "Existing Case" and "Developed Case" channel scenarios is shown in Figure 7-1. These two bathymetric scenarios form the basis for the coastal processes impact assessment. Three-dimensional hydrodynamic simulations were completed for each bathymetric scenario (all other model inputs and settings are identical) and the outputs compared. Differences between the model results are deemed to be impacts associated with the CSDP.

Other potential coastal process impacts are related to the placement and dispersion of dredged material at the proposed DMPA.

The subsequent report sections present the impact assessment of the CSDP for the key coastal processes issues identified in the baseline section which are:

- Hydrodynamics;
- Waves;
- Morphology and Sedimentation; and
- Shoreline and Beach System.

Key assumptions and limitations of the impact assessment are outlined and discussed where relevant.

Impact reporting points and transect locations referred to throughout this Section are shown in Figure 7-2.

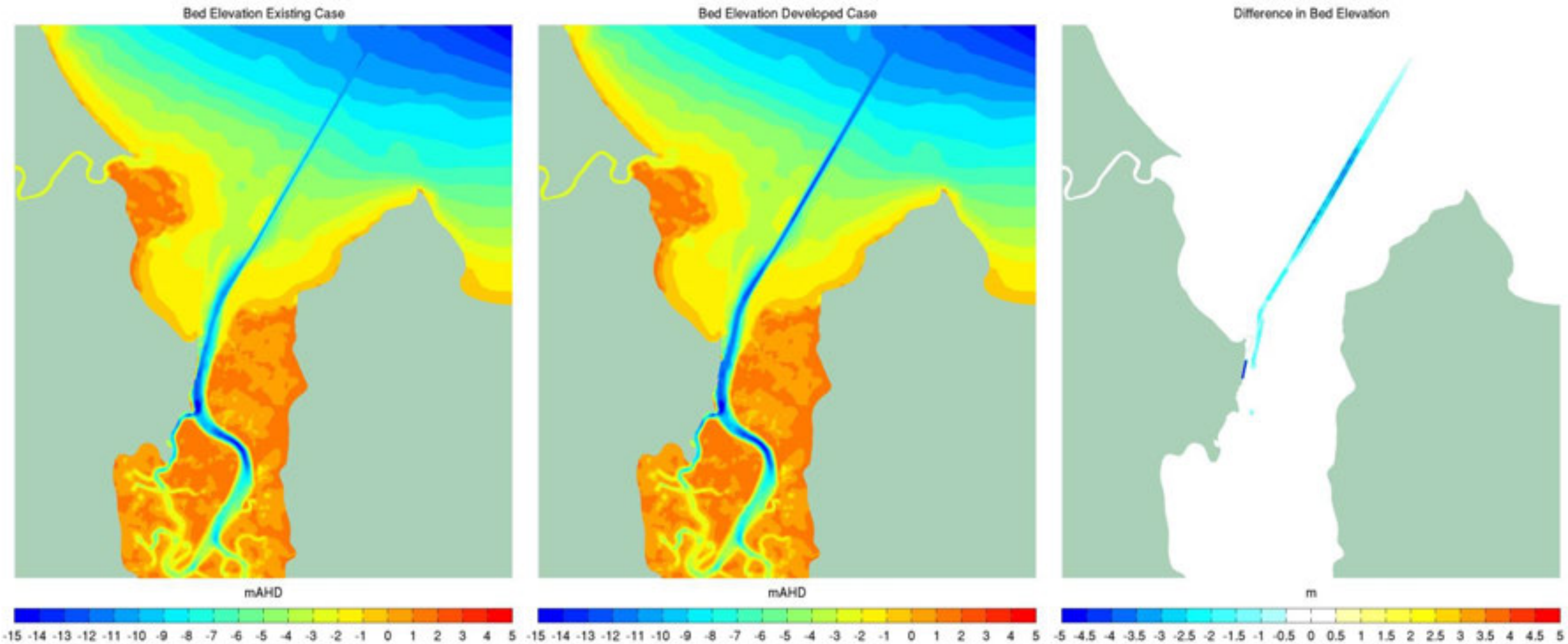
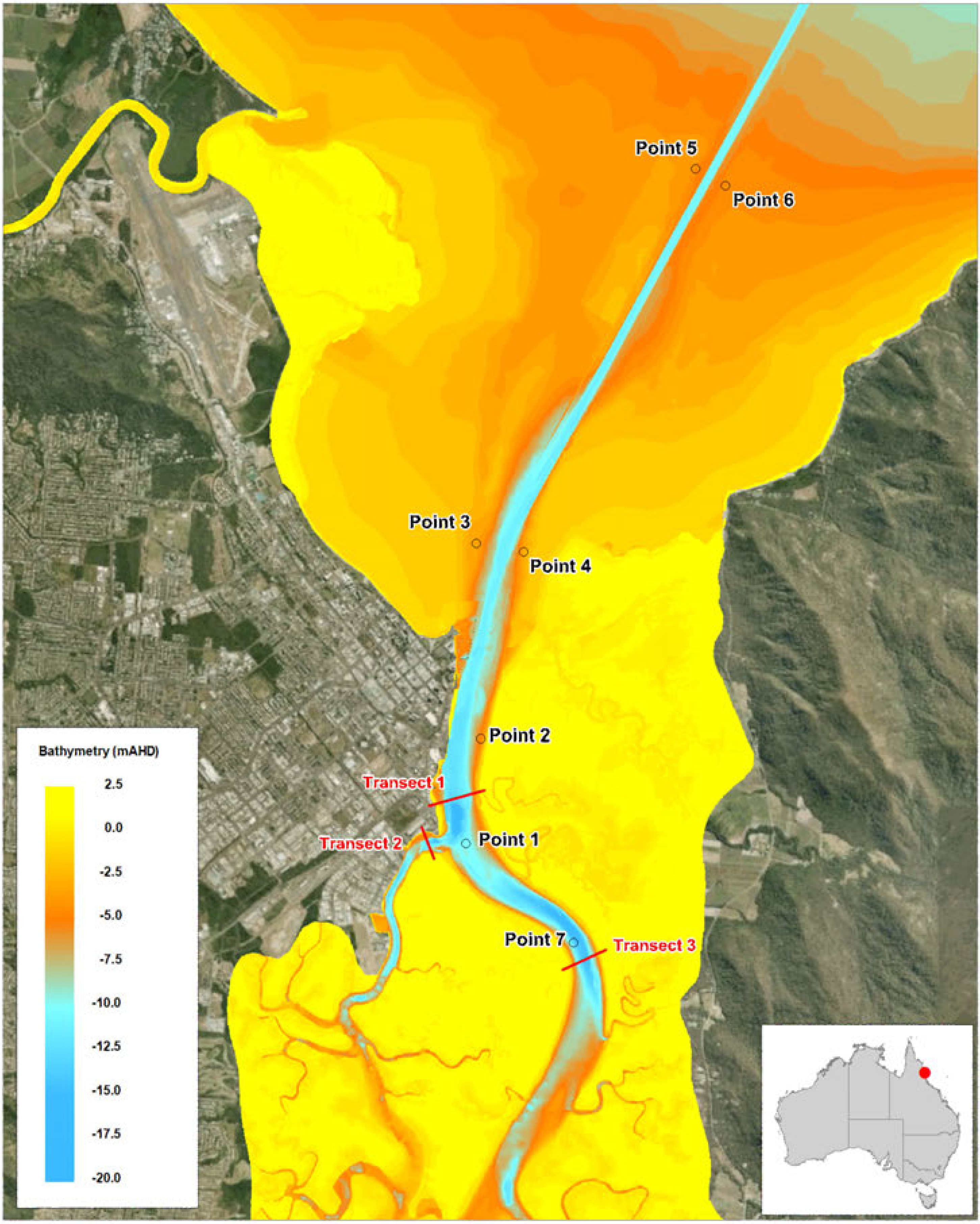


Figure 7-1 Cairns Shipping Channel and Surrounds Bed Elevation: Existing case (left); Developed case (middle) and Difference (right)



Title:

Impact Reporting Points and Transect Locations

Figure: 7-2

Rev: A

N

0 1.25 2.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_016_hydro_impact_locations.wor

7.2 Hydrodynamic Impacts

The CSDP dredging will induce changes to flow patterns in the immediate vicinity of the development. The calibrated and validated 3D hydrodynamic model described in this report was used to assess the magnitude and significance of the impacts. As described below, the assessment has considered impacts to current fields, water levels, bed shear stresses and to tidal prism within Trinity Inlet.

7.2.1 Tidal Current Field Impacts

The CSDP channel dredging will increase the conveyance (flow capacity) of the dredged channel entering Trinity Inlet and has the potential to redistribute flow patterns in the immediate vicinity of the works. Depth-averaged current speeds were extracted from the 3D hydrodynamic model Base Case and Developed Case simulations and analysed in order to understand the dredging impacts on current patterns.

Changes to current patterns in the vicinity of the Port were assessed for a flooding tide and an ebbing tide during a period of spring tides. Spatial plots of the changes in velocity magnitudes between the Existing Case and Developed Case are shown in Figure 7-3 and Figure 7-4 (zoomed view) for the flooding tide. Figure 7-5 and Figure 7-6 (zoomed view) show the equivalent model predictions for the ebbing tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. The vectors (arrows) on these plots represent both the direction and magnitude of the depth-averaged currents. The developed case vectors are overlain on the impact plots in order to aid interpretation.

The velocity impact plots show that the changes in velocity magnitudes associated with the CSDP are confined to the Project Area and the immediate surroundings. The highest magnitude changes are not large (generally up to ±0.1m/s). The velocities in the deepened and widened channel are generally reduced, with some localised areas of increased velocities immediately adjacent to the dredging footprint. Further afield on the relatively shallow Trinity Bay mudflats to the east and west of the channel alignment, current velocities are generally slightly reduced (by less than 10% of their existing case values).

Time series of depth-averaged velocity were extracted at the seven analysis sites shown in Figure 7-2. The timeseries plots are shown in Figure 7-7 for Points 1 to 3, Figure 7-8 for Points 4 to 6 and Figure 7-9 for Point 7. The timeseries correspond to the period from 7th – 13th March, which includes some relatively large spring tide conditions. Notable features of the timeseries plots are summarised below.

- In general differences between the existing and developed case timeseries are difficult to distinguish.
- At Point 1, which is located within 200m upstream from the dredge footprint southern extent, the developed case results are almost indistinguishable from the existing case model predictions. This is also the case at Point 7, which is located 1.8km further upstream within Trinity Inlet.
- Point 2, which is located on the eastern bank of the Trinity Inlet channel, occasionally exhibits developed case current speeds that are up to 0.2m/s higher than the existing case during ebbing spring tide flows. This could indicate an area of flow separation that may be sensitive to the channel dredging works.

- The very slight reduction in current speeds on the adjacent Trinity Bay mudflats can be observed during peak currents at Points 3-6.
- While not explicitly assessed, any changes to current patterns associated with climate change are not likely to be influenced by the CSDP channel expansion.

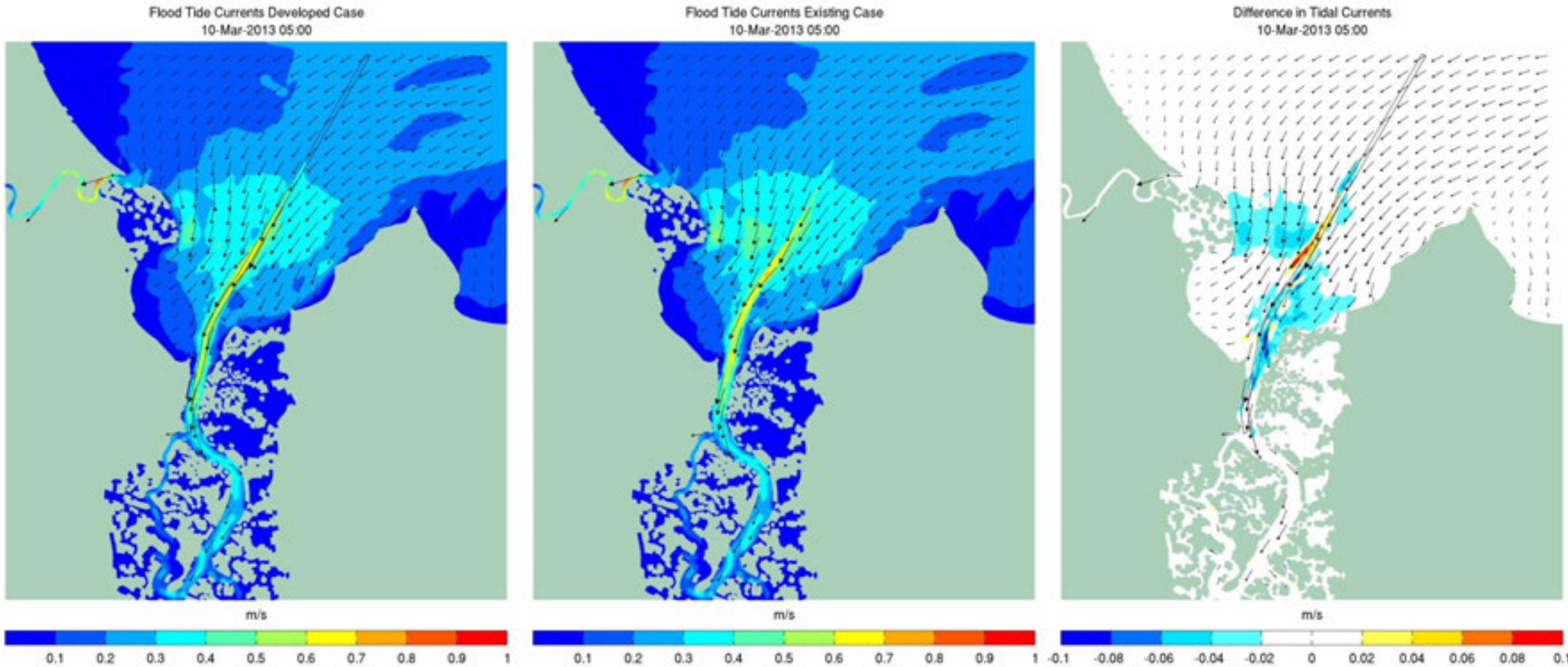


Figure 7-3 Modelled Spring Tide Flood Currents and Impacts. Existing case (left); Developed case (middle) and Impacts (right)

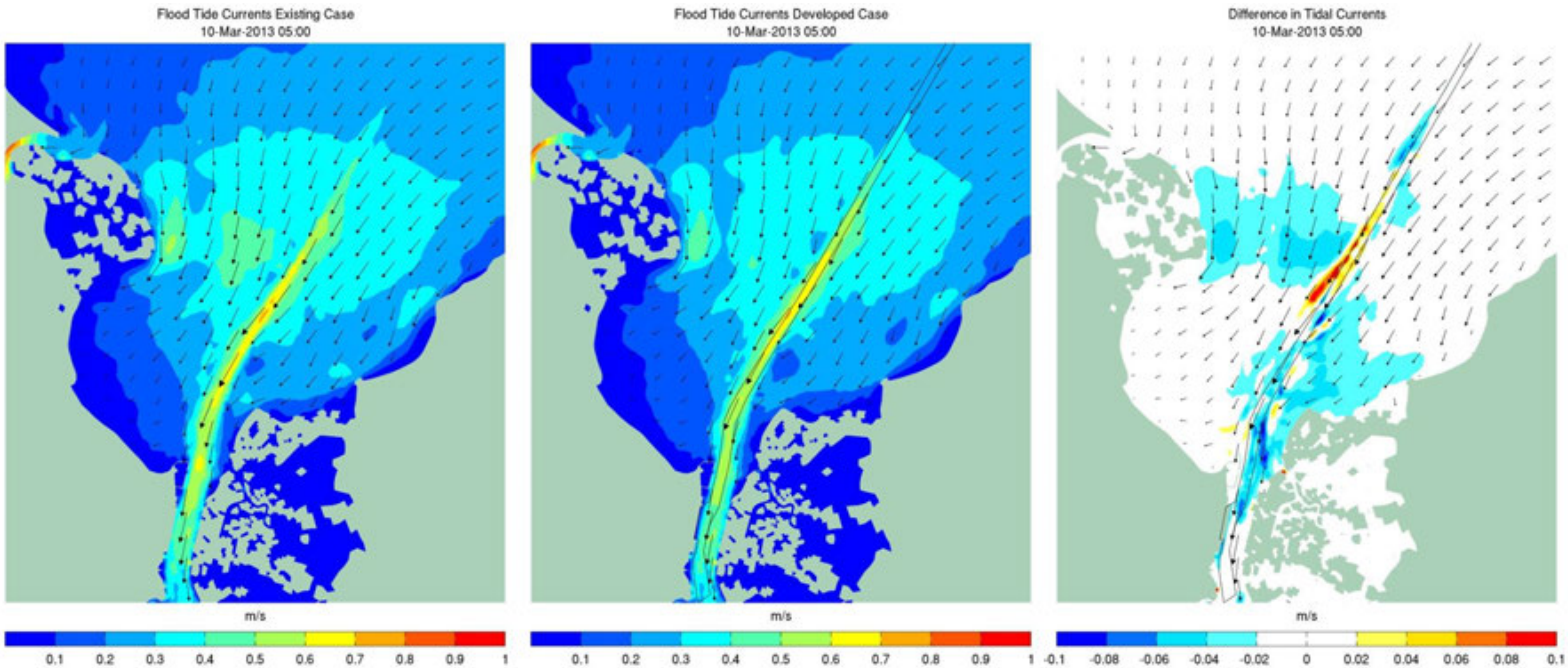


Figure 7-4 Modelled Spring Tide Flood Currents and Impacts – zoomed. Existing case (left); Developed case (middle) and Impacts (right)

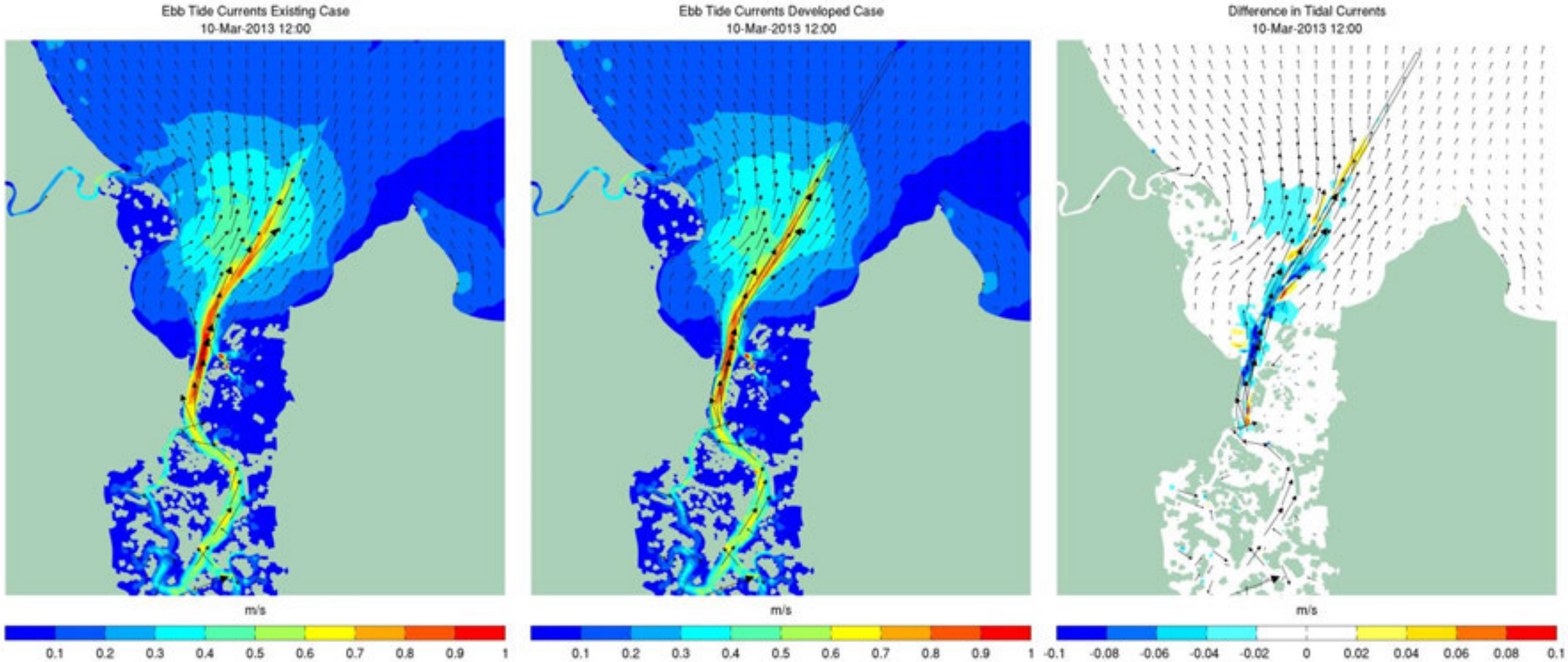


Figure 7-5 Modelled Spring Tide Ebb Currents and Impacts. Existing case (left); Developed case (middle) and Impacts (right)

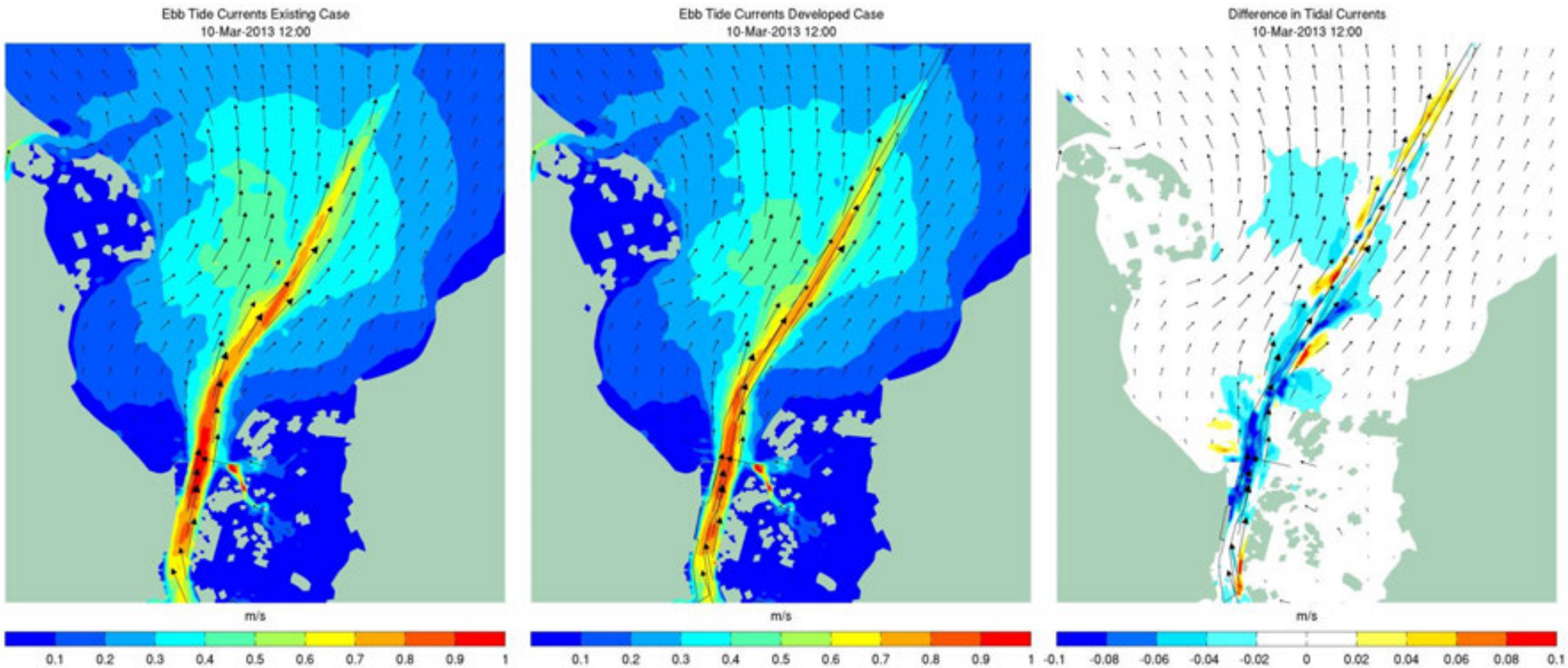


Figure 7-6 Modelled Spring Tide Ebb Currents and Impacts – zoomed. Existing case (left); Developed case (middle) and Impacts (right)

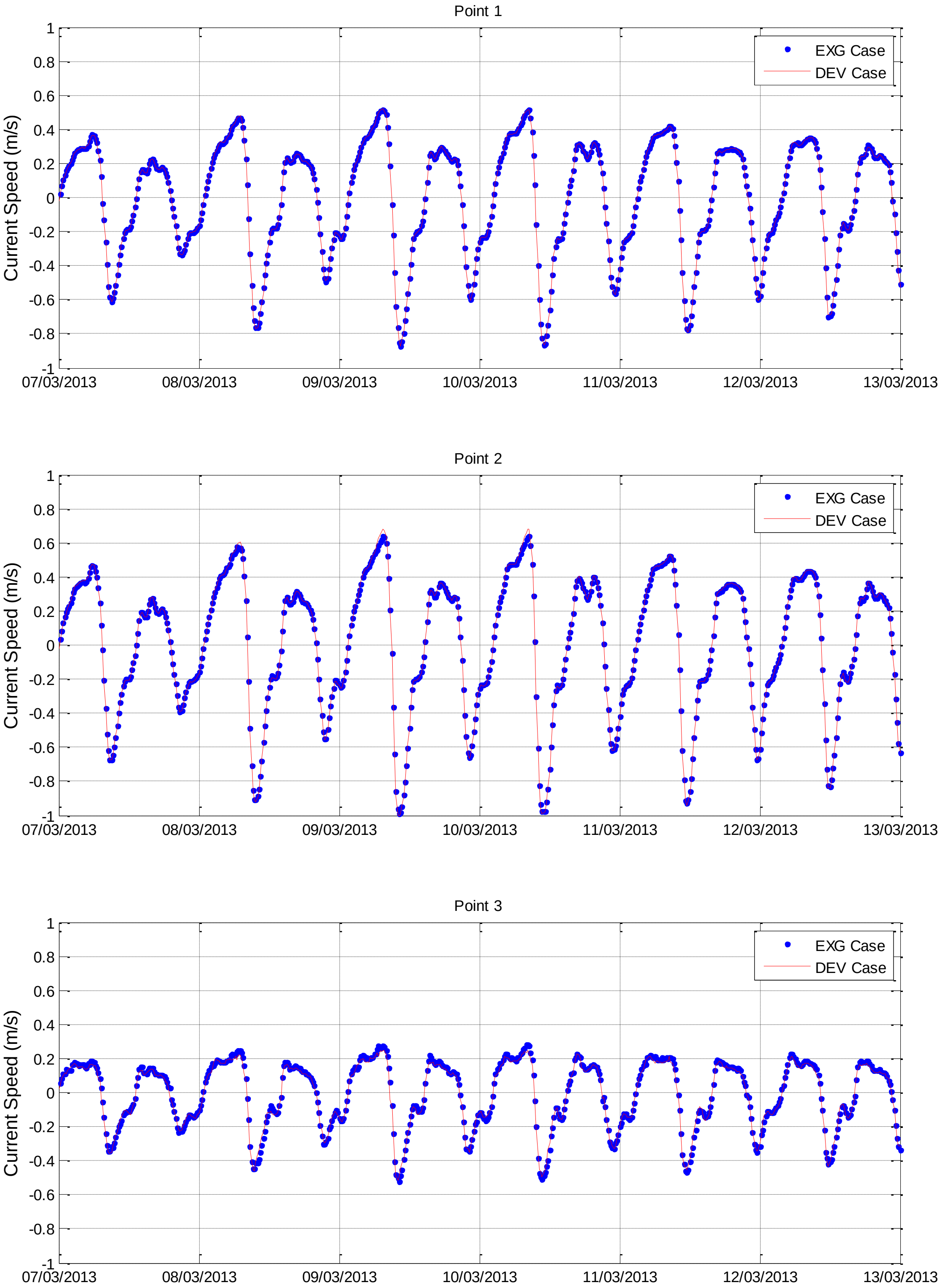


Figure 7-7 Existing and Developed Case Current Speed Timeseries (Points 1 to 3)
Positive current speeds are during flooding tides

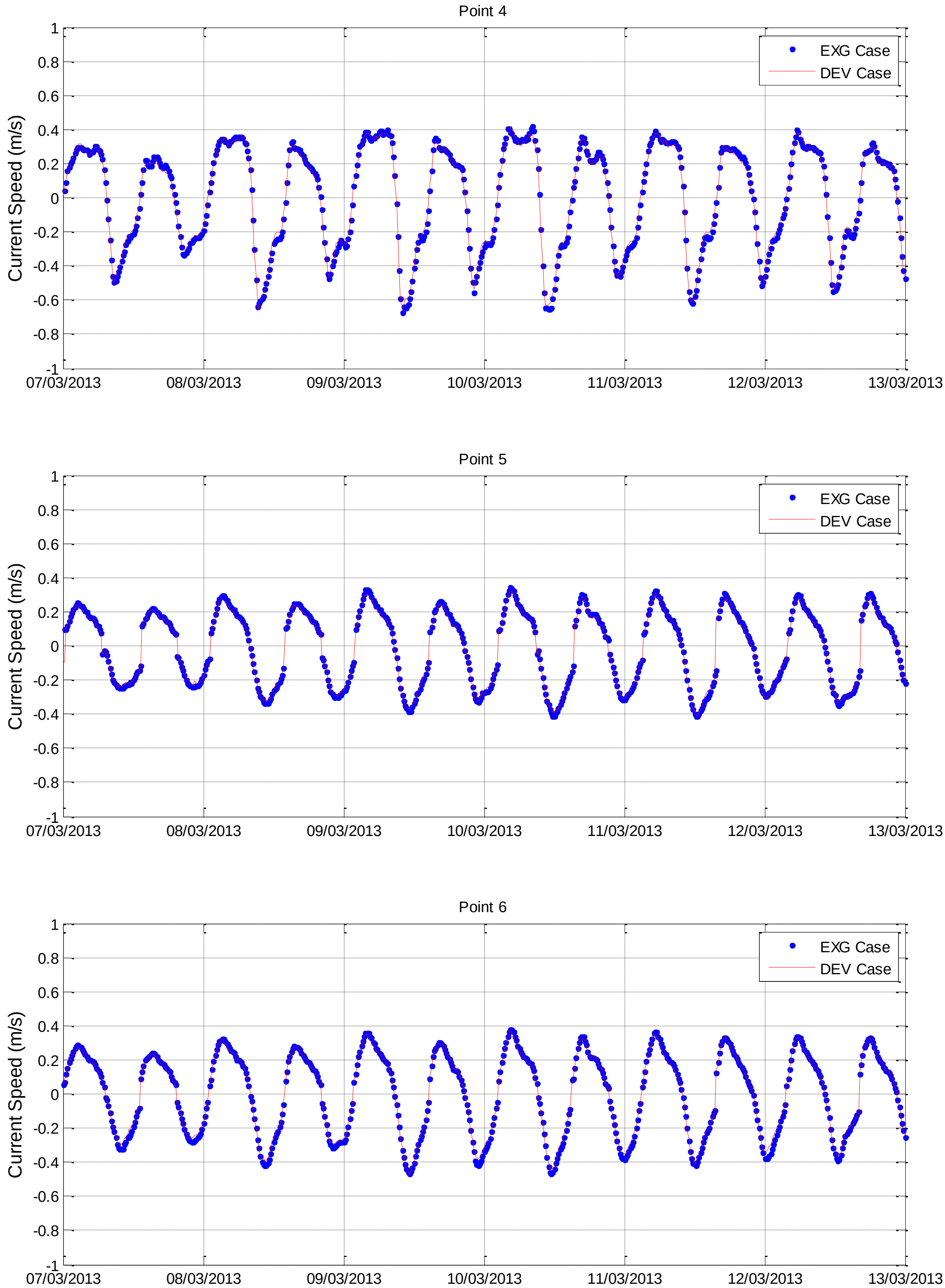


Figure 7-8 Existing and Developed Case Current Speed Timeseries (Points 3 to 6) Positive current speeds are during flooding tides

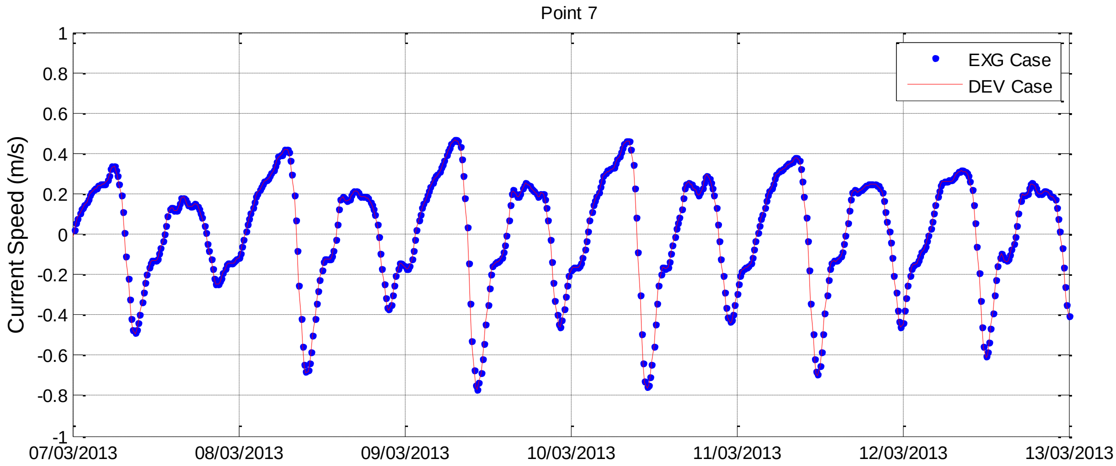


Figure 7-9 Existing and Developed Case Current Speed Timeseries (Point 7)
Positive current speeds are during flooding tides

7.2.2 Water Level Impacts

Water level variations within Trinity Bay are predominantly driven by tidal oscillations. The dredging works have some (limited) potential to impact on flow patterns and hence water levels in the vicinity of the works as well as further upstream within Trinity Inlet.

Spatial water level impacts were analysed by differencing the Existing Case and Developed Case simulation results. The results of this analysis were that water level differences due to the CSDP dredging were everywhere and at all times negligible. Spatial plots of the water level impacts are not shown due to the negligible magnitude of the changes. It is noted that water level impacts would remain negligible under a climate change scenario with increased mean sea level.

Time series of water level were extracted from Existing Case and Developed Case simulations at the analysis sites shown in Figure 7-2. The timeseries comparisons also show no discernible difference between existing case and developed water levels. The water level timeseries comparisons are shown below in Figure 7-10, Figure 7-11 and Figure 7-12 in order to illustrate this result.

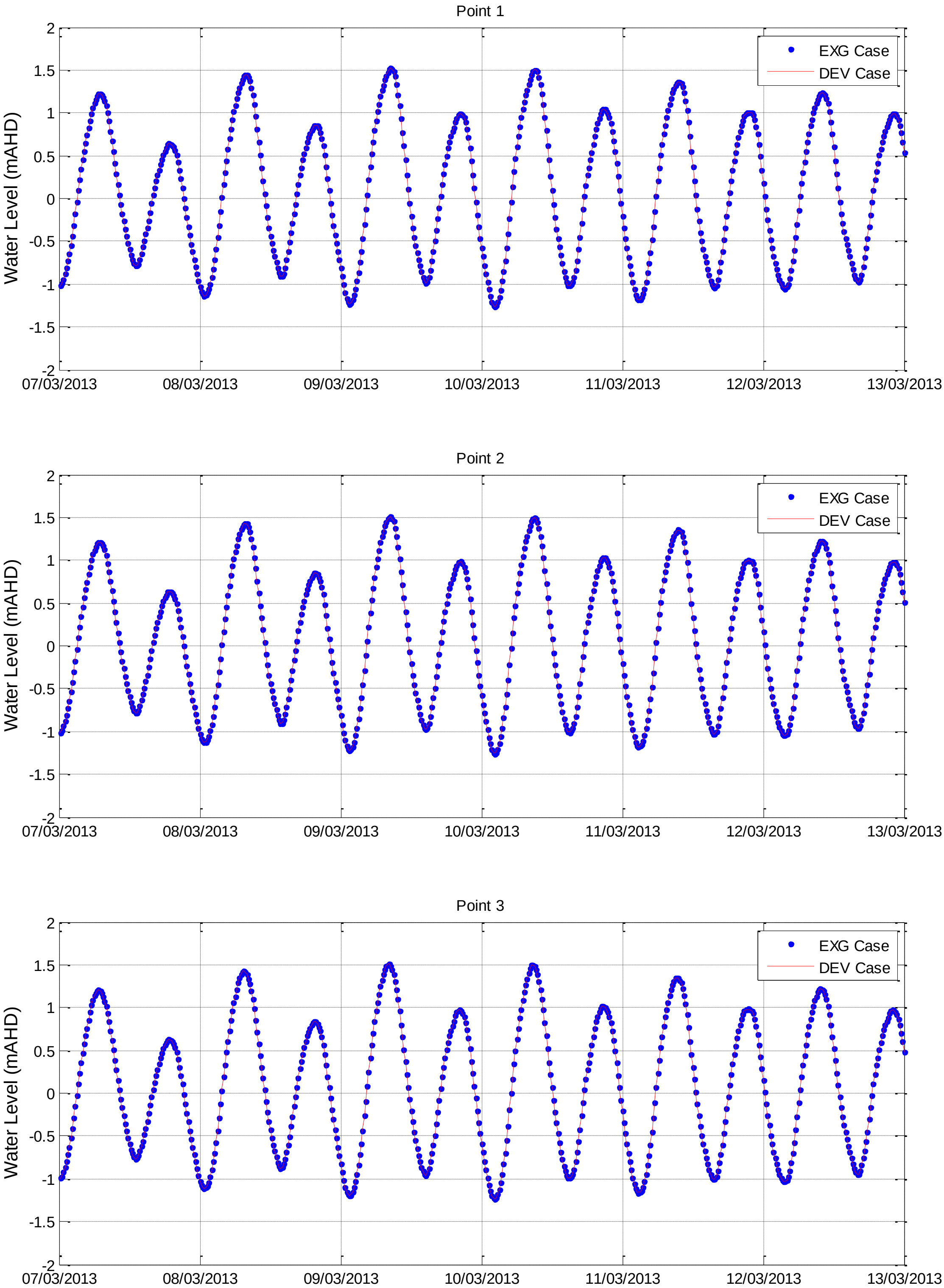


Figure 7-10 Existing and Developed Case Water Level Timeseries (Points 1 to 3)

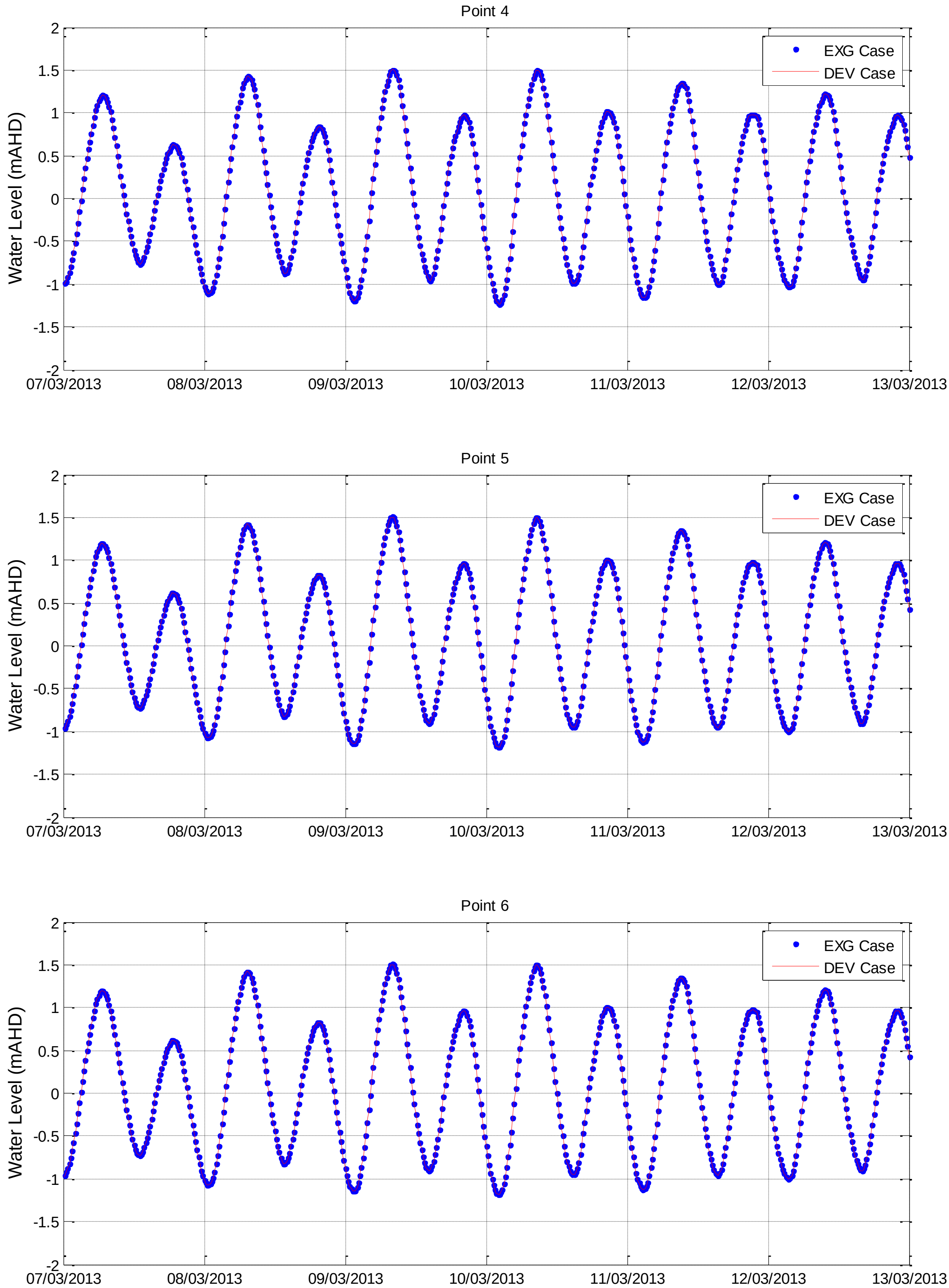


Figure 7-11 Existing and Developed Case Water Level Timeseries (Points 4 to 6)

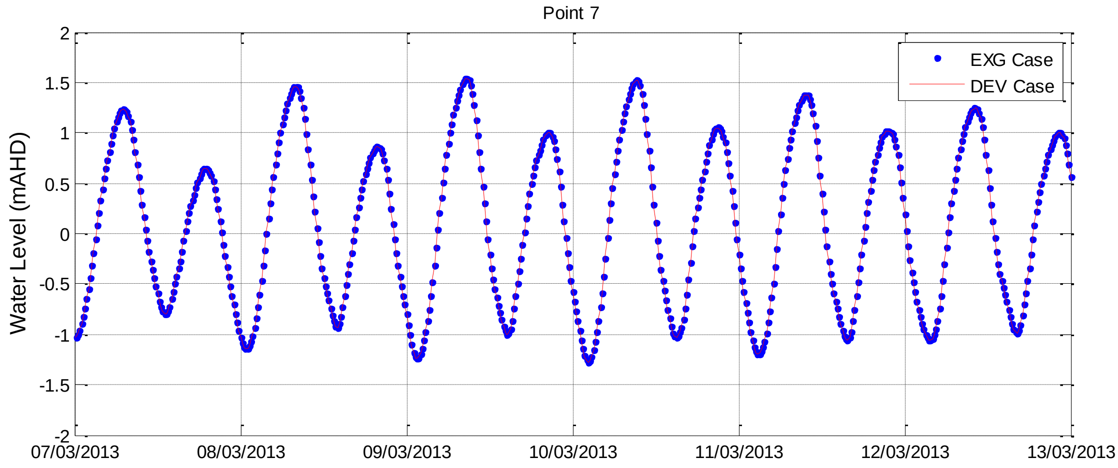


Figure 7-12 Existing and Developed Case Water Level Timeseries (Point 7).

7.2.3 Tidal Flow and Volume Impacts

The impact of the CSDP dredging on tidal flow rates and volumes were analysed in order to assess the implications of the project on tidal flushing of Trinity Inlet.

Flow timeseries were extracted from the existing and developed case model simulations at the three transect locations shown in Figure 7-2. Transect 1 is located across the main Trinity Inlet channel across the Smith Creek swing basin. Transect 2 is located across the northern arm of Smith Creek. Transect 3 is located across the main Trinity Inlet channel around 1.8km upstream of the Smith Creek swing basin. The timeseries comparisons presented in Figure 7-13 show no discernible difference between existing case and developed case flows.

Tidal prism volumes were derived from the extracted flows and are presented in Table 7-1. The 50th percentile and 95th percentile tidal prism volumes and percentage impacts are reported. The 50th percentile represents a typical tidal range, while the 95th percentile represents a fairly large spring tidal range. The change in tidal prism within Trinity Inlet due to the CSDP is less than 0.1% at the 50th percentile and less than 0.2% at the 95th percentile.

Table 7-1 Tidal Prism Impacts

Transect ID	Tidal Prism (m^3) 50th Percentile			Tidal Prism (m^3) 95th Percentile		
	Existing	Developed	Change	Existing	Developed	Change
1	14,814,300	14,824,700	0.07%	33,652,100	33,664,000	0.04%
2	2,191,700	2,192,300	0.02%	5,465,900	5,475,500	0.17%
3	10,565,400	10,557,500	-0.07%	22,590,100	22,597,200	0.03%

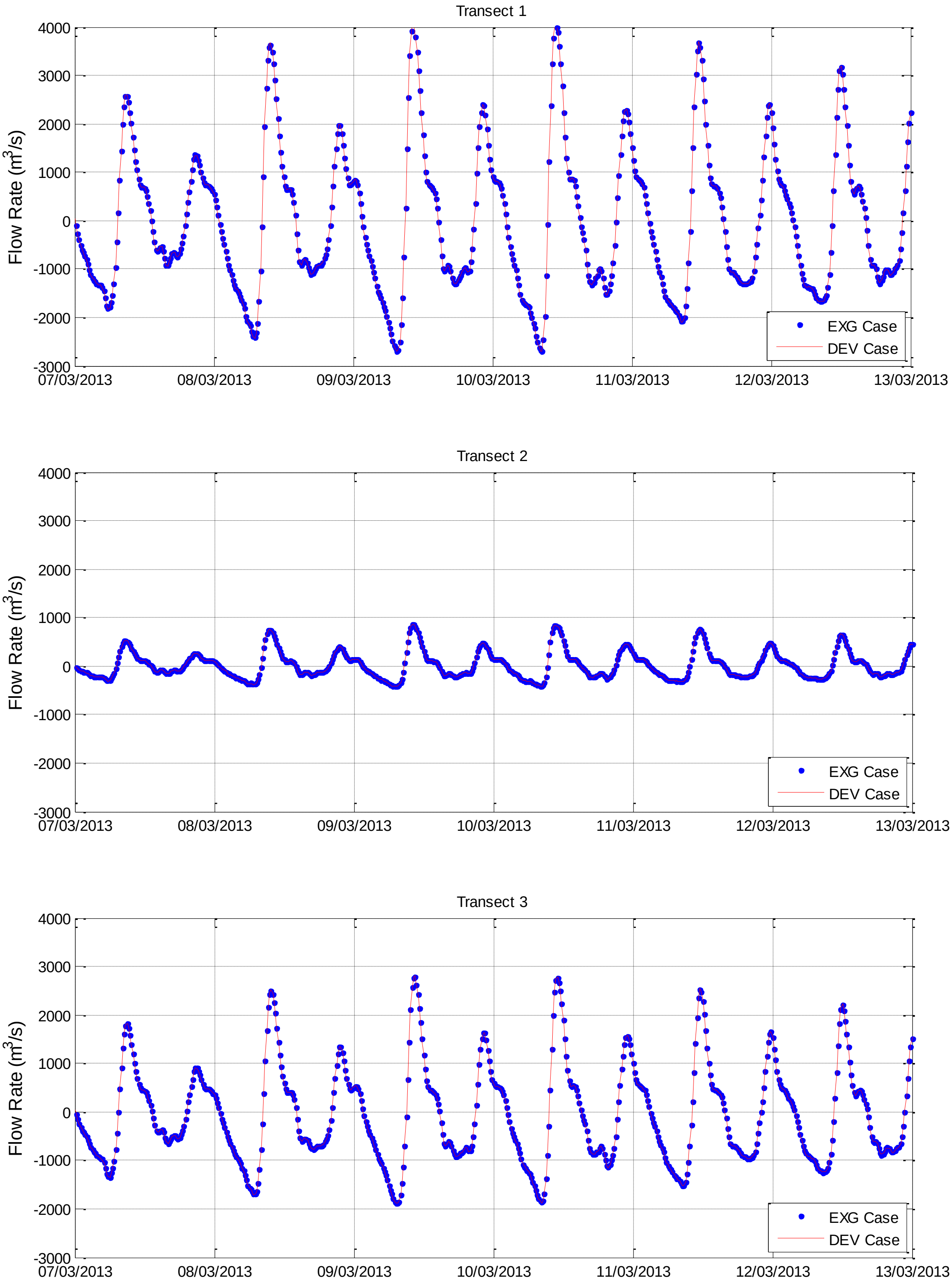


Figure 7-13 Existing and Developed Case Flow Timeseries at the Transects shown in Figure 7-2

7.2.4 Bed Shear Stress Impacts

Bed shear stresses represent the capacity of current (and wave) induced water motions to re-suspend sediment from the seabed and to transport it as bedload. Impacts to current related bed shear stresses have been analysed using the 3D hydrodynamic model output in order to provide a high-level understanding of the potential for morphological change induced by the CSDP dredging.

The 95th percentile current related bed shear stress magnitudes, which represent conditions that are typically exceeded during spring tide flows, are shown in Figure 7-14 and Figure 7-15 (zoomed in). These figures present spatial plots of Existing Case, Developed Case and predicted impacts (the difference between the Existing Case and the Developed Case).

The spatial impacts to current related bed shear stress generally follow the current velocity impacts presented in Section 7.2.1. The changes in bed shear stress magnitude associated with the CSDP are confined to the Project Area and the immediate surroundings. The highest magnitude changes are not large (generally up to ±0.1N/m^2). The bed shear stress in the deepened and widened channel are generally reduced, with some localised areas of increased velocities immediately adjacent to the dredging footprint. Impacts are not predicted within Trinity Inlet of other further afield locations.

Impacts to bed shear stress are not of magnitudes likely to cause undesirable morphological change. The reduced bed shear stresses in the vicinity of the developed channel are likely to cause increased siltation and maintenance dredging requirements. The impact to channel siltation is addressed separately in Section 7.4.1.

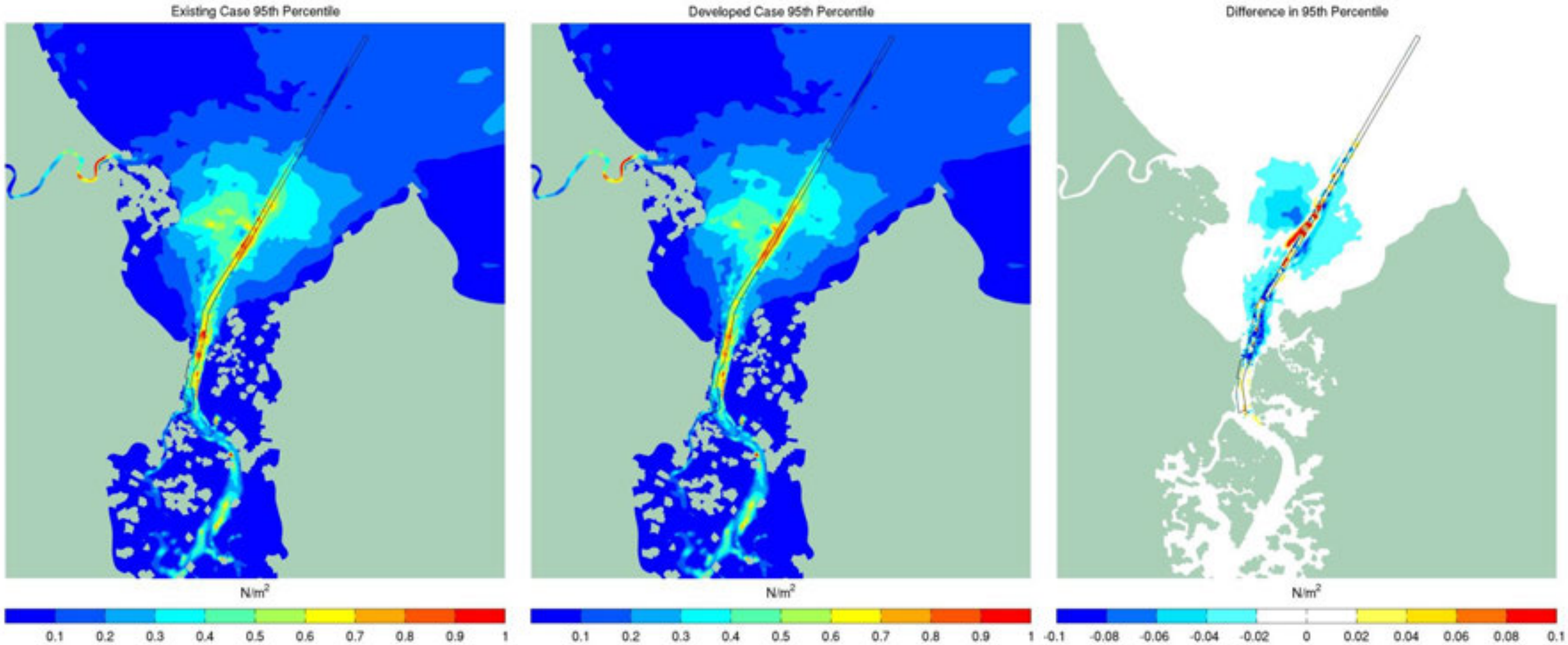


Figure 7-14 Modelled 95%ile Current Related Bed Shear Stress (N/m2) and Impacts. Existing case (left); Developed case (middle) and Impacts (right)

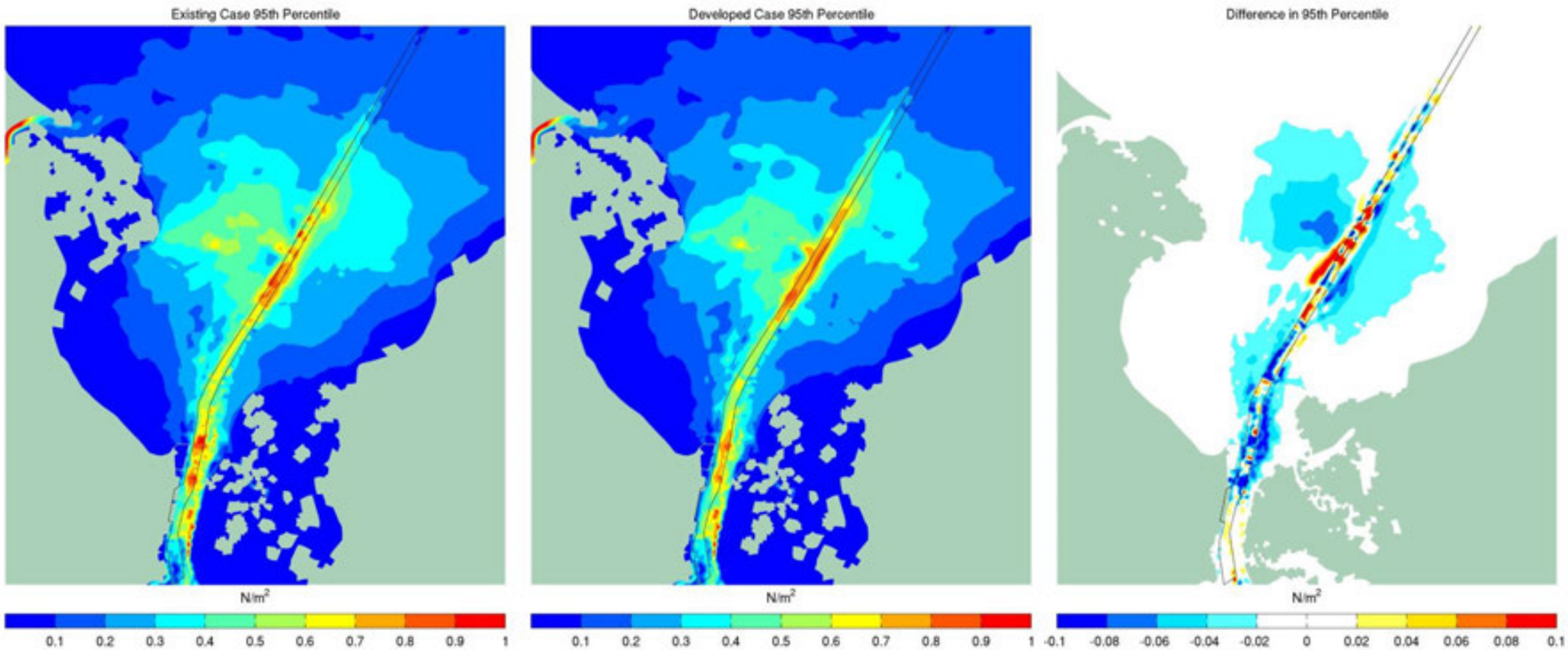


Figure 7-15 Modelled 95%ile Current Related Bed Shear Stress (N/m2) – zoom. Existing case (left); Developed case (middle) and Impacts (right)

7.2.5 Extreme Water Level Impacts

The impact of the channel development on surge propagation was analysed in order to assess the potential of the CSDP to affect vulnerability to storm tide inundation on adjacent properties.

The hydrodynamic model was used to simulate the surge generated by a low atmospheric pressure and wind field representative of a tropical cyclone. The pressure and wind field input was described using the Holland (1980) parametric model. The synthetic event was developed such that it crossed the coast north of Cairns, generating a surge in Trinity Bay close to 1.5m which approximately equivalent to the 200-year ARI surge event (BMT WBM, 2013). It is noted that this assessment considered the surge propagation in isolation of the tide.

Spatial surge level impacts were analysed by differencing the Base Case and Developed Case simulation results. The result of this analysis is shown in Figure 7-17 which demonstrates that the peak surge level difference due to the CSDP dredging is negligible

Timeseries of surge level was extracted from Base Case and Developed Case simulations at the analysis sites shown in Figure 7-16. The timeseries comparison also shows no discernible difference between existing case and developed surge levels. Only the surge level timeseries at Point 1 (within the Inner Port area) is shown to illustrate this result. Any changes to tropical cyclone activity and surge propagation associated with climate change are not expected to be influenced by the channel development.

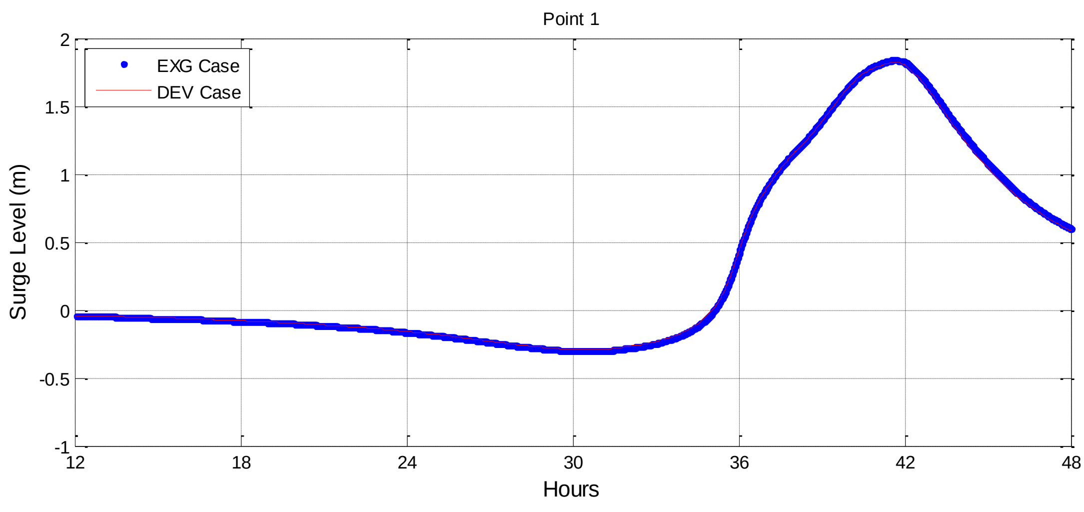


Figure 7-16 Existing and Developed Case Surge Level Timeseries (Point 1 – Inner Port).

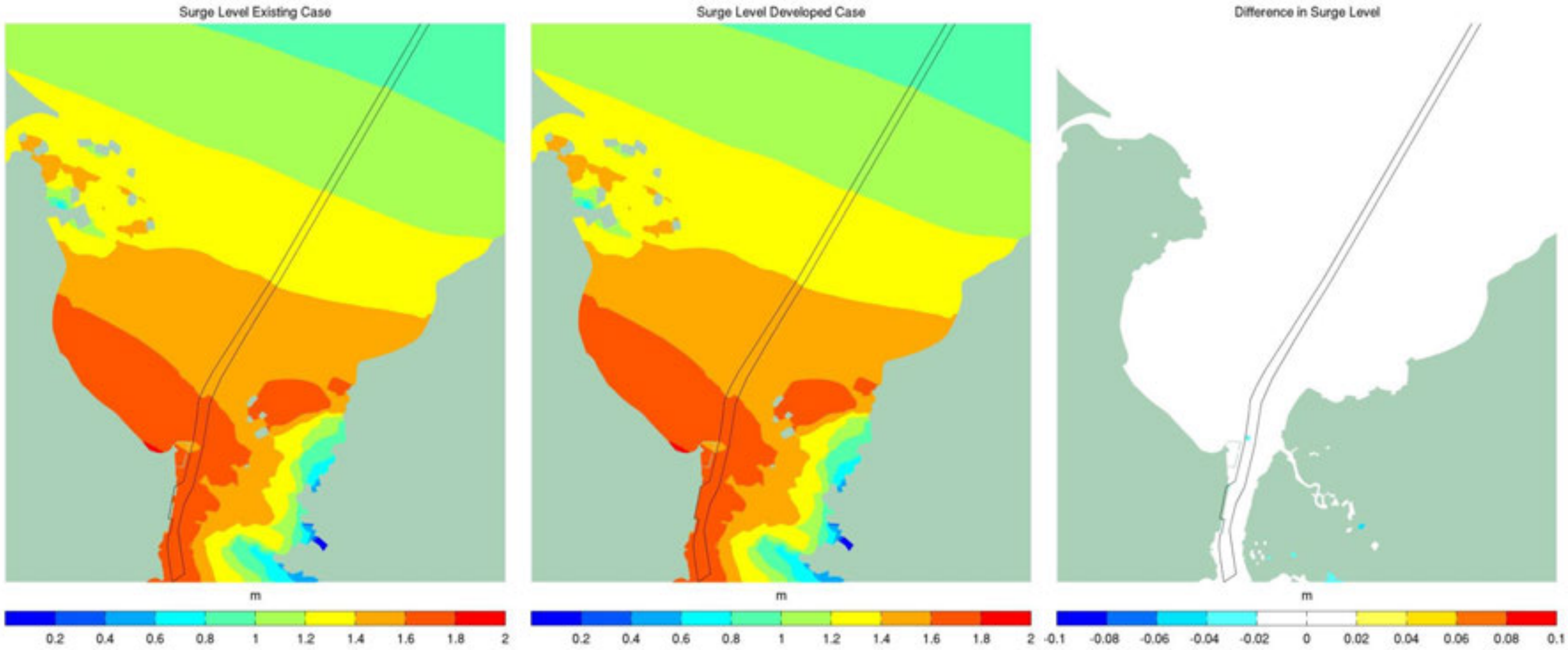


Figure 7-17 Modelled Peak Surge Level (m): Existing case (left); Developed case (middle) and Impacts (right)

7.3 Wave Impacts

The widened and deepened dredge channel may potentially impact the propagation of waves towards the shorelines of the CSDP Project Area. The potential wave impacts were analysed using a high-resolution (25m grid) SWAN model of the Project Area. Boundary conditions for the high-resolution SWAN model were obtained from the calibrated and validated 100m grid SWAN model covering Trinity Bay.

Existing Case and Developed Case simulations were undertaken using the high-resolution SWAN model for the six month period from 01/01/2013 to 01/07/2013. Snapshots from the model simulation representing a typical trade-wind driven south-easterly (SE) wave case and a high-energy northerly (N) wave case (driven by Ex-Tropical Cyclone Oswald) were selected to illustrate the CSDP spatial impacts. The modelled wave fields predicted from the 100m grid SWAN model are shown in Figure 7-18 for the SE waves and Figure 7-19 for the N waves. The Existing Case, Developed Case and Impact predictions from the high-resolution SWAN model are shown in Figure 7-20 for the SE waves and Figure 7-21 for the N waves.

The snapshot model predictions indicate that the existing channel already has some localised influence on wave heights as indicated by larger wave heights on one side than the other. The channel is acting to reflect/refract some of the incident wave energy. This is particularly evident in the N wave case results shown in Figure 7-21. The widened and deepened CSDP channel is predicted to have a slightly increased influence on the wave field. As seen in the difference plots (bottom plots in Figure 7-20 and Figure 7-21), wave heights are slightly increased on the “incident” side and slightly reduced on the “transmitted” side of the channel. The magnitude of the wave height differences are generally relatively small (<5%) and localised to the vicinity of the channel. The relative impacts to wave propagation are not expected to alter significantly under climate change induced sea level rise scenarios.

Timeseries comparisons of significant wave height, wave peak period and direction at the two nearshore locations (Point 3 and Point 4 in Figure 7-2) are shown in Figure 7-22 and Figure 7-23. Energy weighted mean heights and directions were also calculated from the entire continuous timeseries with the results confirming that the CSDP is unlikely to have a significant impact on nearshore wave conditions driving littoral and beach system processes.

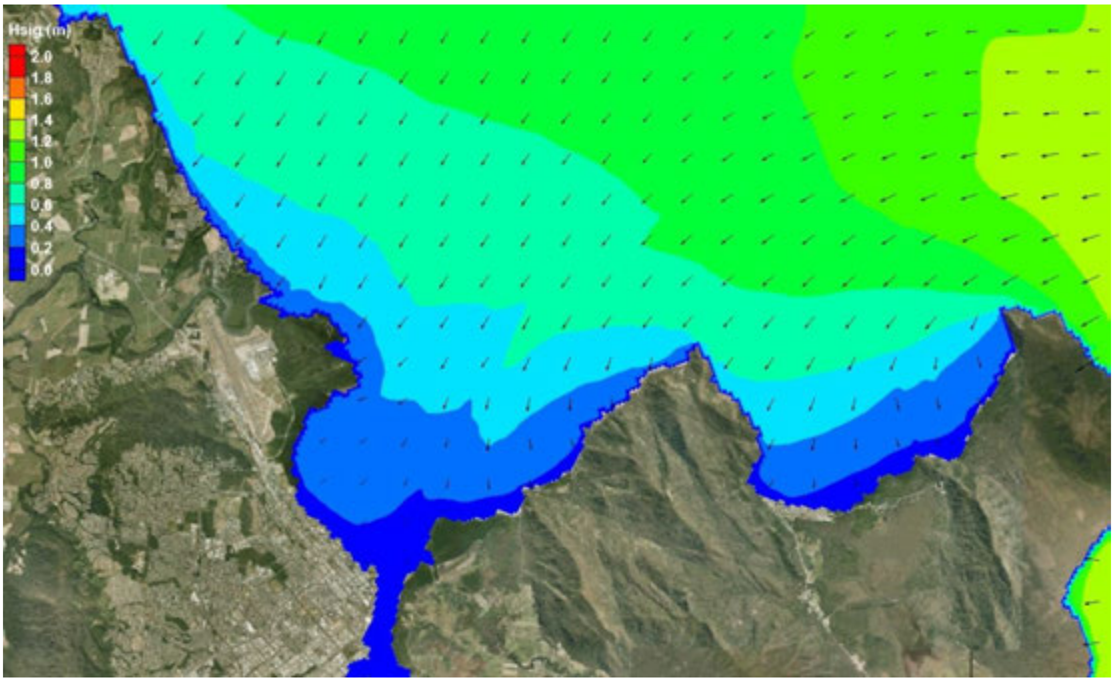


Figure 7-18 100m Grid Modelled Typical South-Easterly Wave Case (09/04/2013 13:00)

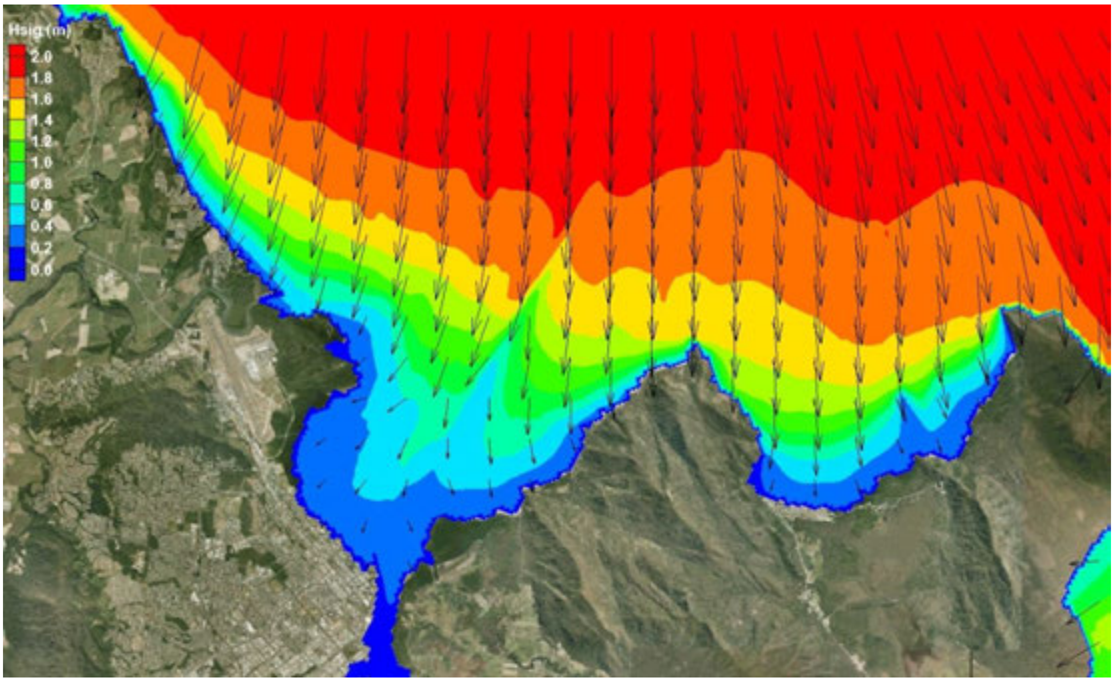


Figure 7-19 100m Grid Modelled Typical Northerly Wave Case (24/01/2013 07:00)

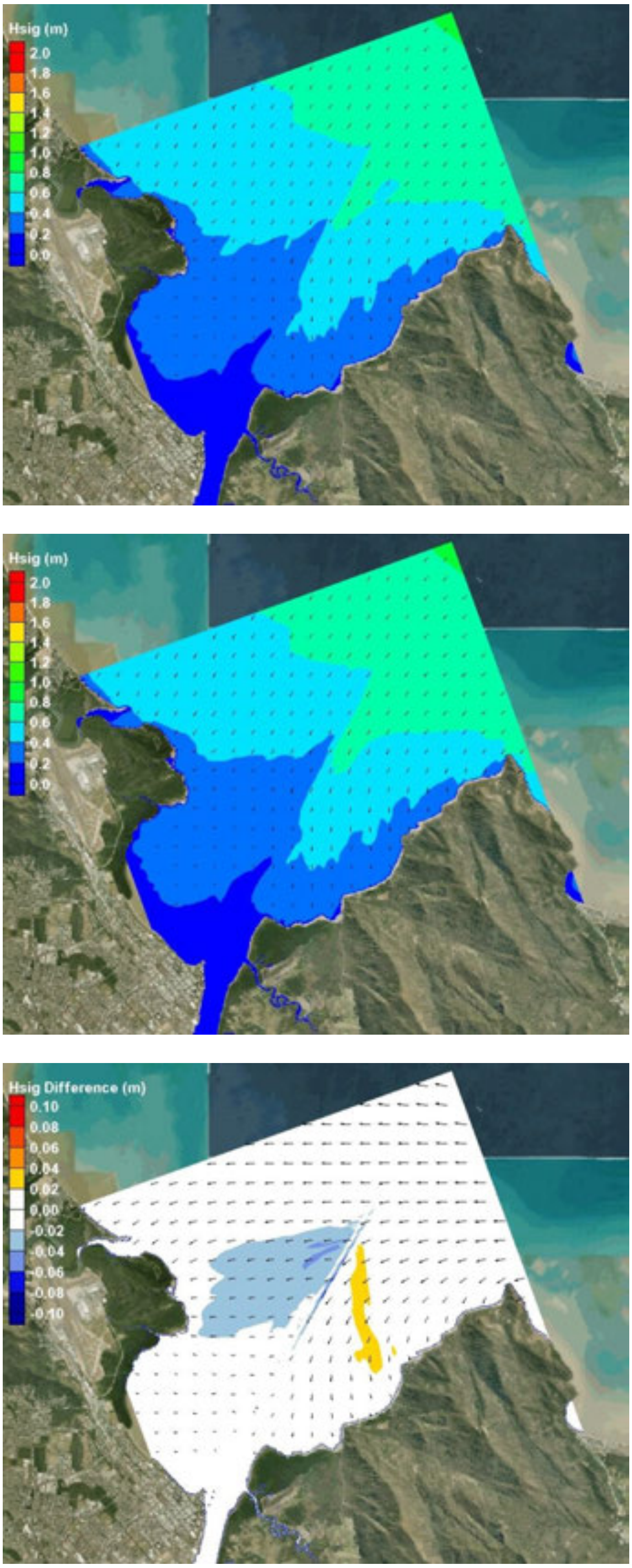


Figure 7-20 25m Grid Typical South-Easterly Wave Case: Base case (top); Developed case (middle); Difference (bottom)

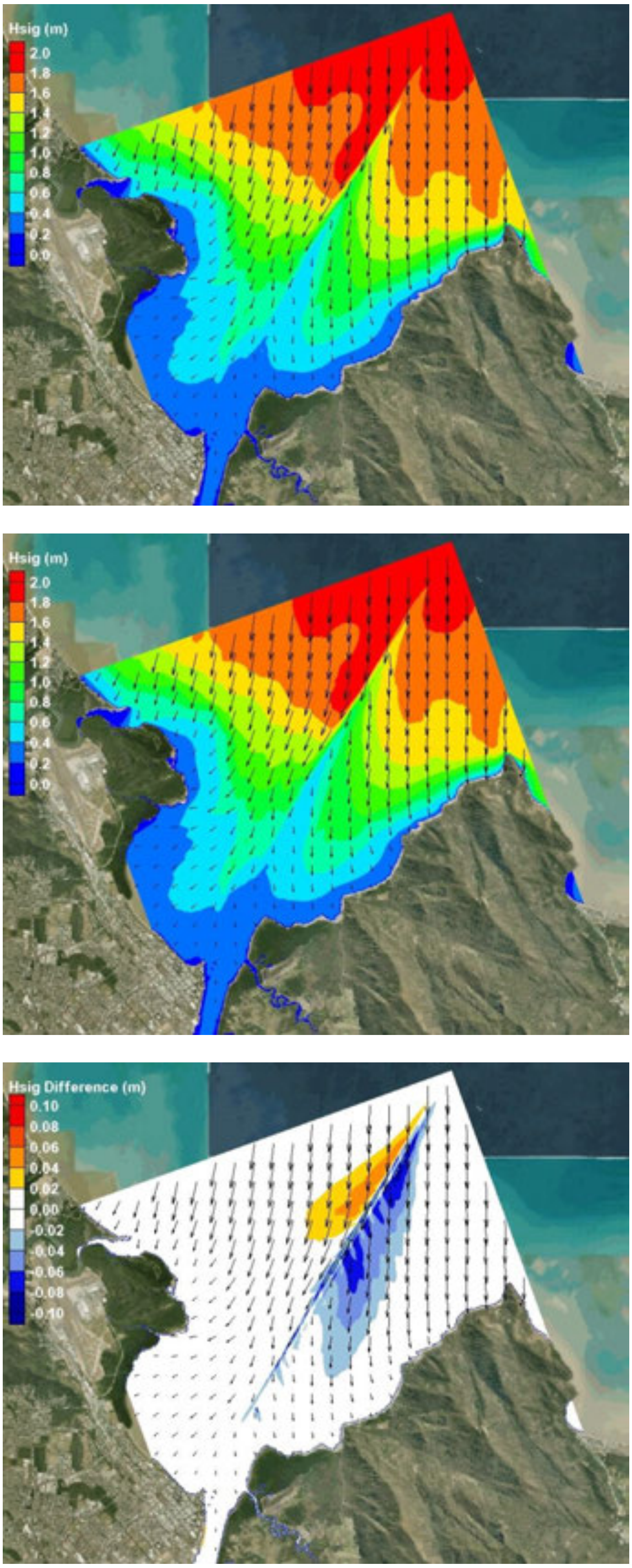


Figure 7-21 25m Grid Northerly Wave Case: Base case (top); Developed case (middle); Difference (bottom)

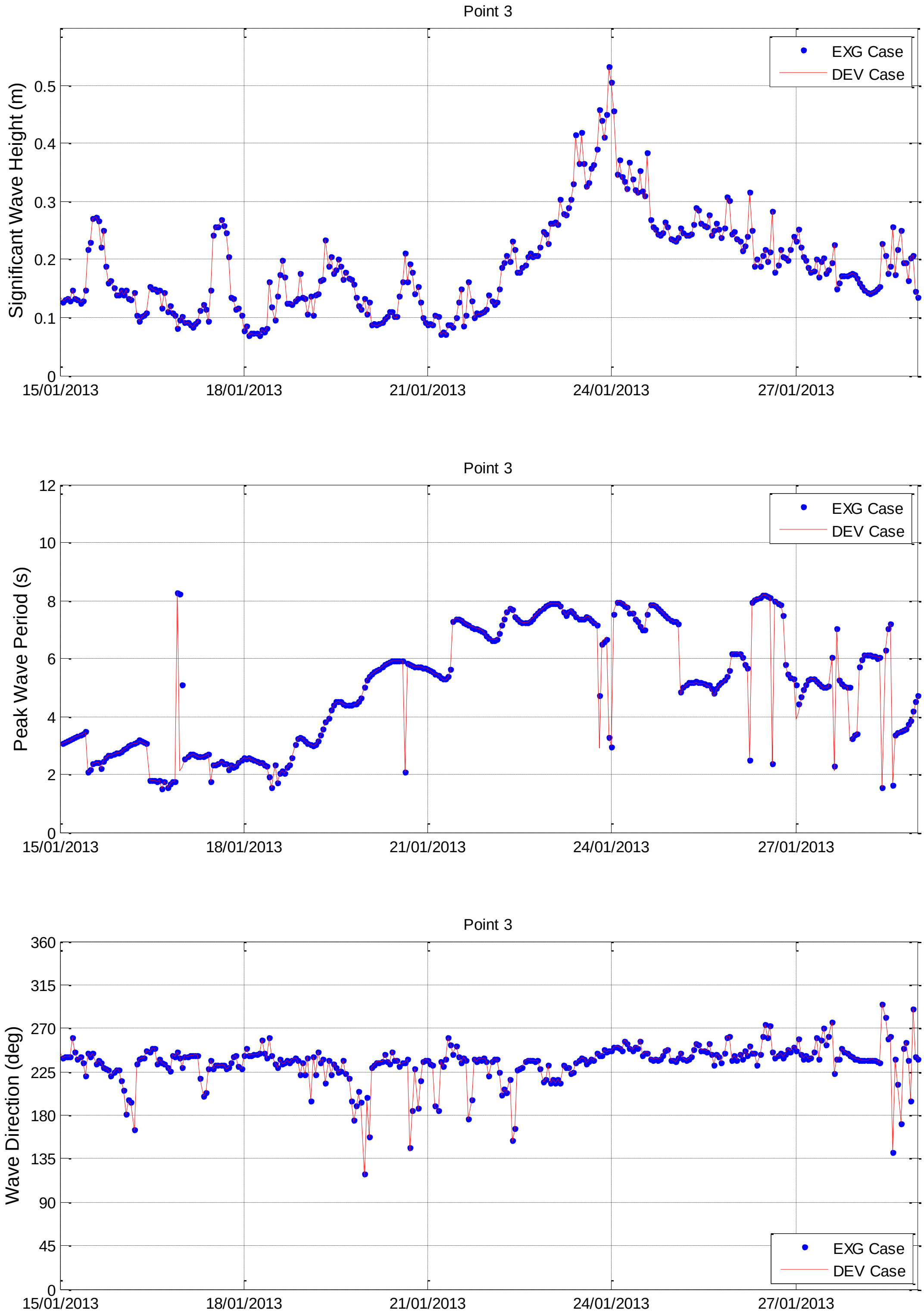


Figure 7-22 Existing Case and Developed Case Wave Parameter Timeseries Comparison (Nearshore Location Point 3 in Figure 7-2)

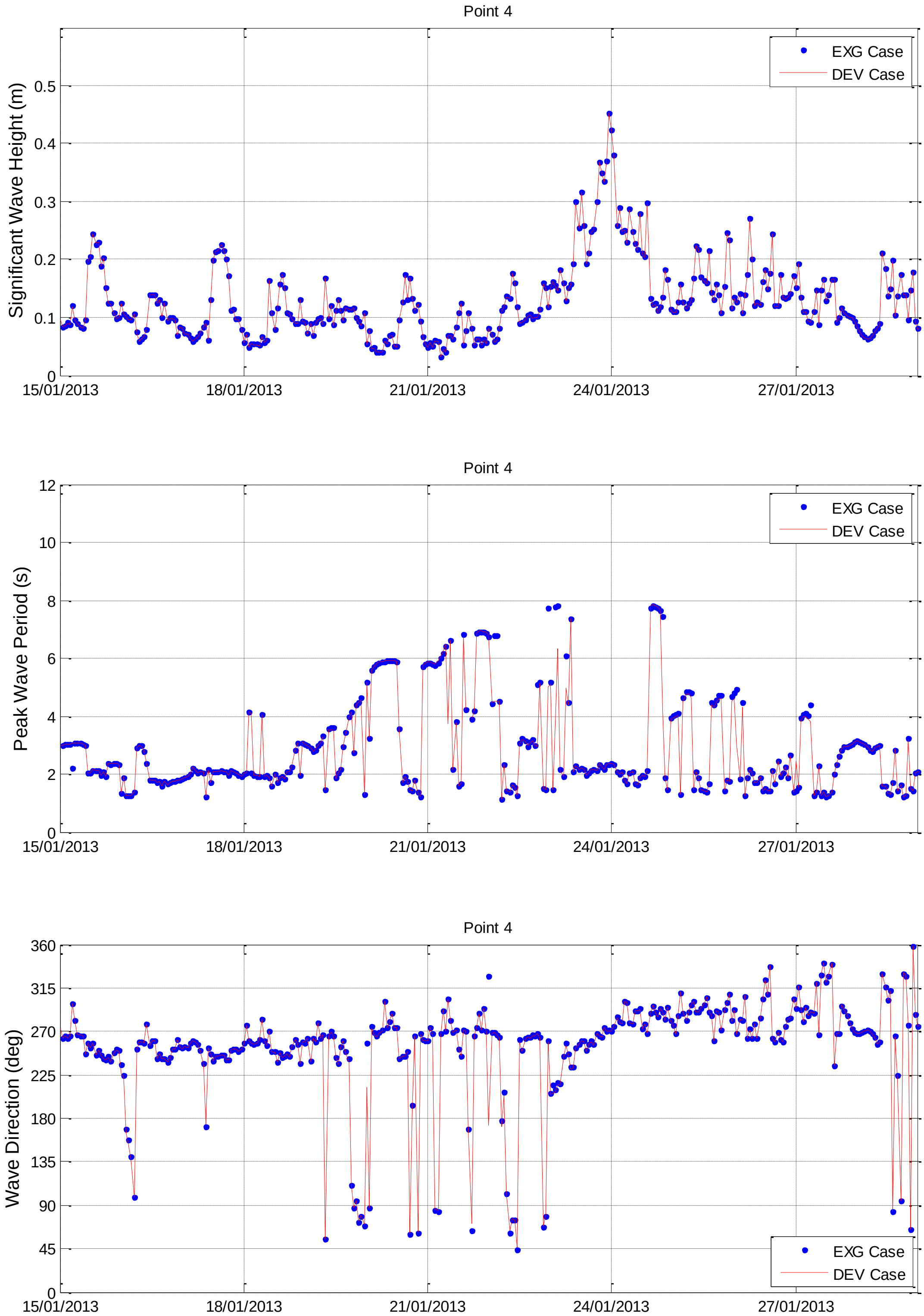


Figure 7-23 Existing Case and Developed Case Wave Parameter Timeseries Comparison (Nearshore Location Point 4 in Figure 7-2)

7.4 Morphology and Sedimentation Impacts

In the context of determining impacts on sedimentation processes, including siltation rates in the harbour and shipping channels, the sediment transport model was used to simulate the re-suspension and transport of seabed material due to the action of waves and currents. This analysis was undertaken for both the Base Case and Developed Case to determine the potential impact of the Project on bed morphology and siltation rates.

7.4.1 Littoral Sediment Transport

Based on the limited hydrodynamic impacts (Section 7.2) and wave impacts (Section 7.3) being restricted to the vicinity of the target dredge area, there are not expected to be any detectable impacts from the CSDP on the adjacent shorelines or littoral beach systems within the wider surrounds.

7.4.2 Marine Sediment Transport

The residual (net) sediment transport throughout the study area occurs shore-parallel in a north-westerly direction.

The base case, developed case net sediment transport and corresponding impact (difference) are shown together in Figure 7-24. The highest transport rates are predicted around Cape Grafton and offshore to depths approximately -8m AHD. It can be seen that the channel deepening and widening is predicted to intercept a relatively small quantity of the sediment load and therefore slightly reduce the net sediment transport to the northwest. This small reduction in fine cohesive sediment transport would not be expected to generate a perceptible morphological change either in the short or long term.

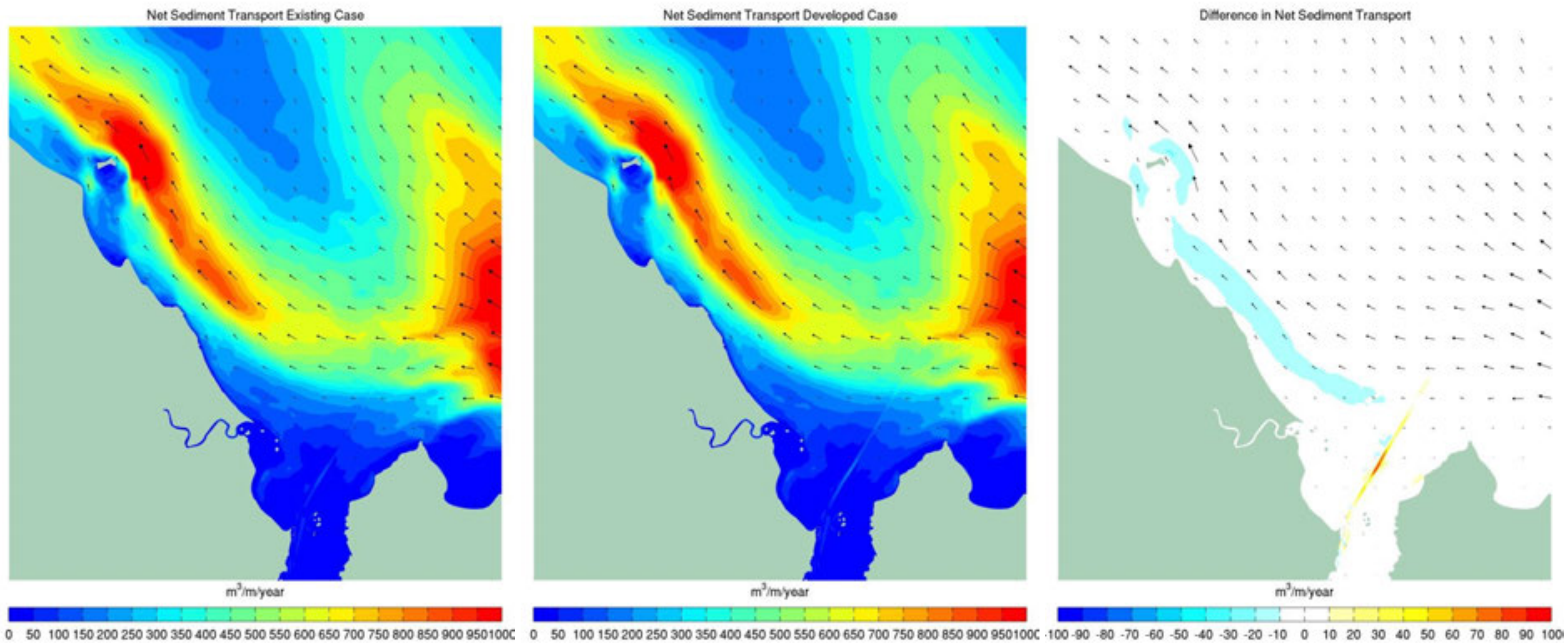


Figure 7-24 Modelled Net Sediment Transport (m3/m/year): Existing case (left); Developed case (middle) and Impacts (right)

7.4.3 Channel Siltation

The purpose of the channel siltation impact assessment is to determine the likely percentage increase in siltation volume due to the developed case dredged channel configuration. The predicted percentage increase can then be more reliably applied to the historical siltation volumes to extrapolate the likely future maintenance dredging requirements.

The siltation impact assessment has been performed by undertaking existing case and developed case simulations using the calibrated 3D hydrodynamic and sediment transport model (Sedimentation Calibration is described in Section 3.5.2.2). The developed case model bathymetry was adjusted within the channel footprint to account for the proposed channel deepening, widening and extending. In all other respects the existing case and developed case models were identical. The developed case dredged channel footprint is approximately 58% larger than the existing area and is therefore expected to experience an increased volume of annual siltation requiring maintenance dredging.

The existing and developed case simulations ran from the 19/02/2013 to the 27/06/2013, with net siltation calculations based on the period 04/03/2013 to 17/06/2013 to ensure that spring-neap cycle periods were equally sampled.

The existing case and developed case siltation distributions are shown in Figure 7-25. The developed case siltation rate and volume is predicted to be 25% higher than the existing case.

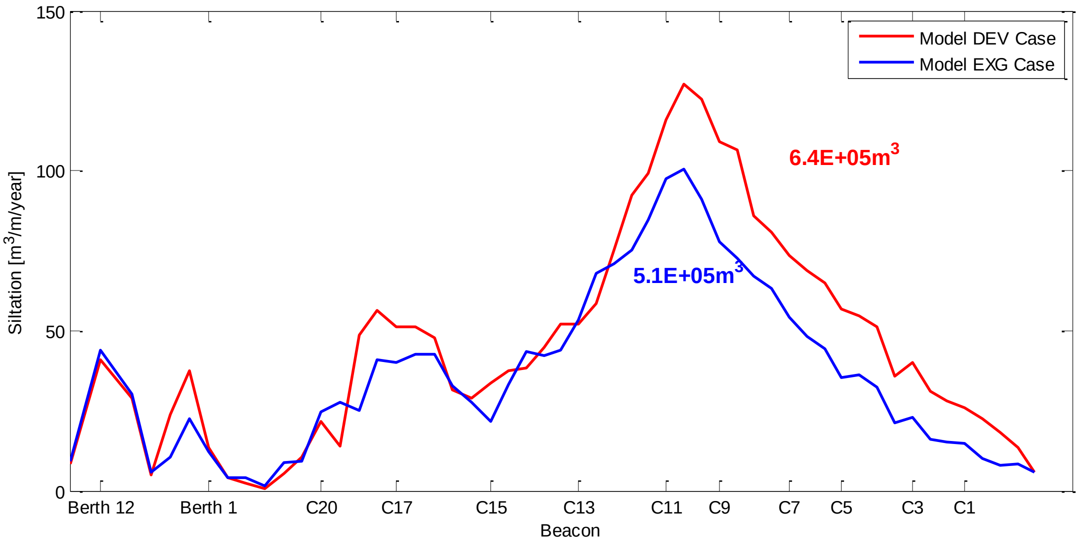


Figure 7-25 Modelled Existing Case and Developed Case Channel Siltation

8 References

Battjes, J.A. and Janssen, J.P.F.M. (1978). Energy loss and set-up due to breaking of random waves, Proceedings 16th International Conference on Coastal Engineering, ASCE, 569-587.

Beach Protection Authority (1984). Mulgrave Shire Northern Beaches. Report, A detailed study of coastline behaviour in north Queensland, Australia.

Beaman, R.J., 2010. Project 3DGBR: A high-resolution depth model for the Great Barrier Reef and Coral Sea. Marine and Tropical Sciences Research Facility (MTSRF) Project 2.5i.1a Final Report, MTSRF, Cairns, Australia, pp. 13 plus Appendix 1.

BMT WBM (2013). TUFLOW FV Science Manual.

BMT WBM (2014). Cairns Shipping Development EIS Climatic and Coastal Oceanographic Data Collection Summary Report, report prepared for Port North Pty Ltd.

Cavaleri, L. and Malanotte-Rizzoli, P. (1981). Wind wave prediction in shallow water: Theory and applications, Journal of Geophysical Research, 86, No. C11, 10,961-10,973.

Collins, J.I., (1972). Prediction of shallow water spectra, Journal of Geophysical Research, 77, No. 15, 2693-2707.

Delft University of Technology (2006). SWAN Technical Documentation, Faculty of Civil Engineering and Geosciences, Environmental Fluid Mechanics Section, Delft, Netherlands.

Devlin, M.J., McKinna L.W., Álvarez-Romero J.G., Petus C., Abott B., Harkness P. and Brodie J. (2012a). Mapping the pollutants in surface riverine flood plume waters in the Great Barrier Reef, Australia, Marine Pollution Bulletin, 65, 224-235.

Devlin, M., Wegner, A., Waterhouse, J., Alvarez-Romero, J., Abbott, B. and Teixeira da Silva, E. (2012b). Reef Rescue Marine Monitoring Program: Flood Plume Monitoring Annual Report 2010-11, ACTFR Report Number 12/02.

GBRMPA (2012). The use of Hydrodynamic Numerical Modelling for Dredging Projects in the Great Barrier Reef Marine Park, August 2012.

Hasselmann, S., Hasselmann, K., Allender, J.H. and Barnett, T.P. (1985). Computations and parameterizations of the nonlinear energy transfer in a gravity wave spectrum. Part II: Parameterizations of the nonlinear transfer for application in wave models, Journal of Physical Oceanography, 15, 11, 1378-1391.

Komen, G.J., Hasselmann, S. and Hasselmann, K. (1984). On the existence of a fully developed wind-sea spectrum, Journal of Physical Oceanography., 14, 1271-1285.

Maritime Safety Queensland (2013). Queensland Tide Tables 2013, Queensland Government.

SKM & APASA (2013). Improved Dredge Material Management for the Great Barrier Reef Region, Long-term Migration Patterns and Disposal Plume of Sediment Modelling, report prepared by Sinclair Knight Merz Pty Ltd and Asia-Pacific Applied Science Associates.

U.S. Army Corps of Engineers (2002). Coastal Engineering Manual. Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

Appendix A Peer Review Report

Prepared for

Ports North

Subject

Stage 2: Cairns Shipping Development (CSD) Project EIS Independent Peer Review of BMT WBM Report on Model Development and Calibration (August 2014)

Author

E/Professor C J Apelt

BE, DPhil (Oxon), FIEAust

18 September 2014

UniQuest Project No: C01503

The main commercialisation company of

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

UNIQUEST

Title

Stage 2

Cairns Shipping Development (CSD) Project EIS Independent Peer Review of BMT WBM Report on Model Development and Calibration (August 2014)

Disclaimer

TABLE OF CONTENTS

EXECUTIVE SUMMARY 3

1. INTRODUCTION 5

2. REVIEW PROCESS 6

3. REVIEW FINDINGS 7

3.1 Overview of Stage 2 Report (August 2014, Ref 2) 7

3.1.1. New material in first part of Stage 2 Report (Sections 1-3) 7

3.1.1.1 Issues raised in Appendix B of Ref 1 7

3.1.1.2 Sediment Transport (ST) (Stage 2 Report, Section 2.3) 8

3.1.1.3 GBRMPA Guidelines Cross-check (Stage 2 Report, Section 2.4) 8

3.1.1.4 Water Temperature Calibration (Stage 2 Report, Section 3.3.3) 9

3.2 Data for calibration/validation of the Numerical Model 9

3.2.1. Baseline calibration/validation data 9

3.2.1.1 Adequacy of baseline data collection 10

3.3 Dredge Plume Advection-Dispersion Calibration (Stage 2 Report, Section 4) 12

3.4 Model Validation (Stage 2 Report, Section 5) 13

3.4.1. Hydrodynamic Model Validation (Stage 2 Report, Section 5.3) 13

3.4.1.1 Site 1 DMPA (Stage 2 Report, Section 5.3.1.1) 15

3.4.1.2 Site 3 Beacon C7 (Stage 2 Report, Section 5.3.1.2) 15

3.4.1.3 Water levels at Cairns Port Gauge and Swallows Landing (Stage 2 Report, Section 5.3.1.3) 15

3.4.1.4 Temperature and Salinity Validation (Stage 2 Report, Section 5.3.2) 16

3.4.1.5 Comment on Hydrodynamic Model Validation Results 16

3.4.2. Wave Model Validation (Stage 2 Report, Section 5.4) 16

3.4.3. Sediment Re-suspension Model Validation (Stage 2 Report, Section 5.5) 17

3.5 Dredging Impact Assessment (Stage 2 Report, Section 6) 17

3.5.1. Modelled Sediment Fractions (Stage 2 Report, Section 6.2.1) 17

3.5.2. Dredging cases modelled and their simulation periods (Stage 2 Report, Sections 6.1 and 6.2.4) 17
3.5.3. Methodology for assessment of impacts of proposed dredging (Stage 2 Report, Section 6.2.5) 18
3.5.4. Results of Dredging Impact Assessments (Stage 2, Sections 6.3-6.9) 19
3.5.4.1 Case 1: Base Case Capital Program 19
3.5.4.2 Case 2: Alternative Base Case Capital Program 20
3.5.4.3 Case 3: "Worst Case" Soft Material Dredging 20
3.5.4.4 Case 4: "Worst Case" Stiff Material Dredging 20
3.5.4.5 Case 5: 12 Month Re-suspension Scenario 20
3.5.4.6 Case 6: "Worst Case" Re-suspension Scenario 20
3.6 Coastal Processes Impact Assessment (Stage 2 Report, Section 7) 21
3.6.1. Hydrodynamic Impacts (Section 7.2) 21
3.6.1.1 Flow patterns in the immediate vicinity of the works (Section 7.2.1) 21
3.6.1.2 Tidal water levels (Section 7.2.2) 22
3.6.1.3 Tidal flows, volumes and flushing (Section 7.2.3) 22
3.6.1.4 Bed shear stresses (Section 7.2.4) 22
3.6.1.5 Extreme water levels (Section 7.2.5) 22
3.6.2. Wave Impacts (Section 7.3) 23
3.6.3. Morphology and Sedimentation Impacts (Section 7.4) 23
3.6.3.1 Channel Siltation (Section 7.4.3) 24
4. CONCLUSIONS 25
5. REFERENCES 30
APPENDIX A – Questions and Comments for BMT WBM 31
APPENDIX B – Response from BMT WBM 36

EXECUTIVE SUMMARY

Emeritus Professor Apelt was engaged by UniQuest Pty Limited to provide for Ports North an Independent Peer Review of the numerical modelling of the hydrodynamic sediment transport and water quality modelling work that will underpin the EIS for the proposed Cairns Shipping Development Project.

It was envisaged that the Peer Review would be undertaken in two stages;

- An initial review of the draft modelling and baseline environment report (Stage 1) (Reference 1);
- A review of the draft final modelling technical report (Stage 2) (Reference 2), considering: The final output from the review will be a consolidated Peer Review report which will be included as part of the EIS documentation.

This Report provides the results of the Peer Review of the draft final modelling report (Stage 2) (Reference 2).

The BMT WBM report on the numerical model development and calibration, dated August 2014 (Reference 2), has been reviewed in detail with regard to the quality of the model, its calibration and validation and its satisfaction of the Cairns Shipping Development (CSD) Project EIS.

The review of the draft modelling report in Stage 1 (Reference 1) is provided in Reference 3. It deals with the model adequacy and the “fitness for purpose” of the modelling system, the adequacy of data sources and the quality of model calibration/validation during the initial period of the process.

The Stage 2 report under review here includes the material of the Stage 1 report (Reference 1) with some minor changes. This material has been reviewed in detail in Stage 1 and that review was reported in Reference 3. This is discussed briefly in the current review but most of the focus is given to the new material in Reference 2 that deals with validation of the model and the assessment of the impacts of dredge plumes from the proposed capital dredging work and of the impacts of the completed capital dredging work on coastal processes.

The conclusions drawn from the review process are given in detail in the Report and in its Conclusions. In summary, this review has satisfied the reviewer:

- that the numerical modelling system is adequate and fit for the purposes and requirements for numerical hydrodynamic modelling of the EIS for the proposed Cairns Shipping Development Project;
- that the data sources are adequate to establish the baseline existing environment assessments and to validate the modelling system for its prediction of the long term indirect impacts of dredging;
- that, overall, the calibration and validation of the numerical model are of good quality; and
- that the numerical modelling is able to predict well the physical impacts of the proposed capital dredging for the CSDP by accurate modelling of the TSS plumes generated by dredging and dredge spoil disposal operations and of sediment settling.

1. INTRODUCTION

Emeritus Professor Apelt was engaged by UniQuest Pty Limited to provide for Ports North an Independent Peer Review of the numerical modelling of the hydrodynamic sediment transport and water quality modelling work that will underpin the EIS for the proposed Cairns Shipping Development Project.

It was envisaged that the Peer Review would be undertaken in two stages:

- An initial review of the draft modelling and baseline environment report (Stage 1) (Reference 1)
- A review of the draft final modelling technical report (Stage 2) (Reference 2), considering: The final output from the review will be a consolidated Peer Review report which will be included as part of the EIS documentation.

This Report provides the results of the Peer Review of the draft final modelling technical report (Stage 2) (Reference 2).

2. REVIEW PROCESS

The BMT WBM report on the numerical model development and calibration, dated August 2014 (Reference 2), has been reviewed in detail with regard to the quality of the numerical model, its calibration and validation and its application to the numerical modelling requirements for the proposed capital dredging required for the Cairns Shipping Development (CSD) Project EIS, including the assessment of the likely impacts of the proposed capital dredging.

The periods of data recording for calibration and for validation of the numerical hydrodynamic model have been completed since the review of Reference 1 and this review has assessed more thoroughly the adequacy of the baseline data that has been collected. Some further developments and applications of the model have been completed since the review of Reference 1 and this review has taken account of these to confirm the adequacy and the "fitness for purpose" of the modelling system. The quality of model calibration and validation has been assessed against the completed sets of data recording

The Stage 2 report provides extensive information about the application of the modelling system to assess the impacts of six variants of the capital dredging and dredge spoil disposal proposed for the CSDP. These are reviewed from the perspective of the numerical modelling and of the physical results produced.

During this review, clarification was sought through Ports North from the modelling team at BMT WBM on a list of matters in Reference 2. The reviewer's request for clarification and the responses by BMT WBM are given in Appendix A. The responses detailed in Appendix A are considered by the Peer Reviewer to be completely satisfactory and the information in them has been incorporated into this review report of Stage 2. No further discussion of these matters is required.

In response to this review report of Stage 2, BMT WBM Brisbane has offered (11 September 2014) clarification on two matters raised in the report concerning:

1. provision of conservation of mass of sediment checks (Section 3.1.1.1); and
2. ambiguity regarding the data collection period and the calibration and validation period (Section 3.2.1).

These clarifications are given in Appendix B. They are considered by the Peer Reviewer to be satisfactory and the information in them has been incorporated into this review report of Stage 2. No further discussion of these matters is required.

3. REVIEW FINDINGS

3.1 Overview of Stage 2 Report (August 2014, Reference 2)

The Stage 2 Report of August 2014 (Reference 2) consists of two parts:

1. The first part, Sections 1, 2 and 3, essentially repeats the material in the Stage 1 Report of November 2013 (Reference 1) with some additional material, including that added to deal with issues raised in Appendix B of Reference 1. This first part of the report provides a detailed description of the TUFLOW FV 3D modelling system that is used in the study and of its calibration. Most of the material of this first part was reviewed in detail in Reference 3. Only the new material is reviewed below;
2. The second part, Sections 4, 5, 6 and 7, is new material that describes the validation of the numerical modelling system and the application of the model to assess the impacts of the proposed capital dredging for the CSD Project. This material is reviewed in detail in this report.

3.1.1. New material in first part of Stage 2 Report (Sections 1-3)

3.1.1.1 Issues raised in Appendix B of Reference 1

Except for the issue of the conservation of mass of non-reacting sediments discussed below, all of the substantial issues raised in Appendix B of Reference 1 have been dealt with satisfactorily by revisions within the relevant parts in Stage 2 Report.

Conservation of mass of non-reacting sediments

The accuracy of the conservation of mass of non-reacting sediments within the TUFLOW FV 3D modelling system was raised in Appendix B of Reference 1. A satisfactory response was provided by BMT WBM in Appendix C of Reference 1, illustrated by an example that demonstrated very accurate conservation of mass. It was acknowledged that "mass of sediment" checks are crucial to dredge program modelling and will be included with the final version of the technical report. This has not been done in the Stage 2 Report.

Revision: after the completion of this review of the Stage 2 Report, BMT WBM has provided in Appendix B a set of plots that show the sediment mass balance check for the six CSDP dredging assessment scenarios. It is noted that these will be added as an Appendix to the final version of the modelling report by BMT WBM. The reviewer recommends that some explanatory commentary about each plot should be included in that proposed Appendix.

3.1.1.2 Sediment Transport (ST) (Stage 2 Report, Section 2.3)

A satisfactory description of the Sediment Transport (ST) module incorporated in the TUFLOW FV model, coupled with calibrated wave and hydrodynamic models, is provided. No comment is required.

It is noted that a critical component of the calibration process – the initialisation of bed material composition (i.e. the relative proportions of each sediment fraction at each computational node within the model domain) – was achieved through running "bed warm-up" simulations that were undertaken prior to running the predictive assessments. This action is endorsed.

3.1.1.3 GBRMPA Guidelines Cross-check (Stage 2 Report, Section 2.4)

This new section of the report provides a detailed assessment of the modelling approach used in the CSDP EIS against the GBRMPA hydrodynamic modelling guidelines.

Comment

Many of the guidelines specify requirements of the numerical modelling system. The numerical modelling system being used consists of the TUFLOW FV 3D hydrodynamic model, incorporating a cohesive sediment module and coupled with the SWAN wave modelling system. It has been reviewed in detail in Reference 3. That review established that the numerical modelling system being used is adequate and fit for purpose with regard to the modelling of the physical coastal processes relevant to the CSDP EIS. It meets all of the requirements specified with regard to these physical coastal processes in the final EIS Guidelines for the CSD Project (SEWPAC & GBRMPA, 2013). In particular the hydrodynamic modelling reviewed in Reference 3 is in accordance with the GBRMPA Guidelines for the Use of Hydrodynamic Numerical Modelling for Dredging Projects in the Great Barrier Reef Marine Park (Australian Government, GBRMPA August 2012) with specific regard to the modelling of physical coastal processes.

Guideline 14 states requirements that imply the degree of mesh resolution required for the modelling to adequately resolve sudden changes in bathymetry. It is recommended that "the minimum resolution as a function of mesh size to pick up changes in hydrodynamic flow associated with a dredge channel is two cells within the width of a dredged channel." In the Stage 2 Report, Figure 2-2 TUFLOW FV Hydrodynamic Model Mesh Detail indicates that a minimum of two cells is used to represent the bottom width of the dredged channel.

No comment is made in this review on the other matters including those relating to water quality, marine ecology, etc. that are not directly relevant to the numerical model development, calibration and validation.

3.1.1.4 Water Temperature Calibration (Stage 2 Report, Section 3.3.3)

Near Bed Temperatures have been modelled for the calibration period from 01/ March 2013 to 14 June 2013 at all four Sites 1, 2, 3 and 4 that were used for the calibration of the numerical model.

Good agreement has been achieved between the modelled predictions and the measured data at all four sites.

3.2 Data for calibration/validation of the Numerical Model

3.2.1. Baseline calibration/validation data

Detailed review of the collection of baseline calibration data was provided in Reference 3 and is not repeated here. However, it is necessary to clarify some apparent ambiguity that is present in that review concerning the duration of the baseline data collection, encompassing both calibration and validation periods.

It was stated correctly that the baseline data for calibration purposes was collected in the period from March to June 2013. However, the statement "*that collection has been continued after June 2013 and this is expected to continue until about February 2014"* is not correct. In fact the second period of baseline data collection for validation purposes continued only until October 2013.

Correction: After the completion of this review of the Stage 2 Report, BMT WBM has clarified this matter with information provided in Appendix B. As stated there, baseline data was in fact collected at Sites 1 and 3 continuously for the twelve months from late February 2013 until February 2014. However, for the purpose of model validation, the data collected for the period July to October 2013 was used, rather than for the longer period from July 2013 to February 2014. BMT WBM has undertaken to ensure that there will be no ambiguity regarding data collection and model simulation periods in the final version of the modelling report.

The period of collection of baseline data used for calibration and validation of the numerical model was, therefore, approximately 8 months from 01 March 2013 to 15 October 2013, split into two halves. The first period from 01 March 2013 to15 June 13 was used for calibration of the numerical model, with data being recorded at 4 sites:

- Existing DMPA - Site 1;
- Alternate DMPA - Site 2;
- Channel Beacon C7 - Site 3; and
- Channel Beacon C11 - Site 4.

The second period of collection of baseline data was from 01 July 2013 to 15 October 2013 for validation of the numerical model, with data being recorded at two sites:

- Existing DMPA - Site 1; and
- Channel Beacon C7 - Site 3

The details of the data collected during the first period are discussed in Reference 3 and this is not repeated here.

3.2.1.1 Adequacy of baseline data collection

In Reference 4, a later Addendum to Reference 3 dated 16 December 2013 that was prepared for Ports North, the adequacy of the baseline data collected for the completed calibration and for the expected validation is appraised in detail. The main conclusions from that appraisal are:

- The data from two of the four sites used for calibration of the numerical model provide sufficient information for the calibration and validation of the hydrodynamic model;

- The data records for all the physical coastal processes at Sites 1 and 2 are very similar in all respects; either of these sites is sufficient for calibration and validation purposes – the other is redundant;

- The data records at Sites 3 and 4 are very similar with respect to all the physical coastal processes except for current velocities and directions; for these the data for Site 4 show increased influence of the channel, as expected. Either of these Sites is sufficient for calibration and validation processes. The choice of Site 3 is supported because it is more representative of the coastal processes for calibration and validation;

- In summary, the two locations (Site 1 and Site 3) chosen for the continuous recording of data for calibration and validation and the type of data recorded are considered completely adequate for the calibration and validation of the hydrodynamic model for the modelling of the physical coastal processes of tidal depths, current velocities and directions, waves and sediment re-suspension and dispersion, for the purposes of the CSD Project EIS.

However there is one statement in Reference 4 that requires correction. It was noted there that "*the continuous recording of data over a period of one year is considered to be of adequate duration for final assessment of the baseline characteristics of the relevant physical coastal processes, listed above. After completion of the one year period of continuous data recording* *the detailed calibration and validation of the hydrodynamic model can be completed."* In fact, it is now known that the total period of collection of baseline data was approximately eight months, from 01 March 2013 to 15 October 2013 (see next paragraph for revision) and whether this duration is sufficient must be re-considered here.

Revision: as stated in Section 3.2.1, after the completion of this review of the Stage 2 Report, BMT WBM has clarified this matter with the information provided in Appendix B. As stated there, baseline data was in fact collected at Sites 1 and 3 continuously for the twelve months from late February 2013 until February 2014. This later information does not require change to the assessments in the following paragraphs.

The collection of baseline data extended over a period of typical "late wet season and early dry season" months in the first half (calibration period) and then into the "dry season" months in the second half (validation period).

Both calibration and validation periods incorporated representative spring and neap tide conditions, with the latter period including some noticeably larger ranges in spring tides. In contrast to the calibration period (March to June), the validation period included months typically characterised by strong Coral Sea trade winds and periods of offshore EAC forcing.

There is one "deficiency" in the data, however, because no substantial fluvial inflow occurred during the period of data collection. Typically, the Barron River and other streams discharge substantial freshwater inflows into Trinity Bay during average wet season months. Unfortunately this has not been the case in recent years and it did not occur during the period of data collection. The most recent substantial flood event in the Barron River was in 2011. As described in the Stage 2 Report section 5.6, the impact of this event on the study area was modelled by hindcasting. This is the best that can be done at this time and it would be inappropriate to extend the period of data collection indefinitely in the hope that a flood event might be monitored.

Comment

Apart from the one deficiency from the lack of substantial fluvial inflow during the period of data collection, it is considered that the combined calibration and validation periods provide sufficient variability in general climatic and tidal conditions to be adequate for use in long term impact assessments required by the CSDP EIS.

It is suggested that consideration be given to maintaining readiness for fast deployment of appropriate instrumentation to measure the impacts in the study area of a significant Barron River flood event, when one is known to be imminent.

However, it is considered to be very unlikely that the capital dredging that is proposed for the CSDP will cause significant changes to the impacts that a significant flood event will have on the receiving waters in the study area. Changes in the conveyance of the access channel that the CSDP capital dredging would cause will be small relative to the total conveyance in the study area. Also, changes to the tidal volumes will be very small. The effects of these small changes on the impacts of a significant flood event are expected to be very small. This judgement is strongly supported by the results of the modelling of potential hydrodynamic impacts that would be caused by the CSDP proposed capital dredging, presented in Section 3.6.1 Hydrodynamic Impacts. These impacts have been shown to very small in all aspects and negligible in most.

3.3 Dredge Plume Advection-Dispersion Calibration (Stage 2 Report, Section 4)

Maintenance dredging of the Port of Cairns and entrance channel was undertaken in August 2011 by the trailing arm suction hopper dredger (TSHD) Brisbane operated by the Port of Brisbane Pty Ltd. BMT WBM was commissioned by Ports North to monitor the extent of turbid plume development during these maintenance dredging operations Dredge plume monitoring was conducted by BMT WBM in the near shore and offshore areas of the Port of Cairns from 28 to 30 August 2011. Monitoring of the extents of dredging and placement plumes within the Port of Cairns occurred over these three days using the research support vessel Viking as a platform for all measurements. These measurements have been used in the CSDP to assist in the validation of the advection-dispersion model and to guide the adoption of specific sediment loading rates for the proposed dredging activities. The details of this monitoring are given in the Stage 2 Report, Section 4.
The major sources of sediment considered for the modelling of the TSHD Brisbane were:

- Sediment entrainment at the drag head during dredging;
- Overflow of sediment from the hopper; and
- Placement of material at the DMPA by hopper release.

The 3D TSS concentrations generated during the maintenance dredging were measured in transects with an ADCP. The results from the measured transects were compared to results from simulations of plume dispersion using the TUFLOW FV cohesive sediment module coupled with the calibrated hydrodynamic models, in order to calibrate the dredge plume source parameters. These comparisons are shown in the Stage 2 Report in Figure 4-2 to Figure 4-6 for channel dredging and Figure 4-7 to Figure 4-10 for DMPA placement. In addition to the vertical transects, the figures show in plan view contour plots that compare the measured and modelled depth-average TSS.

Comment

This is an extremely challenging application of the numerical modelling system that goes far beyond what is needed for the CSD project EIS. The results of the modelling are in general accordance with the data measured – the limitations of each in such a demanding application must be acknowledged. This is an impressive demonstration of the "flexibility and ruggedness" of the modelling system.

3.4 Model Validation (Stage 2 Report, Section 5)

As discussed in Section 3.2.1.1, the validation period experienced substantial differences in the wind, wave and tidal climates from those during the calibration period. This is a pleasing feature because the model must respond to different inputs during validation than was the case during calibration and its robustness was better tested as a consequence. The calibration and validation periods together provided assessment of the model predictive skill for a range of conditions and its suitability for use in long term impact assessments.

3.4.1. Hydrodynamic Model Validation (Stage 2 Report, Section 5.3)

The hydrodynamic model validation period was from 01 July 2013 to 15 October 2013. The validation simulation was completed using the model parameters adopted for the final calibration simulation (Stage 2 Report Section 3.3 and Appendix B). The simulation period incorporated representative spring and neap tide conditions, a range of meteorological conditions and offshore EAC forcing. In contrast to the calibration period (March to June 2013), the validation period includes months typically characterised by strong Coral Sea trade winds. Considering both the calibration and validation periods enabled assessment predictive skill for a range of conditions and its suitability for use in long term impact assessments required by the CSDP EIS.

Two locations were used for validation of the hydrodynamic model (Site 1 at the DMPA and Site 3 at Beacon C7) compared to the four Sites used for the calibration period. As discussed in Section 3.2.1.1, these two Sites are considered completely adequate for the validation.

The Stage 2 Report includes in its section 5.3 model validation plots at the DMPA and Beacon C7 of:

- Water level and depth-average current time series (six day period from 16 August 2013 to 22 August 2013);
- Top, middle and bottom third of water column average current velocity and direction (six day period from 16 August 2013 to 22 August 2013);
- Depth-average current polar plots (entire calibration period);
- Cairns Port and Trinity Inlet (Swallows Landing) water level time series (two week period from 02 August 2013 to 16 August 2013);
- Near-bed water temperature time series (entire calibration period)
- Surface salinity at Site 3 only (seven week period from 01 July 2013 to 19 August 2013)

The six day period from 16 August 2013 to 22 August 2013 selected for detailed visualisation of the time series of the first two items above includes large spring tides and relatively light wind conditions.

More detailed validation plots for the two Sites are provided for the full validation period from 16 August 2013 to 22 August 2013 in:

- Appendix F - Top 50% depth average and Bottom 50% depth average current velocity and direction;
- Appendix G - Top 2m depth average and Bottom 2m depth average current polar plots; and
- Appendix H - Recorded data and model distributions of Top 50% and Bottom 50% depth average current components and current speeds.

3.4.1.1 Site 1 DMPA (Stage 2 Report, Section 5.3.1.1)

Water levels

The modelled prediction of water levels is of generally similar quality to that achieved during calibration. Generally, the tidal variation is predicted well with the match of HW better than that for LW. During the Spring Tides the predicted LWS is higher than the recorded data by 0.1 - 0.2m in the worst cases during validation and about 0.1m higher than recorded during calibration; it is noted that the maximum tidal range is nearly 3m during validation, compared to 2.2m during calibration. These differences could indicate that bed friction may be over-estimated by a small amount but the discrepancy could be caused by other factors, such as local tidal anomalies.

Currents

The modelled predictions of depth averaged current velocity and directions generally correlate reasonably well with the recorded data. The range of current directions is greater than that in the calibration period.

The modelled current velocities averaged over the top, middle and lower thirds of depth show the expected reductions towards the lower layers. However, the model under predicts magnitudes in the bottom third.

The modelled current directions averaged over the top, middle and lower thirds of depth correlate well with the recorded data.

3.4.1.2 Site 3 Beacon C7 (Stage 2 Report, Section 5.3.1.2)

The correlations between the modelled predictions and the data for water levels and for currents are generally good and similar in quality to those for Site 1, except that the bottom third averaged current velocity is better predicted at Site 3 than at Site 1.

Current directions at Site 3 are strongly influenced by the channel direction.

3.4.1.3 Water levels at Cairns Port Gauge and Swallows Landing (Stage 2 Report, Section 5.3.1.3)

The agreement between the modelled predictions for water levels and the recorded data at these locations is excellent.

3.4.1.4 Temperature and Salinity Validation (Stage 2 Report, Section 5.3.2)

Near bed temperatures at Site 1 and Site 3

Overall, the modelled predictions match the warming trend well for the whole period except that the model predicts temperatures higher than the recorded data by up to 1.5ºC for about a month from late July 2013.

Salinity at Site 3

The modelled predictions show little variation over the period with the salinity slightly higher than the recorded data. However, questions exist about the reliability of the data.

3.4.1.5 Comment on Hydrodynamic Model Validation Results

Generally, overall the hydrodynamic model validation results indicate correlations between modelled predictions and recorded data that are consistent with those for the calibration results. The validation results confirm that the adopted parameters are appropriate for the range of seasonal hydrodynamic conditions typically encountered at Cairns.

3.4.2. Wave Model Validation (Stage 2 Report, Section 5.4)

The wave model validation was done for the five month period from 01 June 2013 to 30 October 2013. Significant wave height, peak wave period and wave direction were recorded at Site 1 DMPA and Site 3 Beacon 3 for the whole period and compared with the modelled predictions.

The validation period included intervals of stronger waves compared to the calibration period. Significant wave heights are predicted well by the model at both sites. There is some small over prediction at Site 3 – it is thought that this may be due to some deficiency in the constructed wind field arising from imperfect resolution of the transition from over-land to over-sea winds.

The correlations between predicted and measured peak wave periods are of variable quality throughout the validation but are generally acceptable.

The recorded wave directions are much more coherent during validation than during calibration. The correlations between modelled predictions and the recorded data are generally good at both sites.

3.4.3. Sediment Re-suspension Model Validation (Stage 2 Report, Section 5.5)

The period used for validation of the sediment re-suspension model extended for five weeks from 18 August 2013 to 22 September 2013. Ambient TSS was recorded at three baseline data recording locations: Trinity Bay, Yorkeys Knob and Palm Beach. Plots of the recorded bottom 2m TSS are compared with the modelled predictions. (It is noted that these sites are all some distance to the North of the CSDP.)

The larger peak values of the recorded bottom 2m TSS are generally predicted reasonably well, especially at Yorkeys Knob and Palm Beach. Short periods of elevated TSS values associated with Spring Tides are predicted but the modelled predictions show substantial lags at Yorkeys Knob and Palm Beach for the one week period of elevated TSS in the first week of September 2013. This week corresponds to a period of larger Significant Wave Heights at Sites 1 and 3.

3.5 Dredging Impact Assessment (Stage 2 Report, Section 6)

3.5.1. Modelled Sediment Fractions (Stage 2 Report, Section 6.2.1)

The dredging impact assessments simulated the re-suspension of “ambient” surficial seabed material as well as the re-suspension of “dredged” material that had been placed at the DMPA. Eight sediment fractions (four ambient sediments and four dredge material sediments) were simulated as part of the dredging impact assessments in order to track both the ambient and dredged material. Physical properties and model parameters were generally identical for corresponding size fractions of the ambient and dredge material, with the exception of the dredged material erosion rate constant which was increased by a factor of 1.5 over the calibrated ambient rate within the DMPA perimeter. This increase was undertaken in order to represent the potentially lower degree of consolidation of dredged material (at least initially after placement).

3.5.2. Dredging cases modelled and their simulation periods (Stage 2 Report, Sections 6.1 and 6.2.4)

Six dredging cases were modelled to assess their likely impacts. The scenarios modelled and the simulation period used for each case are summarised in Table 3.5.2.

Table 3.5.2 Summary of dredging cases modelled for impact assessment

Dredging case modelled	Stage 2 Report section	Simulation period	Note
Case 1. Base Case Capital Program	6.3	01 March 2011 to 30 October 2011 (8 months)	(a)
Case 2. Alternative Case Capital Program	6.4	01 April 2011 to 04 September 2011 (22 weeks)	(b)
Case 3. “Worst Case” Soft Material Dredging	6.5	10 June 2011 to 12 July 2011 (30 days within Case 1 at time of most extensive dredge plumes)	(c)
Case 4. “Worst Case” Stiff Material Dredging	6.6	Same as for Case 3	(c)
Case 5. 12 Month Re-suspension Scenario	6.7	30 October 2011 to 01 November 2012 (12 months). Final state at end of Case 1 used as initial conditions	
Case 6. “Worst Case” Re-suspension Scenario	6.8	10 January 2011 to 20 February 2011 including Cat 5 TC Yasi, starting from same initial conditions as Case 5.	(c)

Notes

(a) Estimated period for BHD dredging all material in inner harbour in parallel with TSHD dredging all material elsewhere in parallel - 34 weeks.

(b) Estimated period for BHD dredging stiff material in inner harbour in parallel with TSHD dredging all material elsewhere - 21 weeks.

(c) Worst case assessments are for shorter periods coinciding with the period of maximum impacts within the case to which they are applied**.**

3.5.3. Methodology for assessment of impacts of proposed dredging (Stage 2 Report, Section 6.2.5)

The predicted effect of each CSDP dredging case was assessed from the modelled increases in suspended sediment concentration and sedimentation above natural or ambient levels. Both ambient and dredged related signals have been resolved in the predictive model, which enables an understanding of the significance of the dredged contribution in relation to ambient conditions.

The water column turbidity impacts associated with dredging-related suspended sediment were derived by converting the modelled Total Suspended Solids (TSS) levels into an equivalent turbidity value (NTU) using the relationship previously presented in Figure 3-1 of the Stage 2 Report.

The sedimentation impacts were derived from the daily rate of change in bed sediment mass associated with the dredged fractions. The adopted sedimentation rate units are $mg/cm^2/day$. The predicted effects of dredging have been assessed using two different presentation techniques:

- Time series at sensitive receptor sites; and
- Spatial plots based on percentile analysis.

3.5.4. Results of Dredging Impact Assessments (Stage 2, Sections 6.3-6.9)

The following results are plotted as spatial distributions for each of the six CSDP dredging cases summarised in Table 3.5.2:

- The 95^{th} percentile modelled average ambient turbidity - depth average;
- Impact of dredging on the 95^{th} percentile turbidity - depth average;
- The 95^{th} percentile modelled average ambient turbidity - bottom 1m;
- Impact of dredging on the 95^{th} percentile turbidity - bottom 1m;
- The 50^{th} percentile modelled average ambient turbidity - depth average;
- Impact of dredging on the 50^{th} percentile turbidity - depth average;
- The 50^{th} percentile modelled average ambient turbidity - bottom 1m;
- Impact of dredging on the 50^{th} percentile turbidity - bottom 1m;
- Impact of dredging on the 95^{th} percentile deposition rate; and
- Impact of dredging on the 50^{th} percentile deposition rate.

Some of the main findings of the dredging impacts assessment are summarised below.

3.5.4.1 Case 1: Base Case Capital Program

Deposition of dredged sediments occurs in the vicinity of the channel and at the DMPA during the base case capital program. Outside of the DMPA perimeter, peak deposition rates are less than 80 $mg/cm^2/day$ at the 95^{th} percentile. This corresponds to deposition of less than 1mm/day during the infrequent periods of elevated sedimentation.

Typical sedimentation levels during the base case dredging campaign, represented by the 50^{th} percentile, are generally less than 10 $mg/cm^2/day$, corresponding to less than 0.1 mm/day within the predicted deposition zone. At the DMPA, the deposition zone aligns with the prevailing currents in a north-easterly to south-easterly direction. The additional dredged sediment deposition outside of the immediate project area is generally considered to be of negligible impact in the context of the natural ambient material deposition rates.

3.5.4.2 Case 2: Alternative Base Case Capital Program

Alternative base case deposition rates are of a similar magnitude to those for the base case capital program. At the acute level (95th percentile) deposition rates in areas outside of the project area are very low.

3.5.4.3 Case 3: "Worst Case" Soft Material Dredging

Deposition rates during "worst case" soft material dredging are slightly greater than the capital base case deposition rates. However, they are still predicted to reach only low levels and are generally confined to the project area. Increases to deposition at far field locations are very low and are likely to be undetectable.

3.5.4.4 Case 4: "Worst Case" Stiff Material Dredging

Deposition rates during "worst case" stiff material dredging are similar to those for the soft material case. The predicted increases to deposition are low to very low at the acute (95th percentile) and chronic (50th percentile) and are likely to be undetectable in the context of typical ambient conditions.

3.5.4.5 Case 5: 12 Month Re-suspension Scenario

The redistribution and deposition of dredged related sediments is evident only within the immediate vicinity of the shipping channel. Deposition of dredged material from the DMPA is undetectable for the percentiles and ranges shown.

The quantity of material outside of the DMPA perimeter at the end of the 12 month period is relatively small, being less than 0.1% of the initial DMPA mass.

3.5.4.6 Case 6: "Worst Case" Re-suspension Scenario

The results suggest that re-suspension from the DMPA may occur during the severe conditions associated with significant tropical cyclones. For the simulated period that included Tropical Cyclone Yasi, dredged related material was predicted to deposit southeast of the DMPA in response to the north-easterly wind and wave conditions that occurred in Cairns after the cyclone made landfall near Cardwell.

At the worst case re-suspension 95th percentile, CSDP dredge sediment deposition rates of up to 40 mg/cm^2 /day are predicted outside of the DMPA. Given the significant re-suspension and subsequent deposition of natural ambient sediment during extreme tropical cyclone events, it is considered that the contribution of CSDP dredge sediments to the total deposition rate would be of no consequence.

Very minor deposition of CSDP dredged sediments within the vicinity of the shipping channel is shown at the 95th and 50th percentiles. Again, it is considered that this material would be undetectable within the context of ambient re-suspension during an extreme tropical cyclone event.

The quantity of material dispersed from the DMPA was also predicted using the model. The quantity of material outside of the DMPA perimeter at the end of the assessment was relatively small, at approximately 1.1% of the initial DMPA mass.

Comment
All of the summary assessments of the impacts of the six variants of the proposed CSDP proposed capital dredging are consistent with the evidence presented in the Stage 2 Report.
It is noted that these assessments deal only with the impacts on turbidity and sediment processes within the water column. Issues of water quality and ecology are treated in a different part of the EIS.

3.6 Coastal Processes Impact Assessment (Stage 2 Report, Section 7)

3.6.1. Hydrodynamic Impacts (Section 7.2)

The CSDP channel dredging will increase the conveyance (flow capacity) of the dredged channel entering Trinity Bay and, theoretically, it has the potential to affect the hydrodynamics in the study area. The hydrodynamic model was used to assess these possible impacts.

3.6.1.1 Flow patterns in the immediate vicinity of the works (Section 7.2.1)

The velocity impact plots show that the changes in velocity magnitudes associated with the CSDP are confined to the Project Area and to the immediate surroundings. The largest magnitude changes are small (generally up to ± 0.1m/s). The velocities in the deepened and widened channel are generally reduced, with some localised areas of increased velocities immediately adjacent to the dredging footprint. Further afield on the relatively shallow Trinity Bay mudflats to the east and west of the channel alignment, current velocities are generally slightly reduced (by less than 10% of their existing case values). Time series of depth-averaged velocity were extracted at seven sites distributed along the dredged channel. The time series correspond to a period that includes some relatively large spring tide conditions. In general, differences between the modelling results for the existing and developed case time series are difficult to distinguish.

3.6.1.2 Tidal water levels (Section 7.2.2)

Spatial water level impacts were analysed by differencing the Existing Case and Developed Case simulation results. The results of this analysis were that water level differences due to the CSDP dredging are everywhere and at all times negligible.

3.6.1.3 Tidal flows, volumes and flushing (Section 7.2.3)

The time series of the tidal flow at three transect locations in the region of the Inner Harbour were extracted from the existing and developed case model simulations. Transect 1 is across the main Trinity Inlet channel at the Smith Creek swing basin. Transect 2 is located across the northern arm of Smith Creek. Transect 3 is located across the main Trinity Inlet channel around 1.8km upstream from the Smith Creek swing basin. The time series comparisons show no discernible difference between existing case and developed case flows.

Tidal prism volumes were derived from the flows at these transects. Impacts were derived for the 50^{th} percentile (a typical tidal range) and for the 95^{th} percentile (a fairly large spring tidal range). The change in tidal prism within Trinity Inlet due to the CSDP is less than 0.1% at the 50^{th} percentile and less than 0.2% at the 95^{th} percentile. These small changes to tidal prism will have virtually no impact on the flushing in the Inlet.

3.6.1.4 Bed shear stresses (Section 7.2.4)

The changes in bed shear stress magnitude associated with the CSDP are confined to the Project Area and the immediate surrounds. The largest changes are small (generally up to +/- 0.1N/m^2). The bed shear stresses in the deepened and widened channel are generally reduced, with some localised areas of increased stresses immediately adjacent to the dredging footprint. Impacts are insignificant within Trinity Inlet and at more distant locations. These small changes to bed shear stresses are not likely to cause undesirable morphological change. The reduced bed shear stresses in the vicinity of the developed channel are likely to cause increased siltation and maintenance dredging requirements, discussed in the Stage 2 report (Section 7.4.3).

3.6.1.5 Extreme water levels (Section 7.2.5)

Likely impacts on storm surge propagation, associated extreme water levels and vulnerability of coastal properties to storm tide inundation are modelled in section 7.2.5. A synthetic event was developed such that it crossed the coast north of Cairns, generating a surge in Trinity Bay close to 1.5m, approximately equivalent to the 200-year ARI surge event. The assessment considered the surge propagation in isolation from tidal effects.

Spatial surge level impacts determined by comparison between modelling results for the Base Case and Developed Case simulation results were shown to be negligible.

Comment

The results of the modelling of potential hydrodynamic Impacts that would result from the CSDP proposed capital dredging have been shown to very small in all aspects and negligible in most. This is the expected outcome, since the changes in the volume and general hydrodynamic characteristics of the study area are relatively quite small.

These results provide strong support for the judgement stated in Section 3.2.1.1 Adequacy of Baseline Data Collection that it is very unlikely that the capital dredging that is proposed for the CSDP will cause significant changes to the impacts that a significant flood event will have on the receiving waters in the study area.

3.6.2. Wave Impacts (Section 7.3)

The potential impacts on the wave climate were assessed with simulations using the high-resolution SWAN model for the six month period from 01 January 2013 to 01 July 2013 for the Existing Case and Developed Case. The model predictions indicate that the existing channel already has some localised influence on wave heights, with larger wave heights on one side than the other. The channel is acting to reflect/refract some of the incident wave energy, particularly for waves from the north. Modelling results indicate that the widened and deepened CSDP channel is predicted to have a slightly increased influence on the wave field – wave height differences are slightly increased on the “incident” side and slightly reduced on the “transmitted” side of the channel. The magnitude of these wave height differences are generally relatively small (<5%) and localised to the vicinity of the channel.

Time series comparisons of significant wave height, wave peak period and direction at two near shore locations and energy weighted mean heights and directions calculated from the entire continuous time series predict that the CSDP is unlikely to have a significant impact on near shore wave conditions driving littoral and beach system processes.

3.6.3. Morphology and Sedimentation Impacts (Section 7.4)

Littoral sediment transport

Hydrodynamic impacts (3.6.1) have been shown to be very small in all aspects and negligible in most. Wave impacts (3.6.2) have been shown to be restricted to the vicinity of the target dredge area. Consequently, there are not expected to be any detectable impacts from the CSDP on the adjacent shorelines or littoral beach systems within the wider region.

Marine sediment transport

The residual (net) sediment transport throughout the study area is parallel to the shore in a north- westerly direction.

Modelling of net sediment transport predicts that the highest transport rates are around Cape Grafton and offshore to depths approximately -8m AHD. Comparison between the base case and developed case net sediment transport predicts that the channel deepening and widening will intercept a relatively small quantity of the sediment load and therefore slightly reduce the net sediment transport to the northwest. This small reduction in fine cohesive sediment transport is not expected to generate perceptible morphological change in the short or long term.

3.6.3.1 Channel Siltation (Section 7.4.3)

The developed case dredged channel footprint is approximately 58% larger than the existing area and is expected to experience an increased volume of annual siltation. Simulations were done for the existing and developed cases from 19 February 2013 to 27 June 2013, with net siltation calculations based on the period 04 March 2013 to 17 June 2013 to ensure that spring-neap cycle periods were equally sampled. The developed case siltation rate and volume are predicted to be 25% higher than in the existing case.

Comment

The volume of siltation shown for the existing case in Fig 7-25 (5.1E+05m^3) is larger than that in Fig 3-40 (4.8E+05m^3). The larger amount includes all of Berth 1 and Berth 12 siltation, whereas the smaller amount includes only a part of Berth 1 and none of Berth 12.

4. CONCLUSIONS

The review provided in this report extends and reinforces the assessments of the model adequacy and of the “fitness for purpose” of the modelling system provided in the earlier review of the Stage 1 Report. Since the periods of data recording for calibration and for validation of the numerical hydrodynamic model have been completed, the adequacy of the baseline assessments has been assessed more thoroughly. The following conclusions are based on detailed examination of Reference 2.

1. Conclusions drawn from the review process are given in some detail in the following sections. In summary, this review has satisfied the reviewer

- that the numerical modelling system is adequate and fit for the purposes and requirements for numerical hydrodynamic modelling of the EIS for the proposed Cairns Shipping Development Project;
- that the data sources are adequate to establish the baseline existing environment assessments and to validate the modelling system for its long term prediction of the indirect impacts of dredging;
- that, overall, the calibration and validation of the numerical model are of good quality; and
- that the numerical modelling is able to predict well the physical impacts of the proposed capital dredging for the CSDP by accurate modelling of the TSS plumes generated by dredging and dredged spoil disposal operations and of sediment settling.

2. Numerical Modelling System

The numerical modelling system being used is predictive, fully three dimensional and is capable of modelling direct and indirect impacts of dredge generated sediments. Its capabilities include:

- Hydrodynamic modelling, including stratification effects;
- Wave modelling, coupled with the SWAN wave modelling system;
- Sediment transport modelling where the range of particle fractions (sand, silt and clay) are all modelled;
- Modelling of all types of re-suspension possibilities including currents and wave-induced bottom shear stresses as well as wave induced fluidisation; and
- Accurate conservation of mass of non-reacting sediment.

The numerical modelling system being used is adequate and fit for purpose. It meets all of the requirements specified in the final EIS Guidelines (SEWPAC & GBRMPA, 2013). (See Appendix A.)

3. Baseline calibration data

The locations chosen for the continuous recording of data and the type of data recorded are considered adequate for the calibration and validation of the hydrodynamic model developed for the purposes of the CSD Project EIS.

The inputs applied as boundary conditions and as forcing for the hydrodynamic model are also considered to be adequate for this purpose.

Apart from the one deficiency from the lack of substantial fluvial inflow during the period of data collection, it is considered that the combined calibration and validation periods provided sufficient variability in general climatic and tidal conditions to be adequate for use in long term impact assessments required by the CSDP EIS.

It is considered to be very unlikely that the capital dredging that is proposed for the CSDP will cause significant changes to the impacts that a significant flood event will have on the receiving waters in the study area. For this reason it is considered that the lack of fluvial inflow data does not detract from the adequacy of the data sources for establishing the baseline existing environment assessments and for validating the modelling system for its long term prediction of the indirect impacts of dredging.

4. Dredge Plume Advection-Dispersion Calibration

The modelled predictions from simulations of plume dispersion using the TUFLOW FV cohesive sediment module coupled with the calibrated hydrodynamic model were compared with the measured 3D TSS concentrations generated during a maintenance dredging program along the existing access shipping channel, in order to calibrate the dredge plume source parameters. This is an extremely challenging application of the numerical modelling system that goes far beyond what is needed for the CSD project EIS. The results of the modelling are in general accordance with the data measured - an impressive demonstration of the “flexibility and ruggedness” of the modelling system.

5. Model Validation

- **Hydrodynamic Model Validation**

  Generally, overall the hydrodynamic model validation results indicate correlations between modelled predictions and recorded data that are consistent with those for the calibration results. The validation results confirm that the adopted parameters are appropriate for the range of seasonal hydrodynamic conditions typically encountered at Cairns.

- **Wave Model Validation**

  The correlations between predicted and measured wave climate are of variable quality throughout the validation but are generally satisfactory and of similar quality to those achieved during calibration.

- **Sediment Re-suspension Model Validation**

  The sites used for the validation period differ from those used during the calibration period and it is not considered useful to compare the results from the two periods. In the validation modelling, the larger peak values of the recorded bottom 2m TSS are generally predicted reasonably well, especially at Yorkeys Knob and Palm Beach. Short periods of elevated TSS values associated with Spring Tides are predicted but the modelled predictions show substantial lags at Yorkeys Knob and Palm Beach.

6. Dredging Impact Assessment

The dredging impact assessments simulated the re-suspension of ambient surficial seabed material as well as the re-suspension of dredged material that had been placed at the DMPA. Eight sediment fractions (four ambient sediments and four dredged material sediments), were simulated as part of the dredging impact assessments in order to track both the ambient and dredged material.

Six dredging cases were modelled to assess their likely impacts.

The predicted effect of each CSDP dredging case was assessed from the modelled increases in suspended sediment concentration and sedimentation above natural or ambient levels. Both ambient and dredged related signals are resolved in the predictive model, which enables an understanding of the significance of the dredged contribution in relation to ambient conditions

All of the summary assessments of the impacts of the six variants of the proposed CSDP proposed capital dredging are judged to be consistent with the evidence presented in the Stage 2 Report.

It is noted that these assessments deal only with the impacts on turbidity and sediment processes within the water column. Issues of water quality and ecology are treated in a different part of the EIS.

7. Coastal Processes Impact Assessment

- **Hydrodynamic Impacts**

  Modelling of the potential hydrodynamic impacts that would result from the CSDP proposed capital dredging has shown that the effects on tidal flow patterns, tidal water levels, tidal flows, volumes and flushing, bed shear stresses and extreme water levels associated with storm surges would be very small in all aspects and negligible in most. This is the expected outcome, since the changes in the volume and general hydrodynamic characteristics of the study area are relatively quite small.

- **Wave Impacts**

  Modelling of likely impacts on wave climate predicts that the CSDP is unlikely to have a significant impact on near shore wave conditions driving littoral and beach system processes.

- **Morphology and Sedimentation Impacts**

  Littoral sediment transport

  Since wave impacts have been shown to be restricted to the vicinity of the target dredge area, it is not expected that there would be any detectable impacts from the CSDP on the adjacent shorelines or littoral beach systems within the wider region.

  Marine sediment transport

  Modelling predicts that the channel deepening and widening will intercept a relatively small quantity of the sediment load and therefore slightly reduce the net sediment transport to the northwest. This small reduction in fine cohesive sediment transport is not expected to generate perceptible morphological change in the short or long term.

Channel Siltation

The developed case siltation rate and volume are predicted to be 25% higher than for the existing case.

5. REFERENCES

1 Cairns Shipping Development Project Model Development and Calibration, November 2013, BMT WBM Report R.B20180.003.01 Modelling.

2 Cairns Shipping Development Project Model Development and Calibration, August 2014, BMT WBM Report R.B20180.003.02 Modelling.

3 Cairns Shipping Development (CSD) Project EIS Independent Peer Review of BMT WBM Report on Numerical Model Development and Calibration Stage 1 - Emeritus Professor Colin Apelt, December 2013, UniQuest Project No: OP01503, prepared for Ports North.

4 Addendum to Report prepared for Ports North on Cairns Shipping Development (CSD) Project EIS Independent Peer Review of BMT WBM Report on Numerical Model Development and Calibration (Stage 1 – December 2013) - Emeritus Professor Colin Apelt, 16 December 2013, UniQuest Project No: C01503.

APPENDIX A – QUESTIONS AND COMMENTS FOR BMT WBM

Questions and comments for BMT WBM, with responses, concerning BMT WBM report "*Cairns Shipping Development Project Model Development and Calibration, August 2014*".

Reviewer C J Apelt

Questions for BMT WBM

What is the depth at the DMPA?

20-25m as on p iv of Executive Summary?

Figs 4-2 to 4-6, pp 75-79 and 4-7 to 4-10, pp 80-83

What is the datum for elevations in the transects? AHD?

Does the brown area in each transect indicate measured/modelled values or is it just below the measurements?

The meaning of the following is not clear:

> *'The lower panels show a plan view of depth-averaged TSS, with the model results in the background and the ADCP-measured TSS shown as a black bordered line along the transect. A red cross marks the start point of the transect (0m chainage in the upper panel)'* p 74.

Is the transect what is defined by the faint black dotted line in the plan view the same as the actual measured data in the upper left panel?

Sediment Characteristics

What is the source(s) of the sediment characteristics in Table 3-6 (p 65) and in Table 6-1 (p 111)?

Why is Critical Shear Stress Erosion the same for all sediments?

Why is the Erosion Rate Constant in Table 6-1 0.15 for the four ambient sediment classes for which it appears to be 0.1 in Table 3-6?

Questions for BMT WBM with responses added in red text

What is the depth at the DMPA?

20-25m as on p iv of Executive Summary?

Based on a recent hydrographic survey, the depth range across the proposed DMPA area is -18 to -23mAHD. The mean depth is -20.4mAHD. The Executive Summary will be updated with these values.

It is noted that Figures 4-7 to 4-10 show the existing DMPA which is located in shallower depths.

Figure 3-2 shows the location of instruments deployed at the existing DMPA. References to the "DMPA" throughout the calibration and validation report sections refer to the existing DMPA.

The dredging impact assessments presented in Section 6 refer to the proposed DMPA location which is shown in the numerous percentile plots.

For clarity, the report would benefit from both DMPA locations being distinguished on Figure 1-1. This will be amended in the final report.

Figs 4-2 to 4-6, pp 75-79 and 4-7 to 4-10, pp 80-83

What is the datum for elevations in the transects? AHD?

Yes, the datum is mAHD. This labelling will be added to the figures.

Does the brown area in each transect indicate measured/modelled values or is it just below the measurements?

The square symbols indicate dredger operation condition and also provide a short time history of the dredger activity. The brown squares indicate the that dredger is "dredging" in Figures 4-2 to 4-6 and "dumping" in Figures 4-7 to 4-10

The meaning of the following is not clear:

'The lower panels show a plan view of depth-averaged TSS, with the model results in the background and the ADCP-measured TSS shown as a black bordered line

along the transect. A red cross marks the start point of the transect (0m chainage in the upper panel)' p 74.

Is the transect what is defined by the faint black dotted line in the plan view the same as the actual measured data in the upper left panel?

Yes, for each figure the measured transect is indicated by the faint black dotted line is the same transect shown in the upper left panel. The starting point for the measured location is indicated by the red x-cross and corresponds to 0m chainage in the upper panels.

In addition, on the plan view plots the contouring within the faint black dotted line corresponds to the measured depth-average TSS.

The contouring outside the faint black dotted line corresponds to the predicted depth-average TSS.

Sediment Characteristics

What is the source(s) of the sediment characteristics in Table 3-6 (p 65) and in Table 6-1 (p 111)?

Effective clear water fall velocities are considered to be "typical" literature values for the following approximate sediment grading:

- Ambient Clay — <2 µm
- Ambient Silt — 2 µm to 60 µm
- Ambient Siliceous Sand — 60 µm to 0.2 mm
- Ambient Carbonaceous Sand — >0.2 mm

The threshold shear stress and erosion rate constants are typically adjusted as part of the re-suspension model calibration process. In the case of this EIS, the threshold shear stresses were set based on recent experience in other relevant modelling exercises (e.g. Gladstone and Townsville) and were further calibrated for this study in order to achieve a satisfactory prediction of elevated turbidity associated with the re-suspension of ambient material throughout the study area.

Why is Critical Shear Stress Erosion the same for all sediments?

The flocs on the surface of a cohesive sediment bed are bound together by inter-particle attractive forces (e.g. Whitehouse et al., 2000) and therefore the resistance to erosion is generally considered to be a property of the sediment mixture not of the individual sediment fractions. In the literature, the critical shear stress for erosion is not typically related to the sediment size fractions but may be related to the dry density of the sediment mixture. For the purposes of our modelling we have assumed that the dry density of surficial sediment mixtures will be relatively uniform throughout the majority of our study area and that a spatially uniform critical shear for erosion is therefore an appropriate assumption. The value of critical shear stress, along with the Erosion Rate parameter and effective bed roughness coefficients have been calibrated by comparing the model predictions with the continuous near bed turbidity measurements.

Sediments with >5-15% mud content will tend to become cohesive with behaviour dominated by the finer fraction (e.g. Mitchener & Torfs, 1996). The majority of surficial bed sediments within the study area comprise sand-mud mixtures where the erosion properties are dominated by the cohesive sediment fractions. In this case any mixed non-cohesive sediment fractions will be entrained along with the cohesive fractions when the cohesive fractions critical shear stress for erosion is reached.

The various modelled sediment fractions are primarily differentiated by the effective settling velocities that vary by more than two orders of magnitude between the finest and coarsest particles. Configured in this way, the model will “warm up” towards a realistic spatial distribution of the sediment fractions, with a greater proportion of fine sediments in areas exposed to lower shear stresses and greater proportions of coarse sediment in high-shear stress areas (described in Section 3.5).

The benefit of this approach is demonstrated in the re-suspension model calibration (Section 3.5.2.1) and validation (Section 5.5.2) results which show good spatial and temporal predictive skill considering the complexities involved in modelling these processes.

Why is the Erosion Rate Constant in Table 6-1 0.15 for the four ambient sediment classes for which it appears to be 0.1 in Table 3-6?

The erosion rate constant for the ambient sediment classes is 0.15, Table 3-6 will be updated accordingly.

APPENDIX B – RESPONSE FROM BMT WBM

Response from BMT WBM regarding matters in the Independent Peer Review of
BMT WBM *Report on Model Development and Calibration August 2014* (Stage 2), September 2014

BMT WBM Pty Ltd
Level 8, 200 Creek Street
Brisbane Qld 4000
Australia
PO Box 203, Spring Hill 4004

Tel: +61 7 3831 6744
Fax: + 61 7 3832 3627

ABN 54 010 830 421

www.bmtwbm.com.au

Our Ref: : L.B20180.015.modelling_peer_review_reponse.docx

11 September 2014

Attention: Ports North

RE: CAIRNS SHIPPING DEVELOPMENT PROJECT EIS INDEPENDENT PEER REVIEW OF BMT WBM REPORT ON MODEL DEVELOPMENT AND CALIBRATION AUGUST 2014 (STAGE 2)

This letter provides responses to questions and comments regarding the independent peer review of the Cairns Shipping Development Project Model Development and Calibration August 2014 (BMT WBM, 2014)

Reviewer: Emeritus Professor Colin J Apelt

Responder: Matthew Barnes (BMT WBM)

The review report includes a number of supportive statements regarding the adequacy of the numerical models developed for the CSDP EIS and considers the tools to be suitable for assessing impacts associated with the project.

The two relatively minor issues raised by the reviewer are:

(1) Conservation of mass of sediments checks has not been included; and

(2) Ambiguity regarding the data collection period and the modelling calibration and validation periods.

The response and proposed actions to address these concerns are summarised below.

Section 3.1.1.1 (UniQuest, 2014)

Comment: Conservation of mass of sediments checks not included in the Stage 2 report.

Response: The question of mass balance checks was originally raised following the Stage 1 peer review in November 2013. At this time, BMT WBM committed to including sediment mass balance checks in the Stage 2 report which was accidently overlooked. Plots showing the sediment mass balance check for the six (6) CSDP dredging assessment scenarios will be added as an Appendix to the final version of the report. These are provided as an attachment to this letter.

Section 3.2.1 (UniQuest, 2014)

Comment: It is necessary to clarify some ambiguity… concerning the duration of baseline data collection, encompassing both calibration and validation periods.

Response: BMT WBM will ensure that there is no ambiguity regarding data collection and model simulation periods in the final version of the report. Baseline data collection for the purpose of model calibration and validation commenced in late February 2013 and continued until February 2014. Continuous hydrodynamic and wave were obtained at the following locations:

- Existing DMPA – Site 1 (Feb 2013 to Feb 2014)
- Alternative DMPA – Site 2 (February to August 2013)
- Channel Beacon C7 – Site 3 (February 2013 to February 2014)
- Channel Beacon C11 – Site 4 (February to August 2013)

Within this data collection period, two periods were selected for model calibration and validation simulations:

- Calibration simulation period: March to June 2013
- Validation simulation period: July to October 2013

The range of conditions observed during the entire data collection period is suitably represented within the chosen simulation periods. As indicted by the reviewer, *"…the combined calibration and validation periods provide sufficient variability in general climatic and tidal conditions"*.

It is acknowledged that additional hydrodynamic and wave data recorded at the Existing DMPA and Beacon C7 between November 2013 and February 2014 is available and has not been used for model validation purposes. Considering that no substantial Barron River flows occurred during this period, and that conditions were generally consistent with those observed during the preceding months, there is little value in undertaking additional hydrodynamic and wave validation using the November 2013 to February 2014 data. Furthermore, it is expected that the adopted model calibration and validation periods will be sufficient to meet the GBRMPA Modelling Guidelines.

Please don't hesitate to contact us if you require any further information. Responses to Ports North comments on BMT WBM (2014) will be addressed separately.

Yours Faithfully
BMT WBM

Dr Matthew Barnes

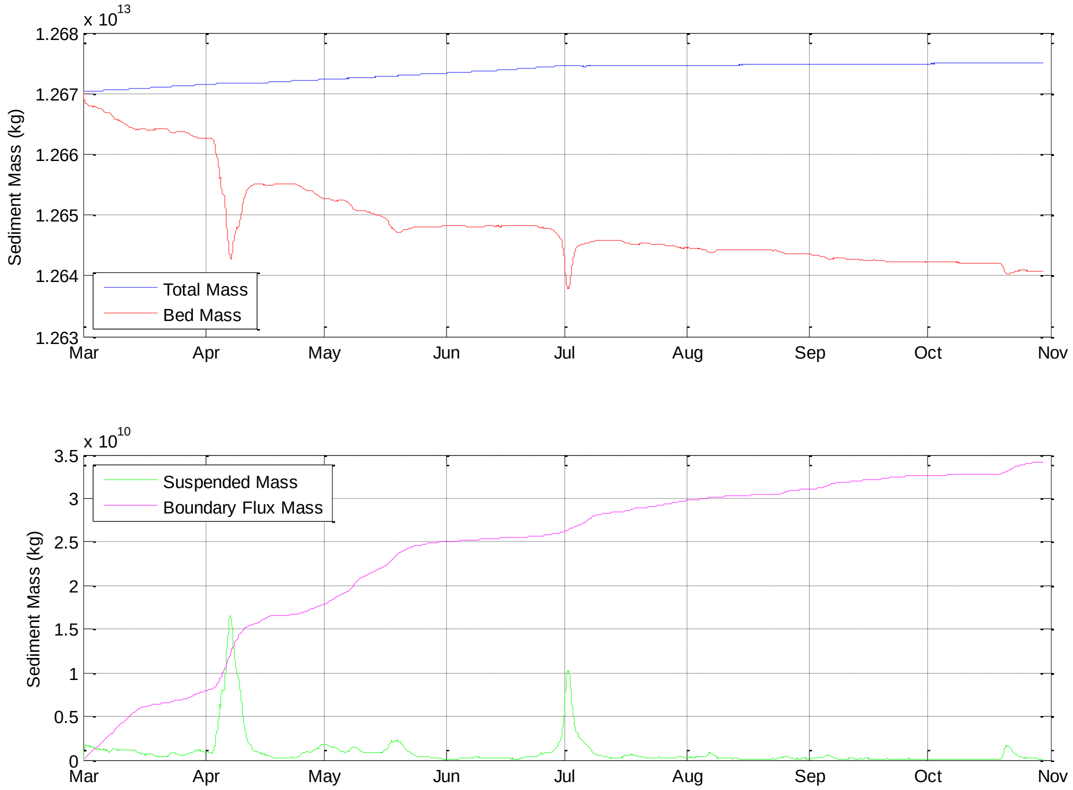


Figure 1. Sediment Mass Balance Checks - Capital Base Case

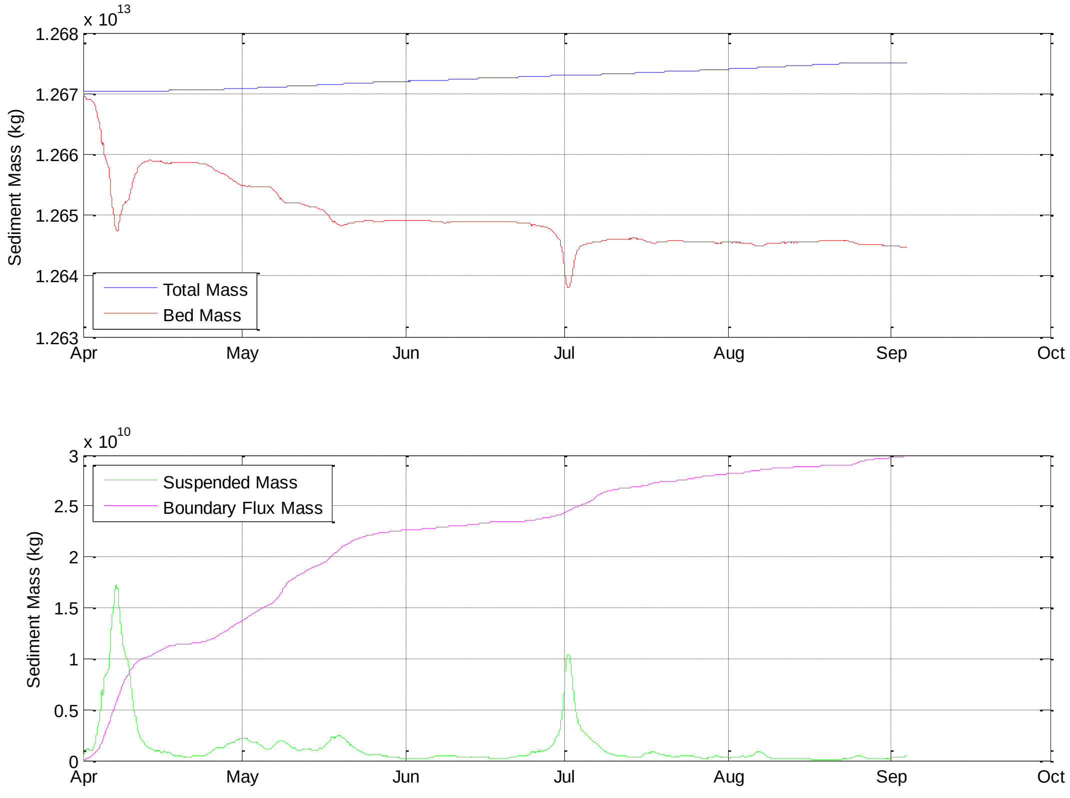


Figure 2. Sediment Mass Balance Checks - Capital Alternative Case

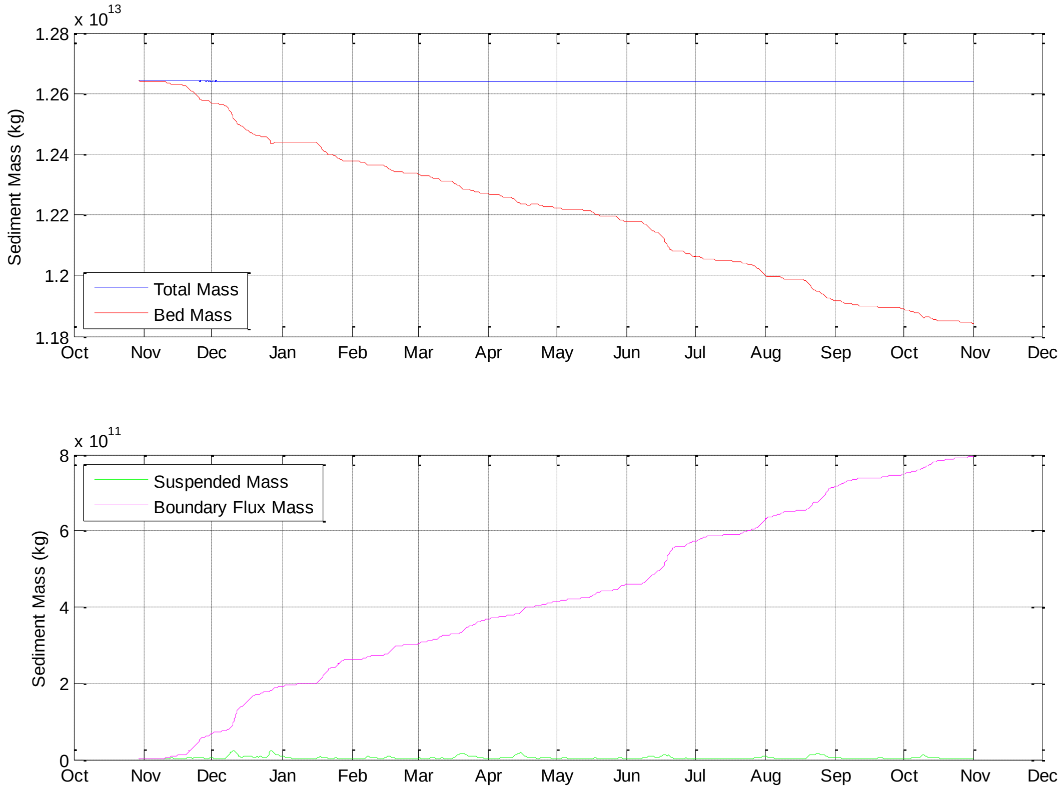


Figure 3. Sediment Mass Balance Checks - Re-suspension Period

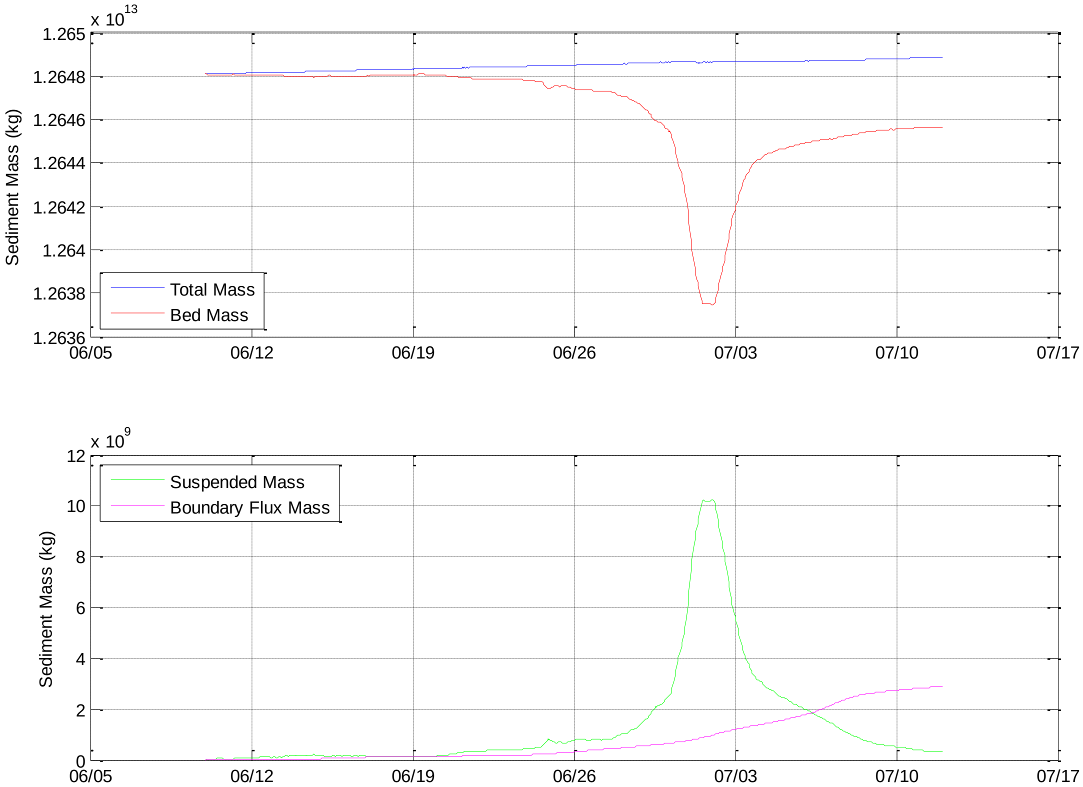


Figure 4. Sediment Mass Balance Checks - Worst Case Soft Material Dredging

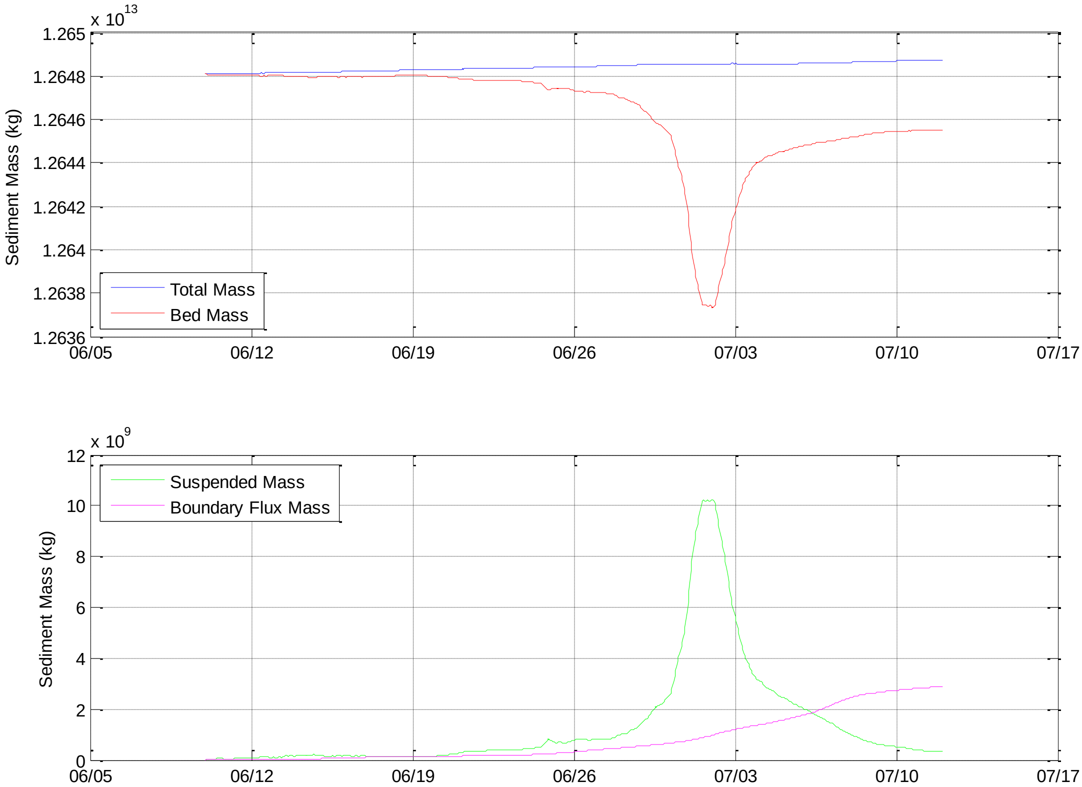


Figure 5. Sediment Mass Balance Checks - Worst Case Stiff Material Dredging

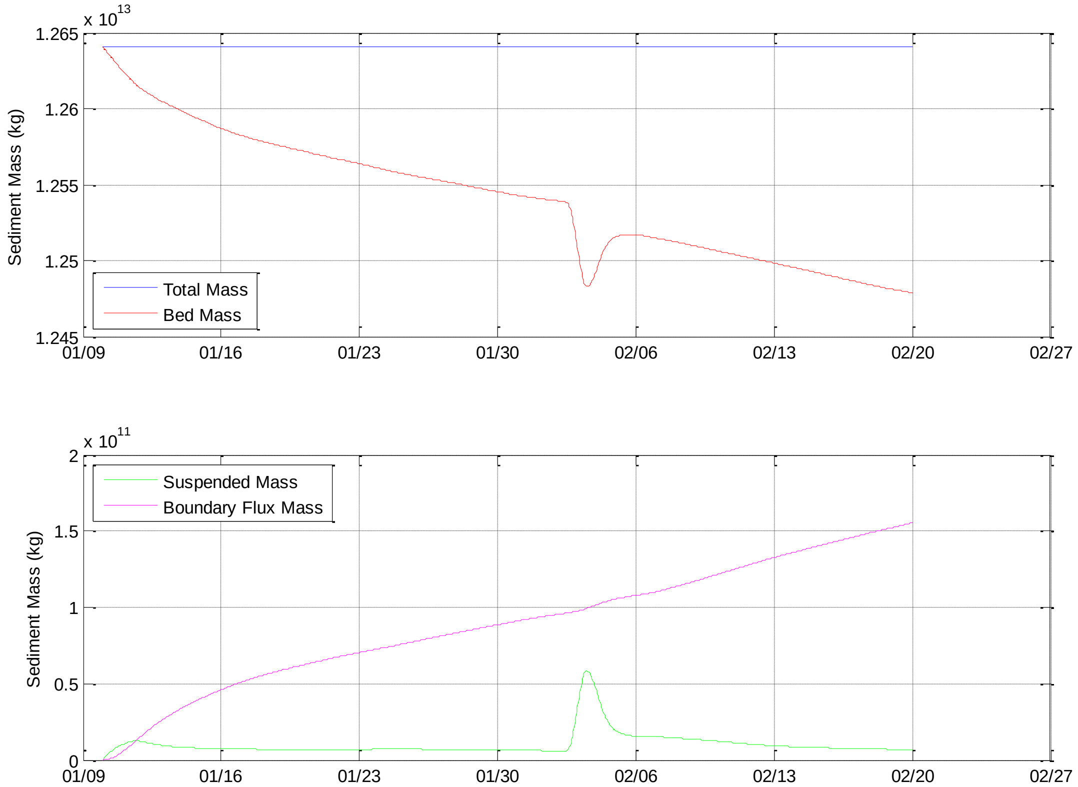


Figure 6. Sediment Mass Balance Checks - Worst Case DMPA Re-suspension

Appendix B Example TUFLOW FV Simulation Control File

An example TUFLOW FV hydrodynamic simulation control file show model settings and parameters is presented in Figure B-1 and Figure B-2. The adopted model parameters are typically “default” values and/or within the range of accepted literature values.

```
! Cairns local model

! SIMULATION CONFIGURATION
!________________________________________________________________
spherical == 1
include salinity == 1,1
include temperature == 1,1
include heat == 1
momentum mixing model == Smagorinsky
scalar mixing model == Smagorinsky
vertical mixing model == External
bottom drag model == ks
spatial order == 2,2
equation of state == UNESCO
!________________________________________________________________

!TIME COMANDS
!________________________________________________________________
cfl external == 0.9
cfl internal == 0.9
time format == ISODATE
start time ==  17/02/2013 00:00:00
end time ==   27/06/2013 08:00:00
display dt == 300.
timestep limits == 0.1, 15.0
turbulence update dt == 300.

!MODEL PARAMETERS
!________________________________________________________________
stability limits == 10.,20.
cell wet/dry depths == 5.0e-3, 1.0e-1
cell 3d depth == 5.0e-1
reference density == 1025.0
reference salinity == 35.0
reference temperature == 26.0
kinematic viscosity == 1.0e-6
global horizontal eddy viscosity == 0.5
global horizontal eddy viscosity limits == 1.0, 9999.0
global horizontal scalar diffusivity == 0.2
global horizontal scalar diffusivity limits == 1.0, 9999.0
global vertical eddy viscosity limits == 1.0e-4, 1.0
global vertical scalar diffusivity limits == 0., 1.0

!GEOMETRY
!________________________________________________________________
geometry 2d == ..\geo\CAI_EIS_013_EIS_option1a.2dm
cell elevation file == ..\geo\cell_centres\CAI_EIS_013_EIS_option1a_centres_inspected.csv

vertical mesh type == z
layer faces == ..\geo\zfaces\CAI_zlayer_003.csv
sigma layers == 4
min bottom layer thickness == 0.5

echo geometry == 1

material == 1,6,7,8,9        !default
  bottom roughness  == 0.05
end material

material == 2        !reefs (<20 depth) in GBR chain
  bottom roughness  == 1.0
  vertical eddy viscosity limits == 1.0, 1.0
end material

material == 3  !reef pass
```

Figure B-1 Example TUFLOW FV Hydrodynamic Model Simulation Control File (continued over page)

```
  bottom roughness == 0.1
end material

material == 4 !open boundary
  bottom roughness == 1.0
  vertical eddy viscosity limits == 1.0e-4, 1.0
  horizontal eddy viscosity limits == 10.0, 9999.0
end material

material == 5 !mangroves and inner reefs
  bottom roughness == 0.5
end material

material == 10 !deep water
  bottom roughness == 0.05
end material

!BOUNDARY CONDITIONS
!_________________________________________________________________

! ncep
include == ..\bc\ncep\BC_ncep_2013.fvc

! hycom
include == ..\bc\hycom\BC_hycom_2013.fvc

! tides
include == ..\bc\tides\BC_Tide_2013_002_sub-type5.fvc

! wind
include == ..\bc\wind\BC_Wind_2011-2013_001.fvc

!INITIAL CONDITIONS
!_________________________________________________________________
initial condition ogcm
initial condition quiescent

!OUTPUT COMMANDS
!_________________________________________________________________
output dir == /scratch2/B20180/TUFLOWFV/output

output == netcdf
  output parameters == h,v,w,sal,temp
  output interval == 1800.
  output compression == 1
end output

write restart dt == 6.0
```

Figure B-2 Example TUFLOW FV Hydrodynamic Model Simulation Control File (continued from previous page)

Appendix C Calibration Period Current Time Series Plot

Top and bottom half of water column current velocity and direction time series calibration plots are presented for the entire simulation period:

- DMPA, Figure C-1 to Figure C-7.
- Site 2, Figure C-8 to Figure C-14.
- Beacon C7, Figure C-15 to Figure C-21.
- Beacon C11, to Figure C-28.

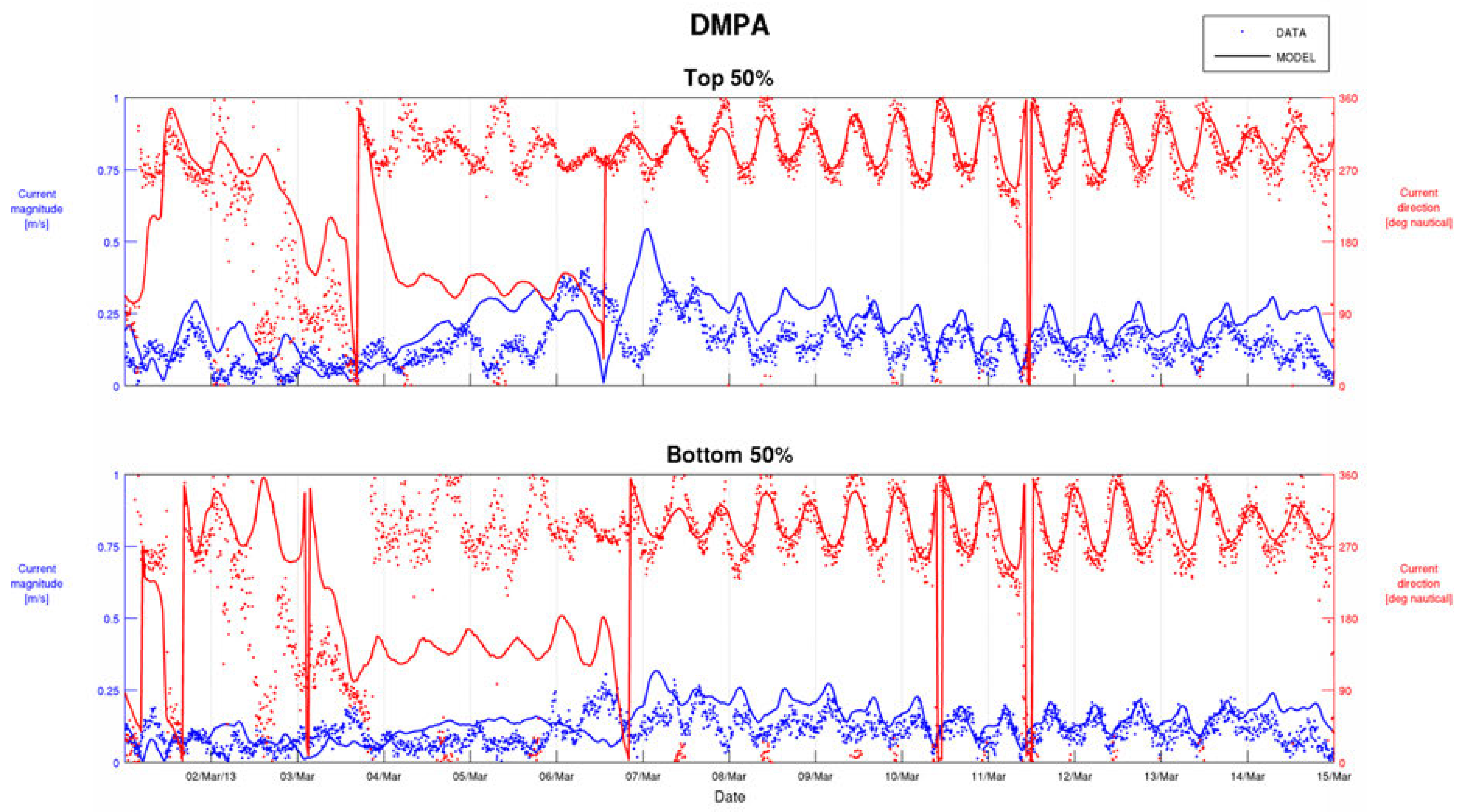


Figure C-1 Top 50% and Bottom 50% Current Calibration – DMPA 01/03/2013 to 15/03/2013

Calibration Period Current Time Series Plot

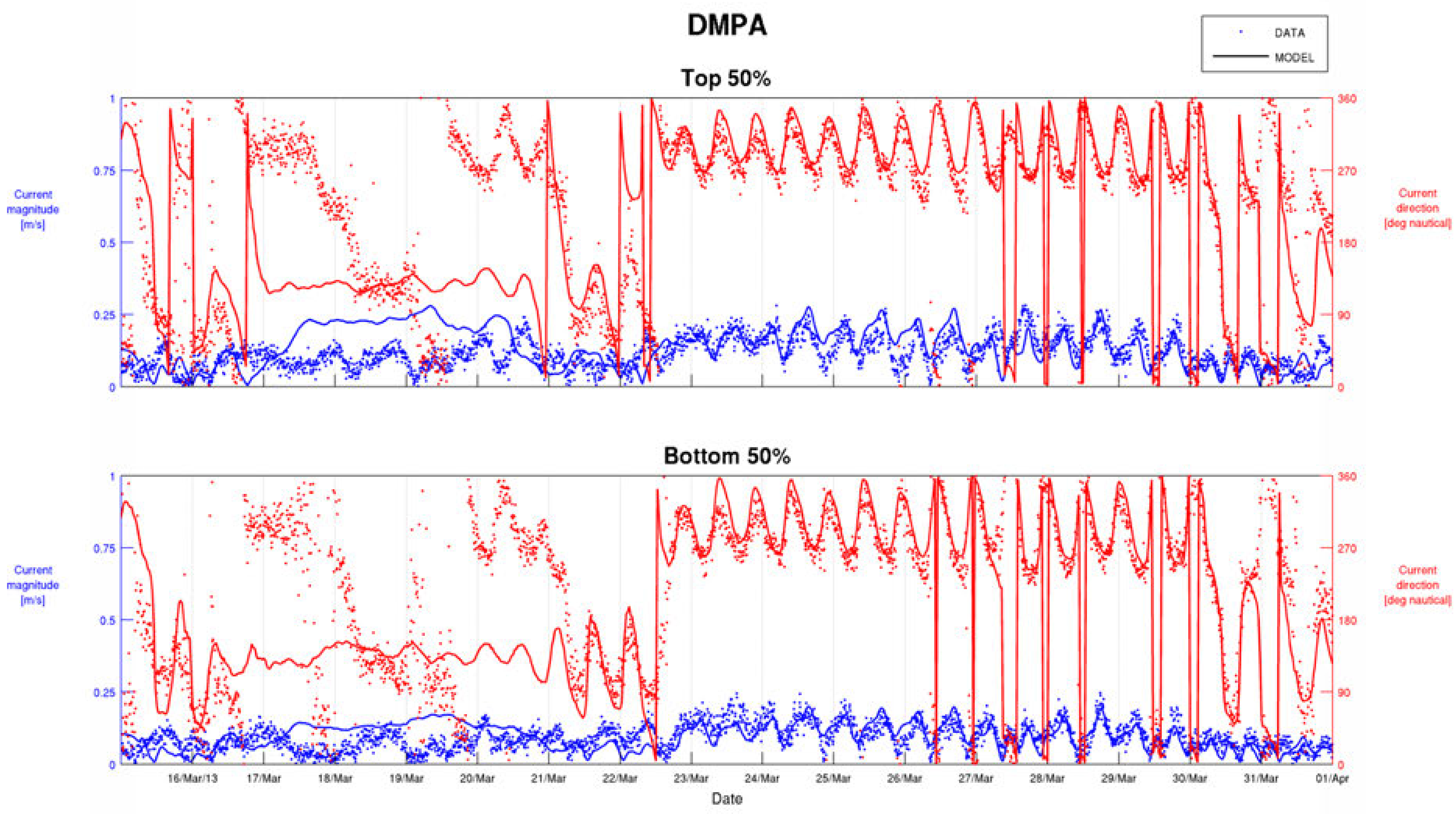


Figure C-2 Top 50% and Bottom 50% Current Calibration – DMPA 15/03/2013 to 01/04/2013

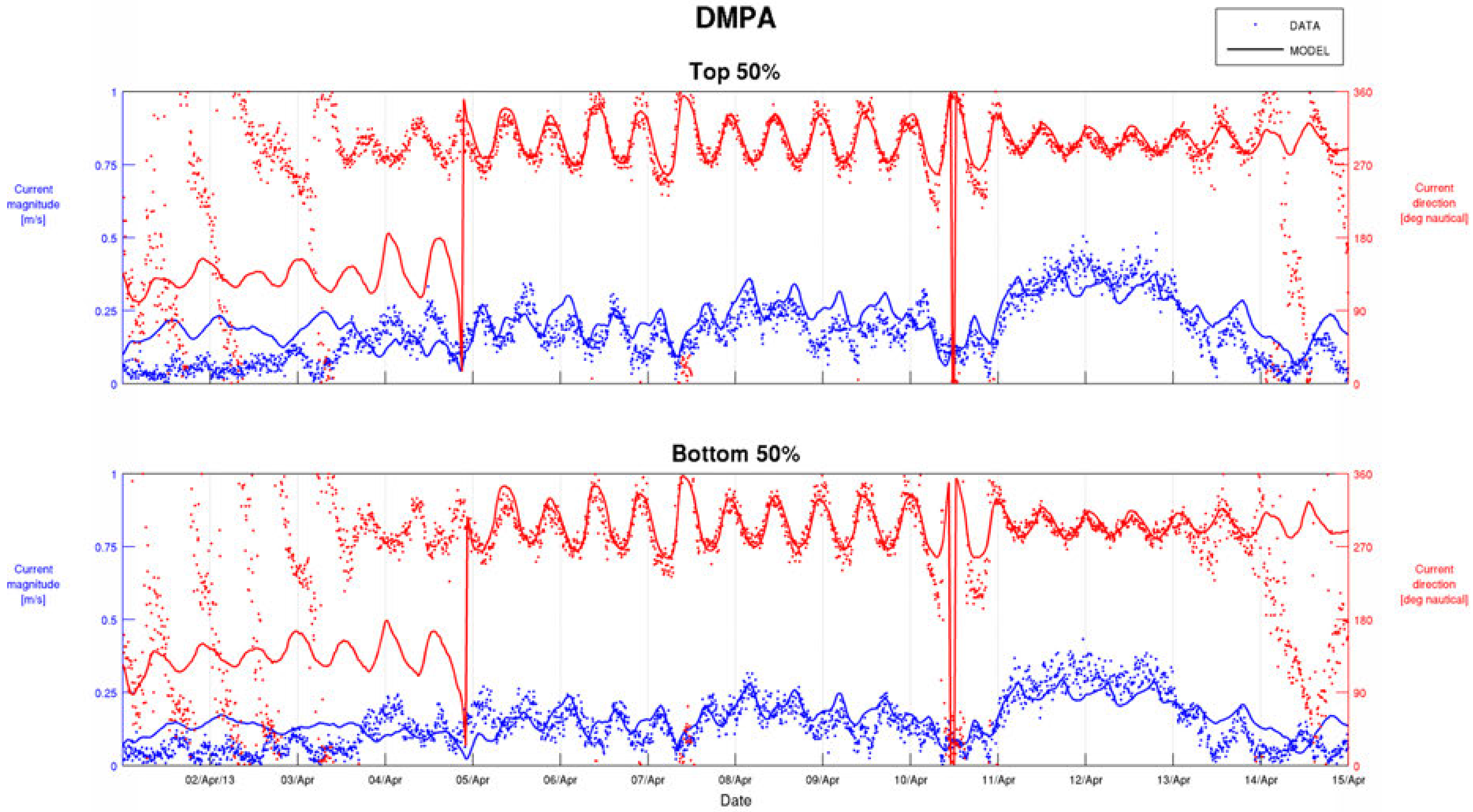


Figure C-3 Top 50% and Bottom 50% Current Calibration –DMPA 01/04/2013 to 15/04/2013

Calibration Period Current Time Series Plot

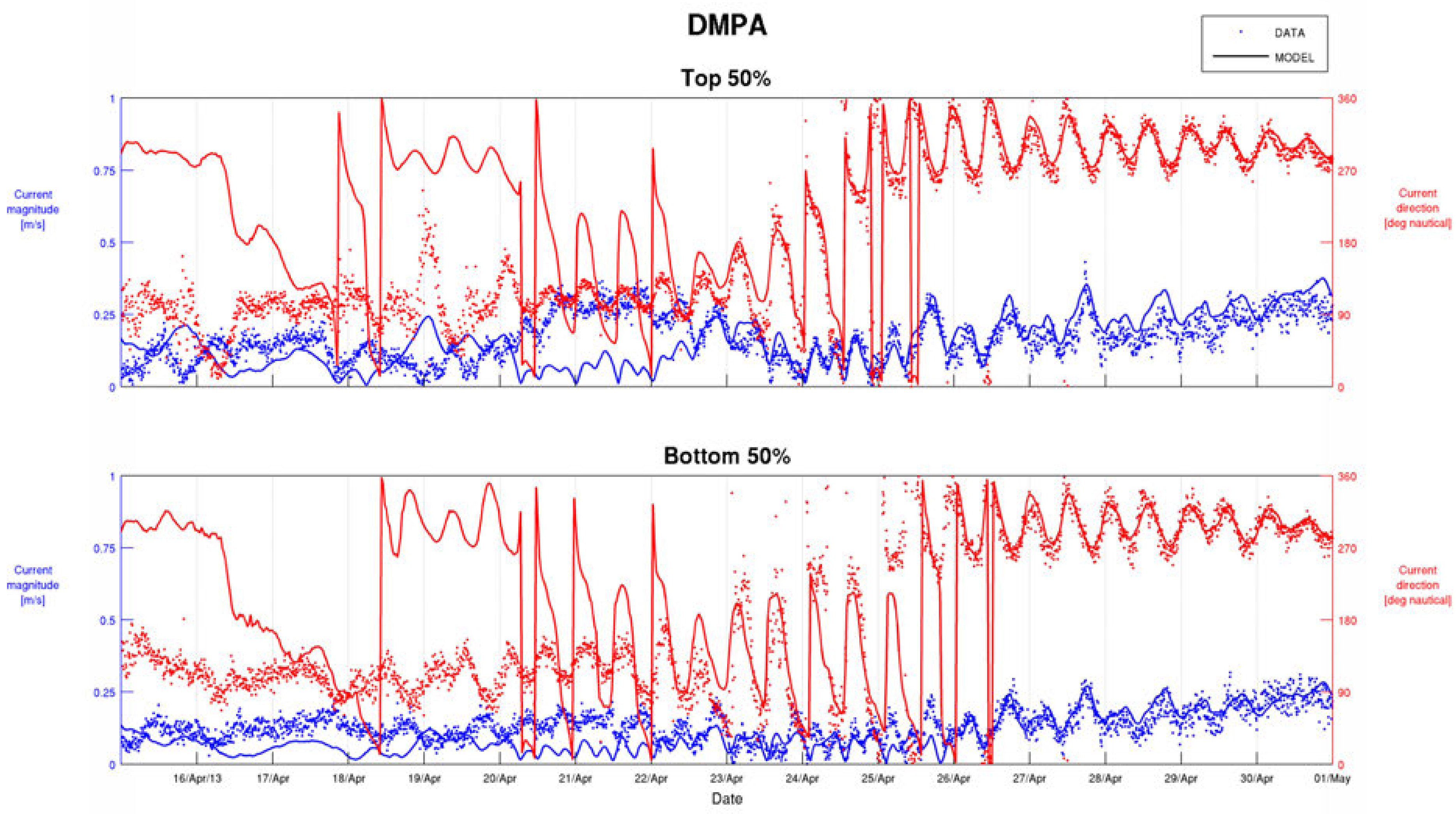


Figure C-4 Top 50% and Bottom 50% Current Calibration – DMPA 15/04/2013 to 01/05/2013

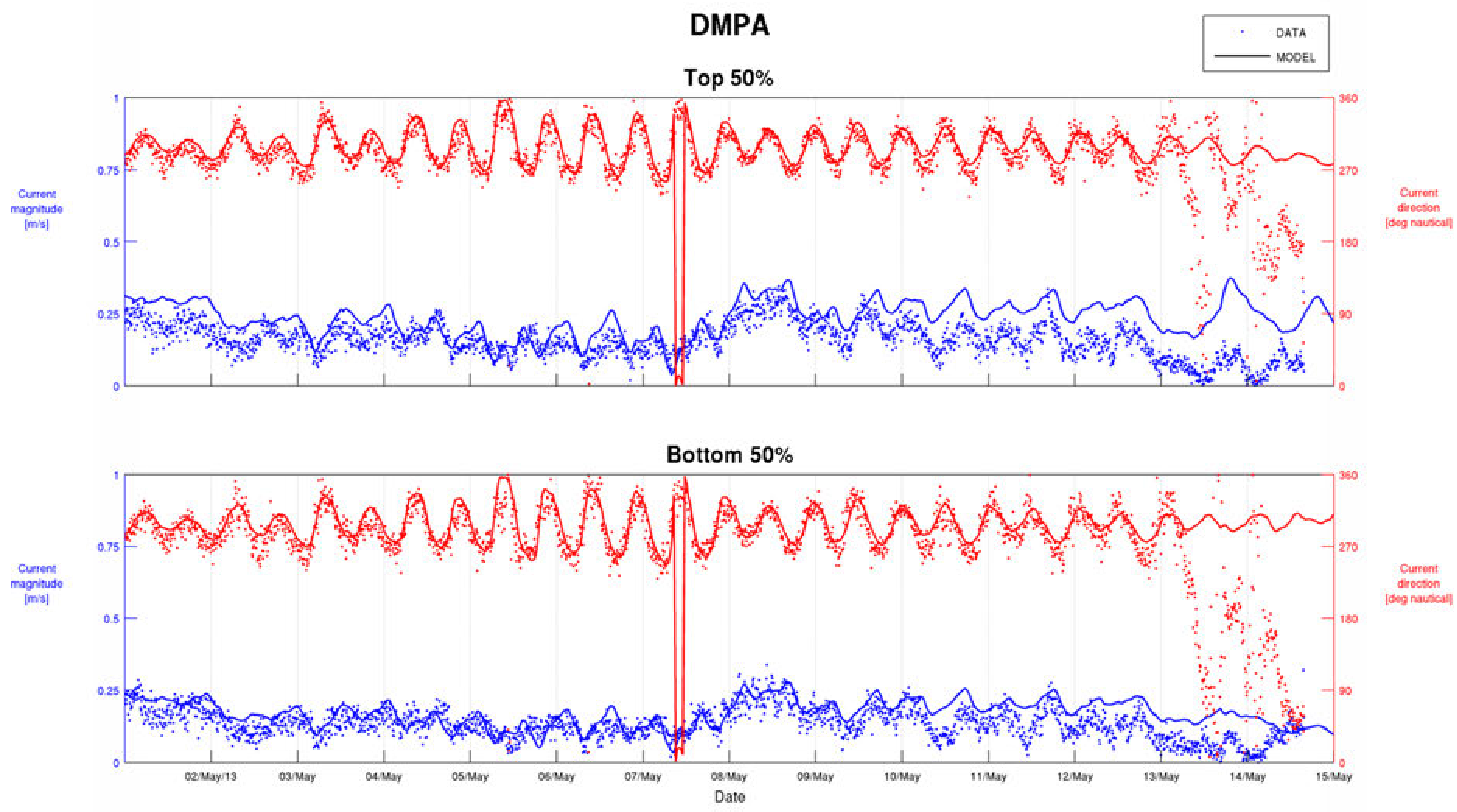


Figure C-5 Top 50% and Bottom 50% Current Calibration – DMPA 01/05/2013 to 15/05/2013

Calibration Period Current Time Series Plot

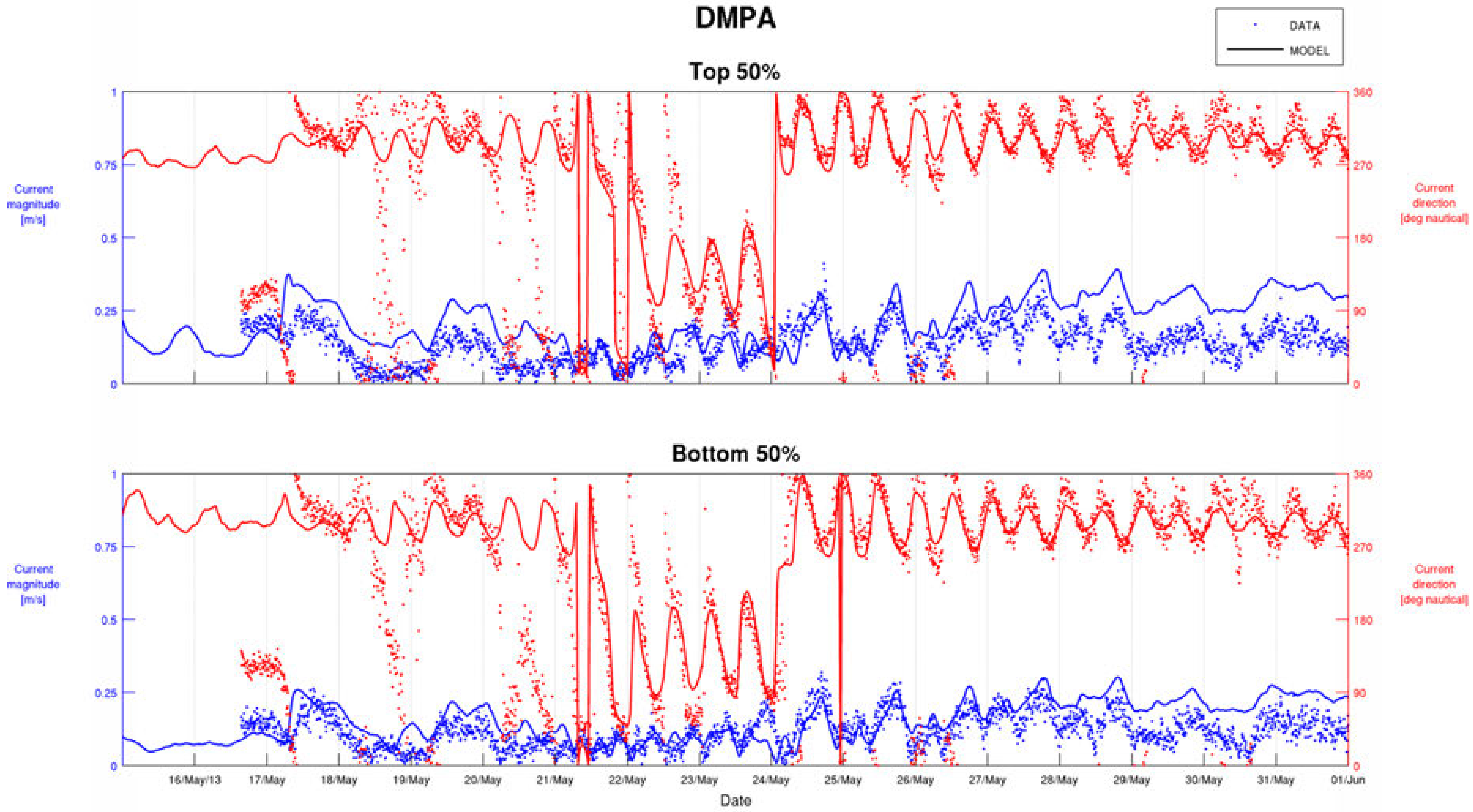


Figure C-6 Top 50% and Bottom 50% Current Calibration – DMPA 15/05/2013 to 01/06/2013

Calibration Period Current Time Series Plot

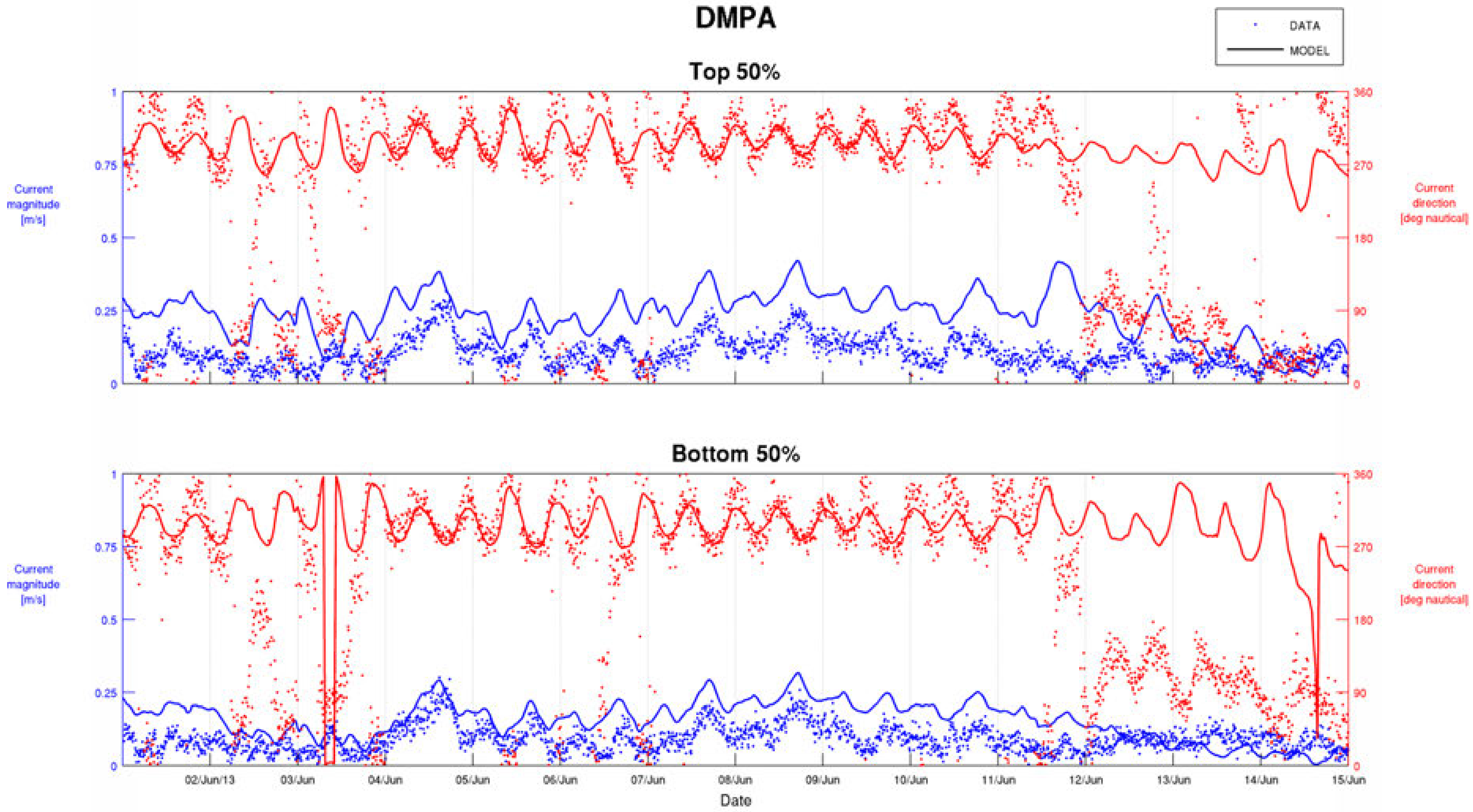


Figure C-7 Top 50% and Bottom 50% Current Calibration – DMPA 01/06/2013 to 15/06/2013

Calibration Period Current Time Series Plot

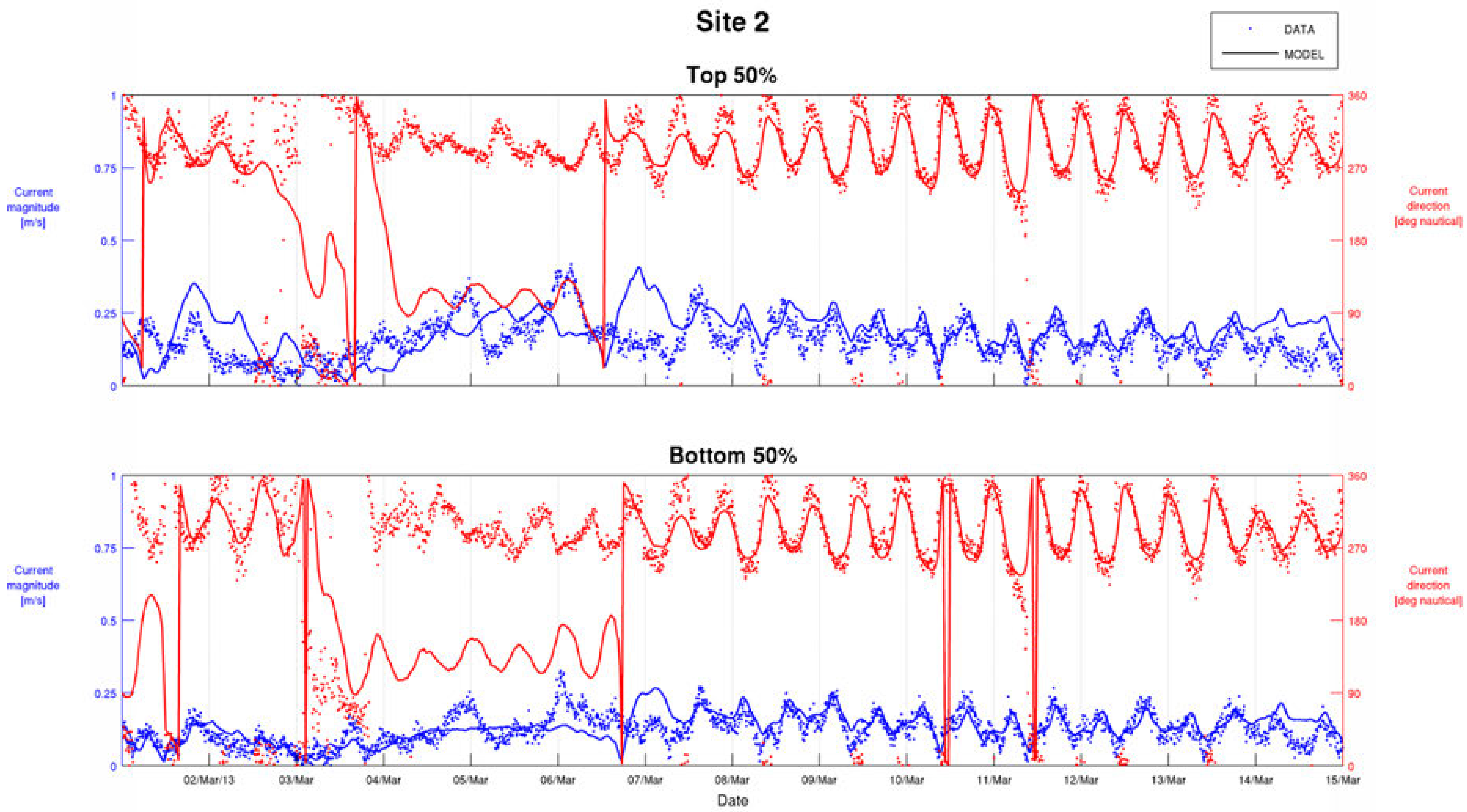


Figure C-8 Top 50% and Bottom 50% Current Validation – Site 2 01/03/2013 to 15/03/2013

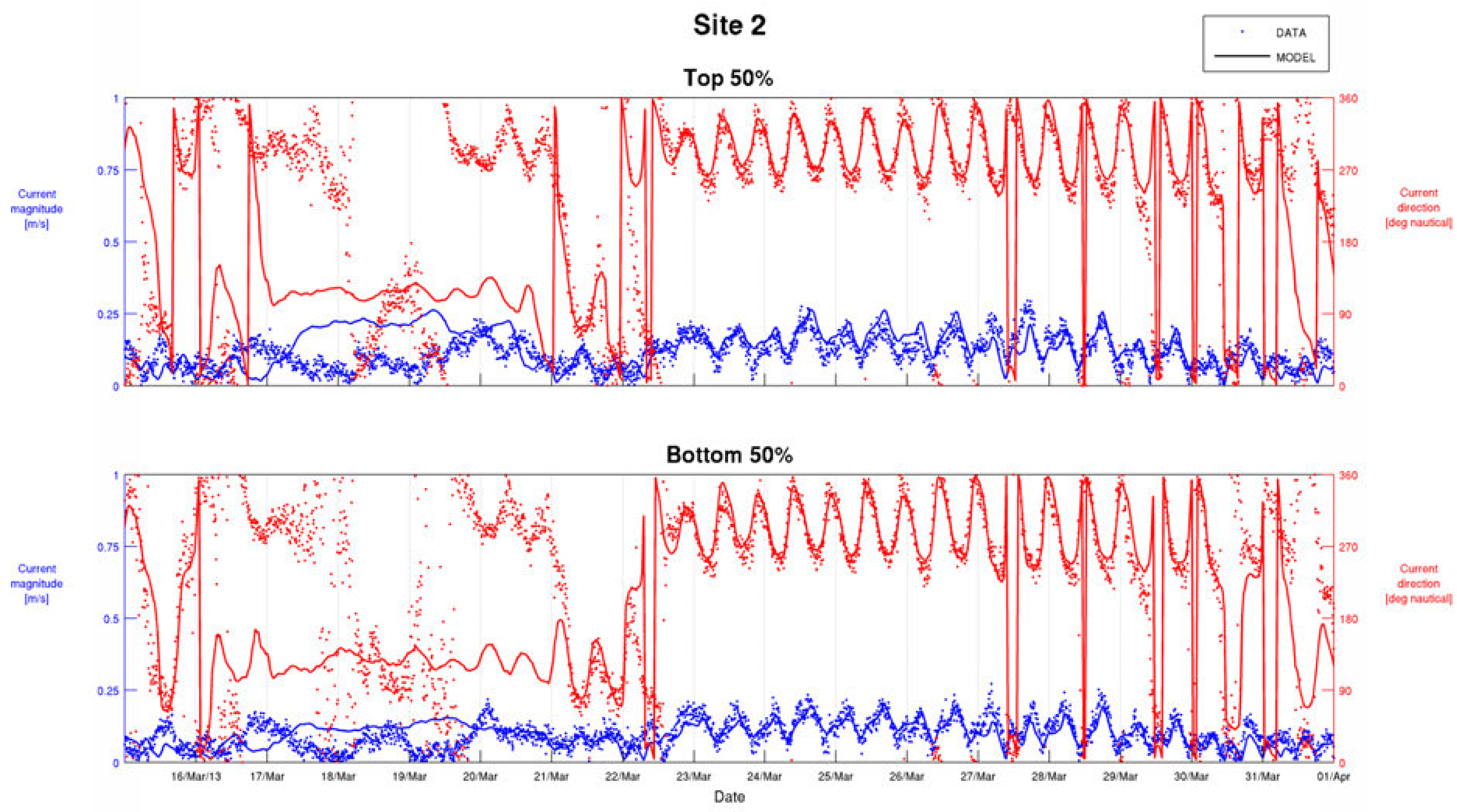


Figure C-9 Top 50% and Bottom 50% Current Calibration – Site 2 15/03/2013 to 01/04/2013

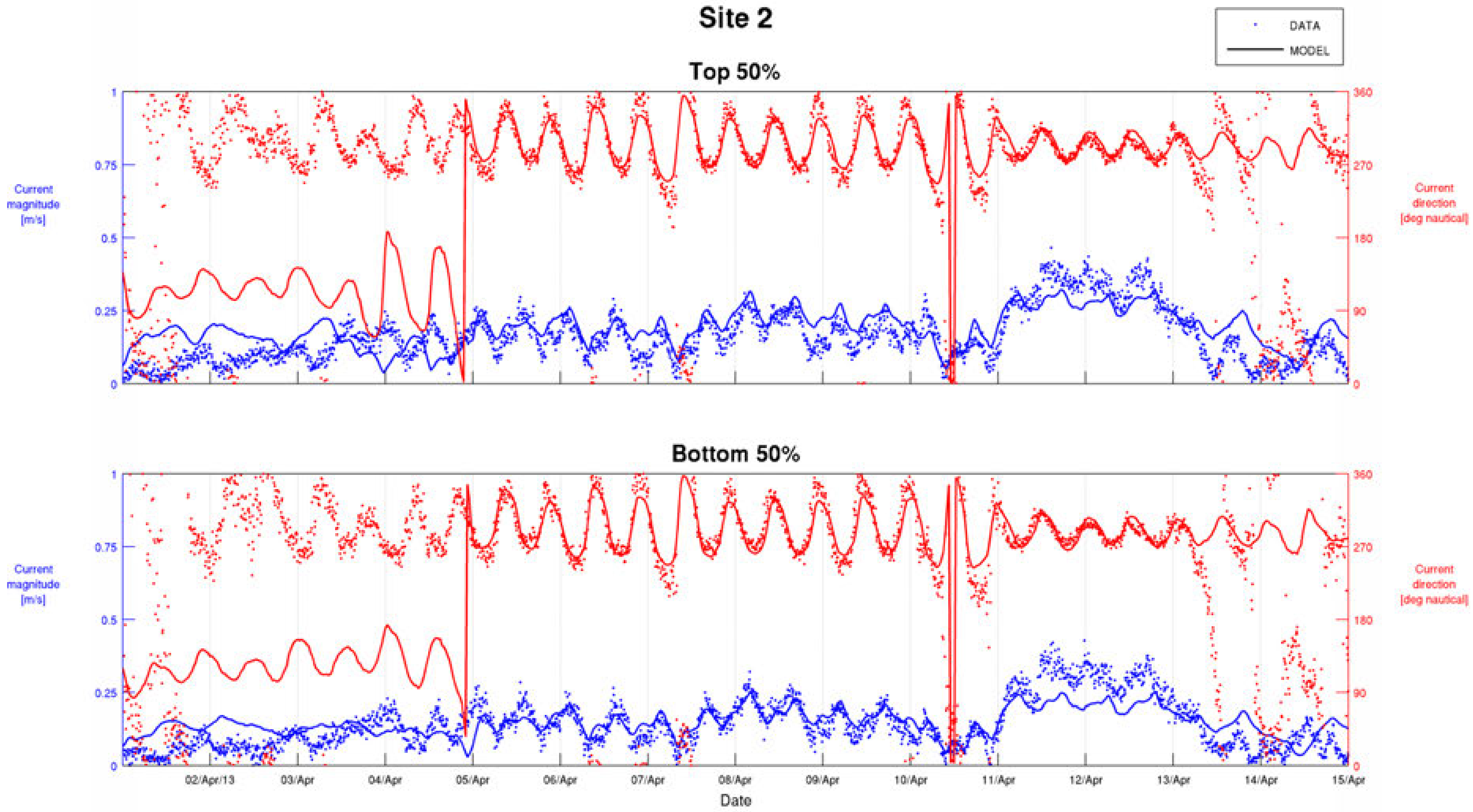


Figure C-10 Top 50% and Bottom 50% Current Calibration – Site 2 15/04/2013 to 01/05/2013

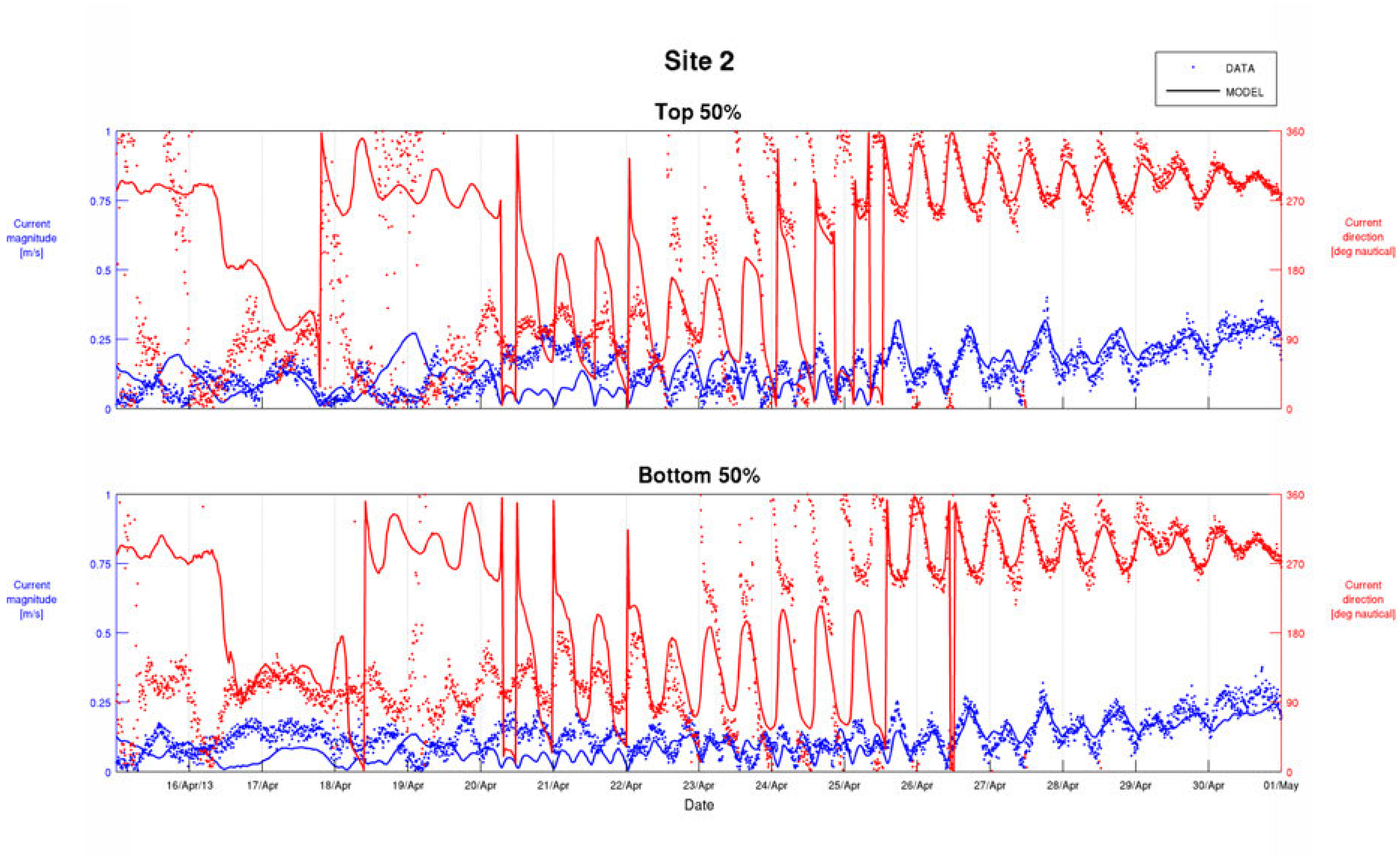


Figure C-11 Top 50% and Bottom 50% Current Calibration – Site 2 15/04/2013 to 01/05/2013

Calibration Period Current Time Series Plot

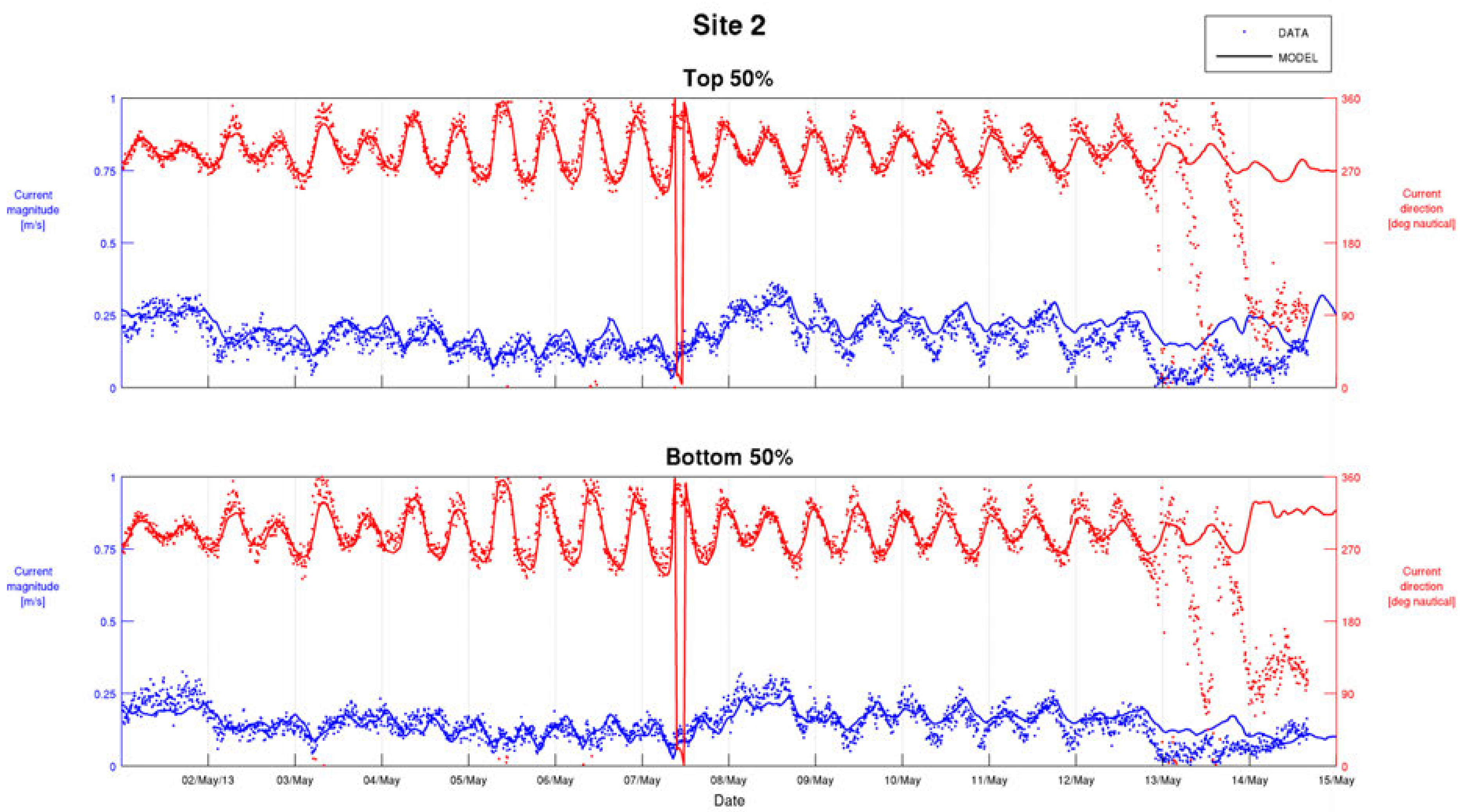


Figure C-12 Top 50% and Bottom 50% Current Calibration – Site 2 01/05/2013 to 15/05/2013

Calibration Period Current Time Series Plot

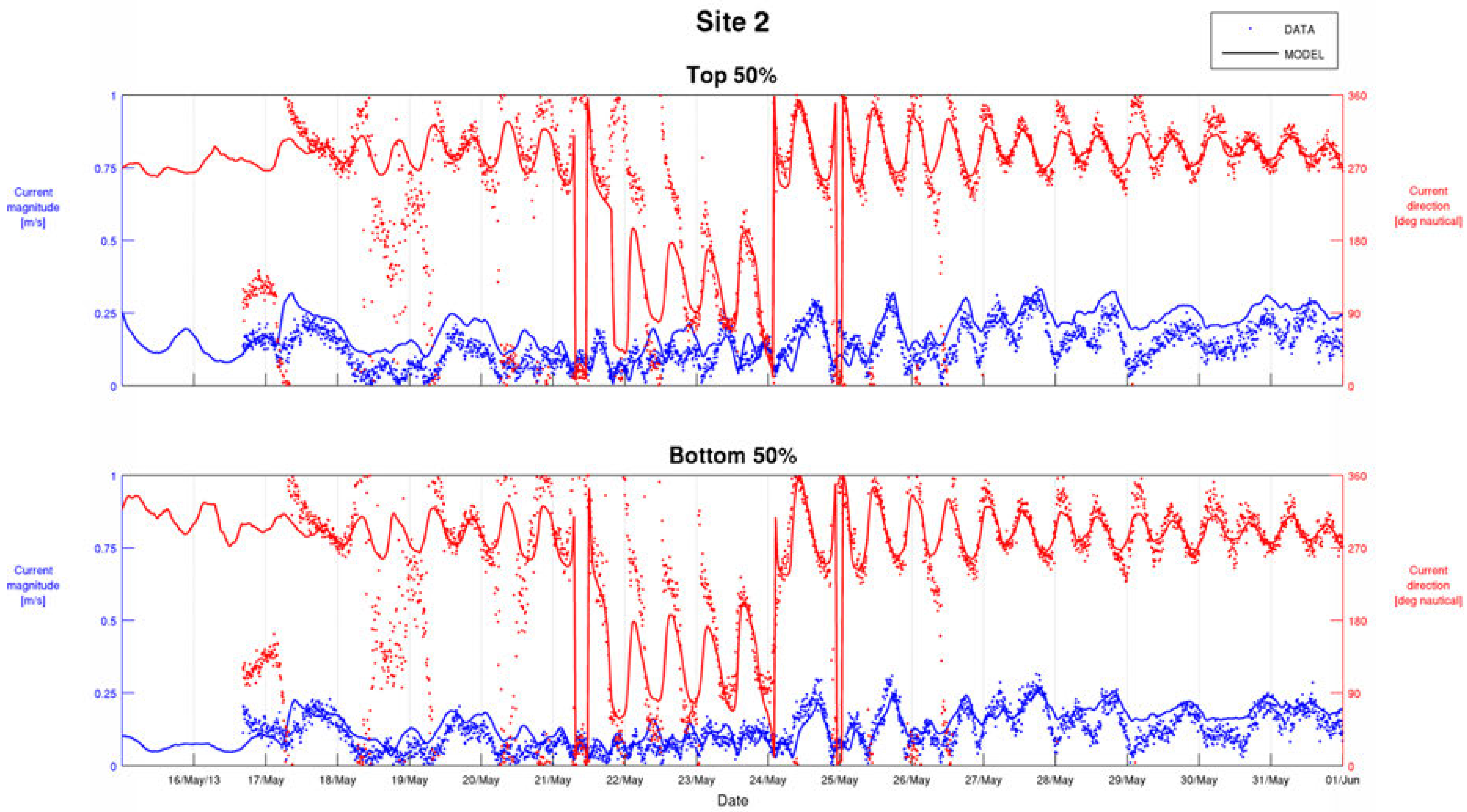


Figure C-13 Top 50% and Bottom 50% Current Calibration – Site 2 15/05/2013 to 01/06/2013

Calibration Period Current Time Series Plot

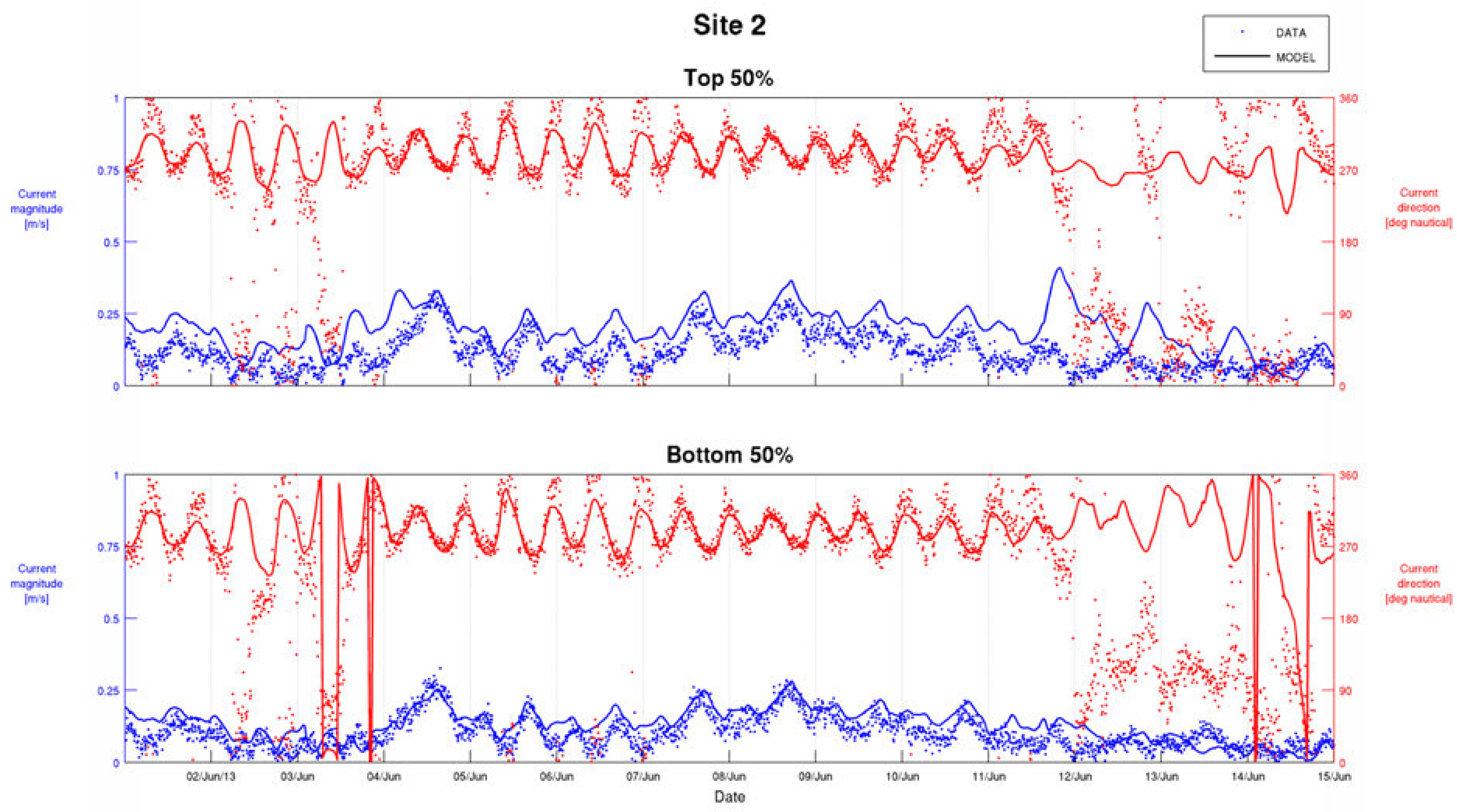


Figure C-14 Top 50% and Bottom 50% Current Calibration – Site 2 01/06/2013 to 15/06/2013

Calibration Period Current Time Series Plot

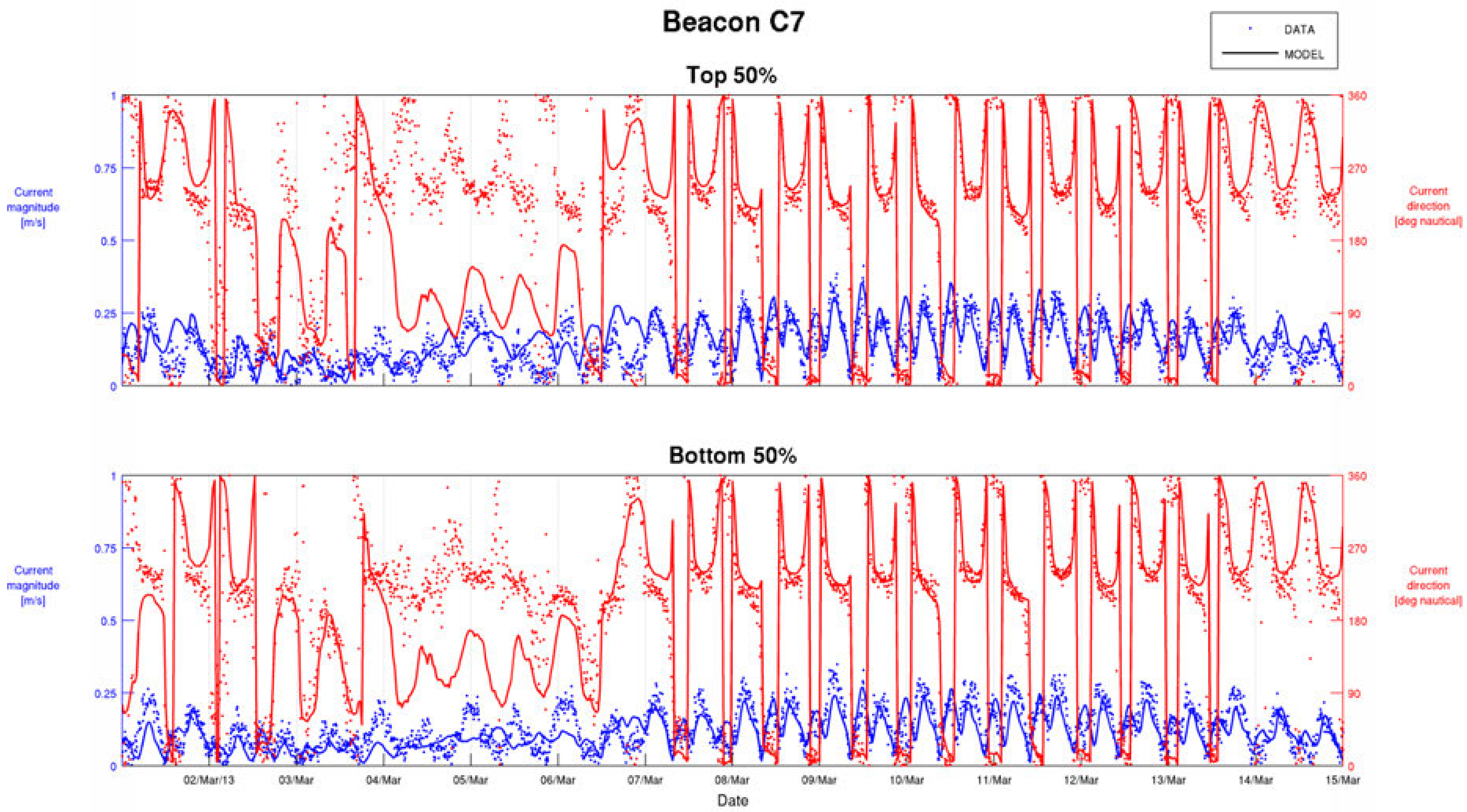


Figure C-15 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/03/2013 to 15/03/2013

Calibration Period Current Time Series Plot

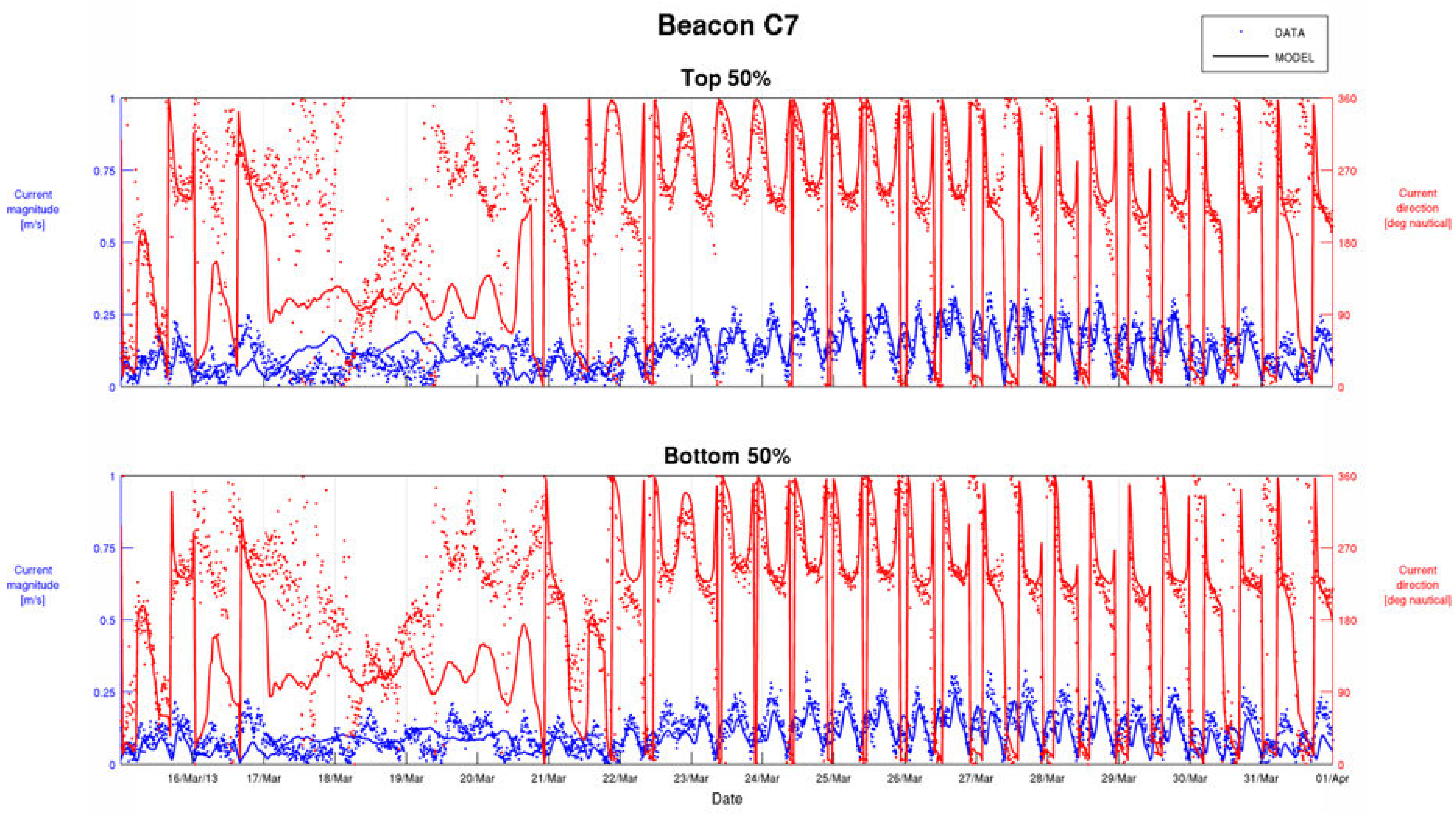


Figure C-16 Top 50% and Bottom 50% Current Calibration – Beacon C7 15/03/2013 to 01/04/2013

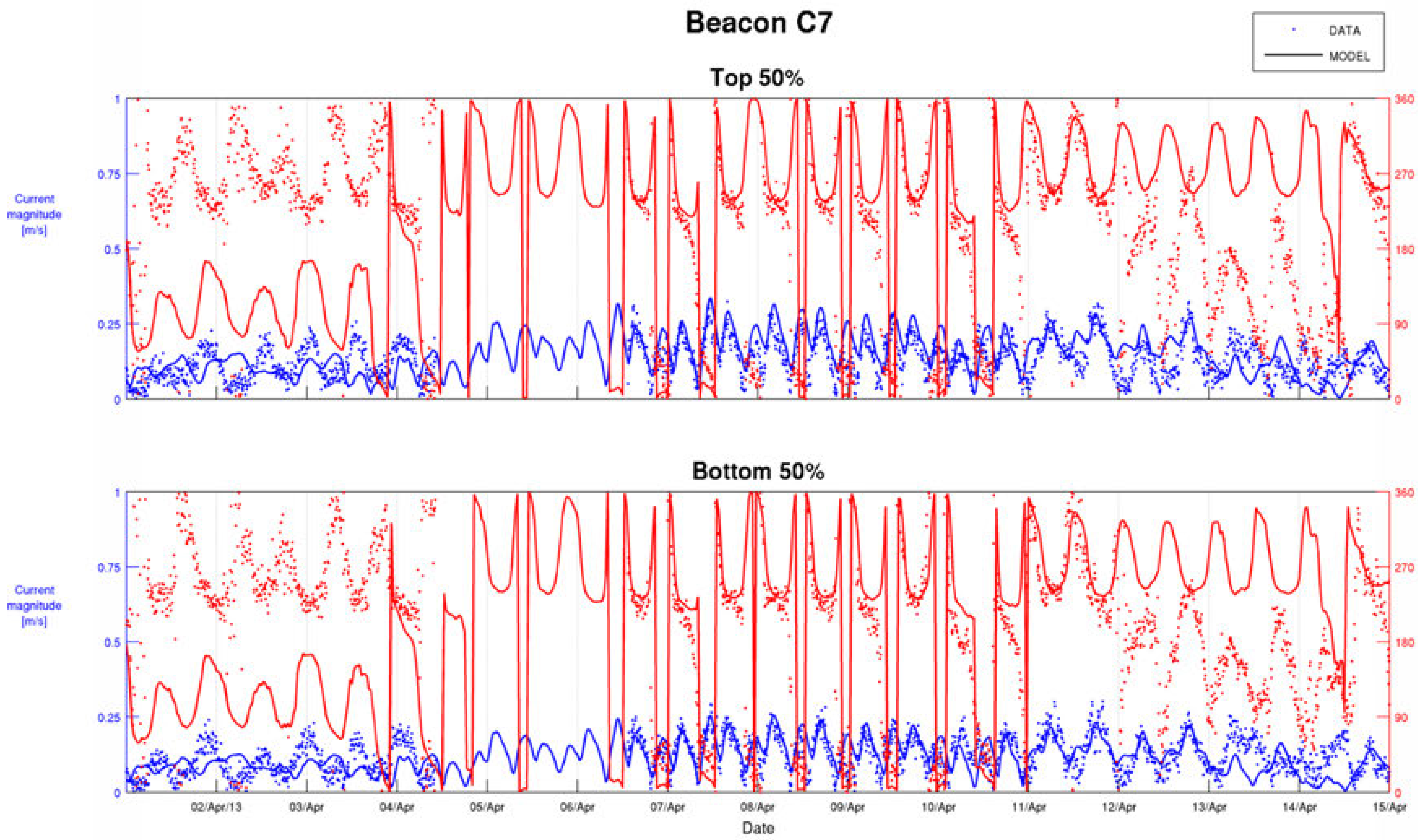


Figure C-17 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/04/2013 to 15/04/2013

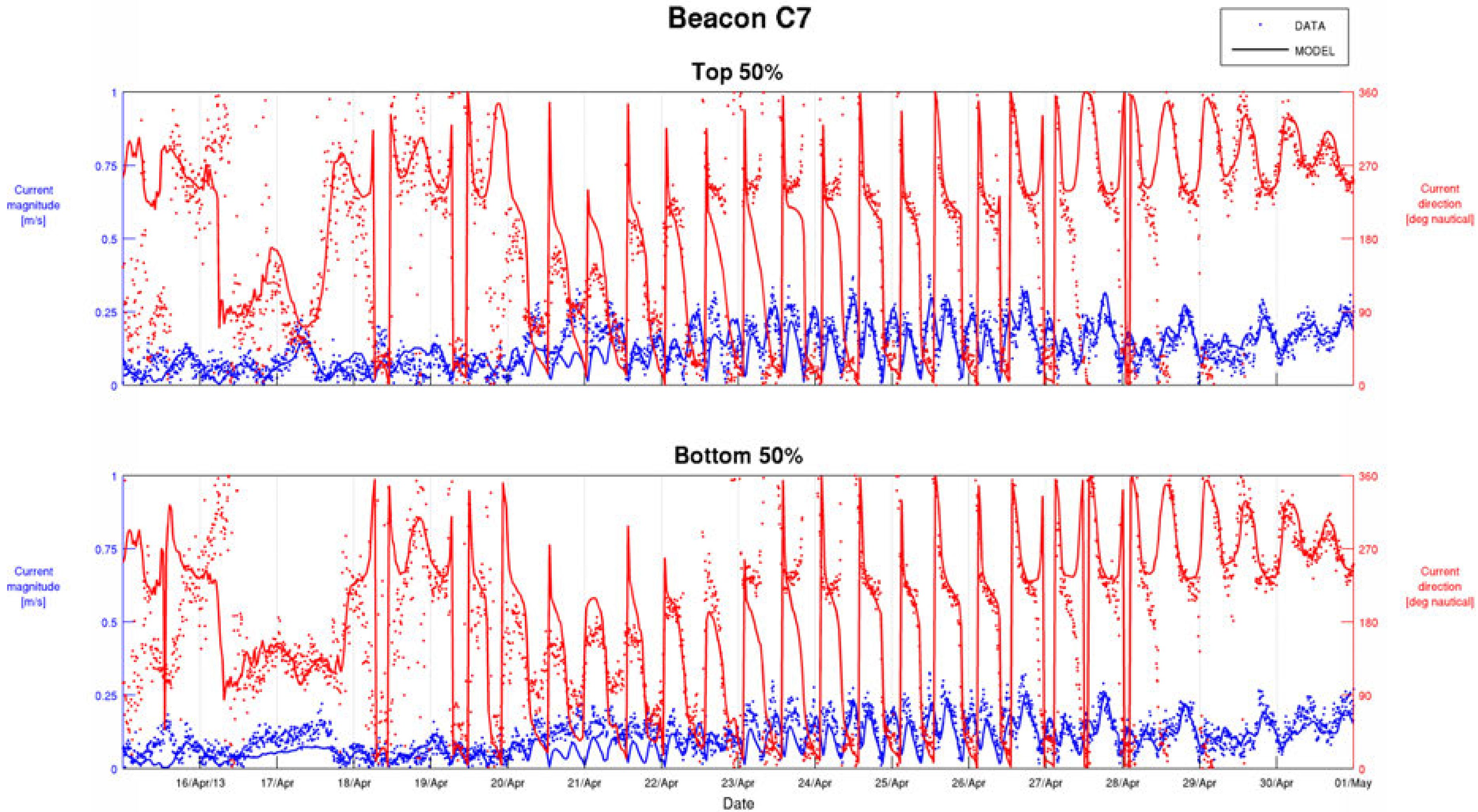


Figure C-18 Top 50% and Bottom 50% Current Calibration – Beacon C7 15/04/2013 to 01/05/2013

Calibration Period Current Time Series Plot

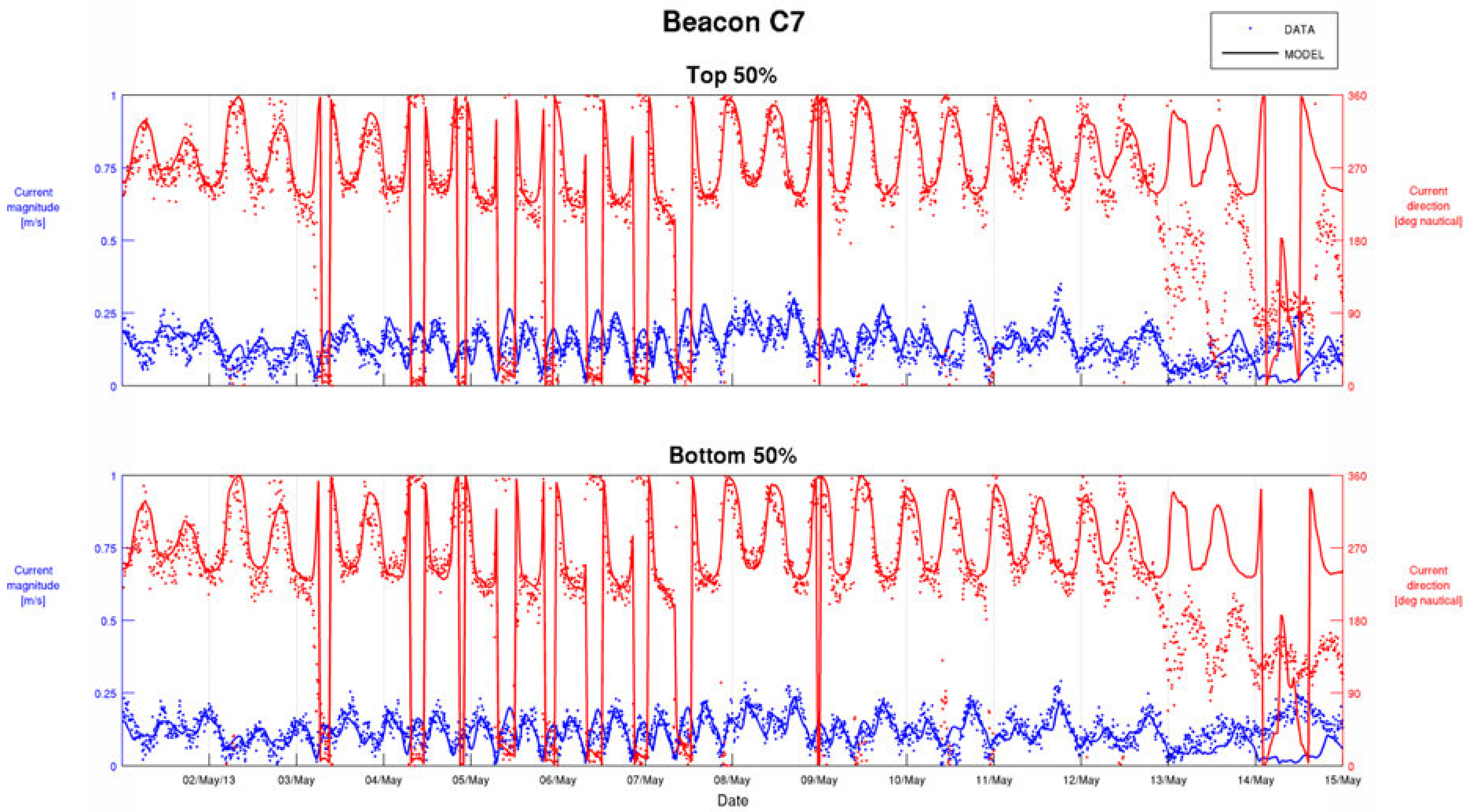


Figure C-19 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/05/2013 to 15/05/2013

Calibration Period Current Time Series Plot

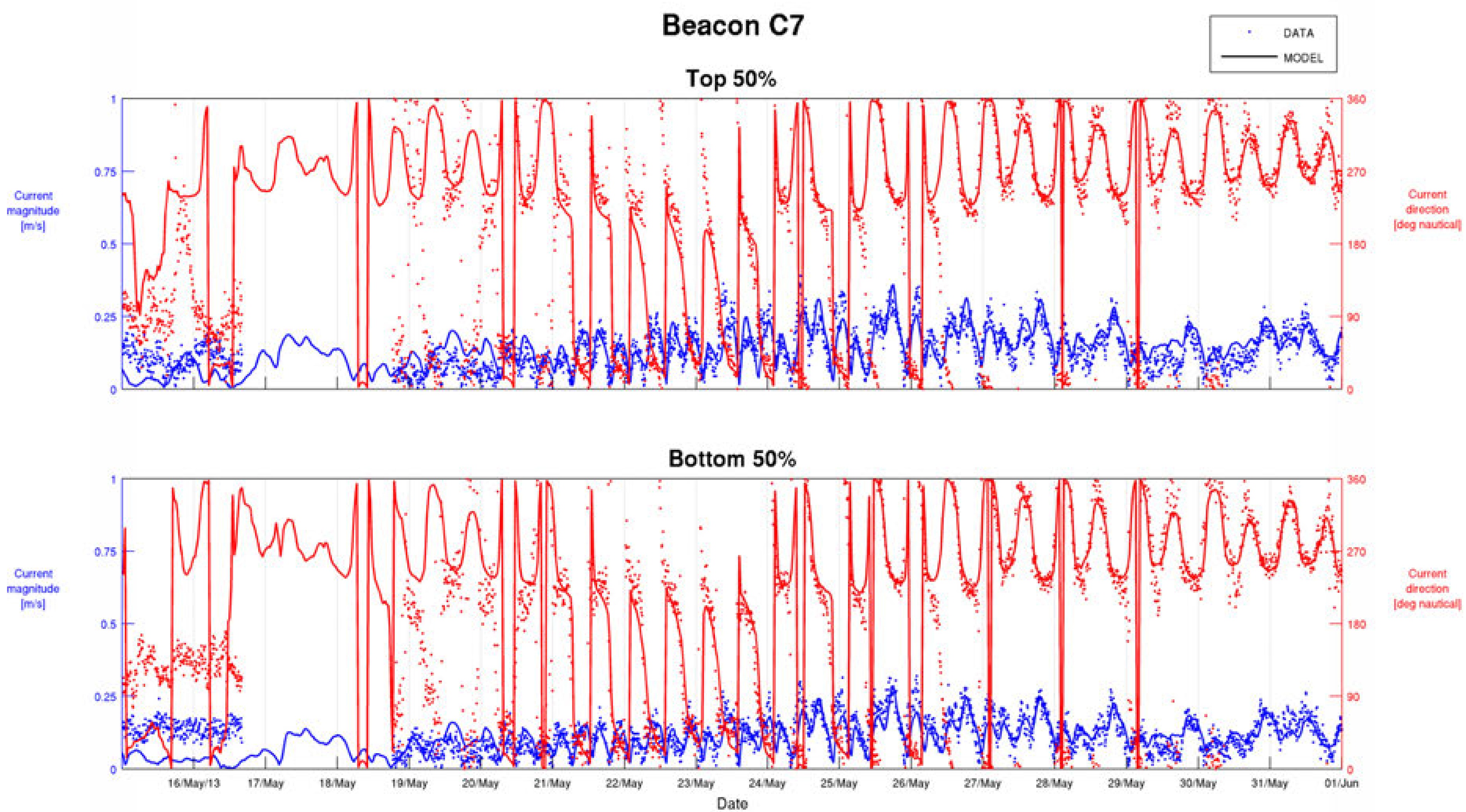


Figure C-20 Top 50% and Bottom 50% Current Calibration – Beacon C7 15/05/2013 to 01/06/2013

Calibration Period Current Time Series Plot

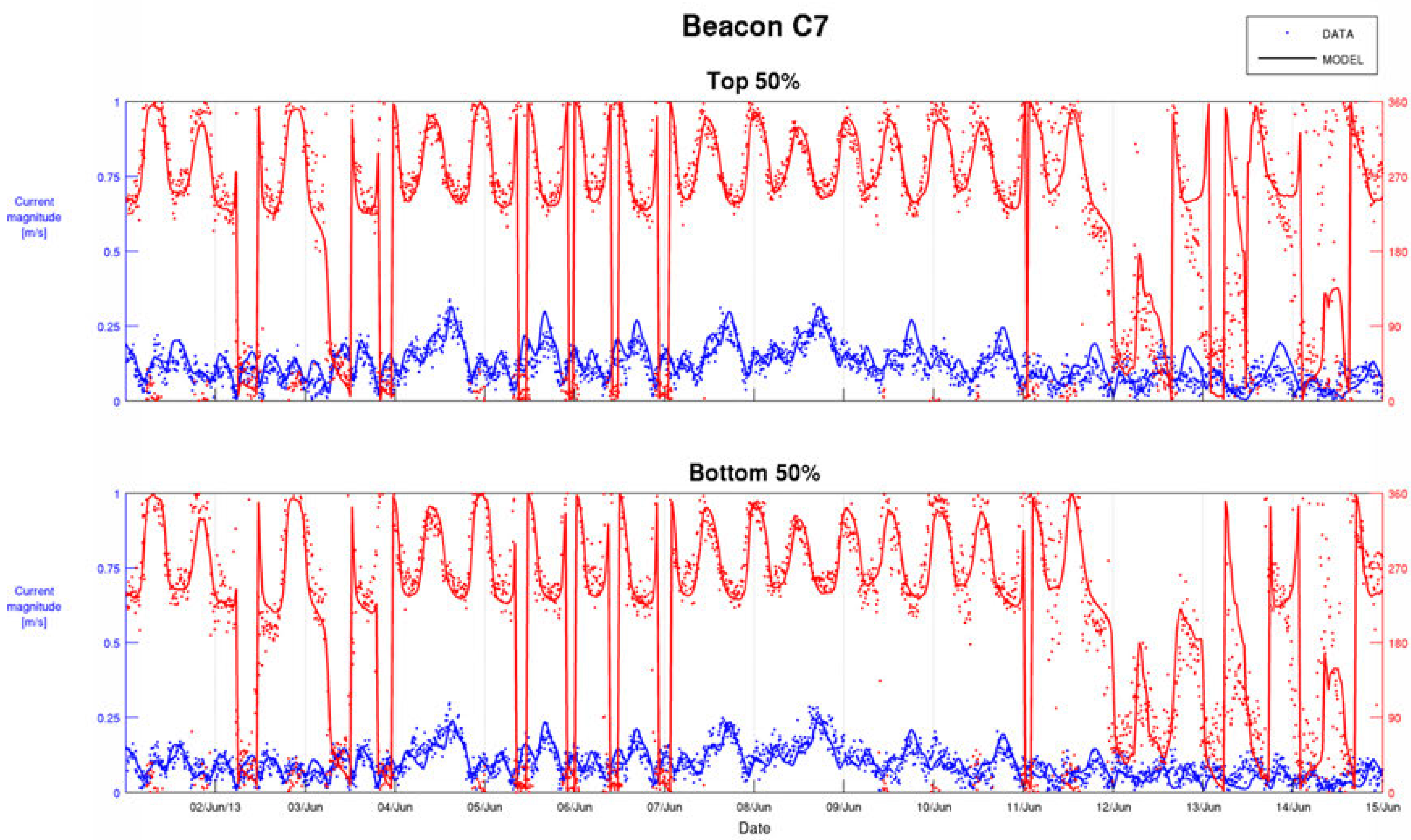


Figure C-21 Top 50% and Bottom 50% Current Calibration – Beacon C7 01/06/2013 to 15/06/2013

Calibration Period Current Time Series Plot

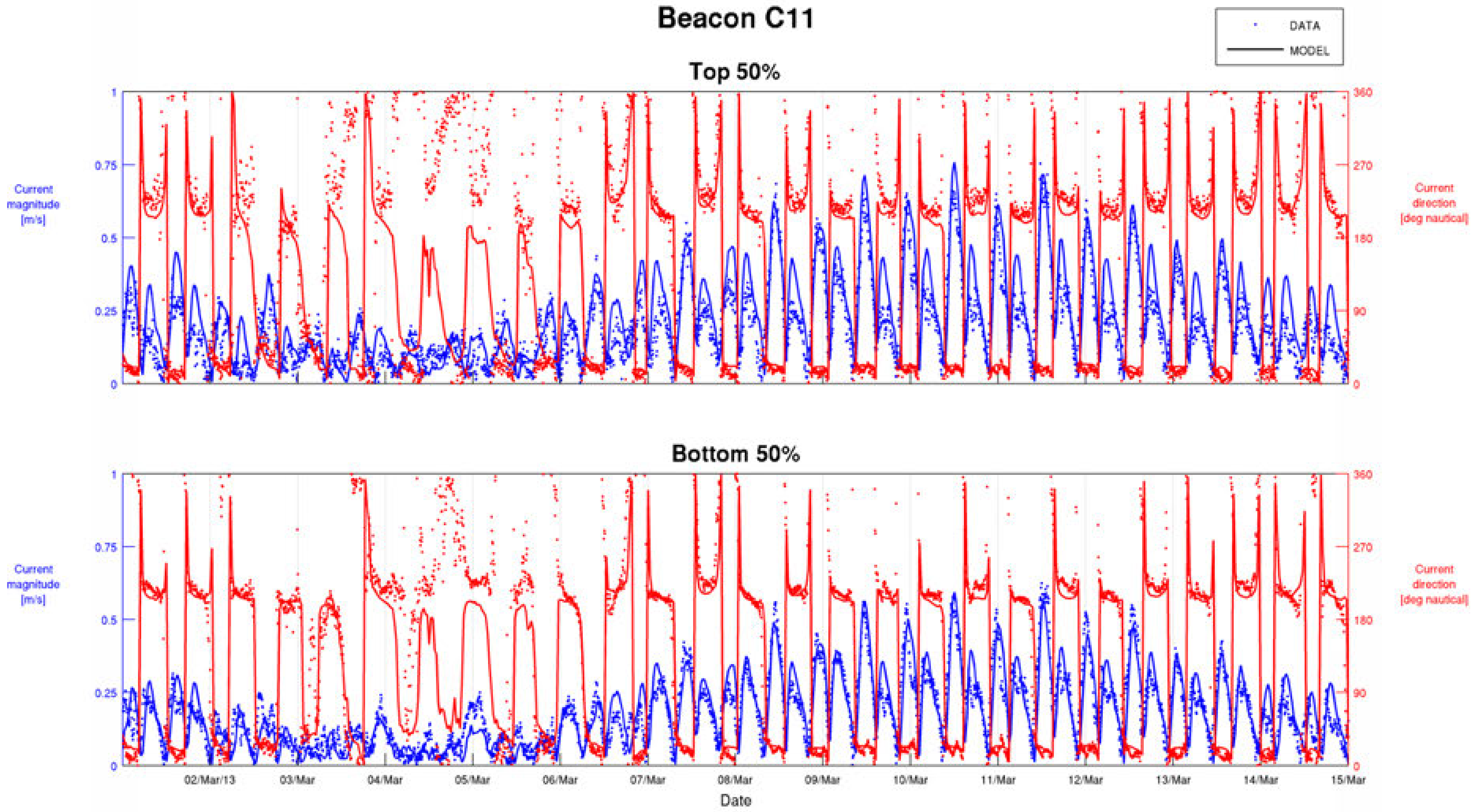


Figure C-22 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/03/2013 to 15/03/2013

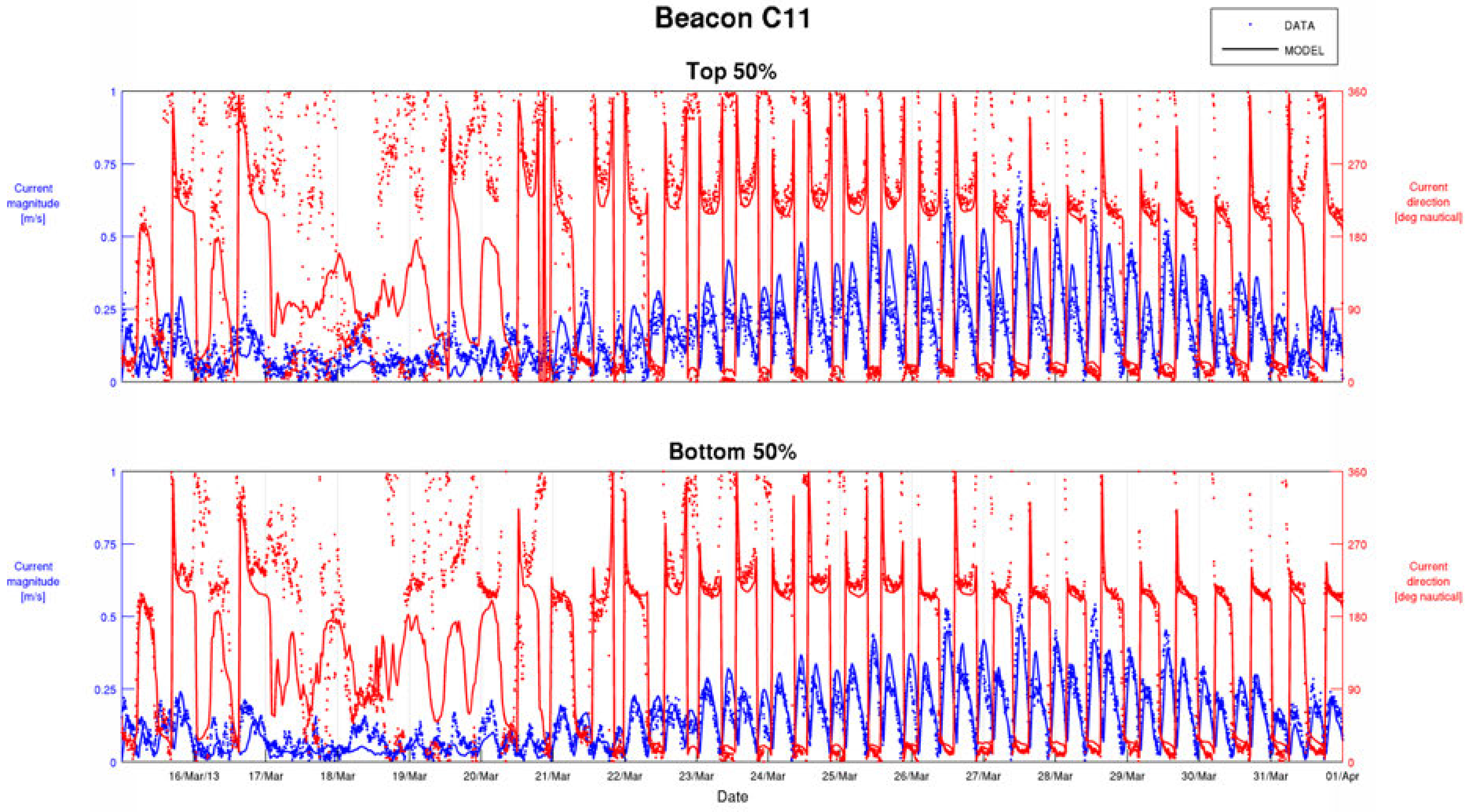


Figure C-23 Top 50% and Bottom 50% Current Calibration – Beacon C11 15/03/2013 to 01/04/2013

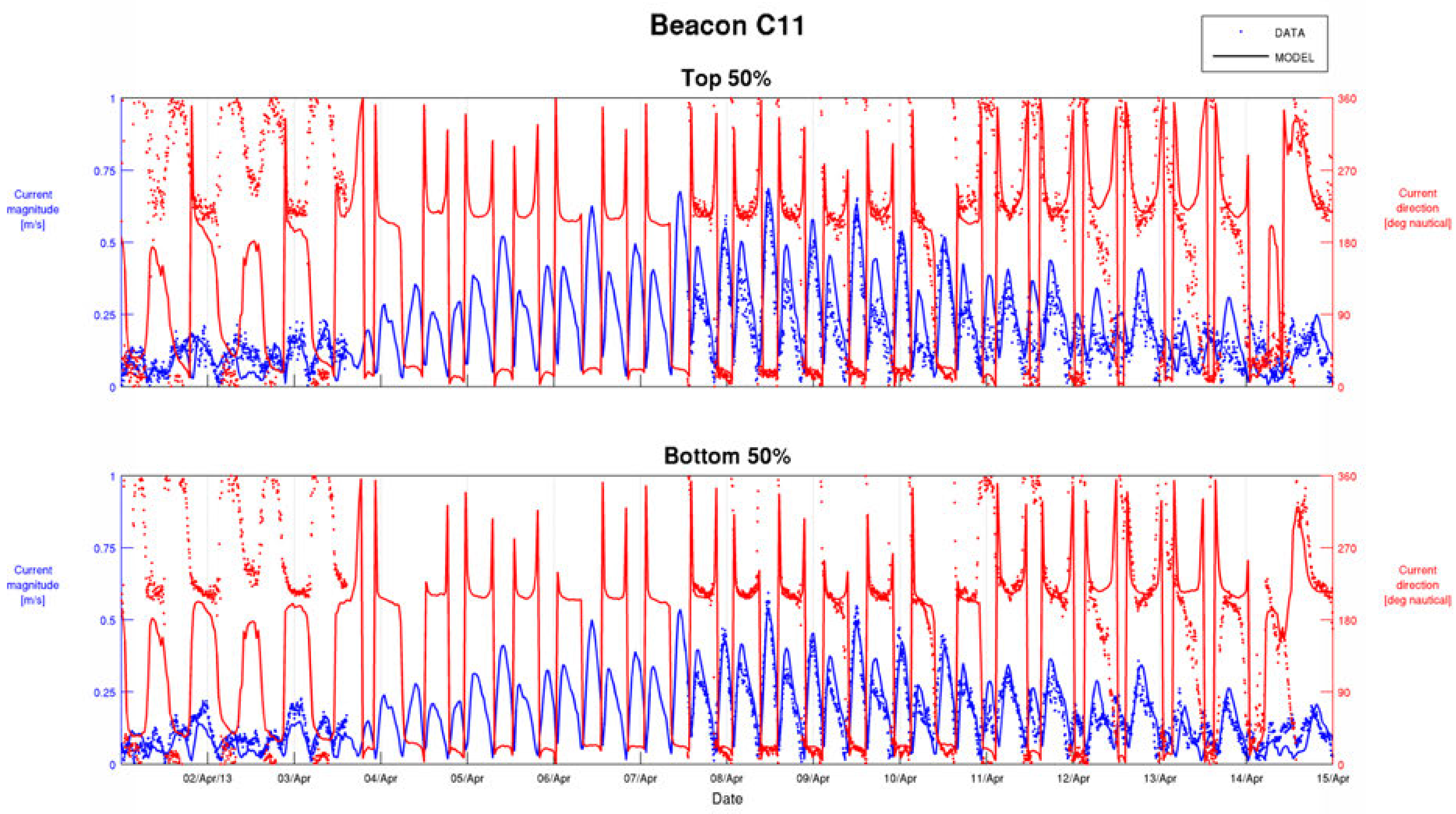


Figure C-24 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/04/2013 to 15/04/2013

Calibration Period Current Time Series Plot

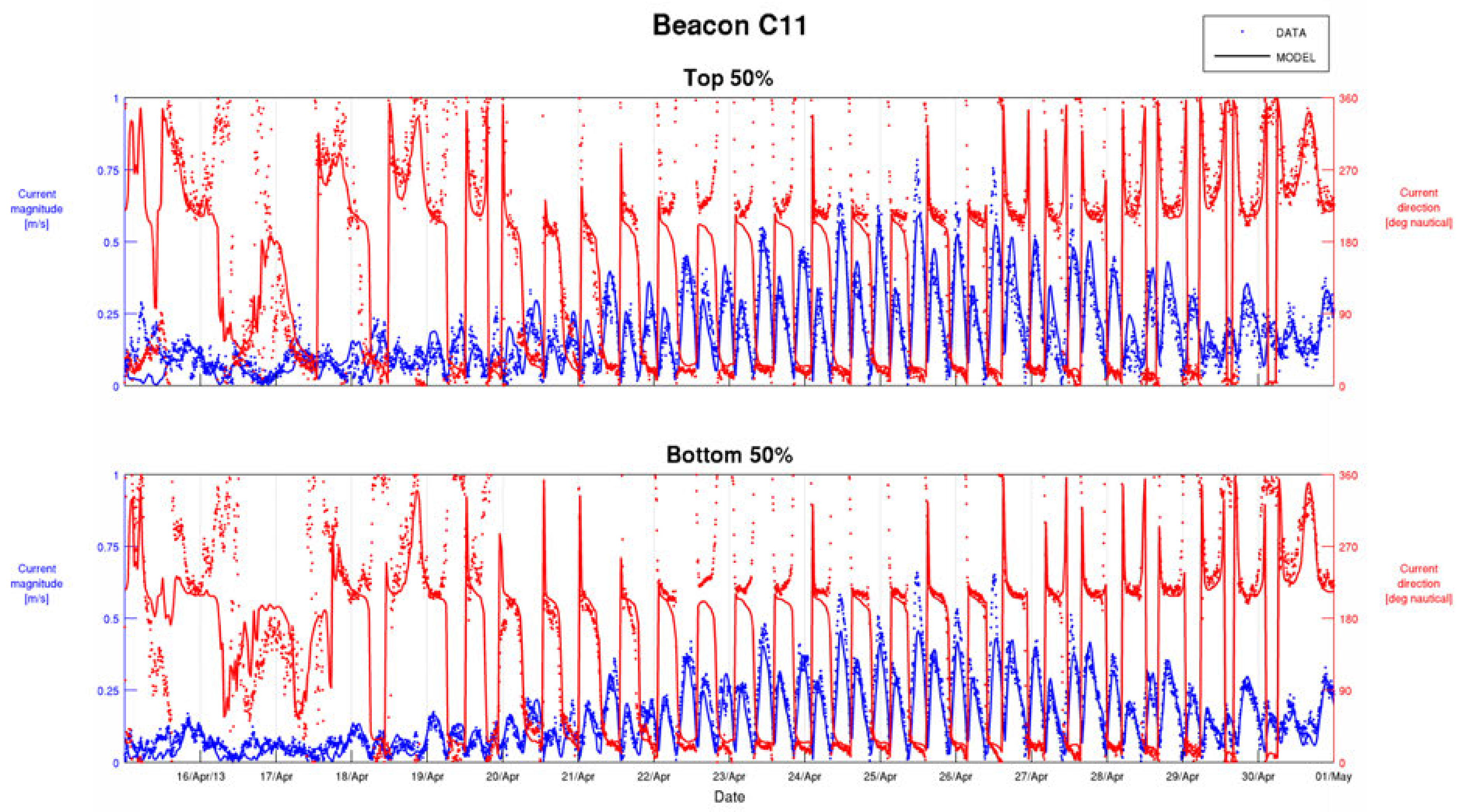


Figure C-25 Top 50% and Bottom 50% Current Calibration – Beacon C11 15/04/2013 to 01/05/2013

Calibration Period Current Time Series Plot

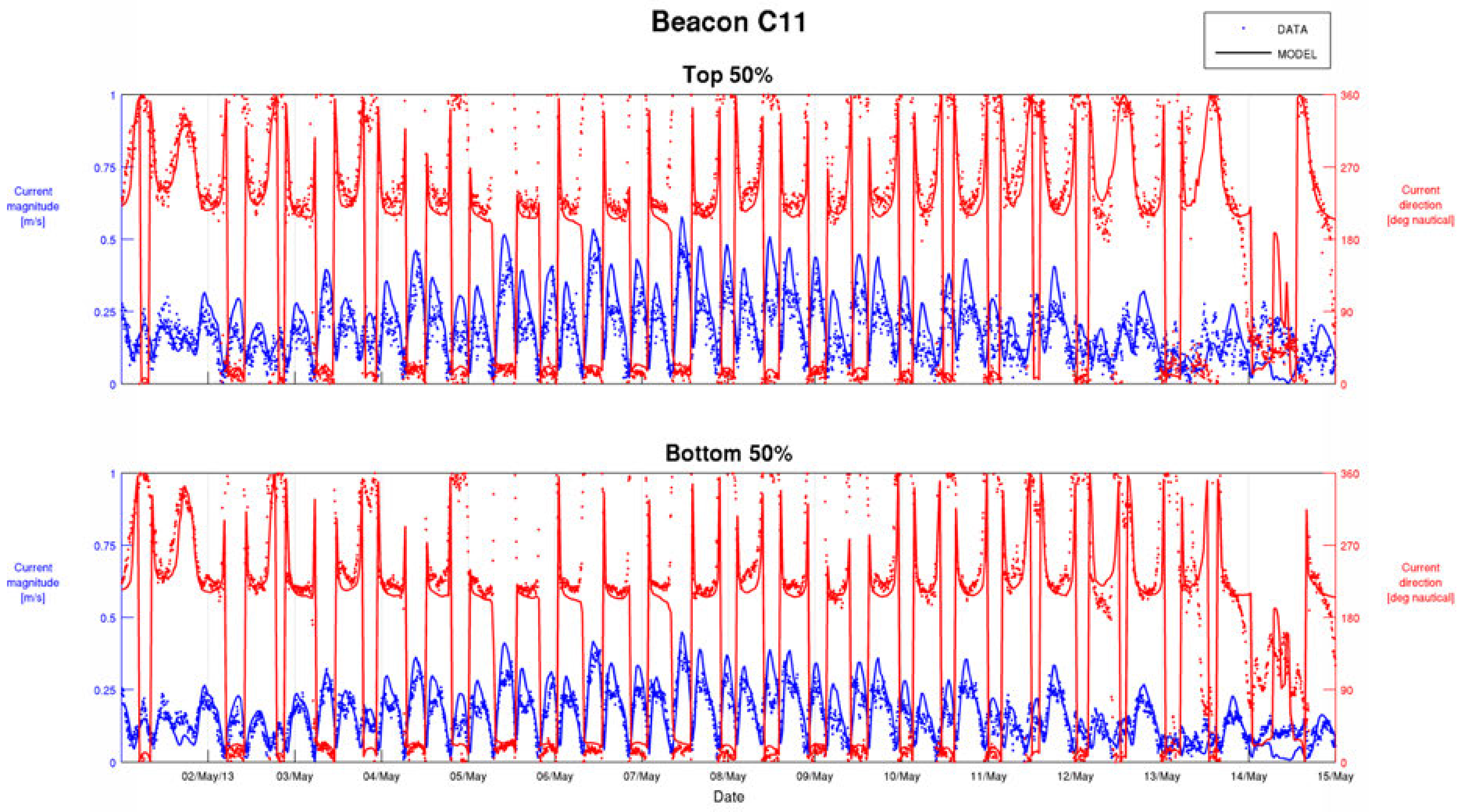


Figure C-26 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/05/2013 to 15/05/2013

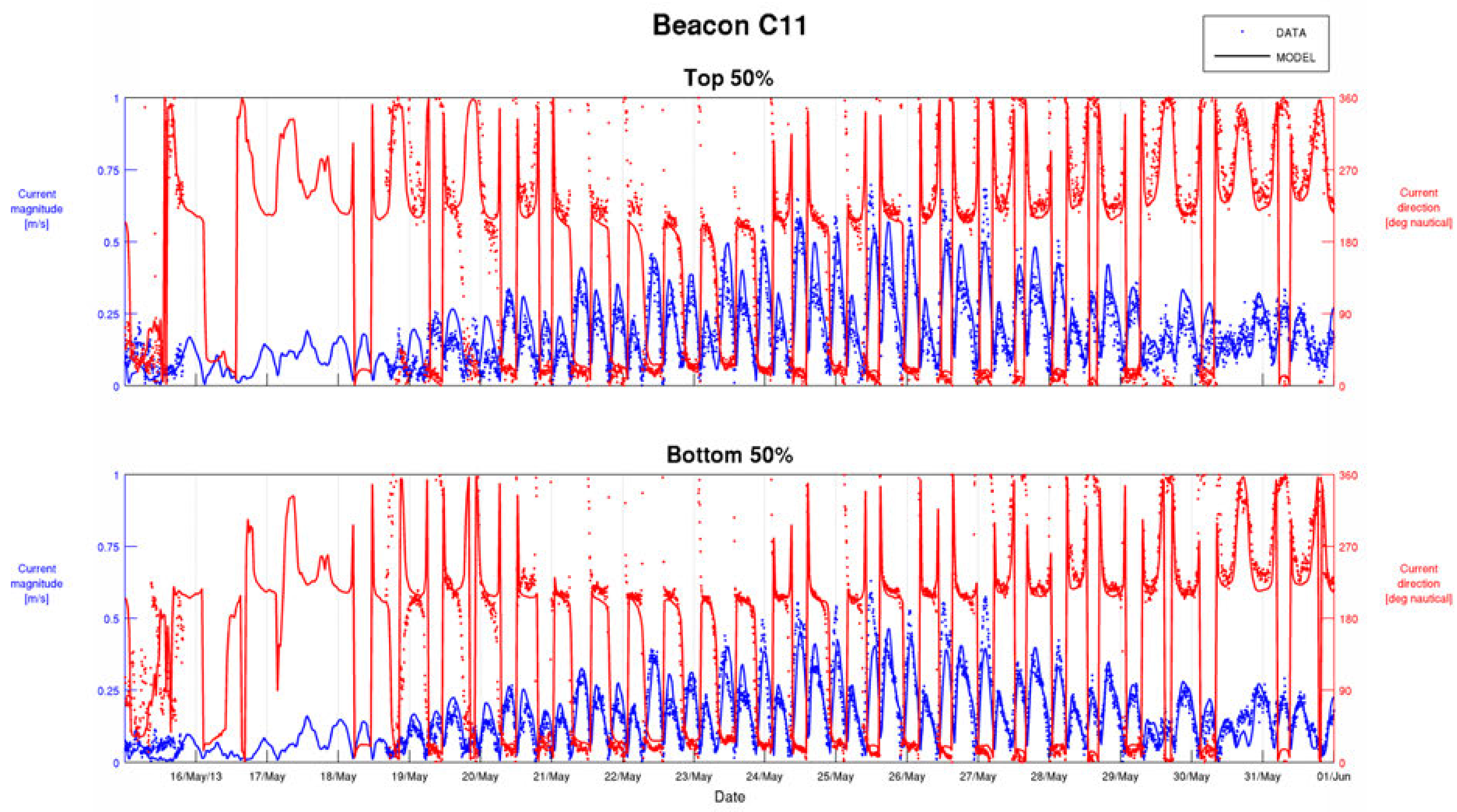


Figure C-27 Top 50% and Bottom 50% Current Calibration – Beacon C11 15/05/2013 to 01/06/2013

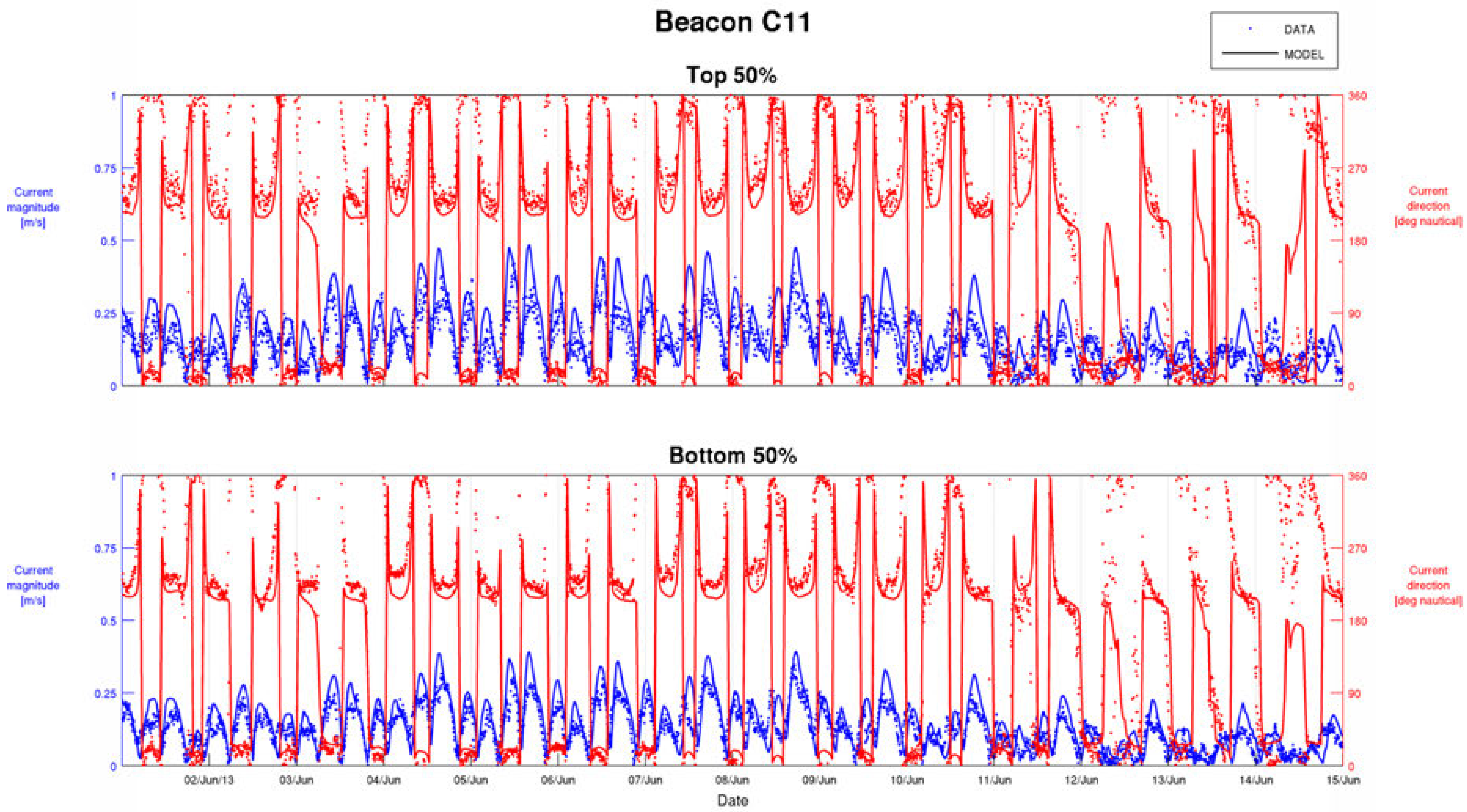
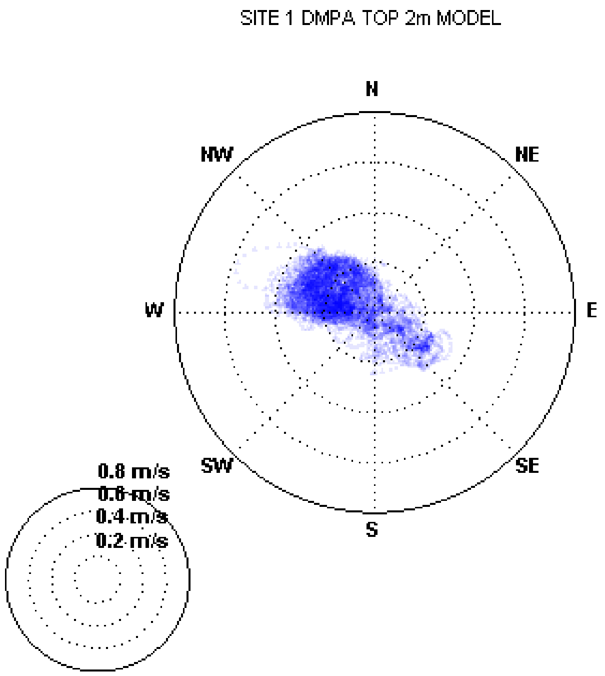


Figure C-28 Top 50% and Bottom 50% Current Calibration – Beacon C11 01/06/2013 to 15/06/2013

Appendix D Calibration Period Current Polar Plots

Top and bottom half of water column current polar plots for the entire simulation period are presented:

- DMPA, Figure D-1 and Figure D-2.
- Site 2, Figure D-3 and Figure D-4.
- Beacon C7, Figure D-5 and Figure D-6.
- Beacon C11, Figure D-7 and Figure D-8.



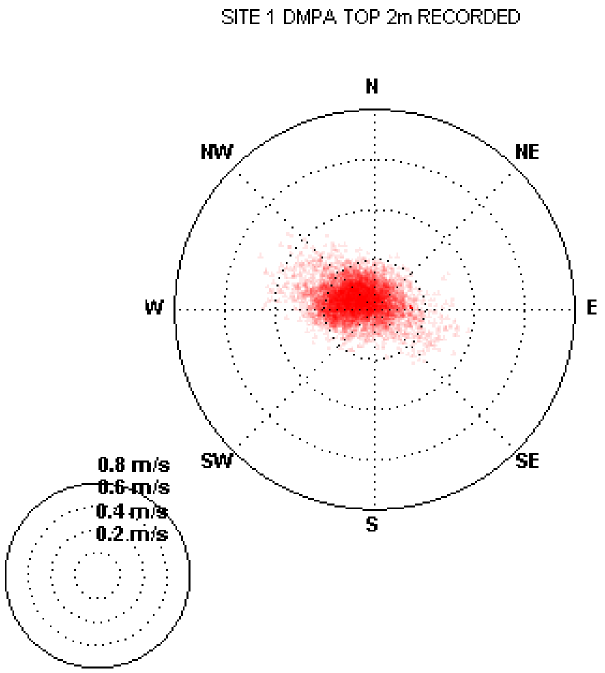
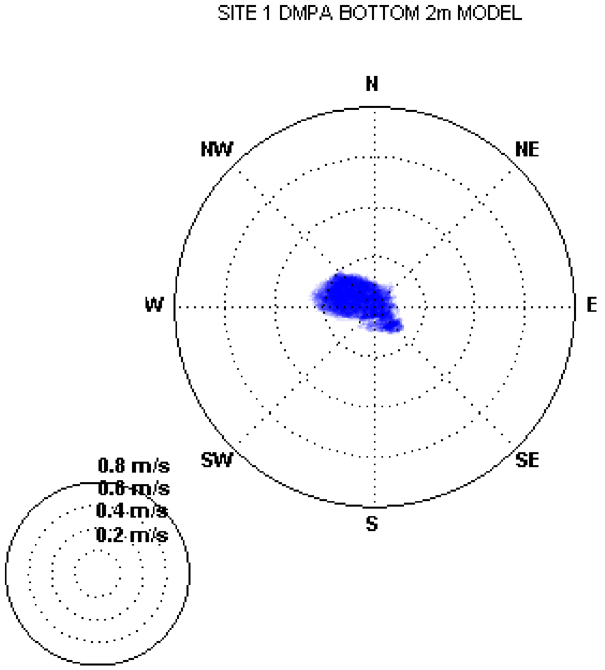


Figure D-1 Current Polar Plot Calibration – DMPA Top 2m of Water Column



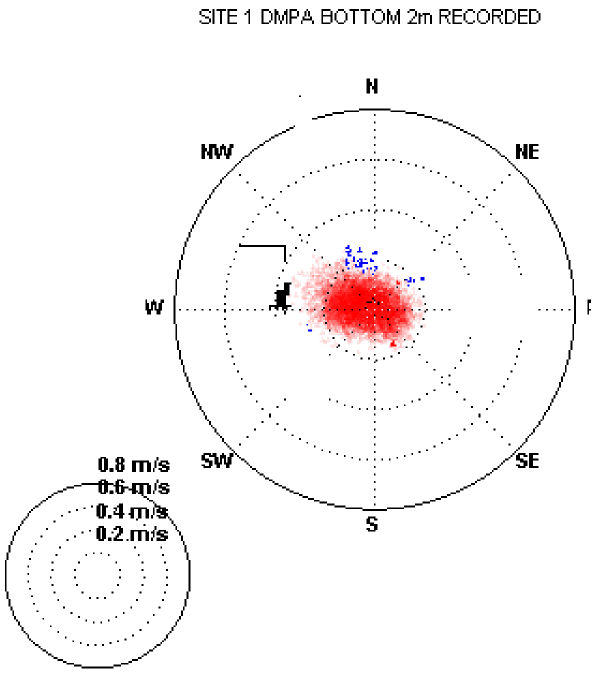


Figure D-2 Current Polar Plot Calibration – DMPA Bottom 2m of Water Column

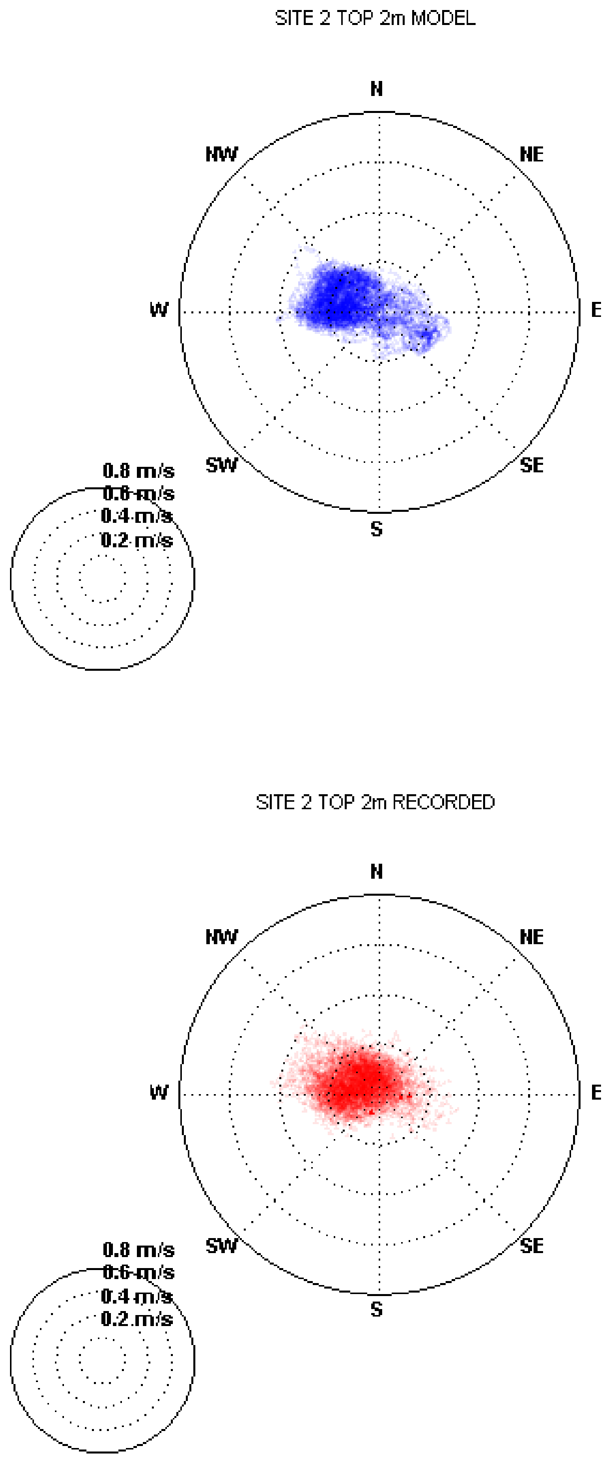


Figure D-3 Current Polar Plot Calibration – Site 2 Top 2m of Water Column

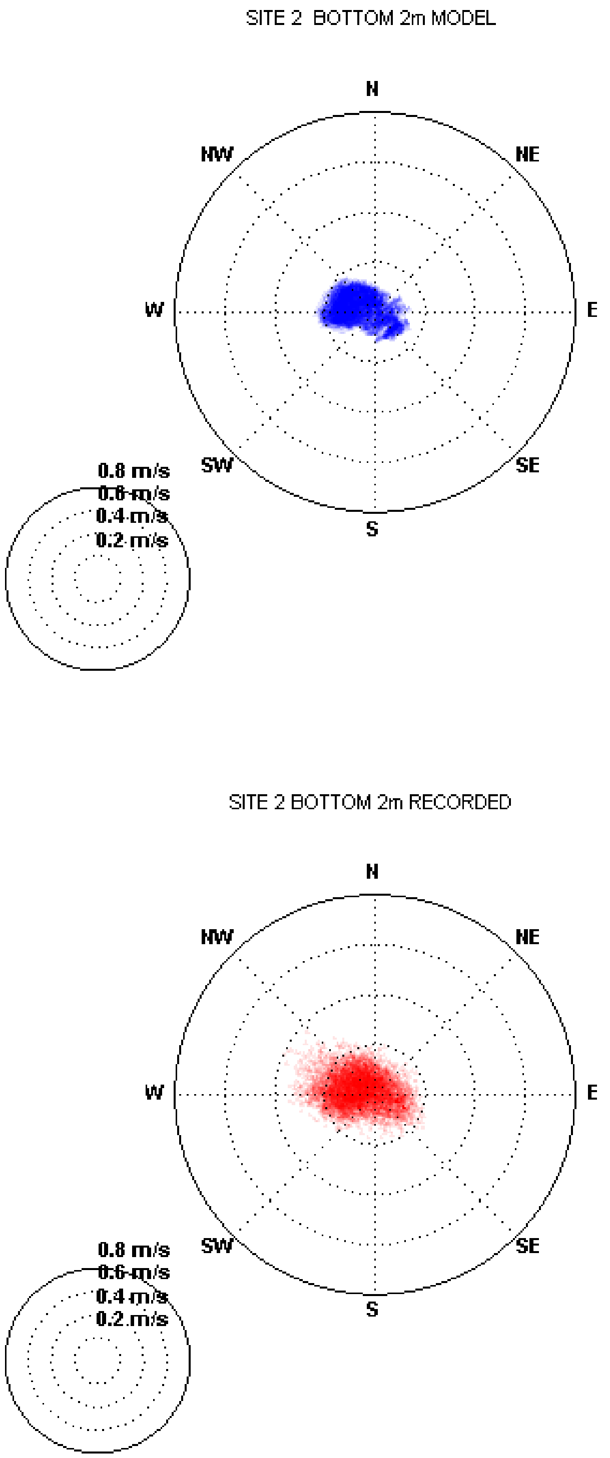
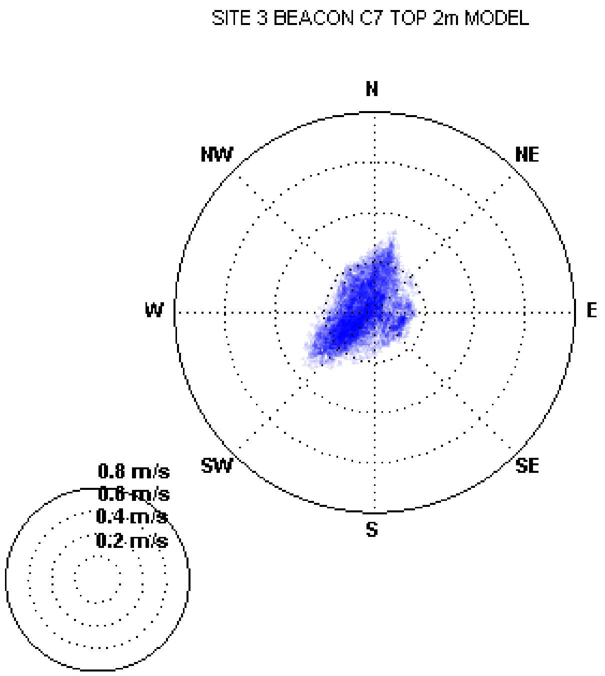


Figure D-4 Current Polar Plot Calibration – Site 2 Bottom 2m of Water Column



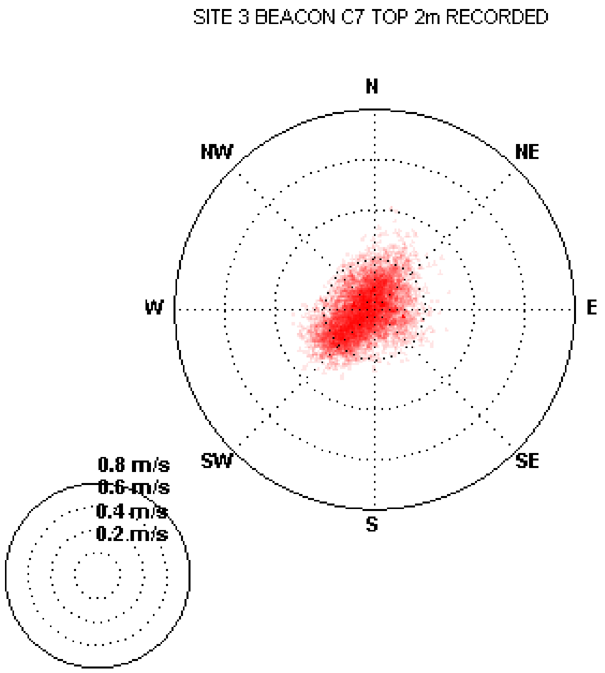
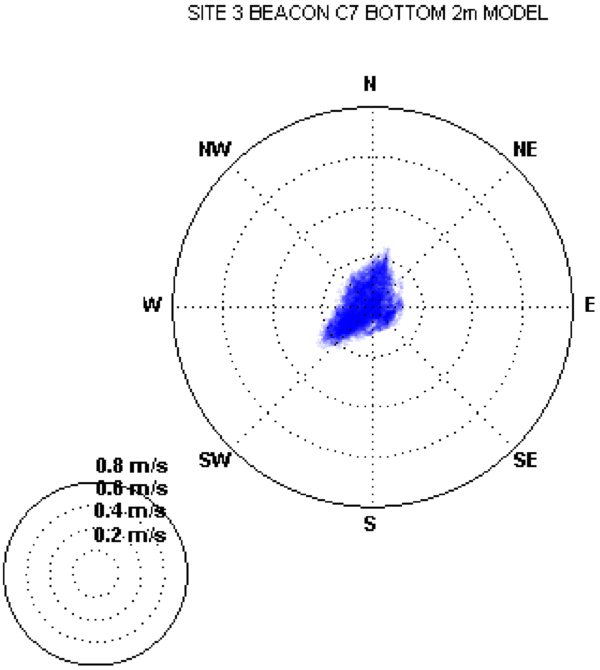


Figure D-5 Current Polar Plot Calibration – Beacon C7 Top 2m of Water Column



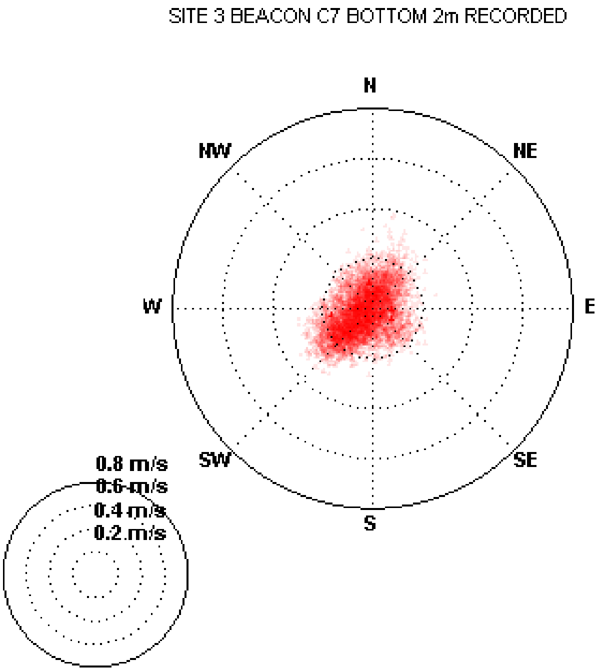
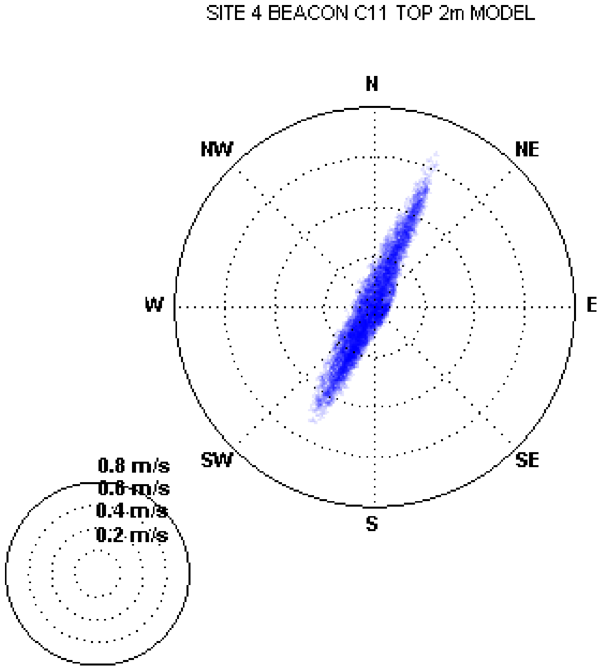


Figure D-6 Current Polar Plot Calibration – Beacon C7 Bottom 2m of Water Column



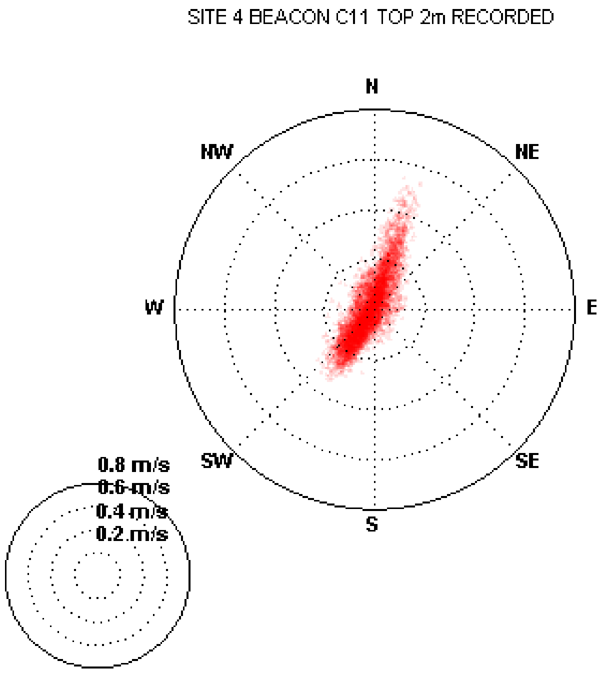
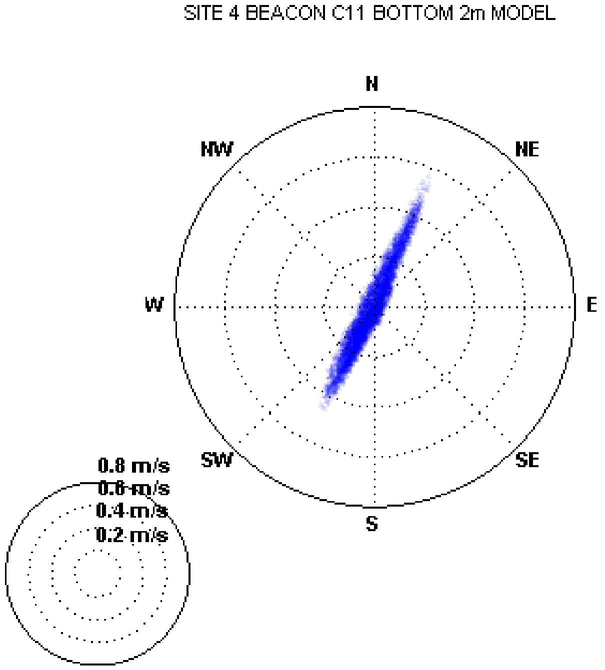


Figure D-7 Current Polar Plot Calibration – Beacon C11 Top 2m of Water Column



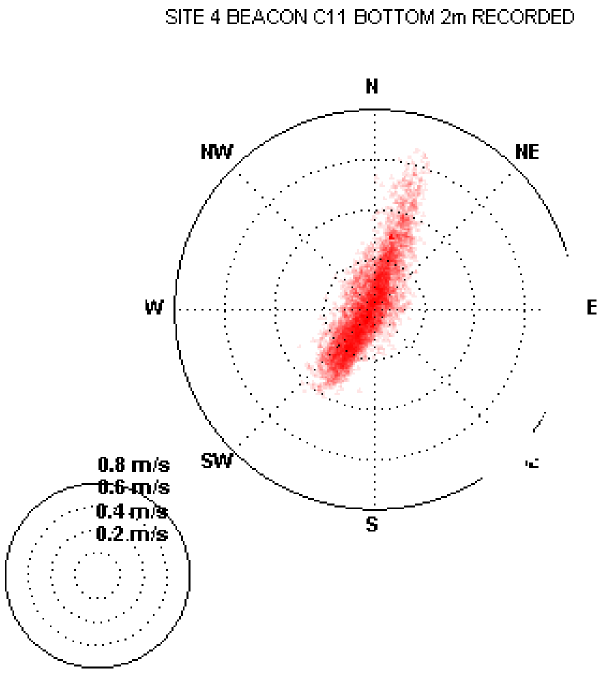


Figure D-8 Current Polar Plot Calibration – Beacon C11 Bottom 2m of Water Column

Appendix E Calibration Period Current Q-Q Plots

Recorded data and model output distributions of current components (x and y) and current speed are compared:

- DMPA, Figure E-1.
- Site 2, Figure E-2.
- Beacon C7, Figure E-3.
- Beacon C11, Figure E-4.

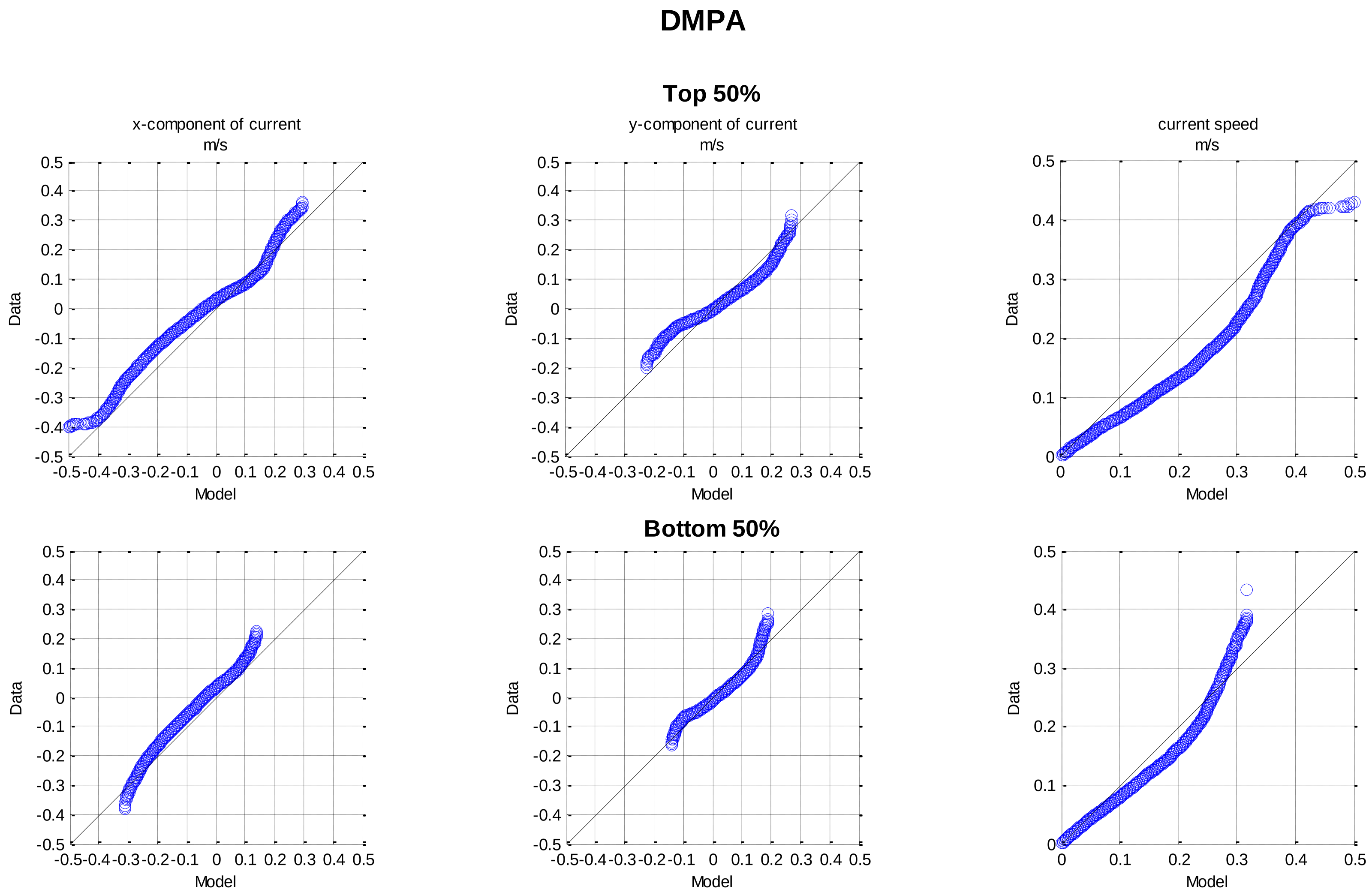


Figure E-1 Current Q-Q Plot – DMPA

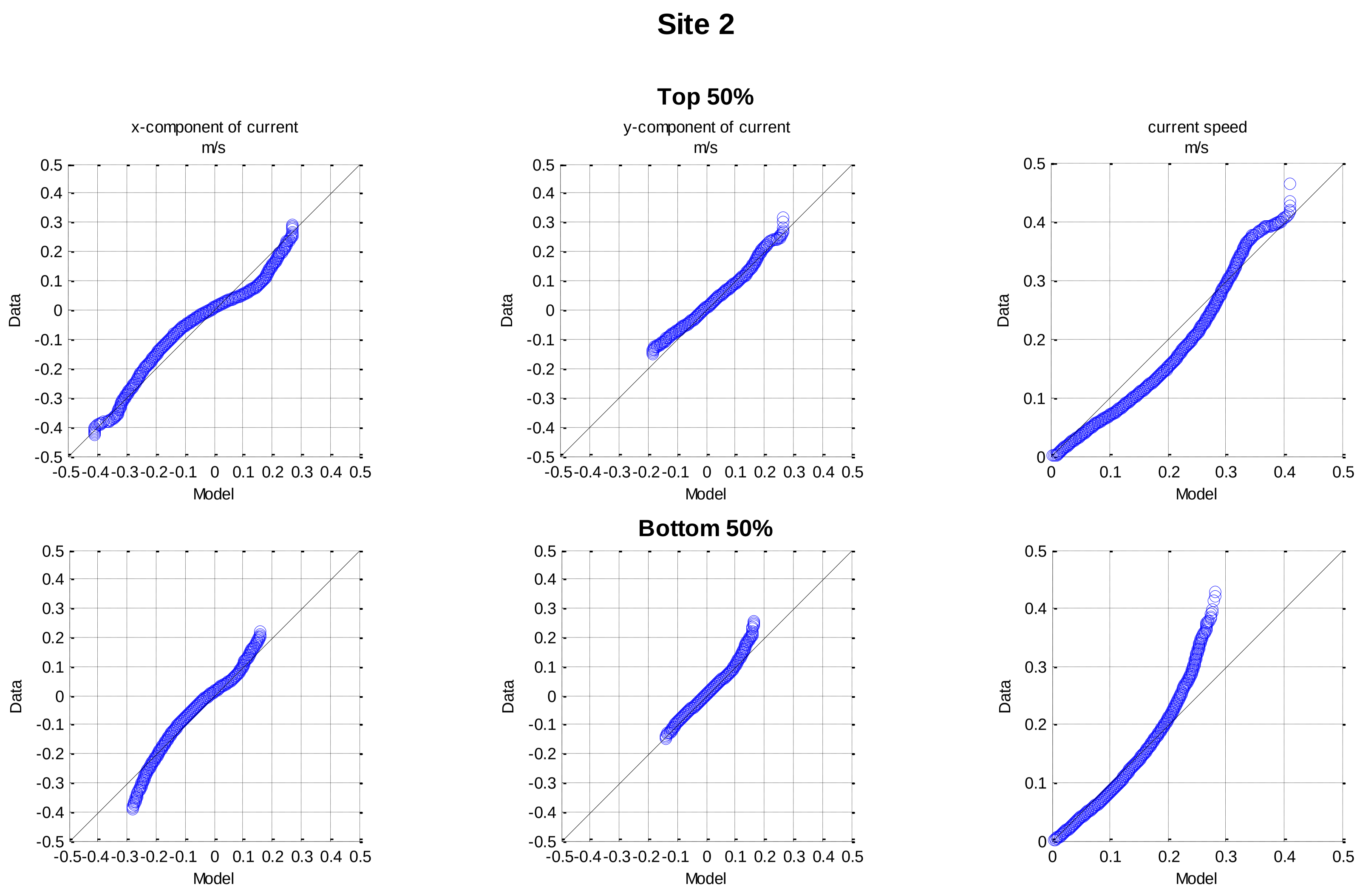


Figure E-2 Current Q-Q Plot – Site 2

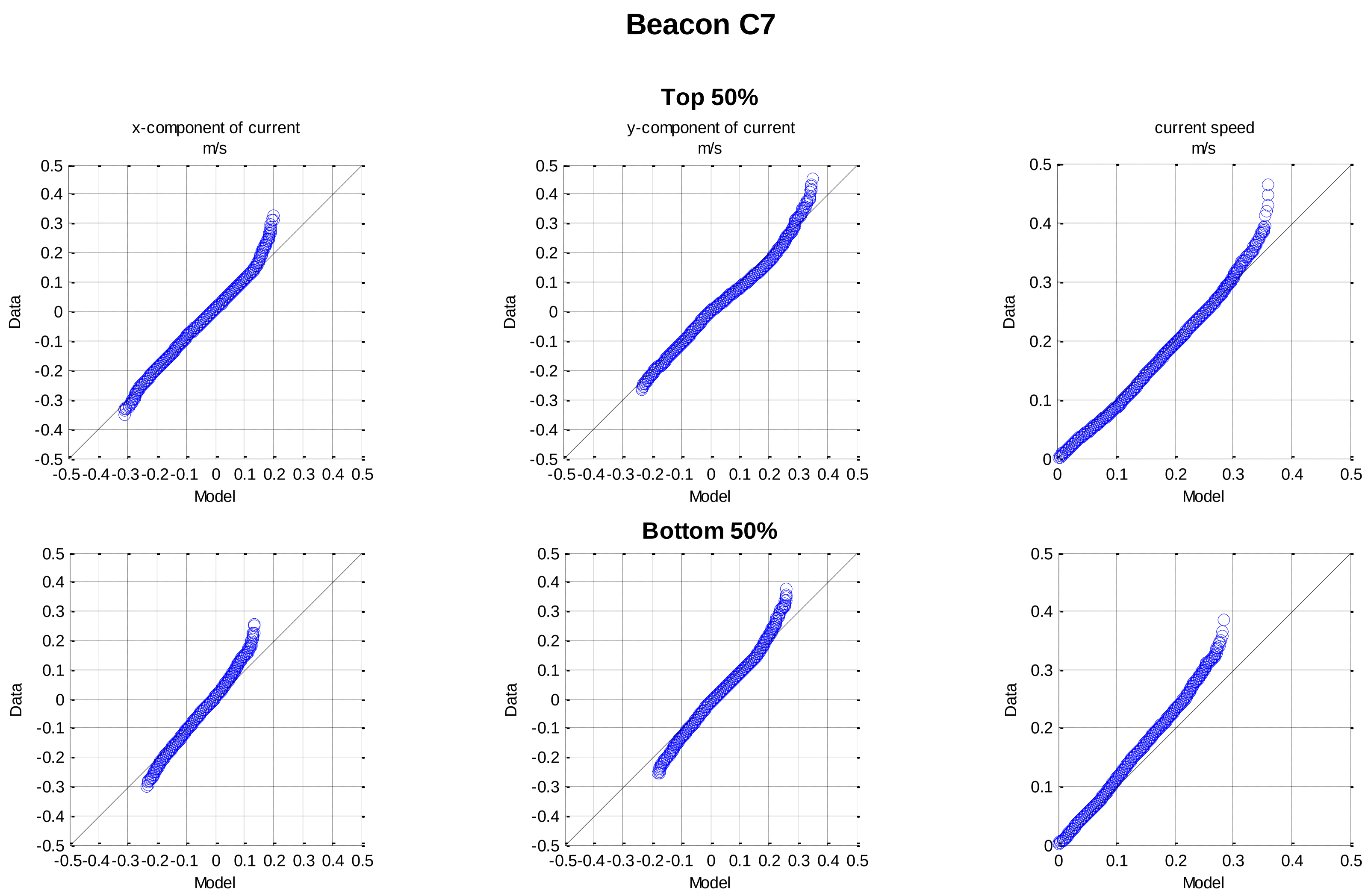


Figure E-3 Current Q-Q Plot – Beacon C7

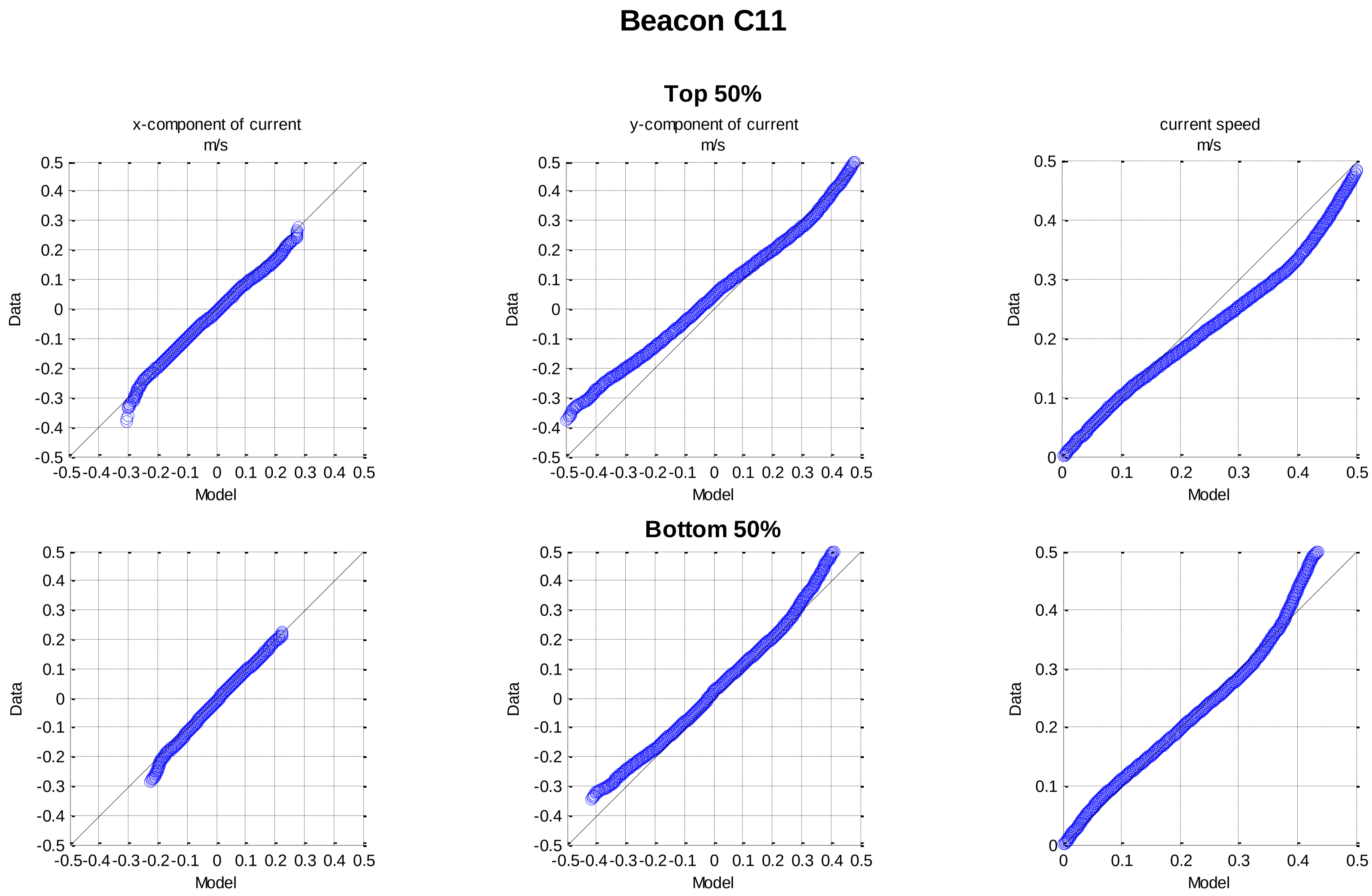


Figure E-4 Current Q-Q Plot – Beacon C11

Appendix F Validation Period Current Time Series Plots

Top and bottom half of water column current velocity and direction time series calibration plots are presented for the entire simulation period:

- DMPA, Figure F-1 to Figure F-8.
- Beacon C7, Figure F-9 to Figure F-15.

Validation Period Current Time Series Plots

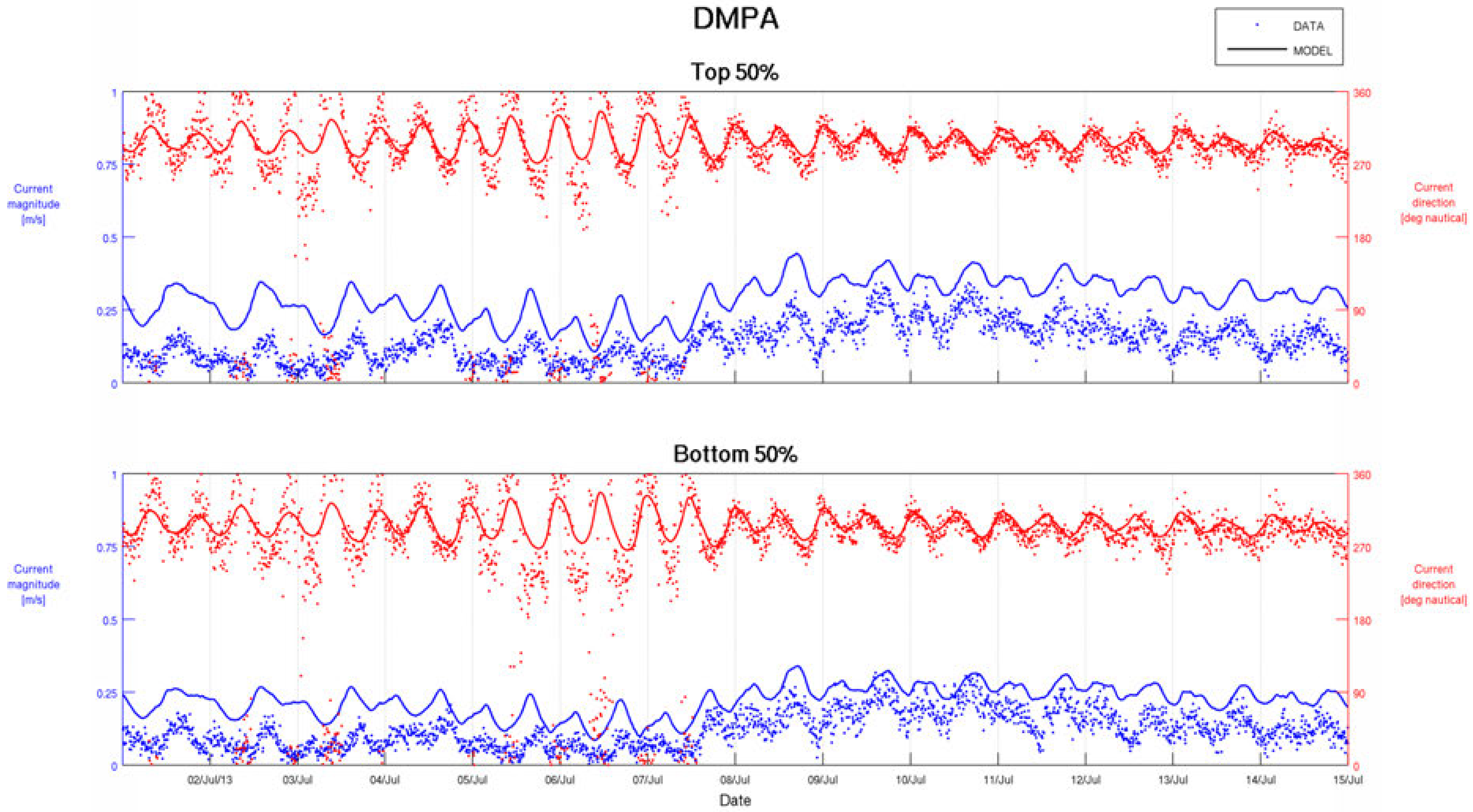


Figure F-1 Top 50% and Bottom 50% Current Validation – DMPA 01/07/2013 to 15/07/2013

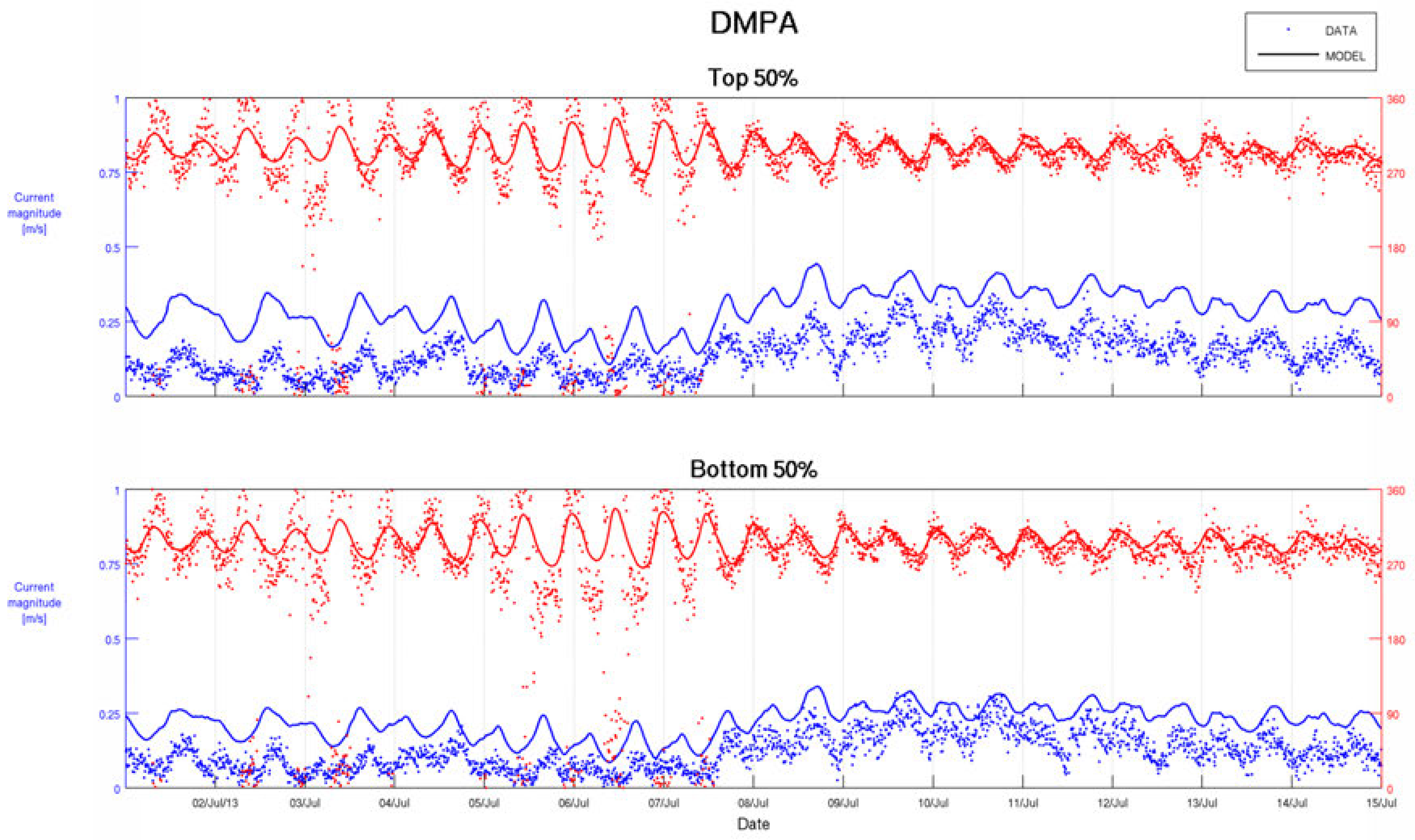


Figure F-2 Top 50% and Bottom 50% Current Validation – DMPA 01/07/2013 to 15/07/2013

Validation Period Current Time Series Plots

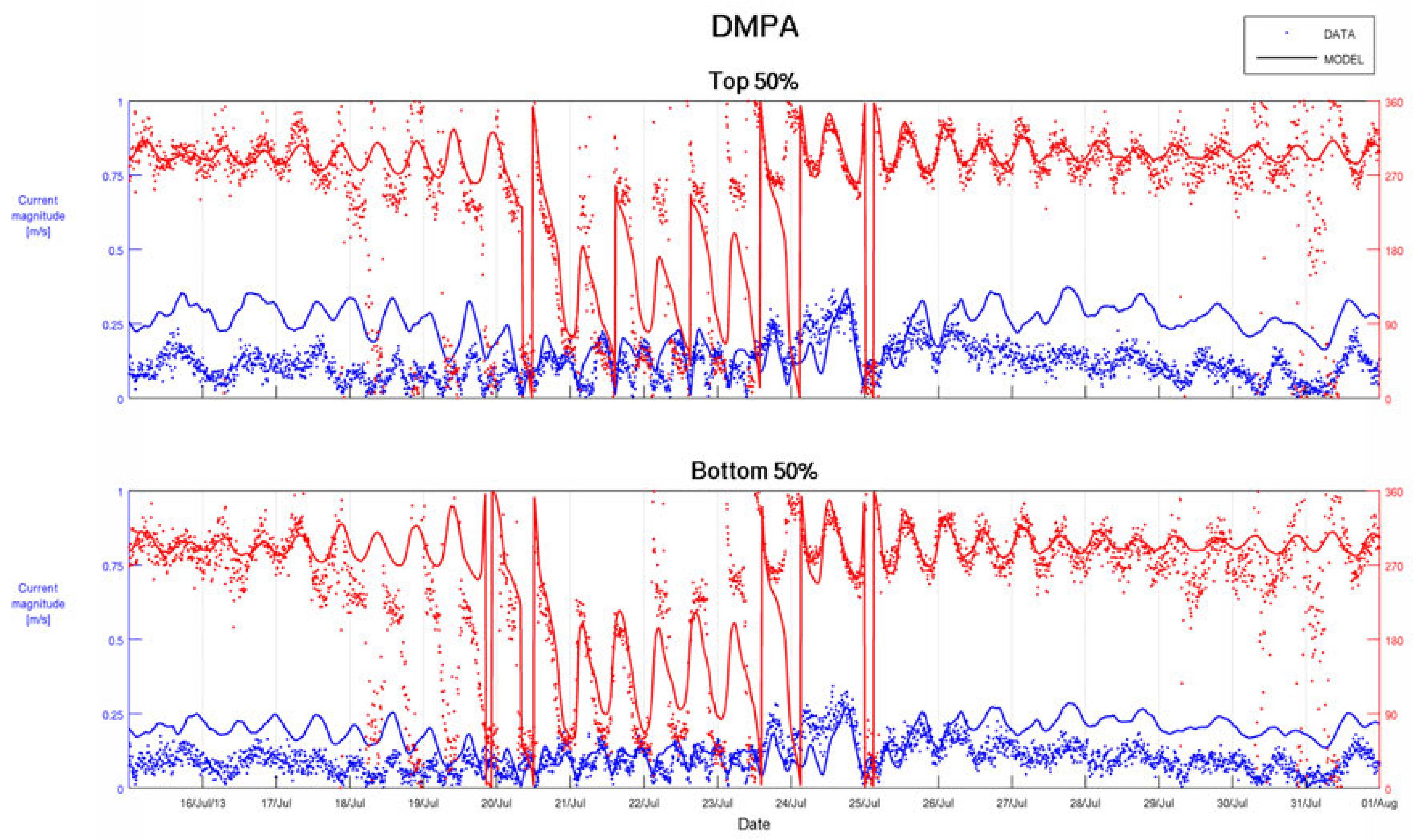


Figure F-3 Top 50% and Bottom 50% Current Validation – DMPA 16/07/2013 to 01/08/2013

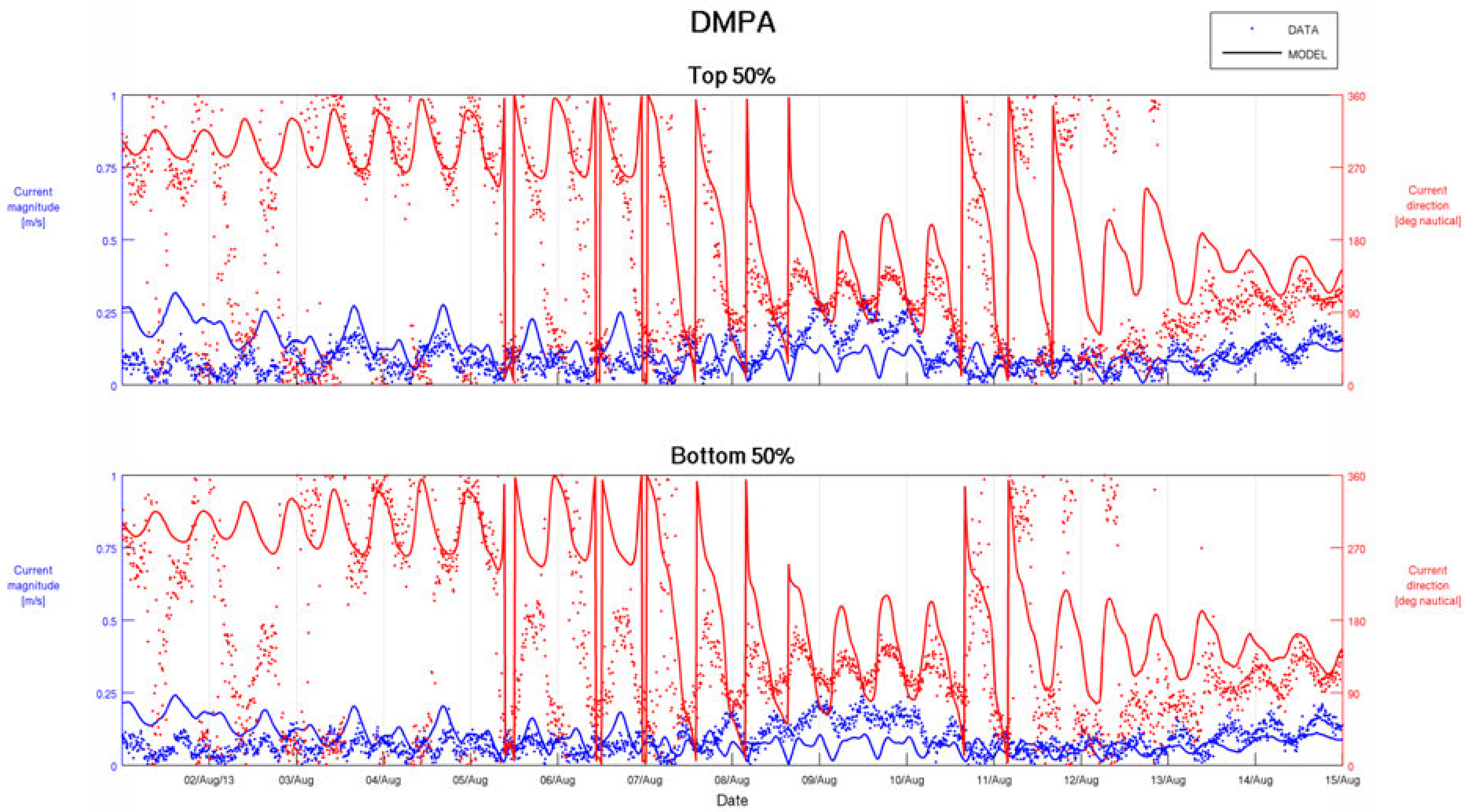


Figure F-4 Top 50% and Bottom 50% Current Validation – DMPA 01/08/2013 to 15/08/2013

BMT WBM

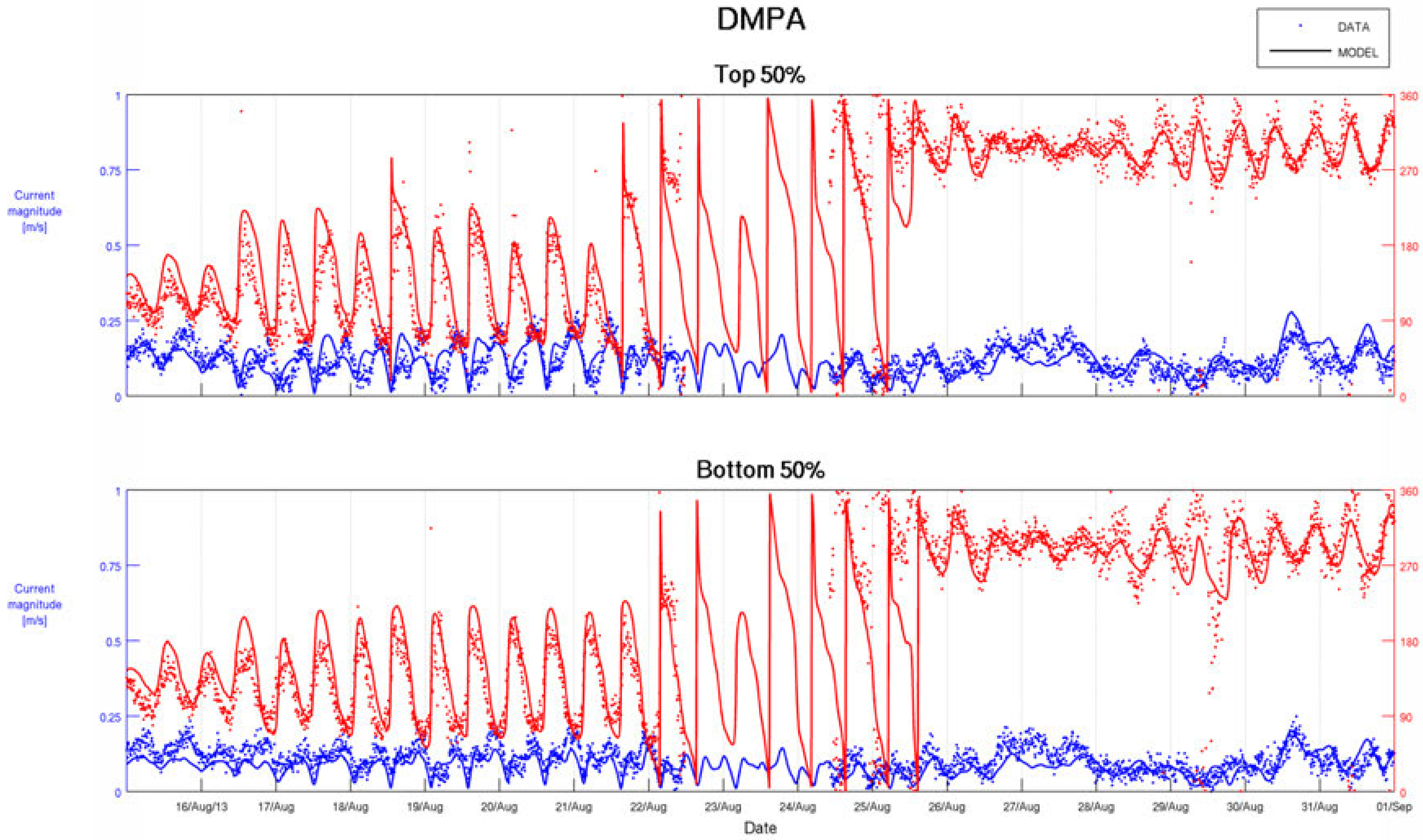


Figure F-5 Top 50% and Bottom 50% Current Validation – DMPA 15/08/2013 to 01/09/2013

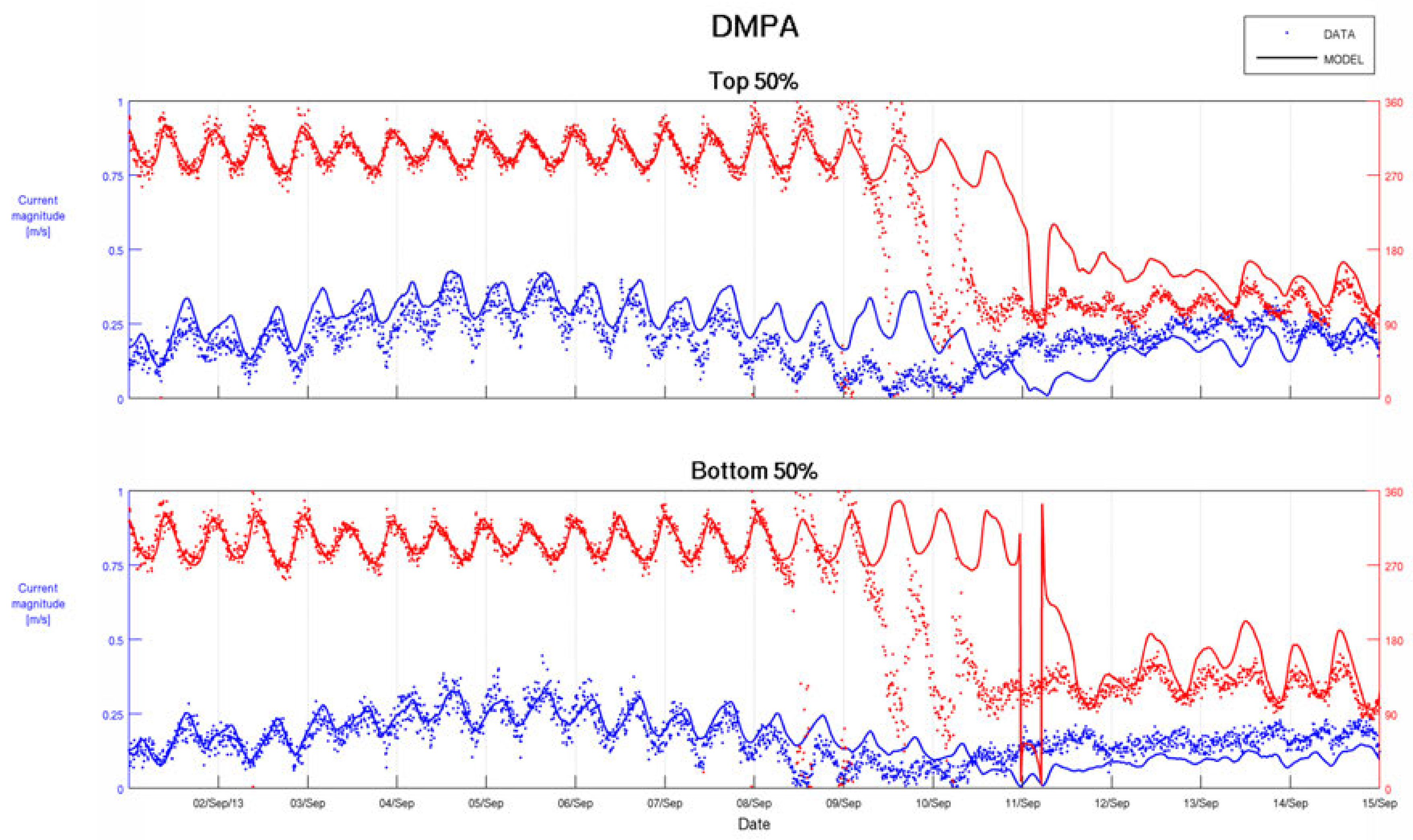


Figure F-6 Top 50% and Bottom 50% Current Validation – DMPA 01/09/2013 to 15/09/2013

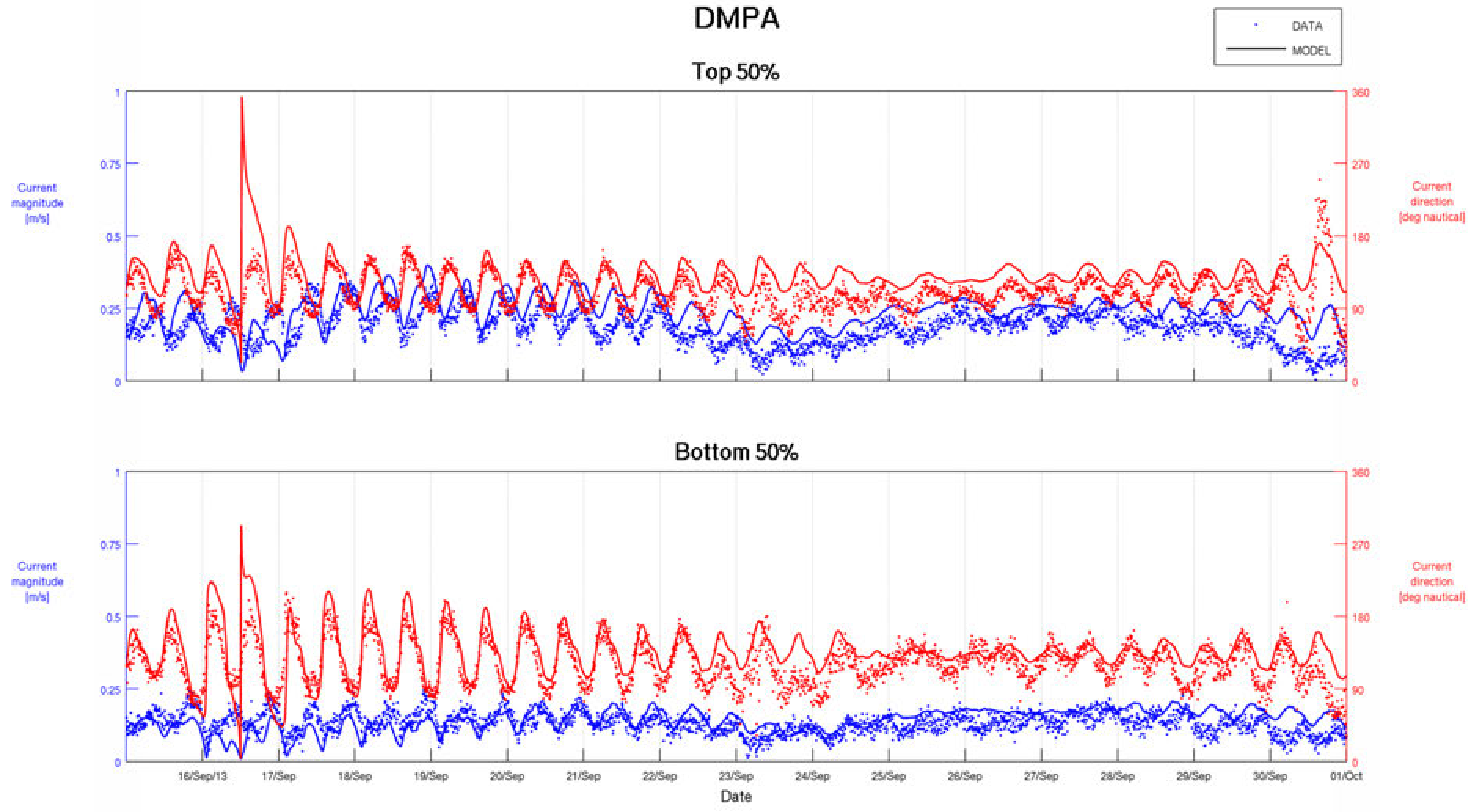


Figure F-7 Top 50% and Bottom 50% Current Validation – DMPA 15/07/2013 to 01/10/2013

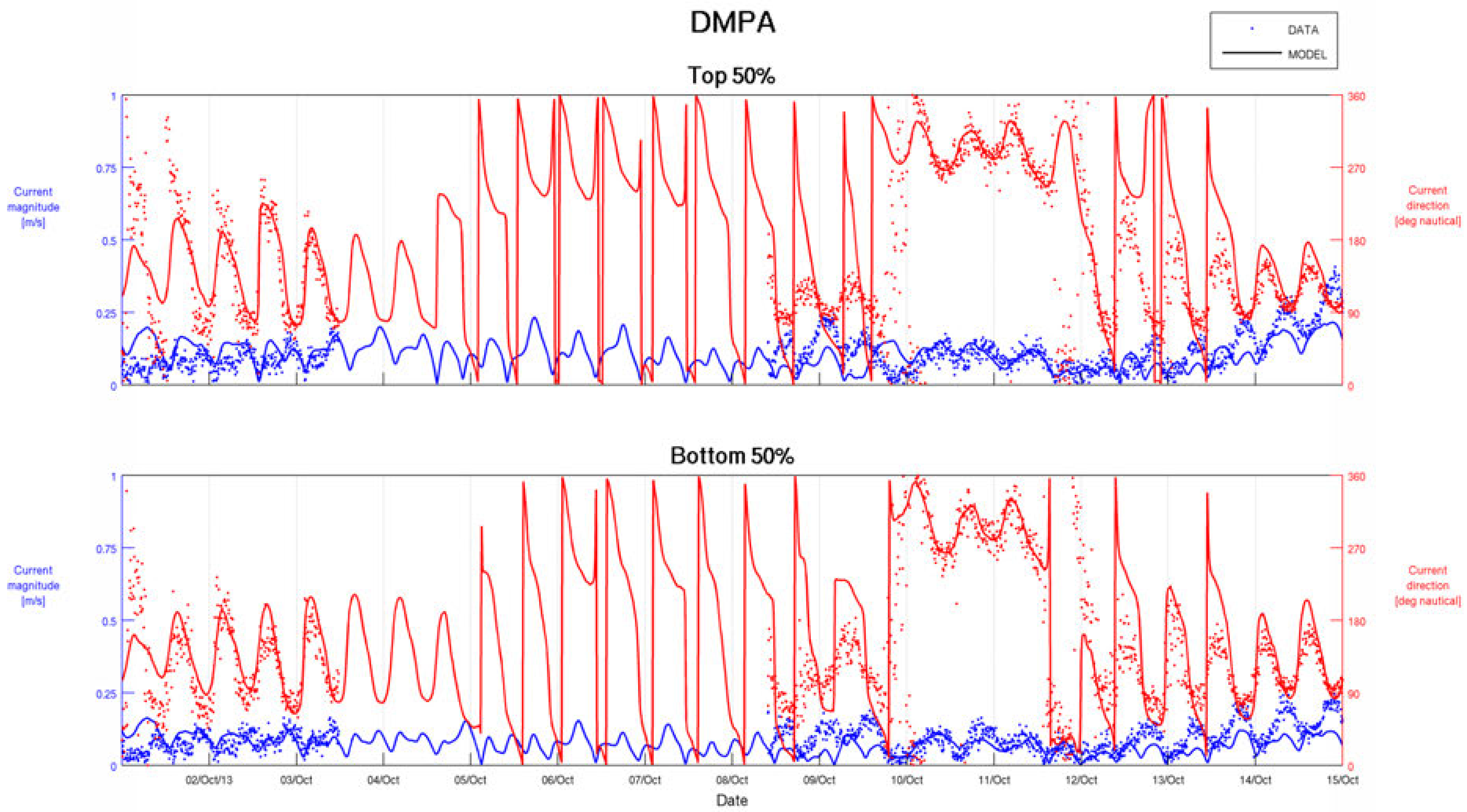


Figure F-8 Top 50% and Bottom 50% Current Validation – DMPA 01/10/2013 to 15/10/2013

Validation Period Current Time Series Plots

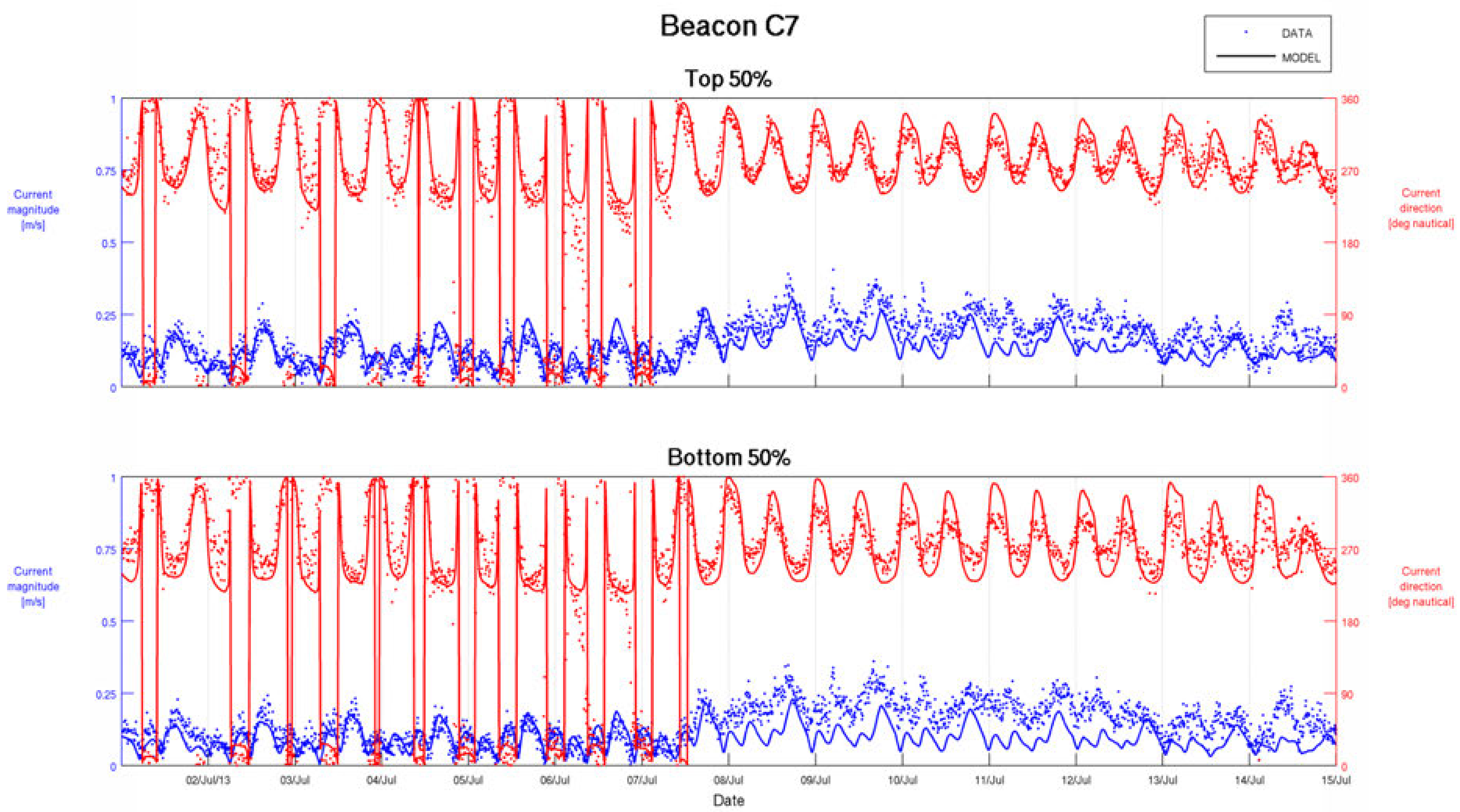


Figure F-9 Top 50% and Bottom 50% Current Validation – Beacon C7 01/07/2013 to 15/07/2013

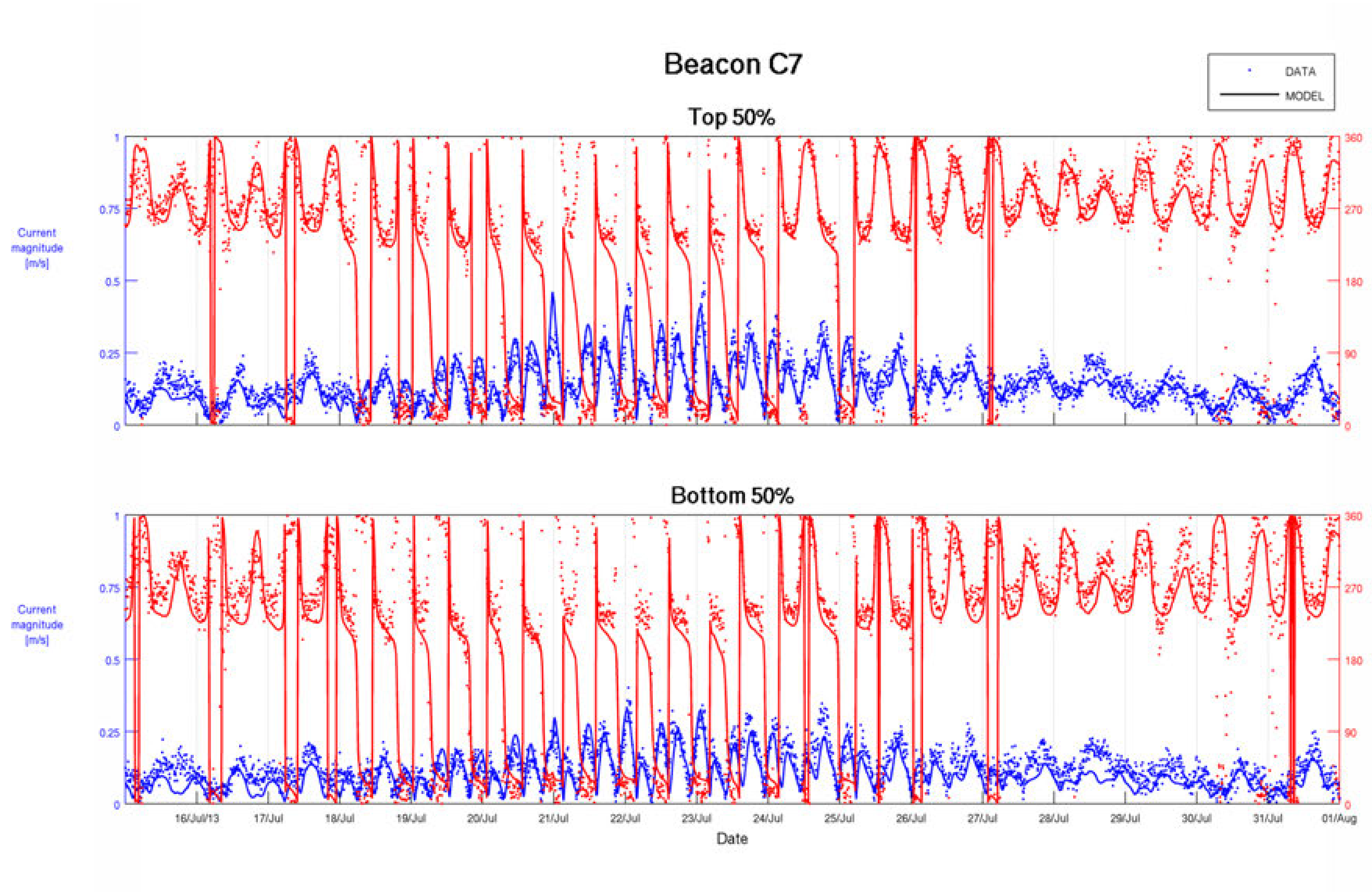


Figure F-10 Top 50% and Bottom 50% Current Validation – Beacon C7 15/07/2013 to 01/08/2013

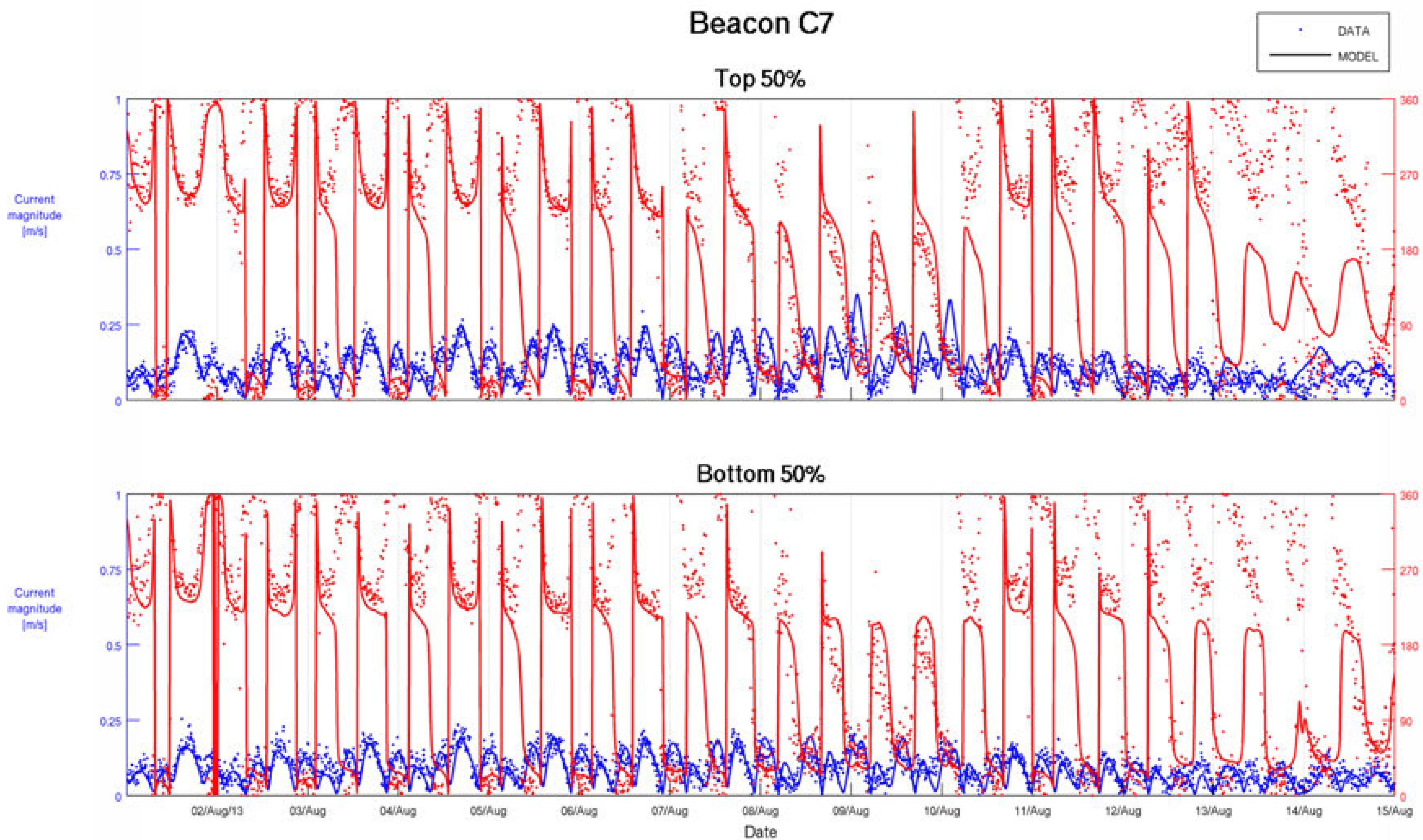


Figure F-11 Top 50% and Bottom 50% Current Validation – Beacon C7 01/08/2013 to 15/08/2013

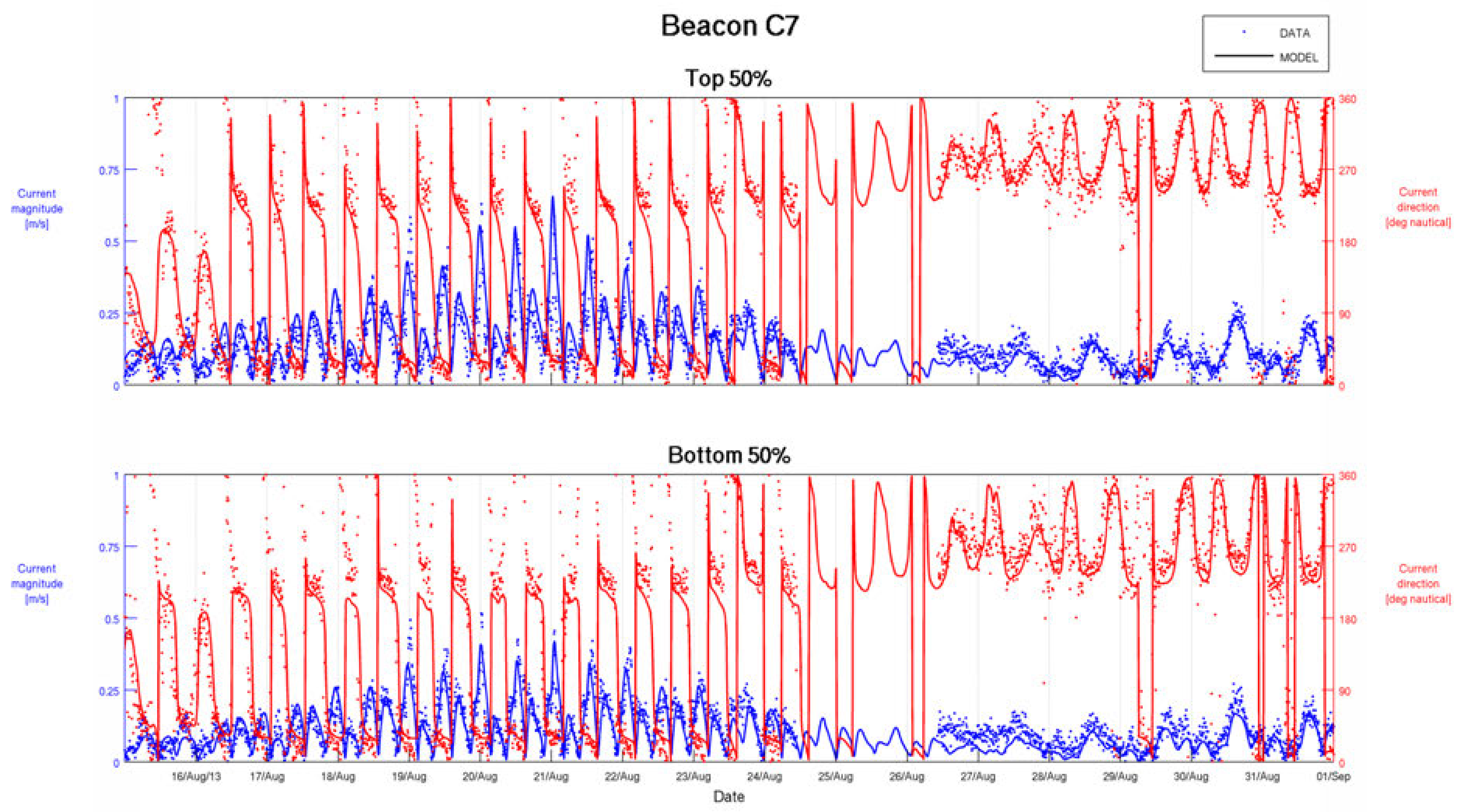


Figure F-12 Top 50% and Bottom 50% Current Validation – Beacon C7 15/08/2013 to 01/09/2013

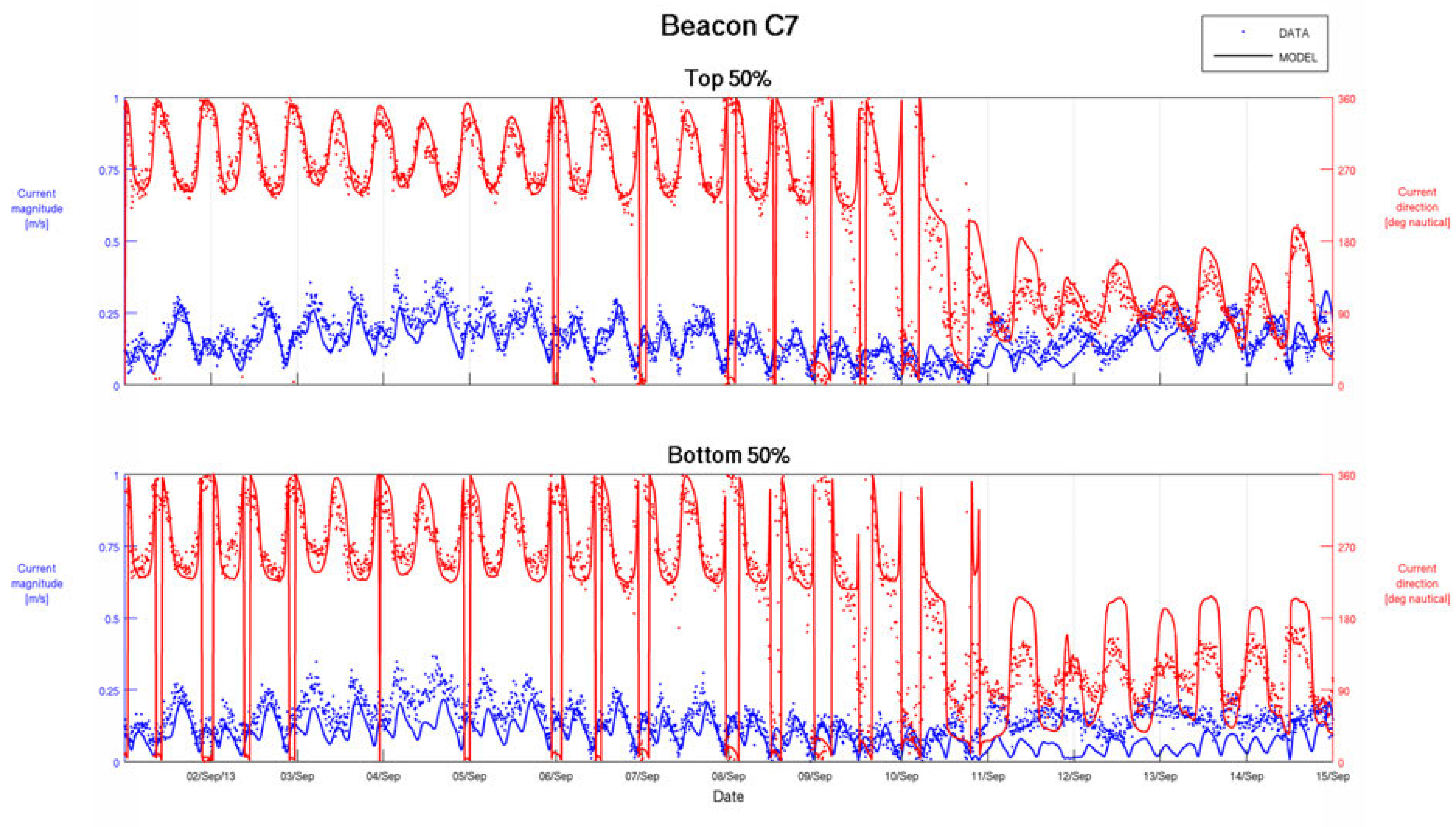


Figure F-13 Top 50% and Bottom 50% Current Validation – Beacon C7 01/09/2013 to 15/09/2013

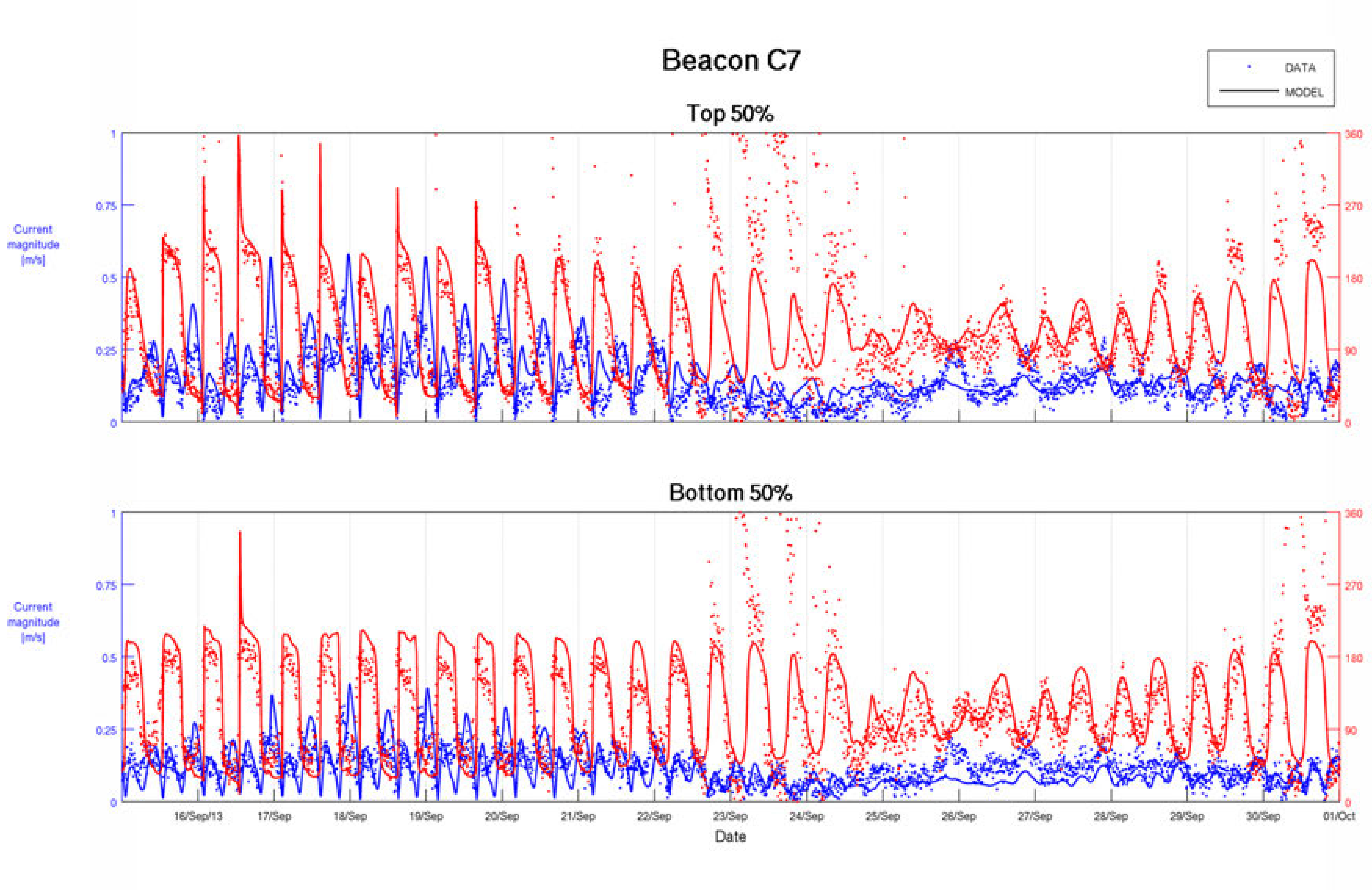


Figure F-14 Top 50% and Bottom 50% Current Validation – Beacon C7 15/09/2013 to 01/10/2013

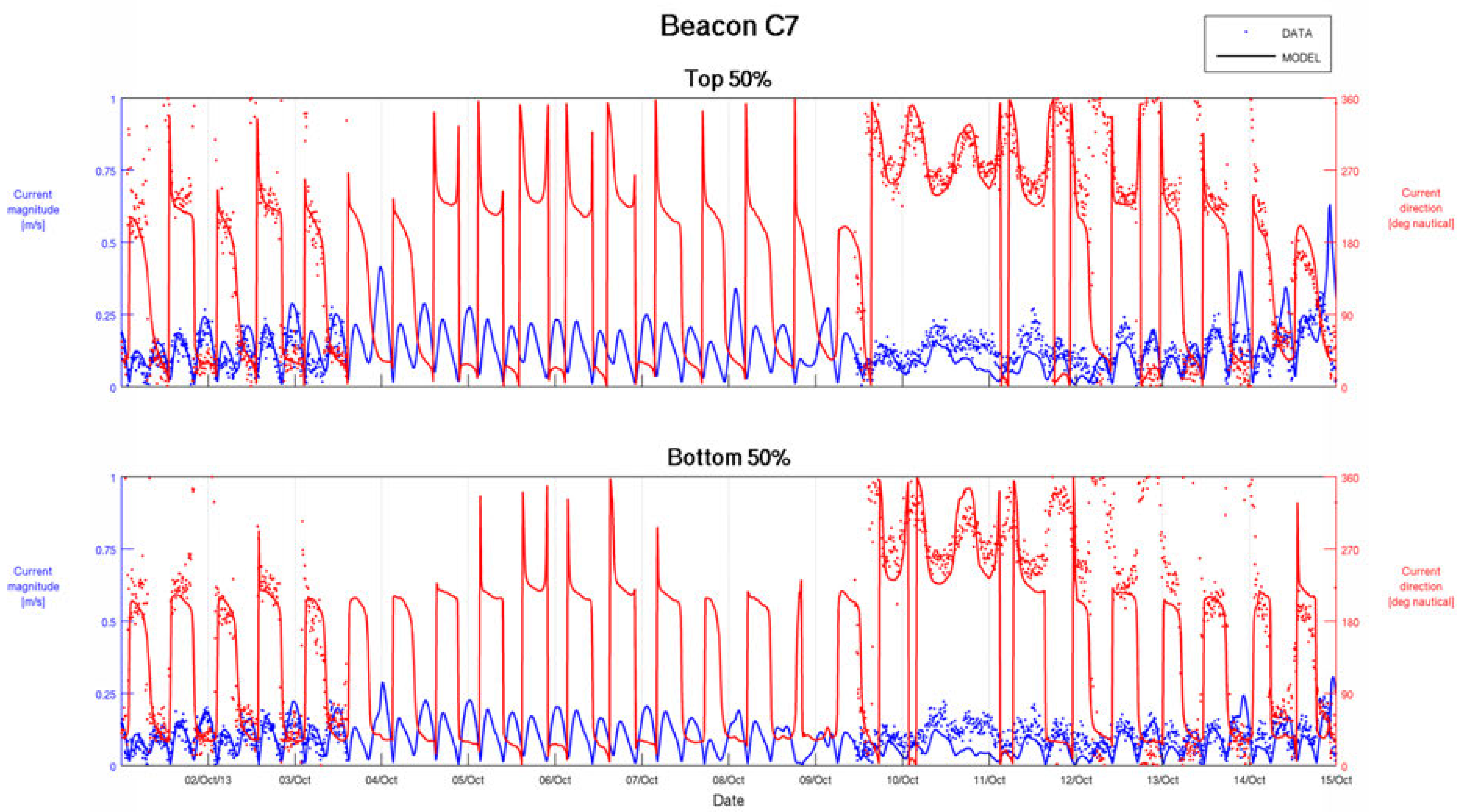


Figure F-15 Top 50% and Bottom 50% Current Validation – Beacon C7 01/10/2013 to 15/10/2013

Appendix G Validation Period Current Polar Plots

Top and bottom half of water column current polar plots for the entire simulation period are presented:

- DMPA, Figure G-1 and Figure G-2.
- Beacon C7, Figure G-3 and Figure G-4.

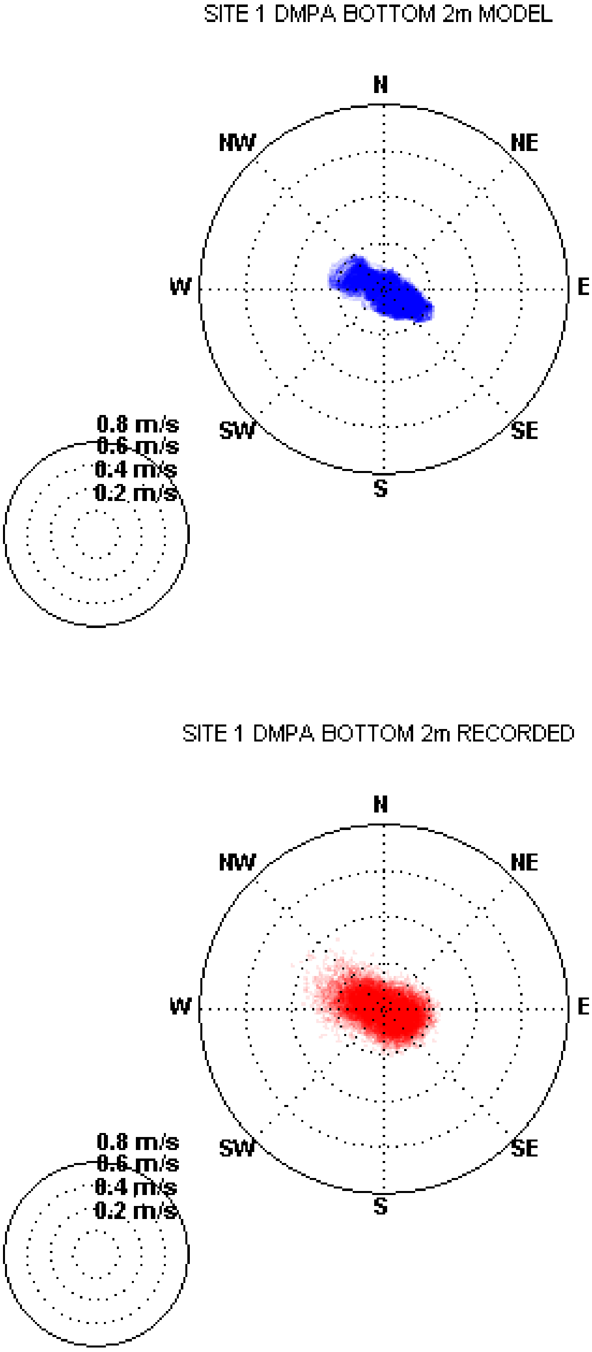


Figure G-1 Current Polar Plot Calibration – Site 1 Bottom 2m of Water Column

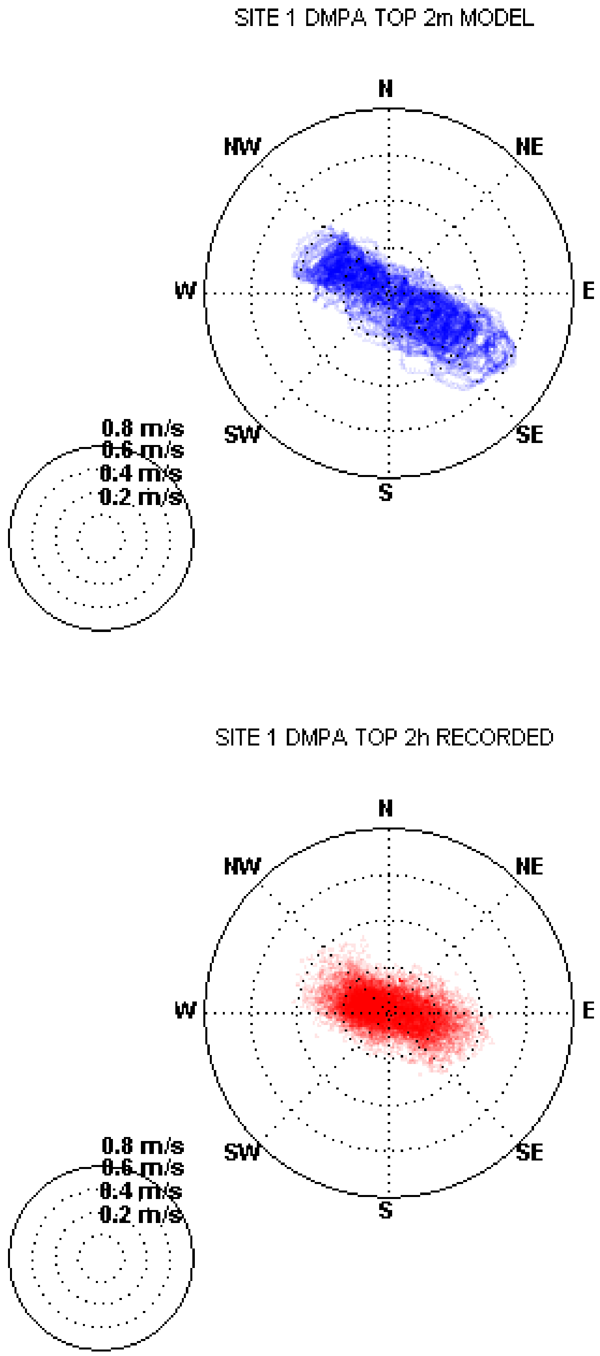
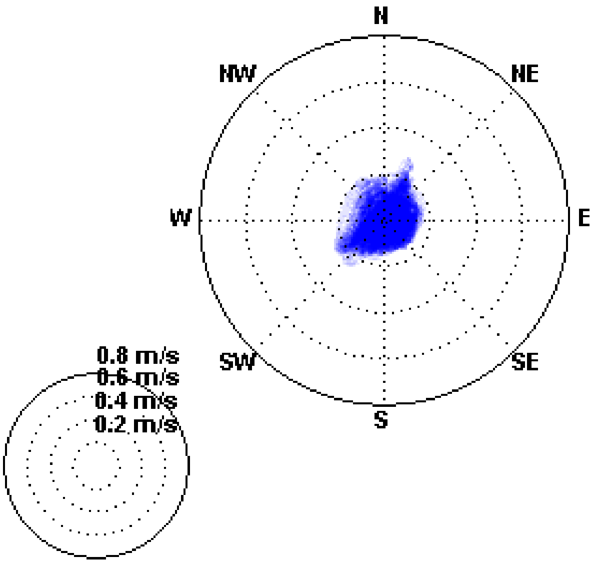


Figure G-2 Current Polar Plot Calibration – Site 1 Tom 2m of Water Column

SITE 3 BEACON C7 BOTTOM 2m MODEL



SITE 3 BEACON C7 BOTTOM 2m RECORDED

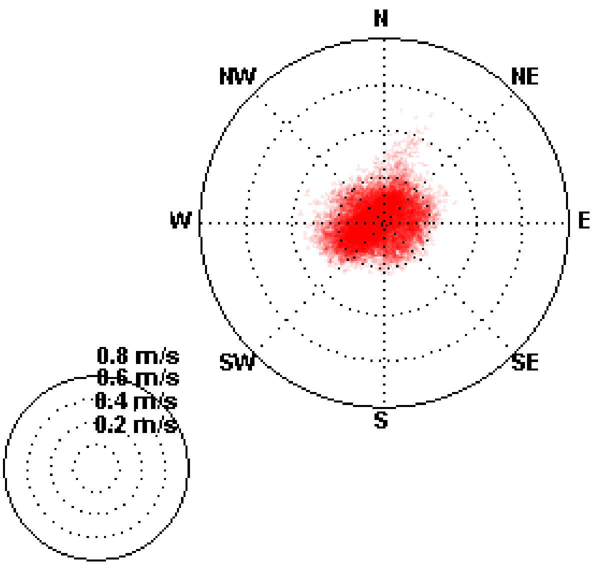
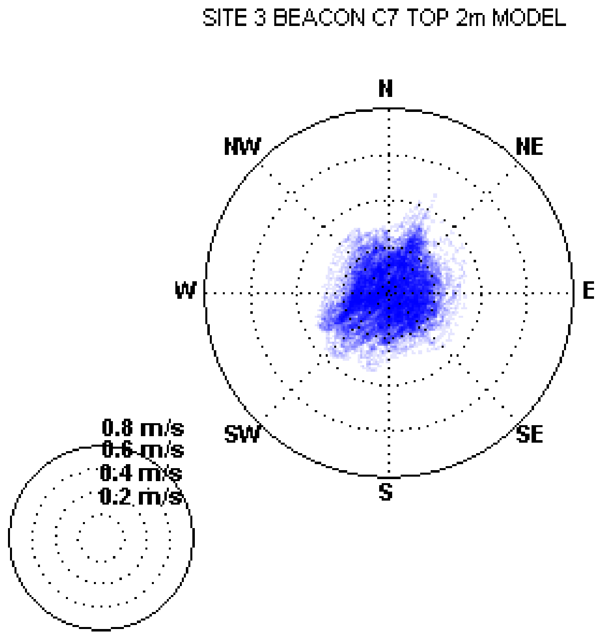


Figure G-3 Current Polar Plot Calibration – Site 3 Bottom 2m of Water Column



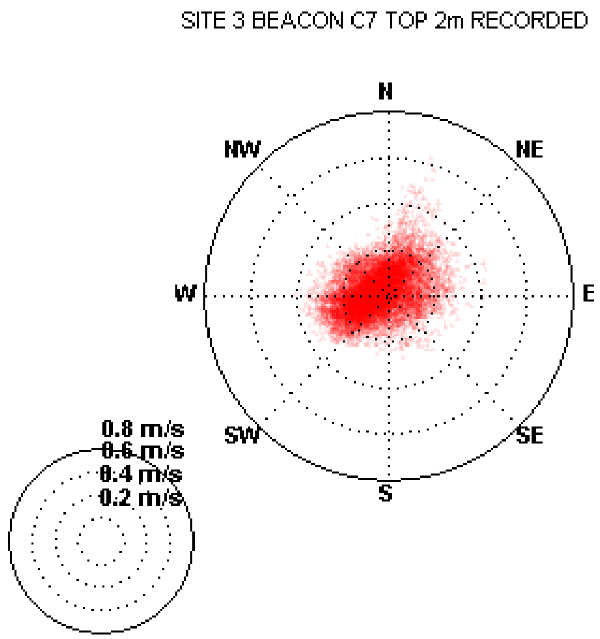


Figure G-4 Current Polar Plot Calibration – Site 3 Top 2m of Water Column

Appendix H Validation Period Current Q-Q Plots

Recorded data and model output distributions of current components (x and y) and current speed are compared:

- DMPA, Figure H-1.
- Beacon C7, Figure H-2.

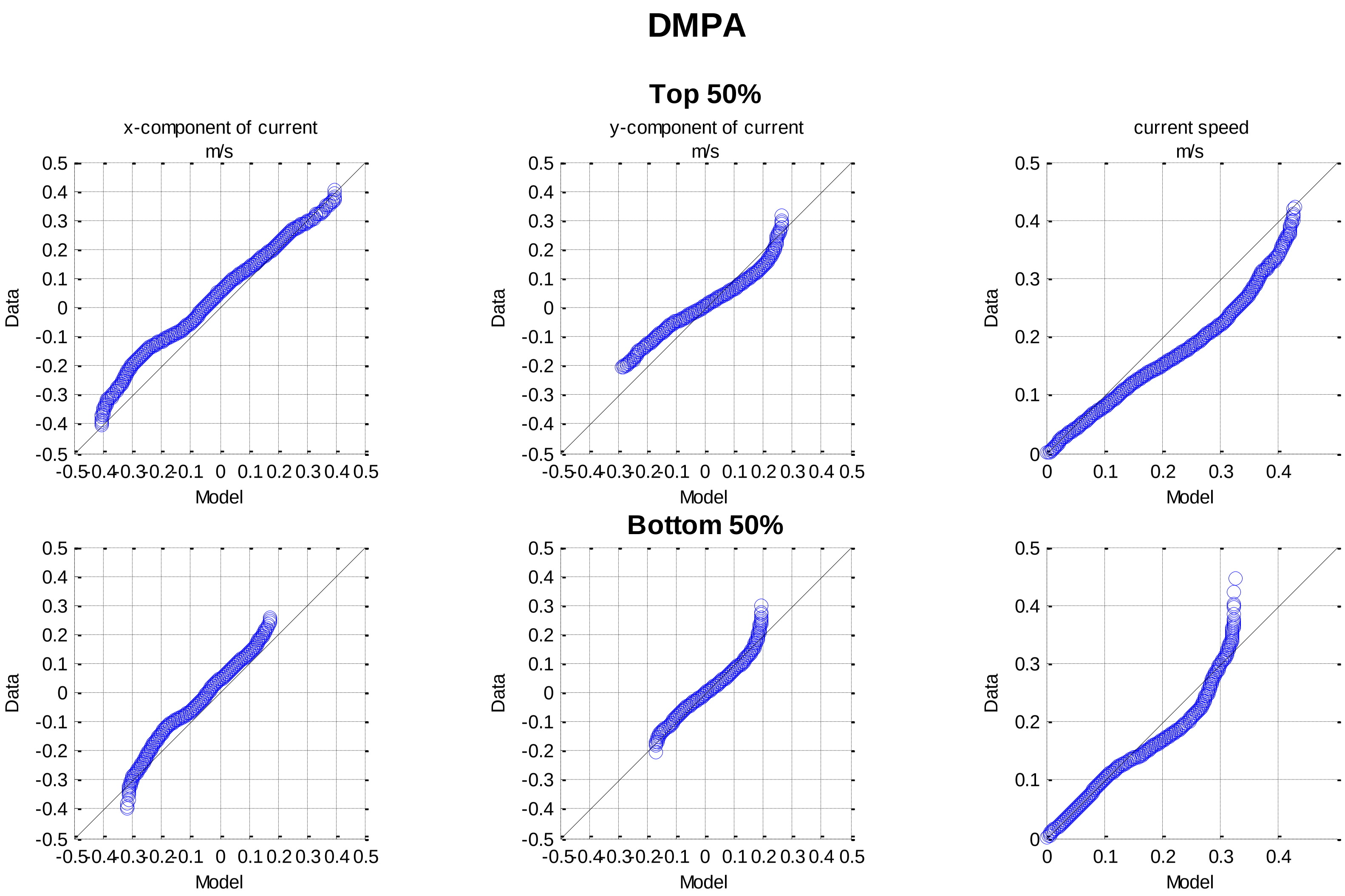


Figure H-1 Current Q-Q Plot – DMPA

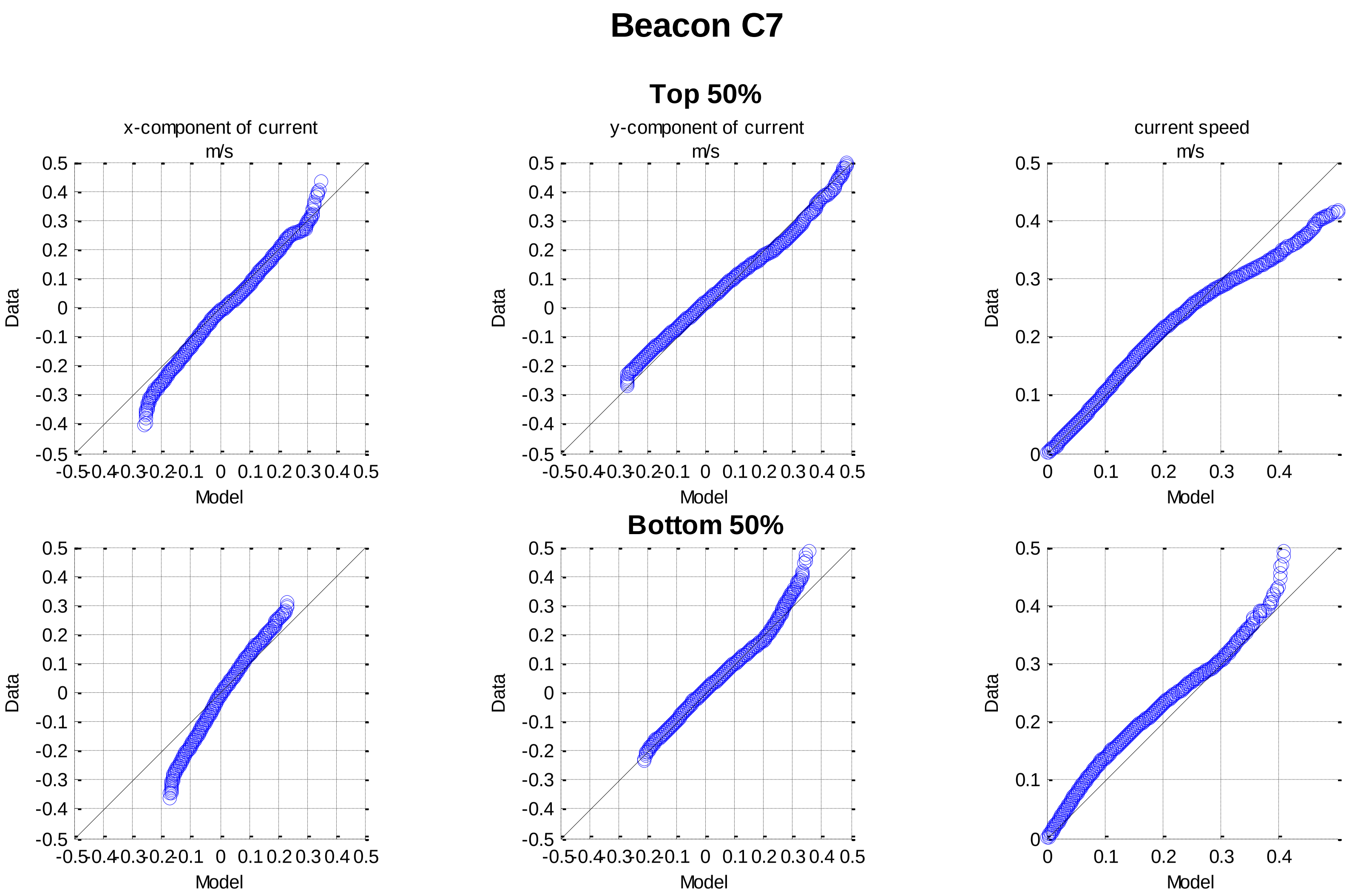


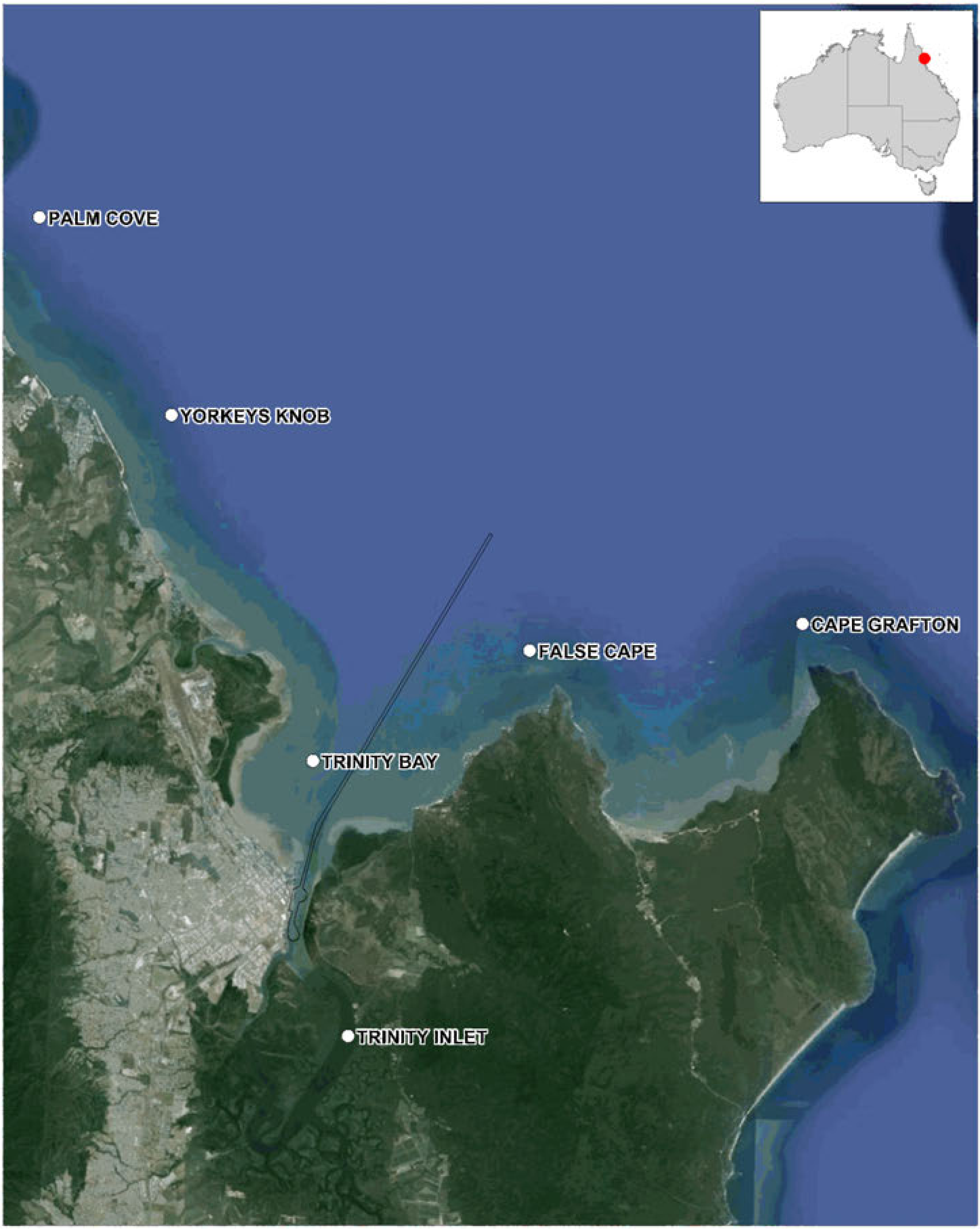
Figure H-2 Current Q-Q Plot – Beacon C7

Appendix I Turbidity Timeseries Plots

Predicted depth average and bottom 1m turbidity timeseries plots for each impact assessment scenario are presented, namely:

- Base Case Capital Program;
- Alternative Case Capital Program;
- "Worst Case" Soft Material Dredging;
- "Worst Case" Stiff Material Dredging;
- 12 month Re-suspension (following on from the Base Case Capital scenario; and
- "Worst Case" DMPA re-suspension.

The locations selected for turbidity timeseries reporting correspond to the baseline water quality monitoring sites shown in Figure I-1 (refer to the Water Quality Chapter B7 for more detail). For these locations and assessment scenarios, the dredge sediments typically represent only a very small fraction of the total turbidity.



Title:

Turbidity Timeseries Locations

Figure: J-1

Rev: A

N

0 4 8km

Approx.Scale

BMT WBM

www.bmtwbm.com.au

Filepath : I:\B20180_I_Port of Cairns EIS\DRG\COA_017_turbidity_timeseries_locations.wor

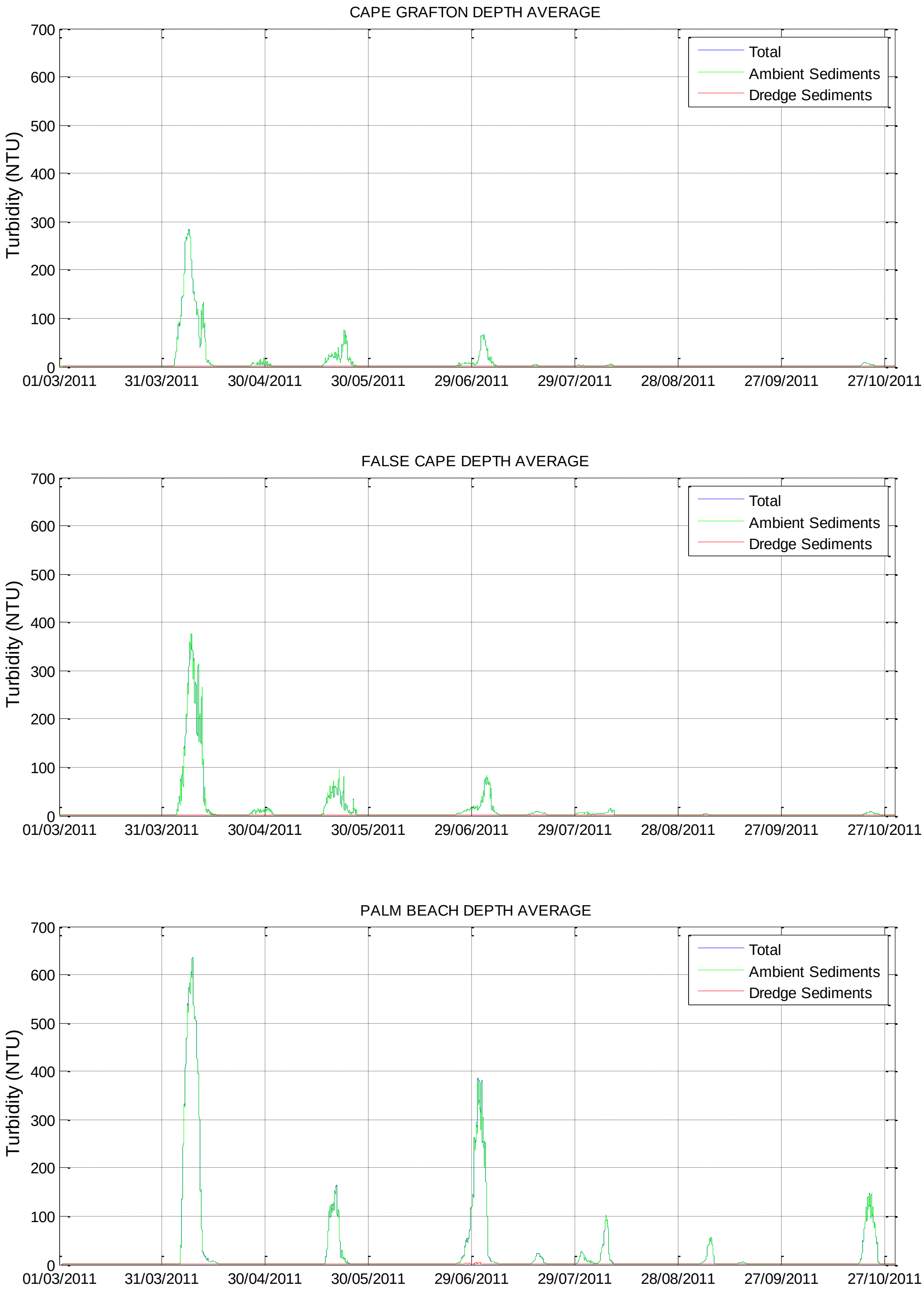
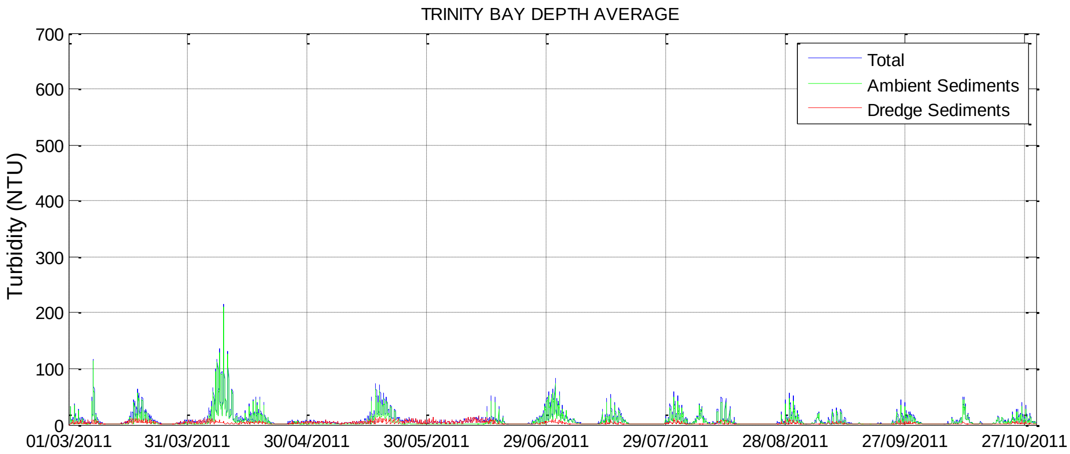
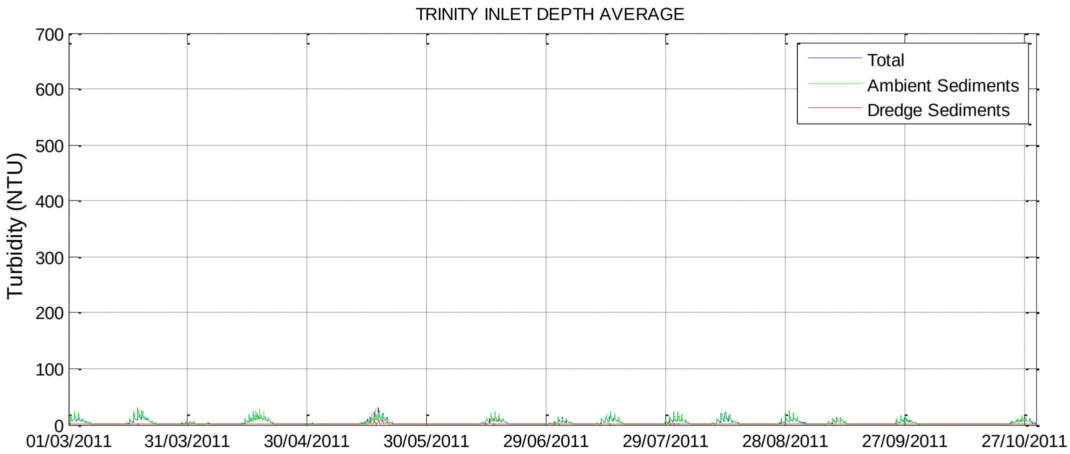


Figure I-2 Base Case Capital Program Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)





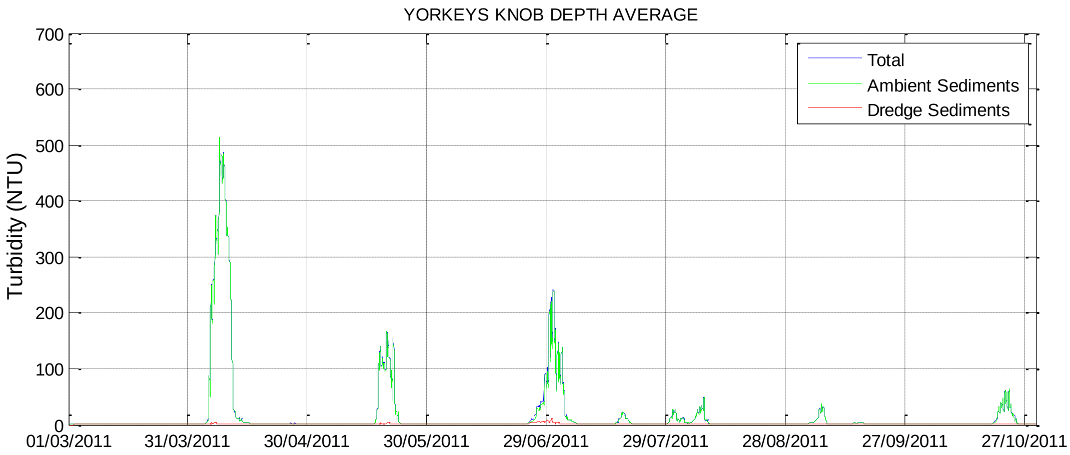


Figure I-3 Base Case Capital Program Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

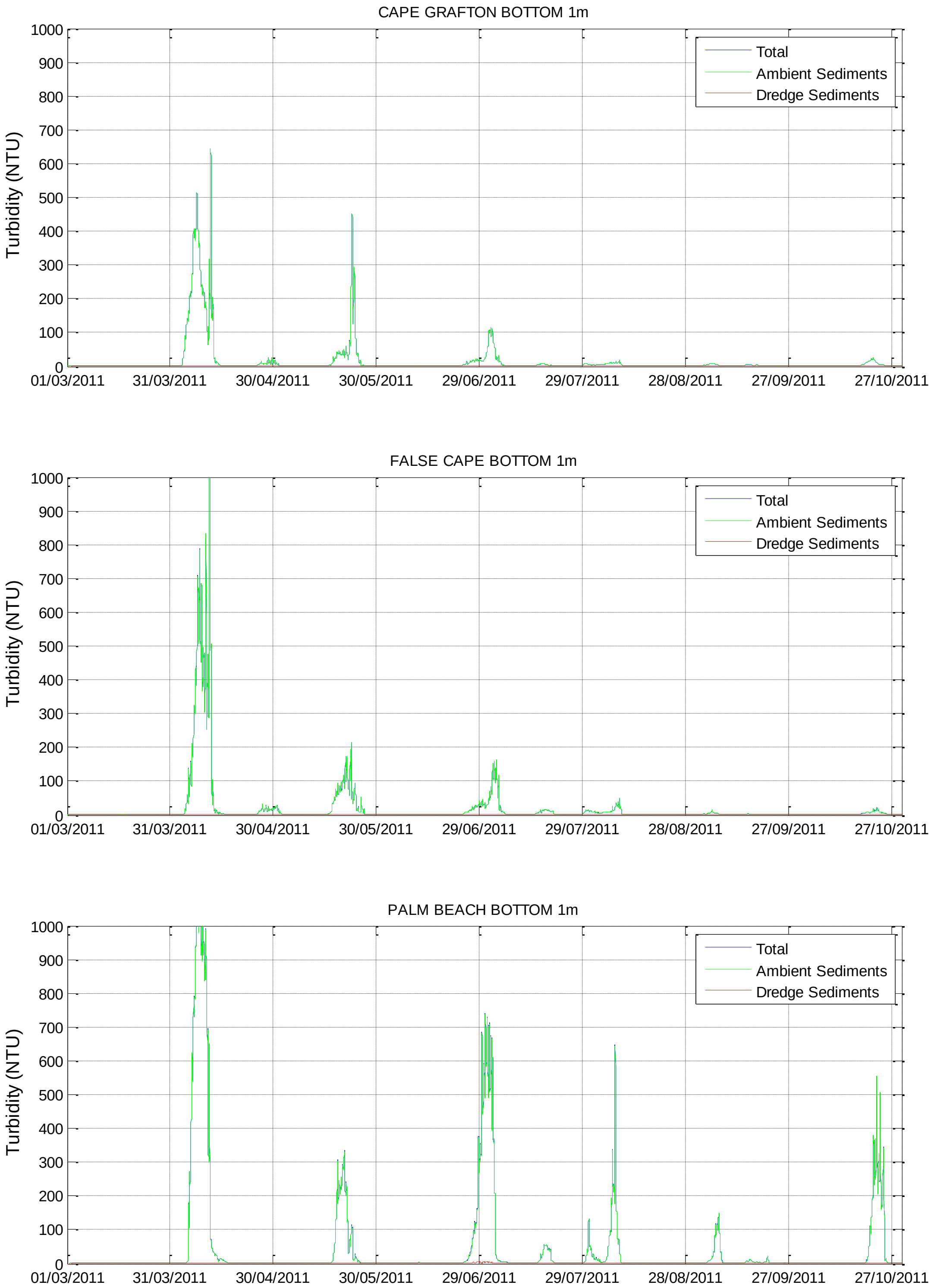


Figure I-4 Base Case Capital Program Bottom 1m Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

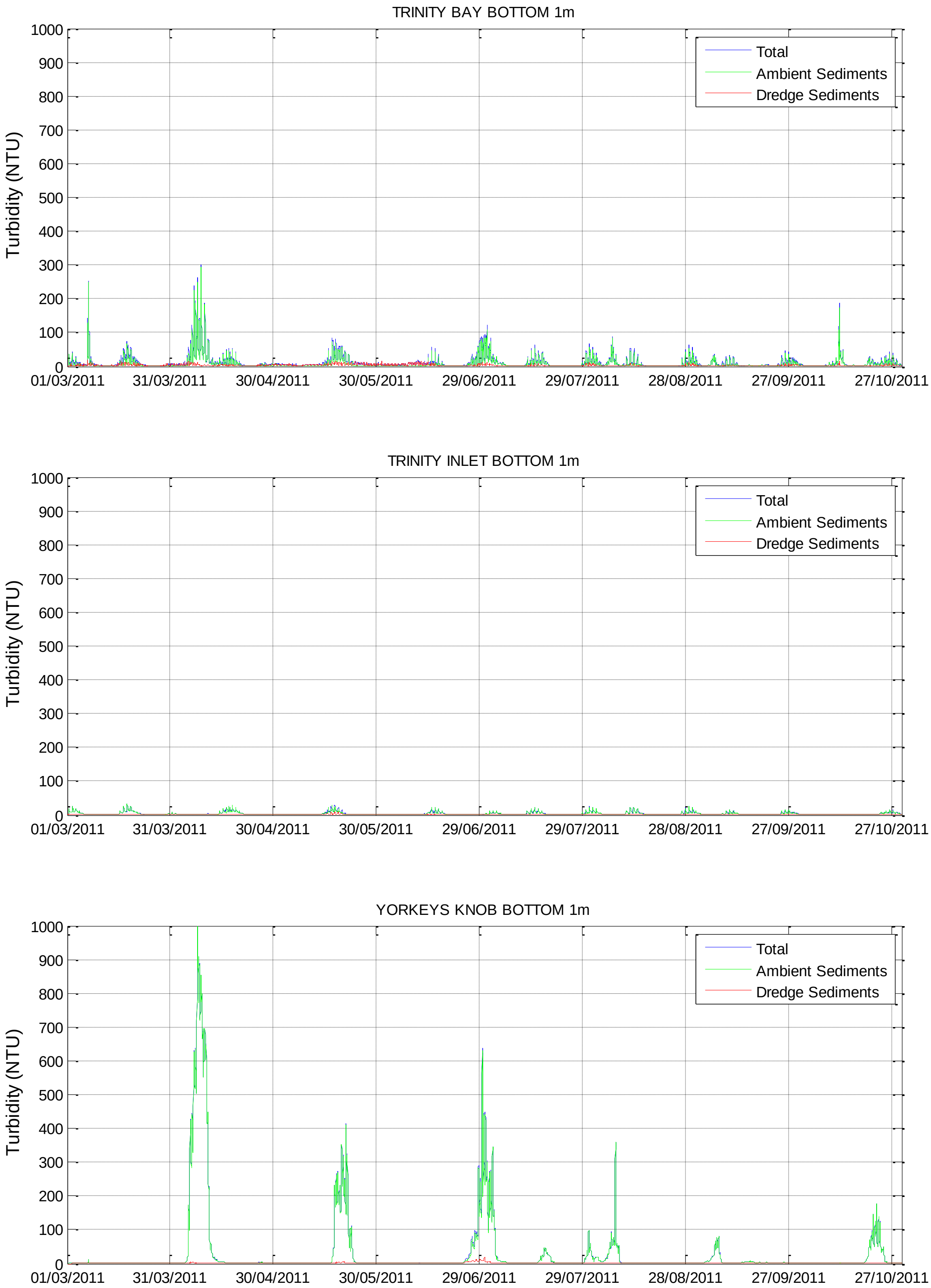


Figure I-5 Base Case Capital Program Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

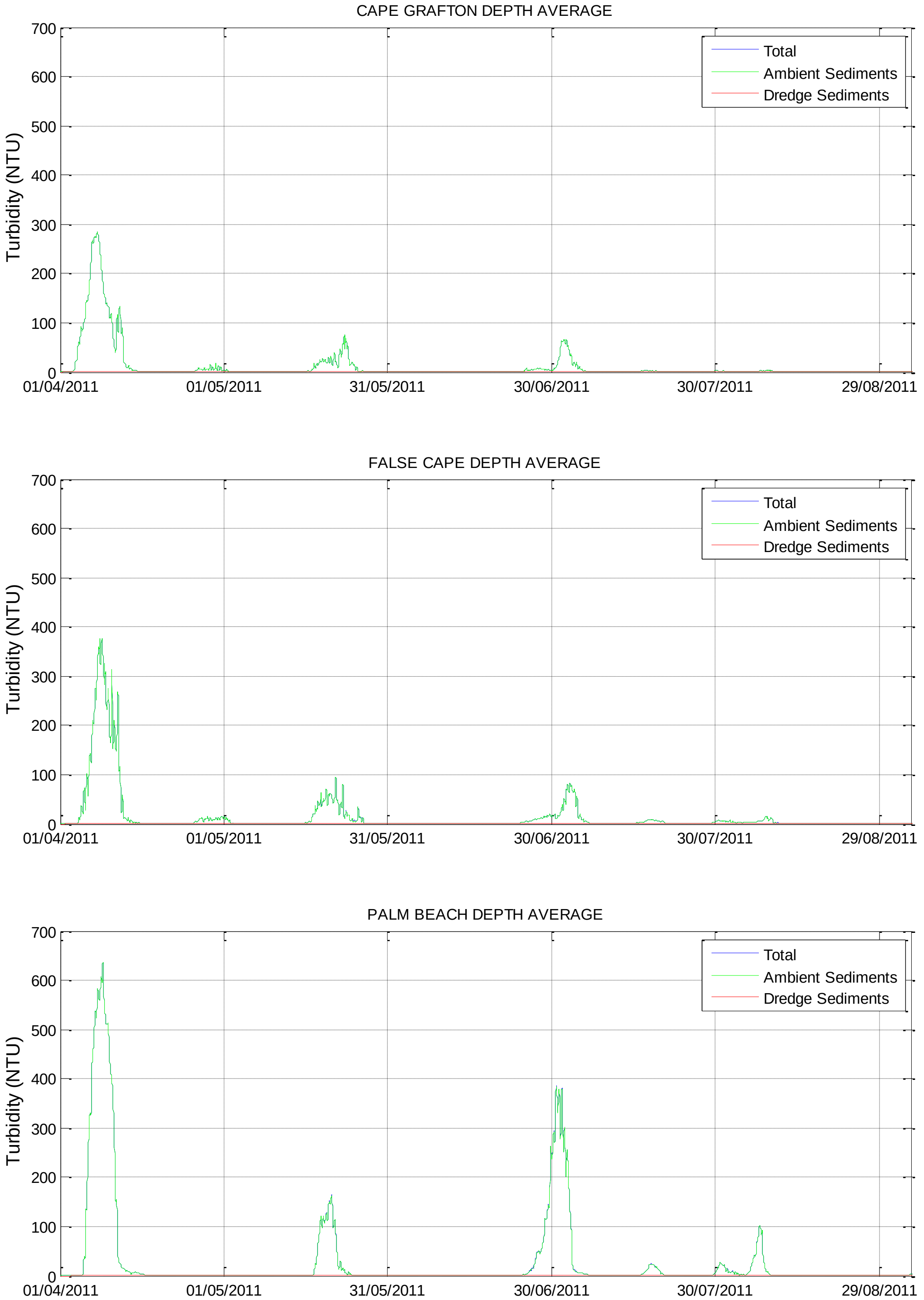


Figure I-6 Alternative Case Capital Program Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

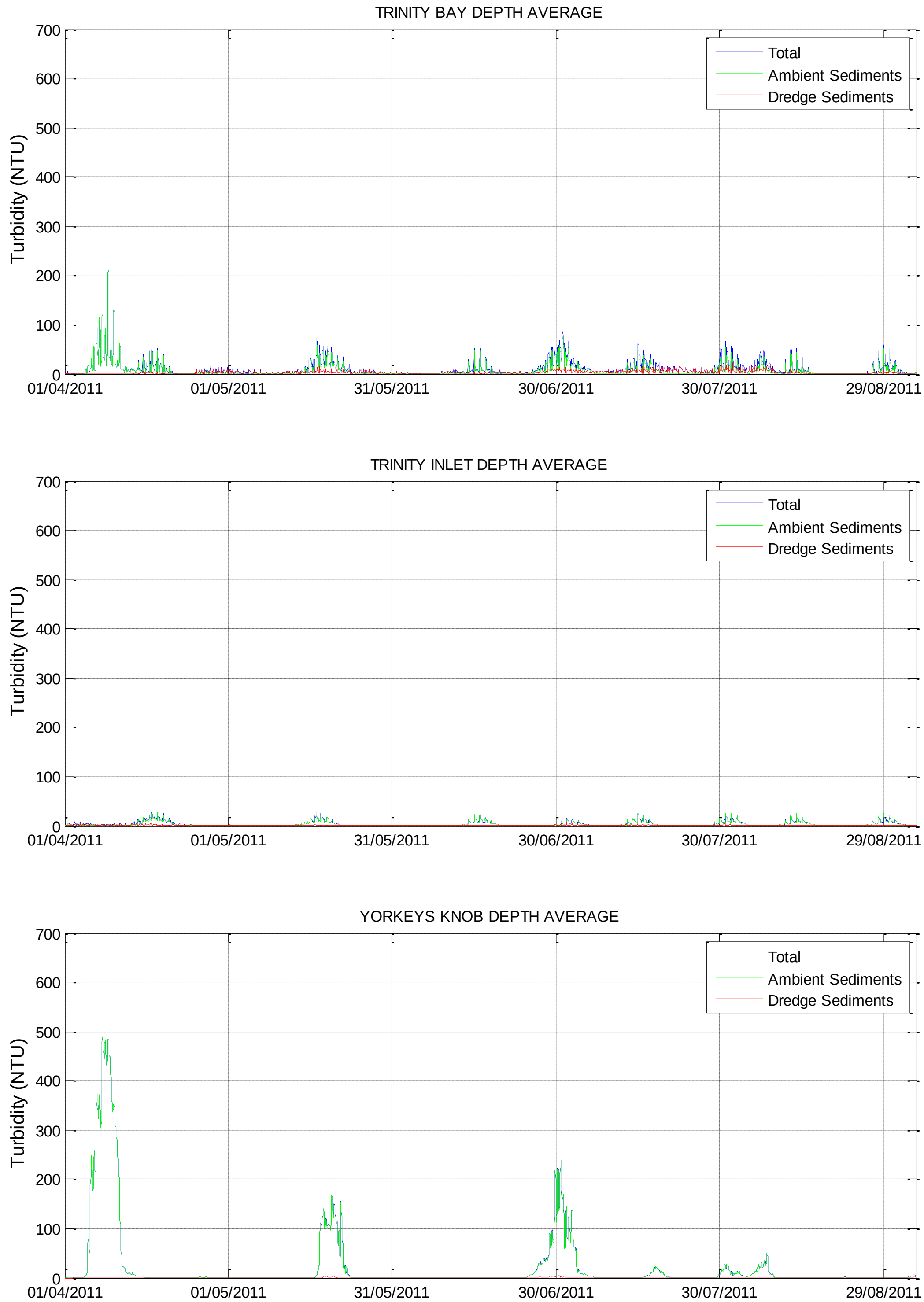
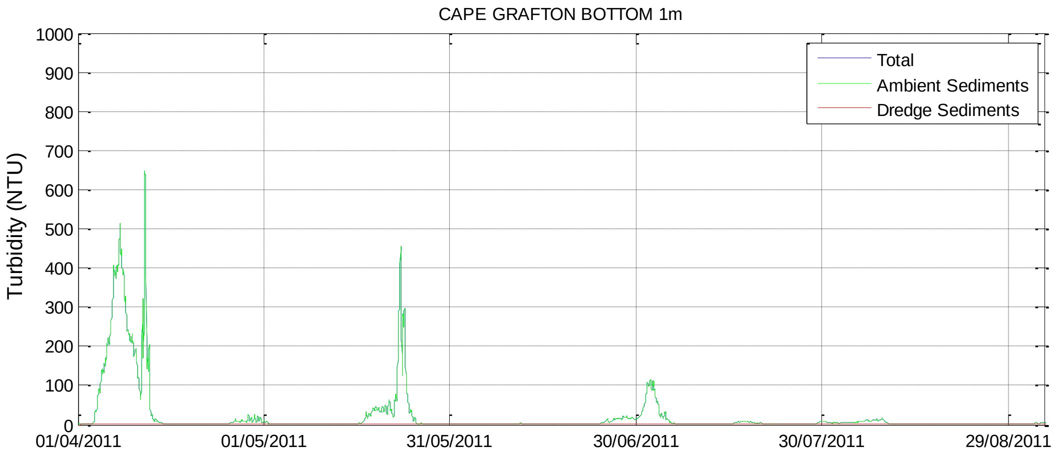
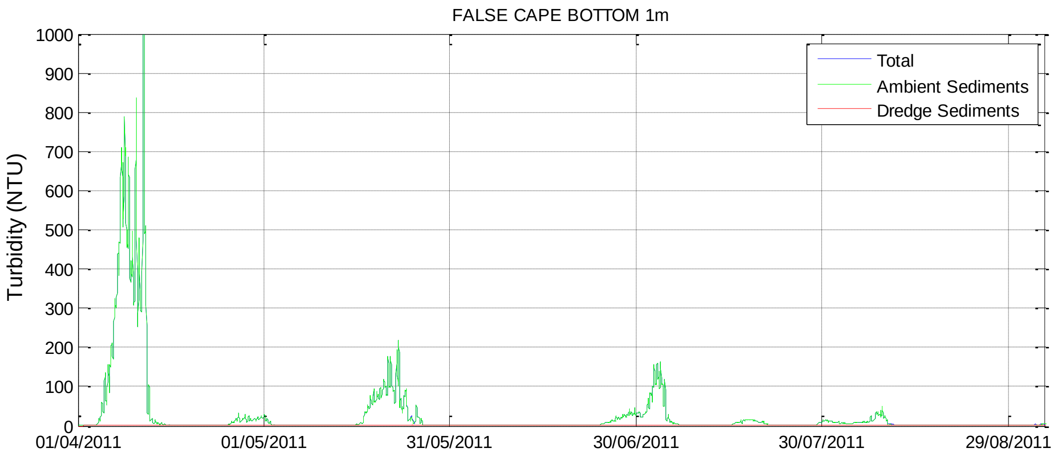


Figure I-7 Alternative Case Capital Program Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)





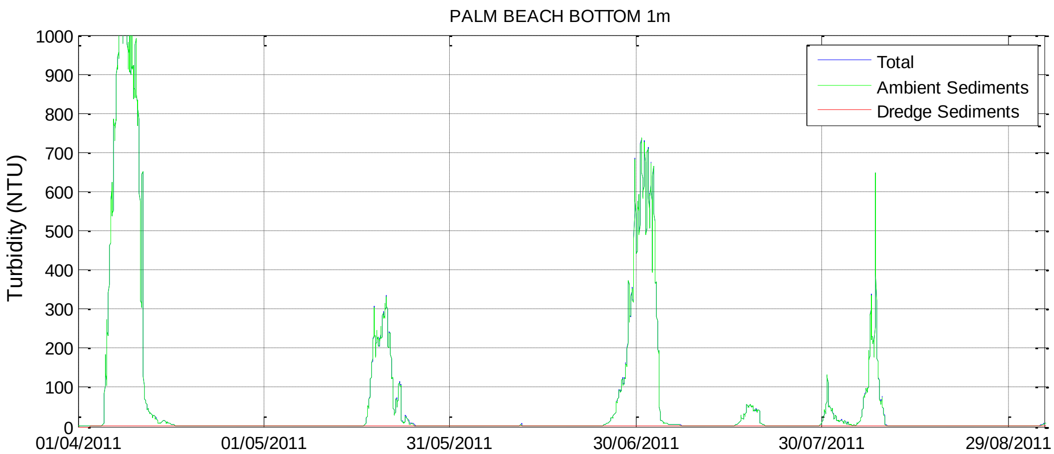


Figure I-8 Alternative Case Capital Program Bottom 1m Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

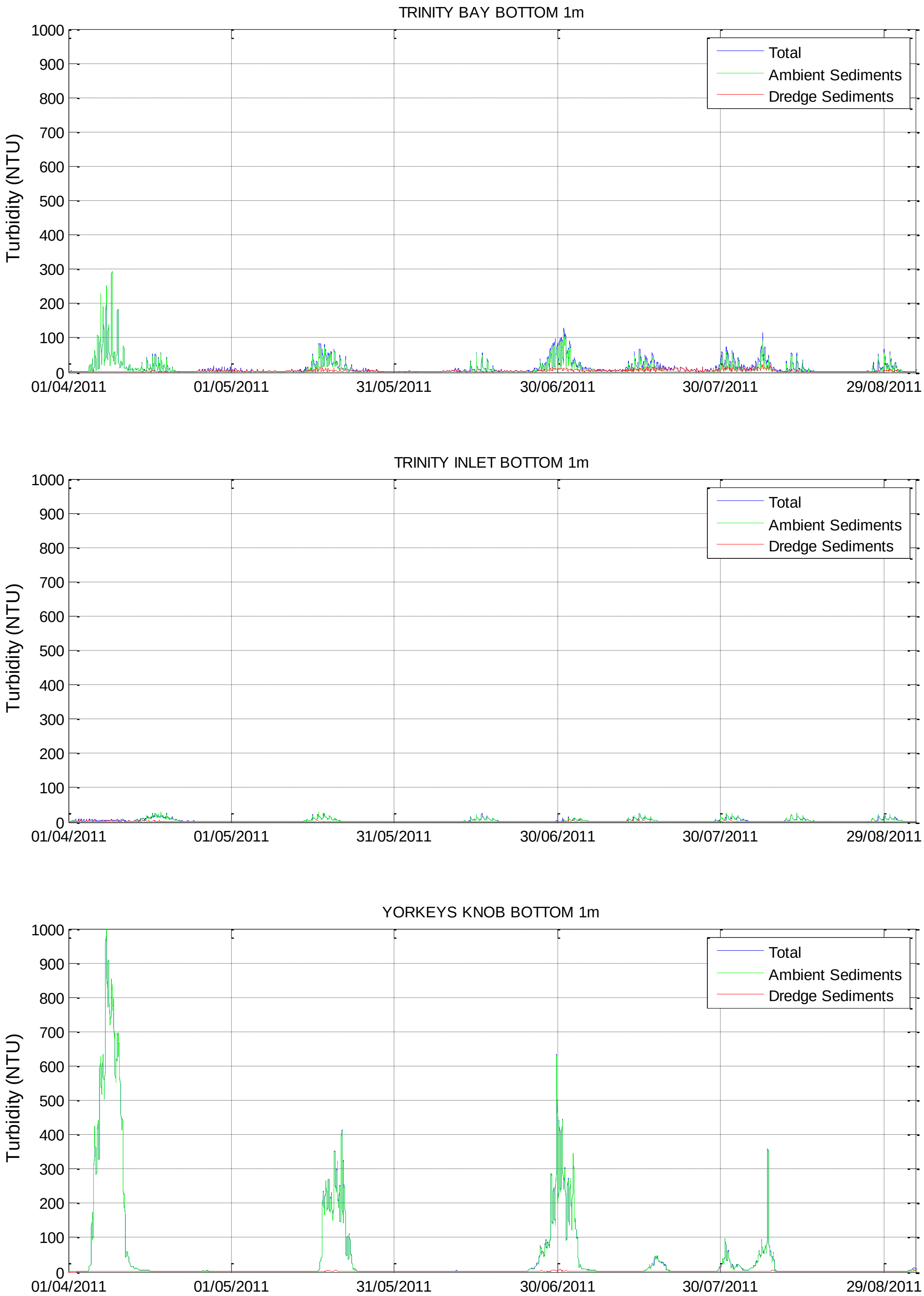


Figure I-9 Alternative Case Capital Program Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

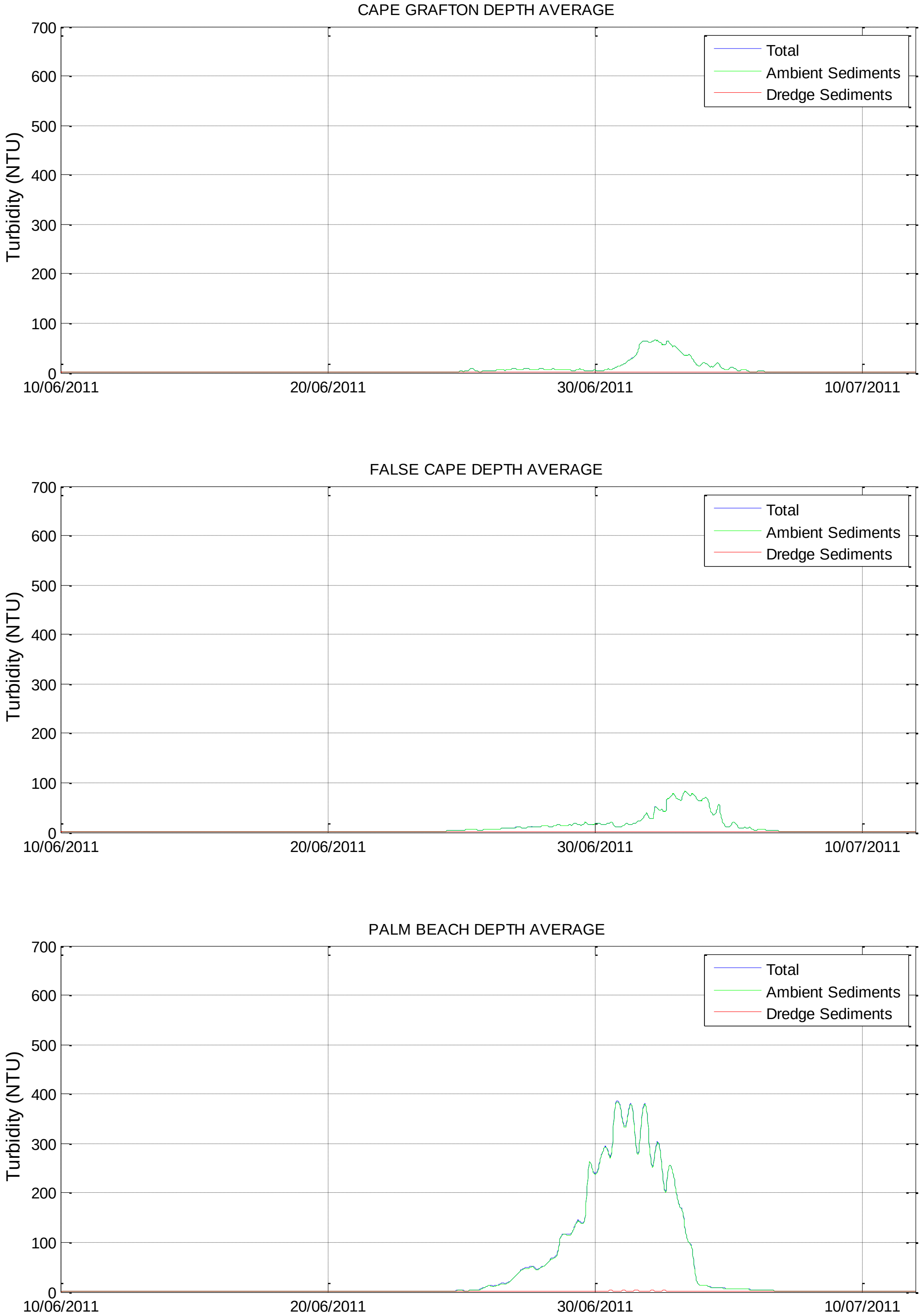
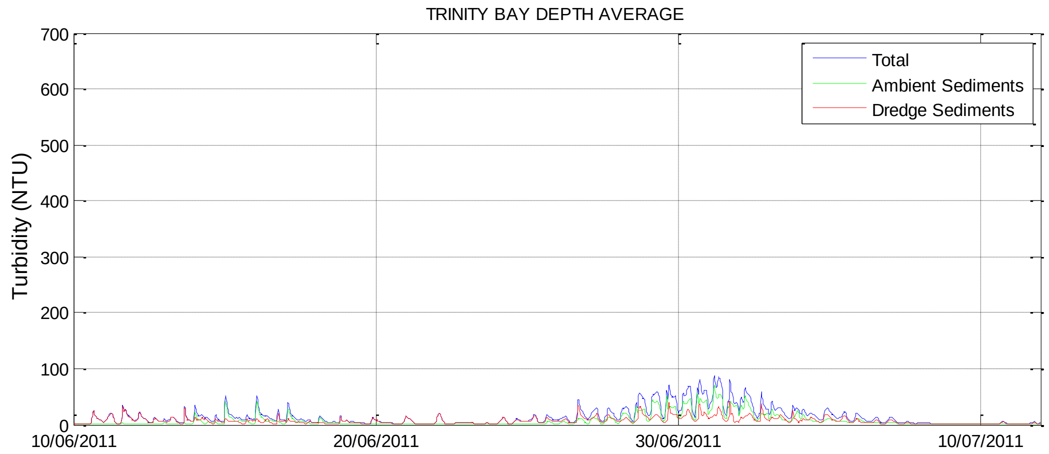
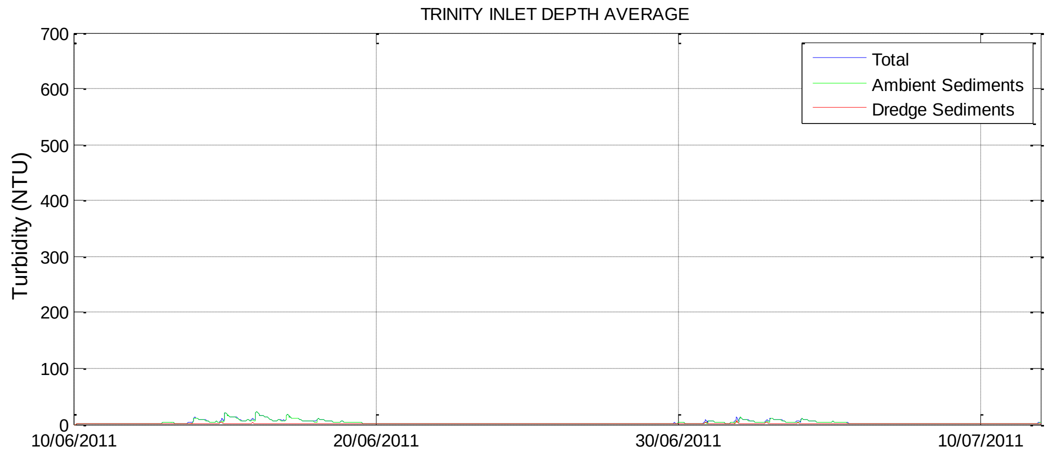


Figure I-10"Worst Case" Soft Material Dredging Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)





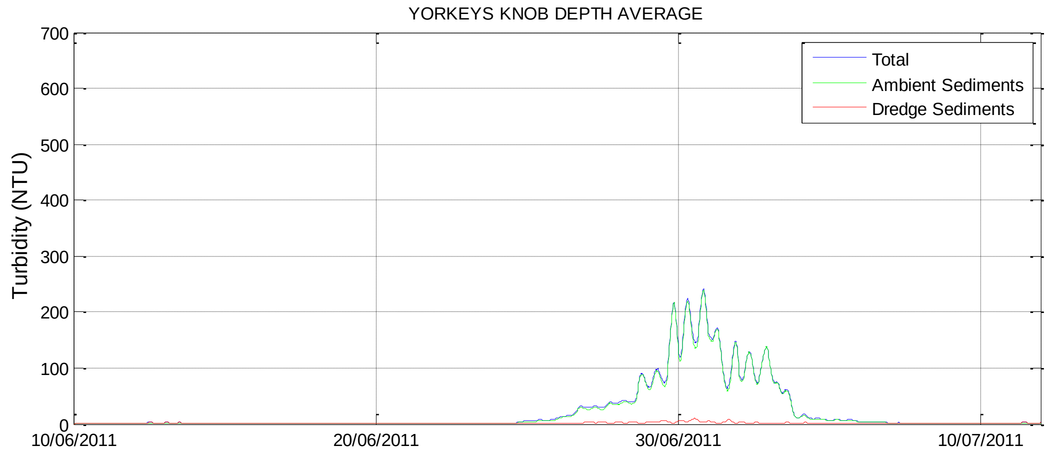


Figure I-11"Worst Case" Soft Material Dredging Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

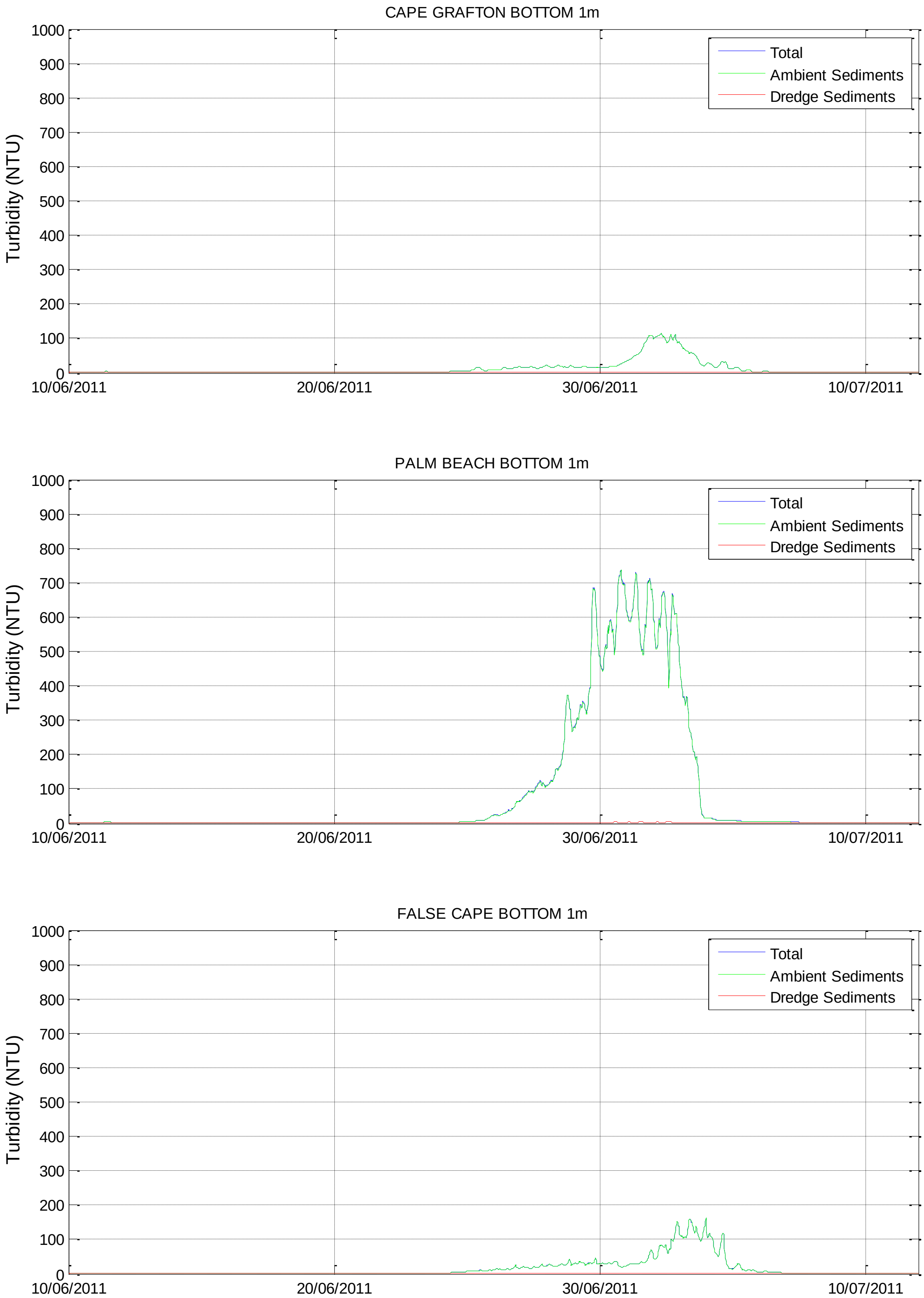
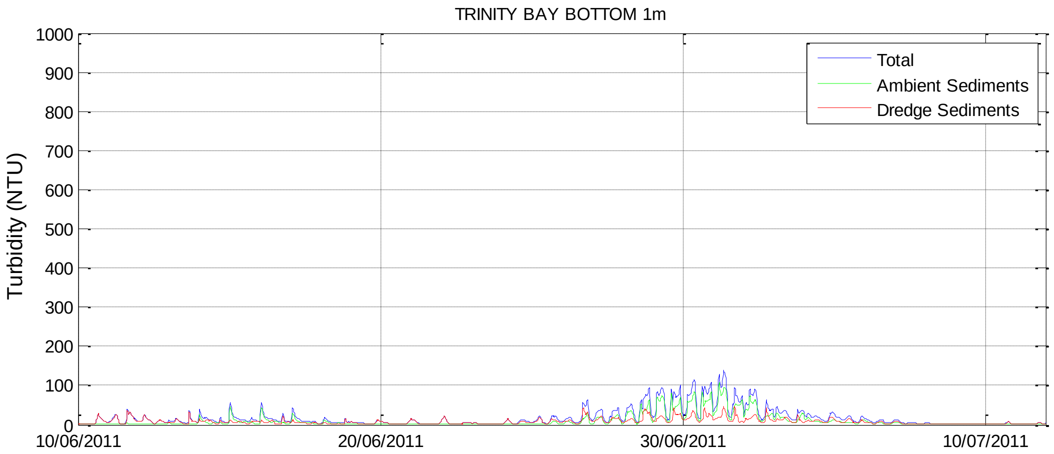
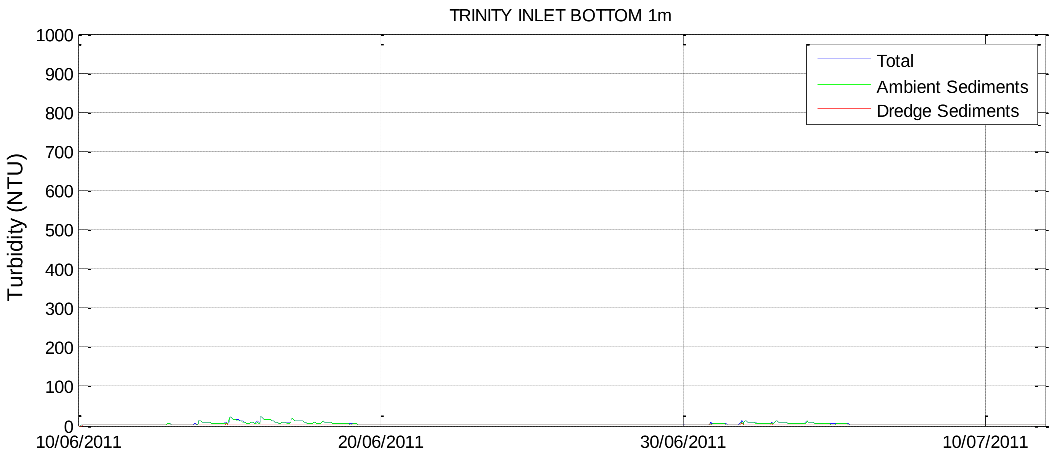


Figure I-12“Worst Case” Soft Material Dredging Bottom 1mTurbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)





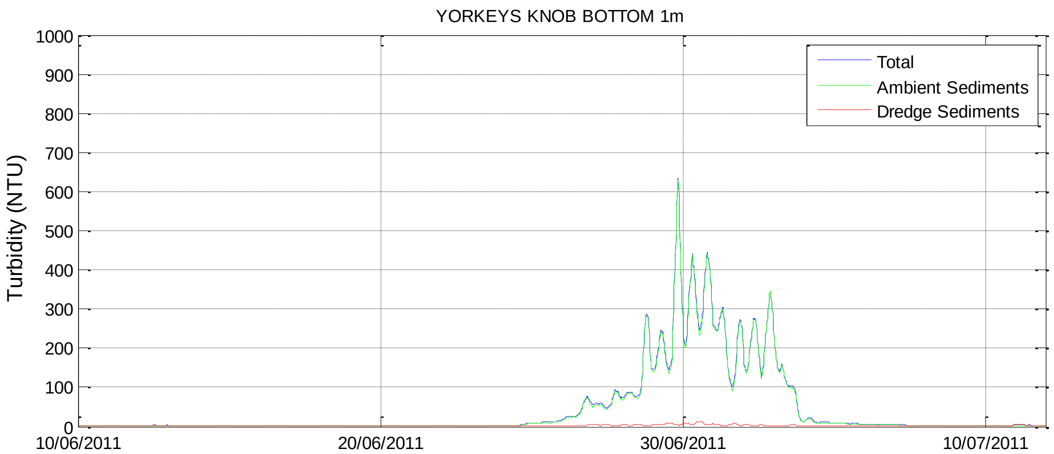


Figure I-13“Worst Case” Soft Material Dredging Bottom 1mTurbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

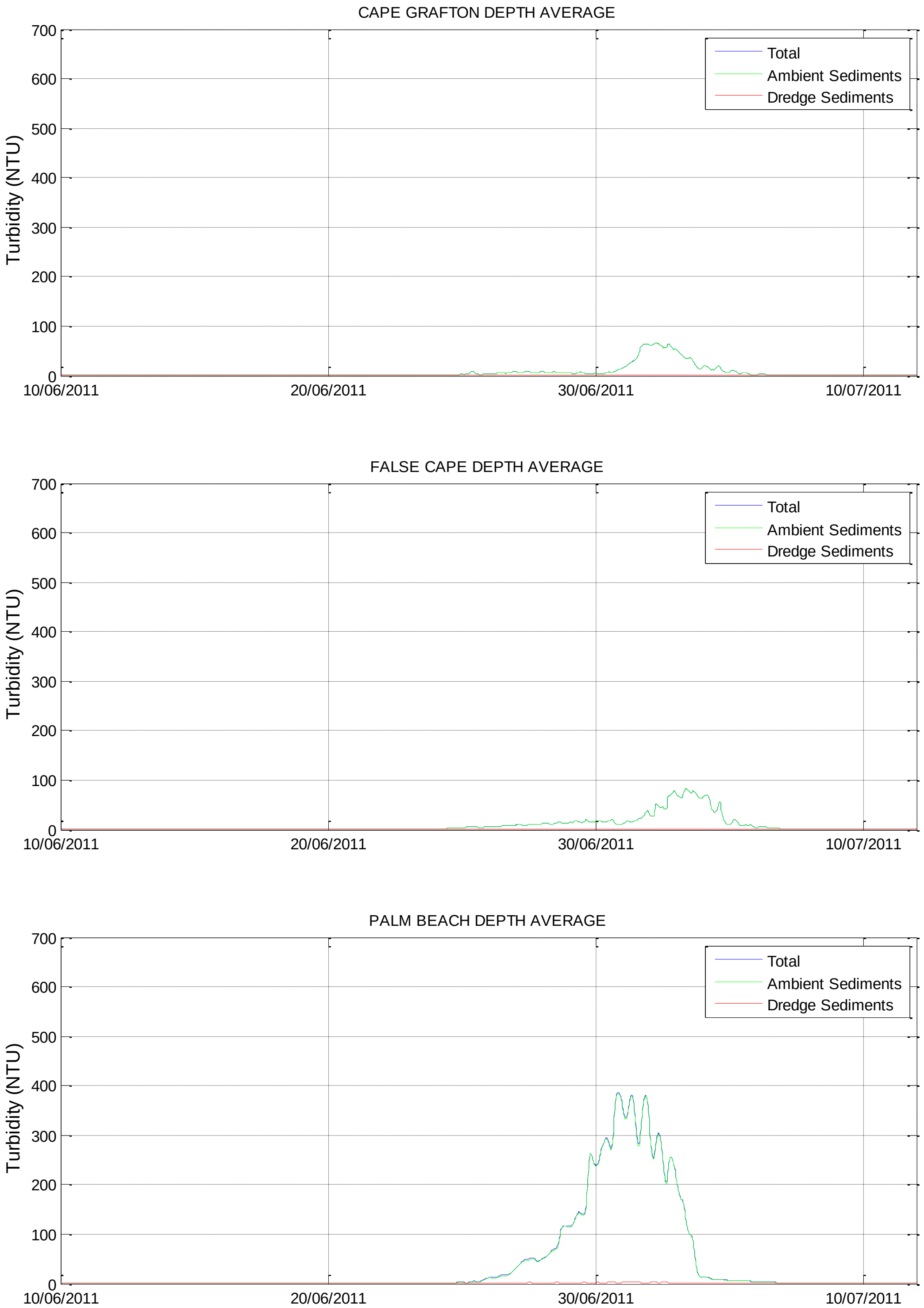


Figure I-14“Worst Case” Stiff Material Dredging Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

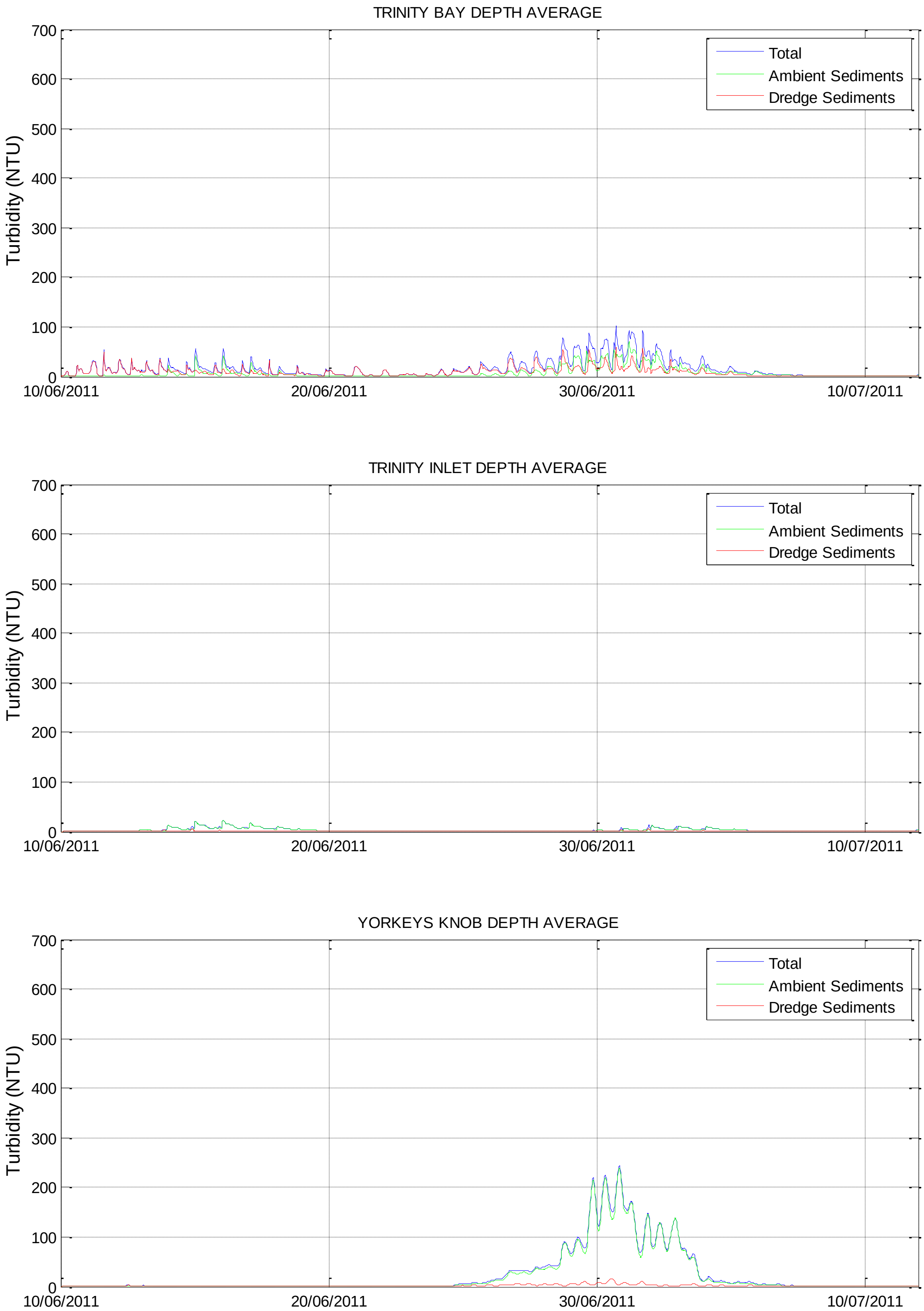
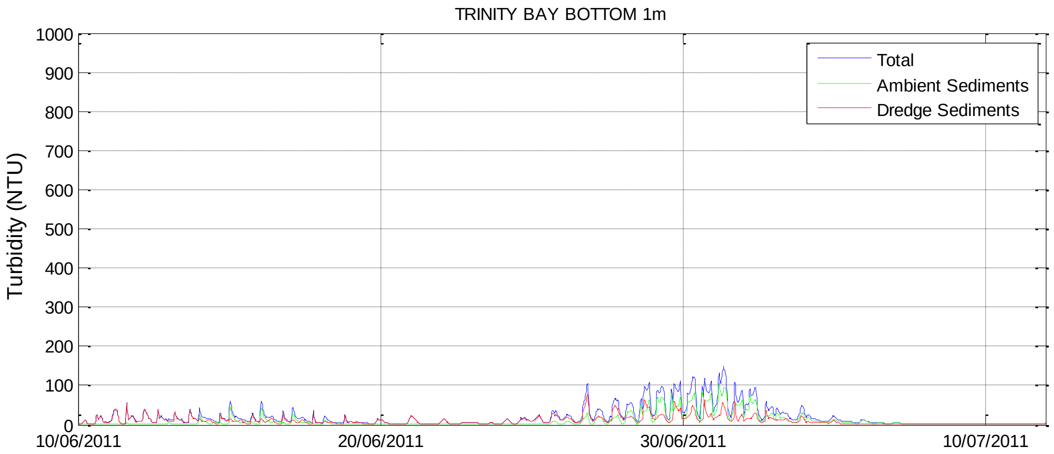
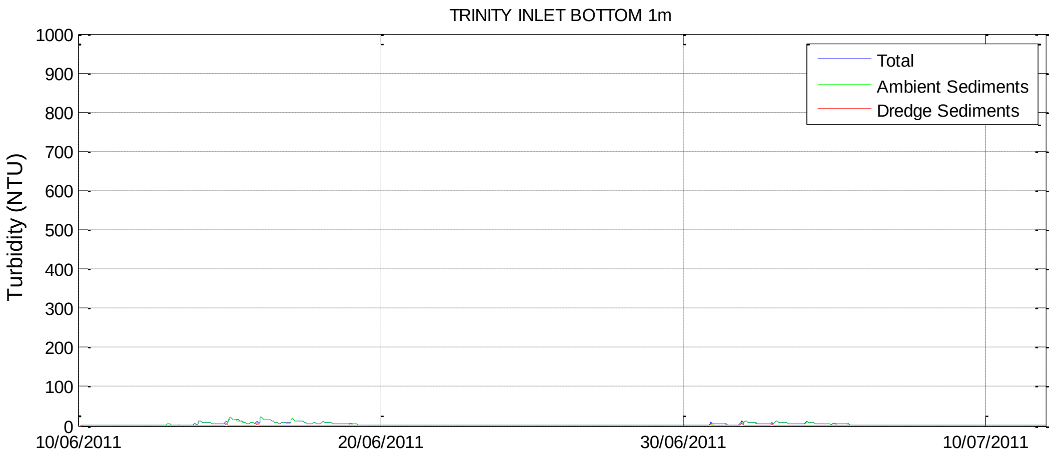


Figure I-15“Worst Case” Stiff Material Dredging Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

Figure I-16“Worst Case” Stiff Material Dredging Bottom 1mTurbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)





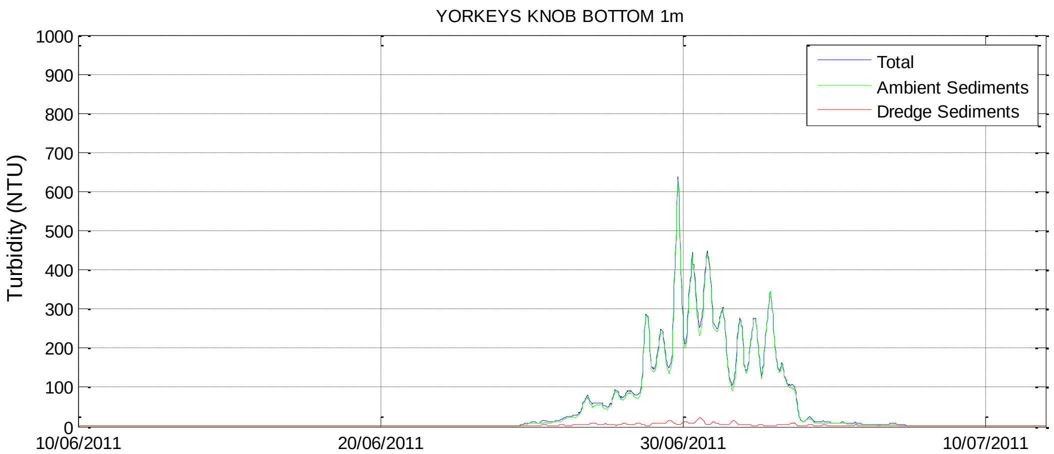


Figure I-17 "Worst Case" Stiff Material Dredging Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

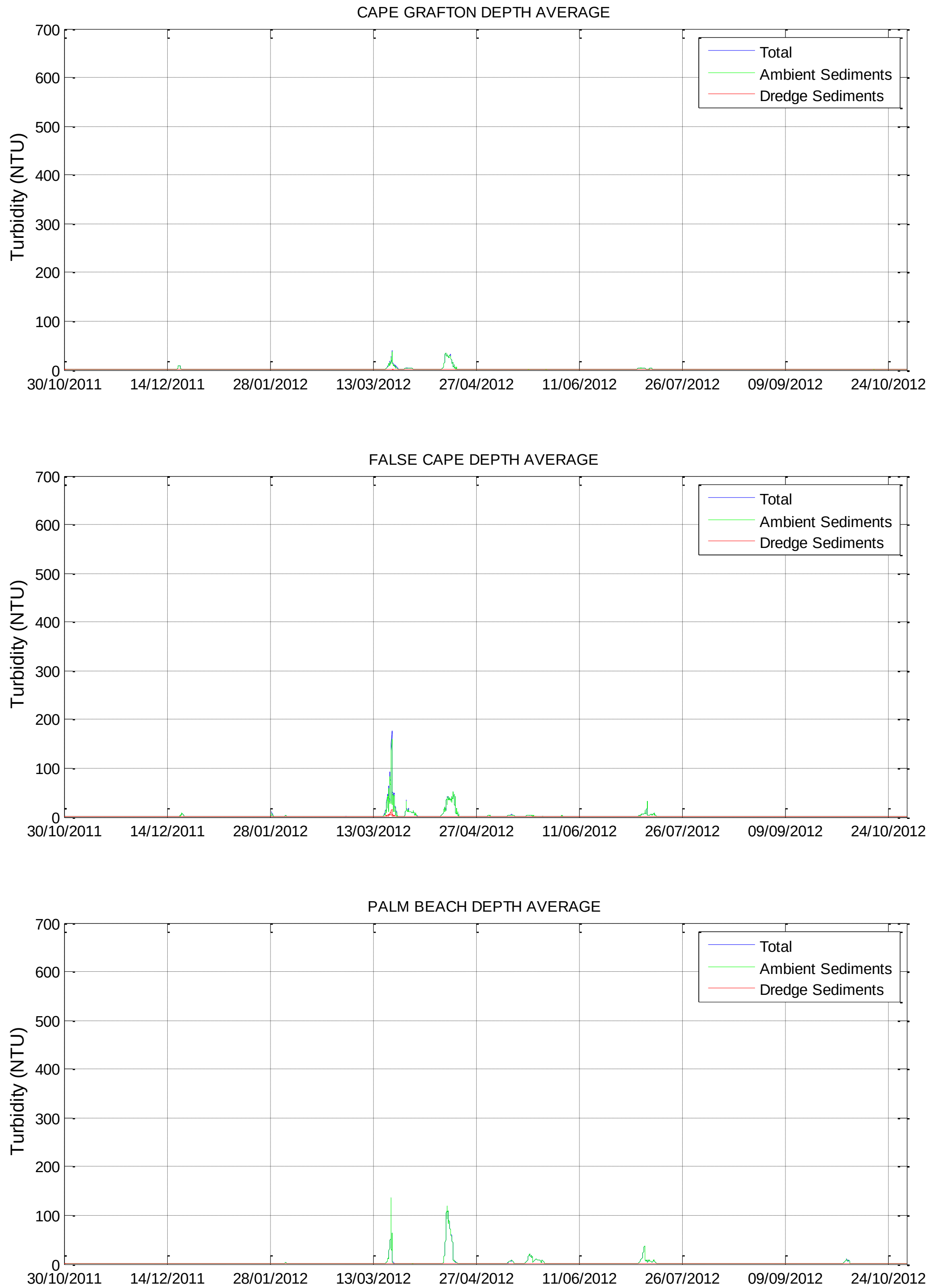


Figure I-18 12mo Re-suspension Period Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

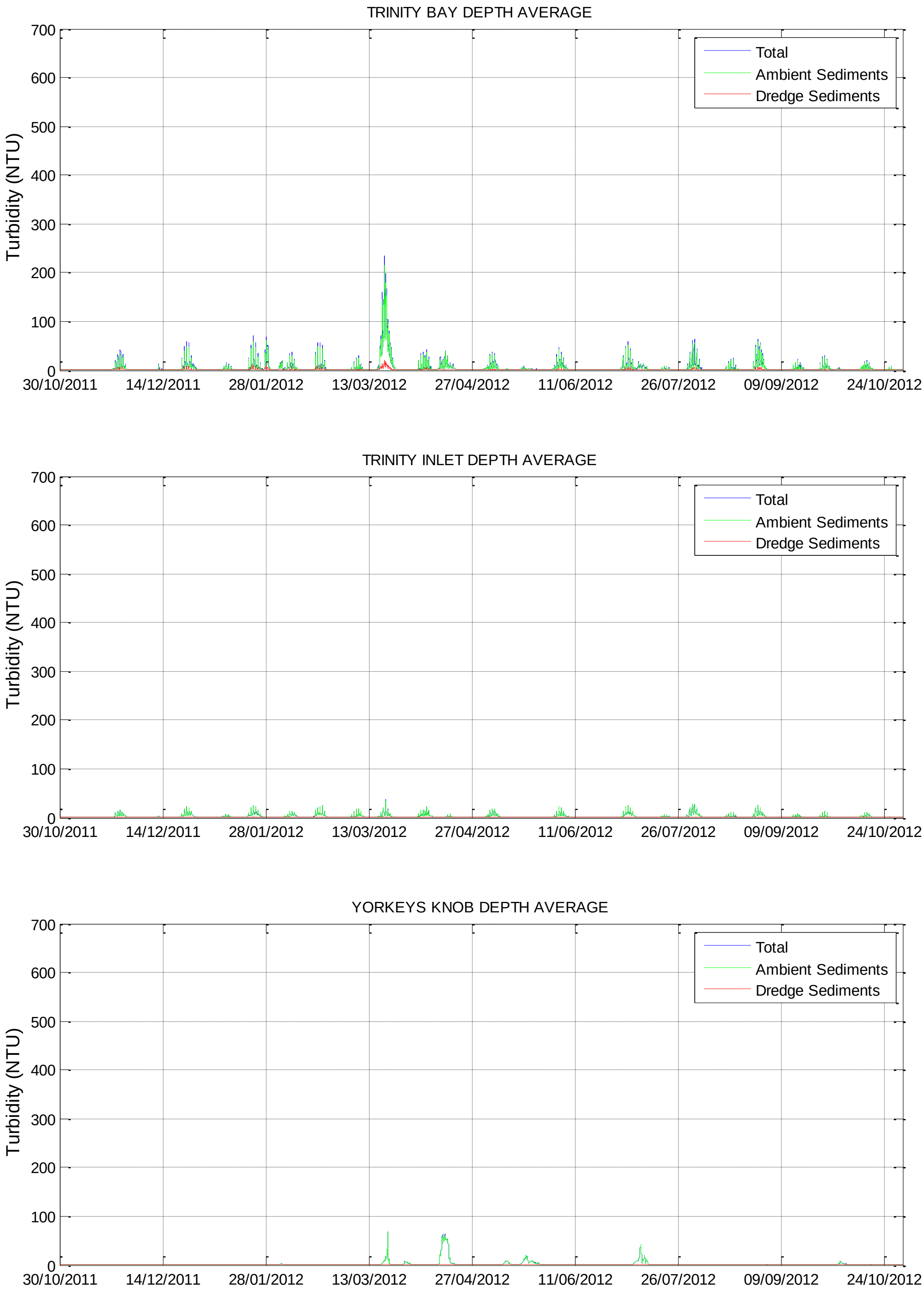


Figure I-1912mo Re-suspension Period Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

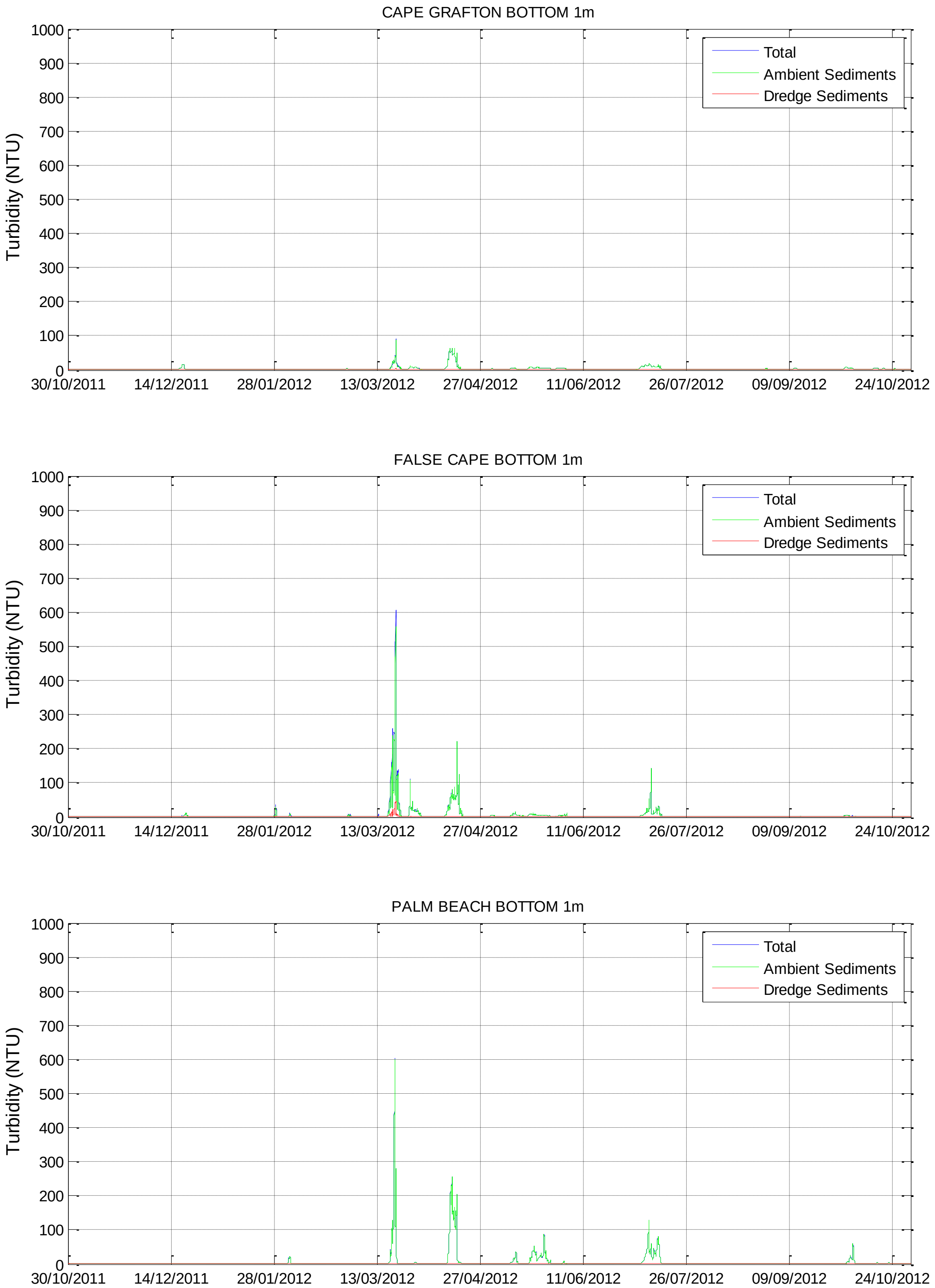


Figure I-20 12mo Re-suspension Period Bottom 1mTurbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

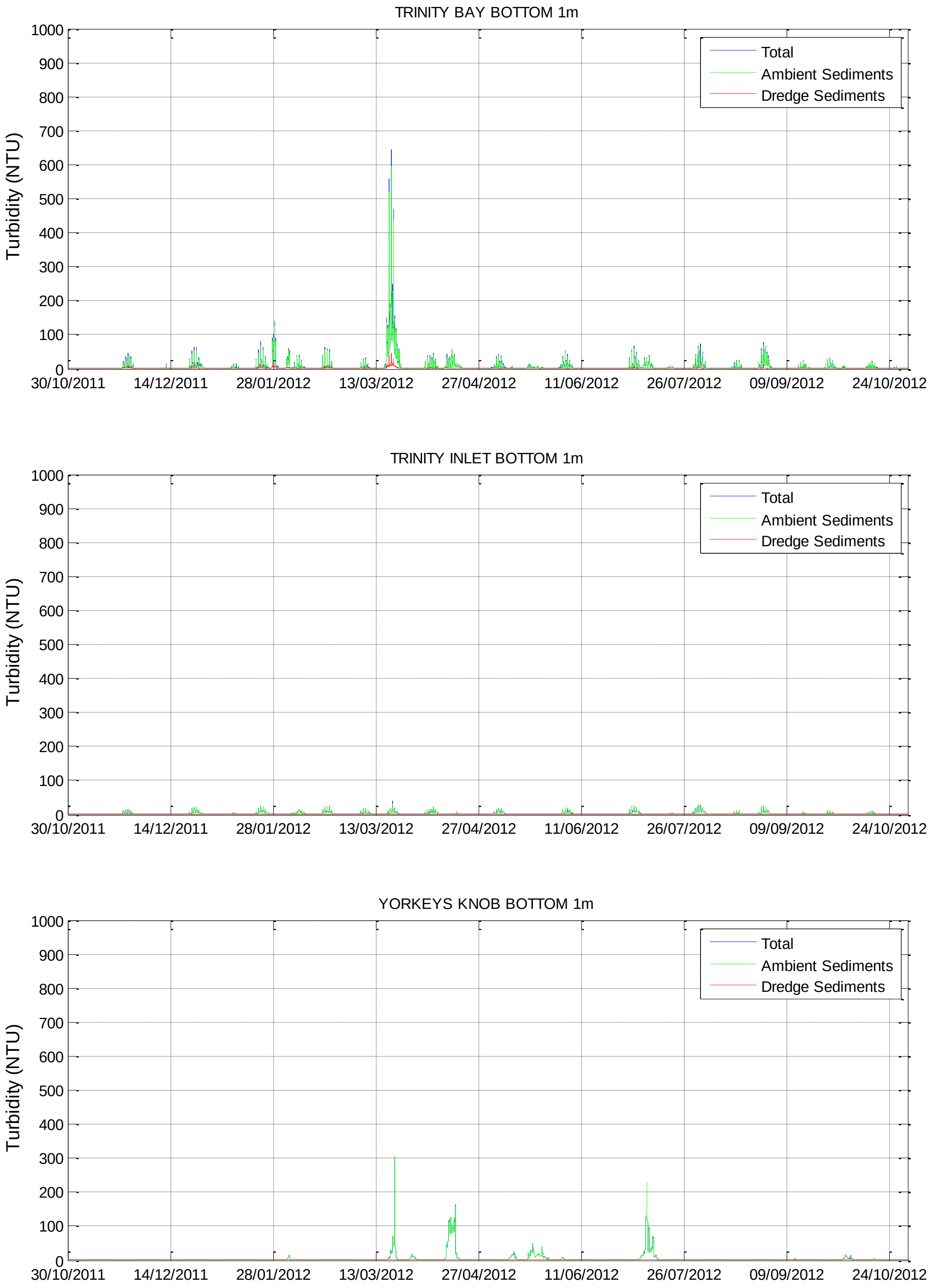


Figure I-2112mo Re-suspension Period Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

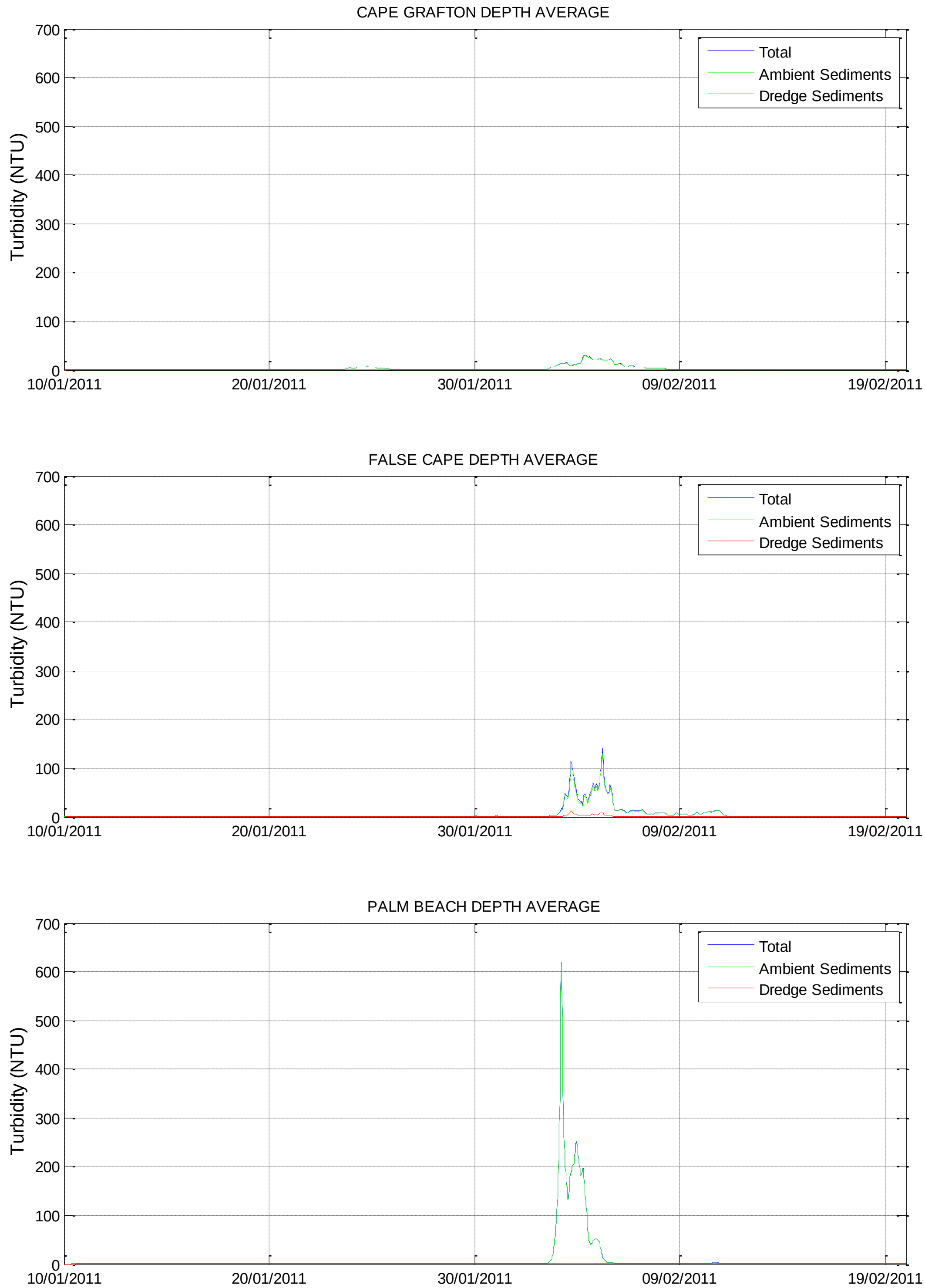
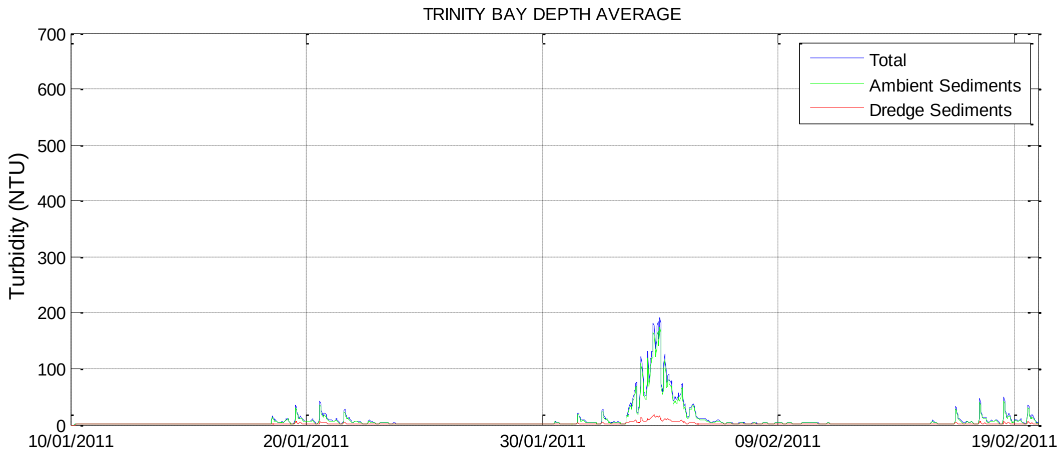
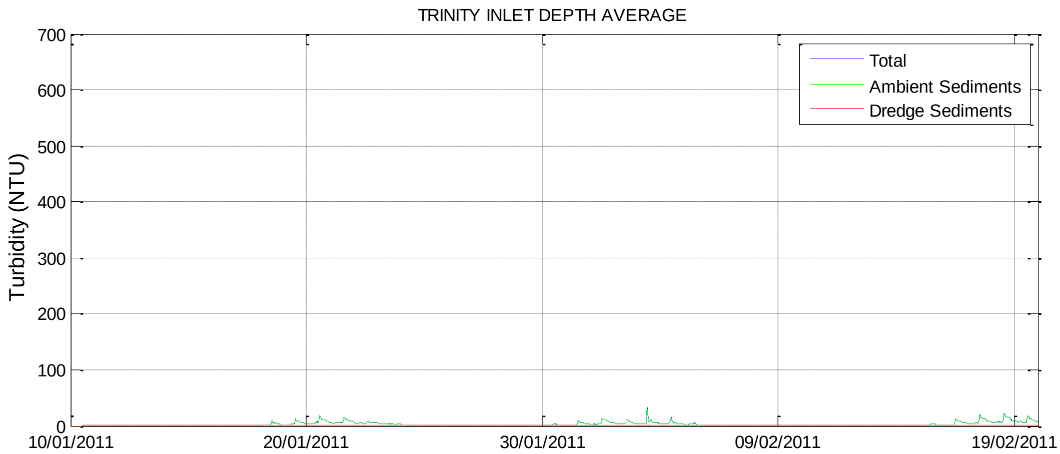


Figure I-22 "Worst Case" DMPA Re-suspension Depth Average Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)





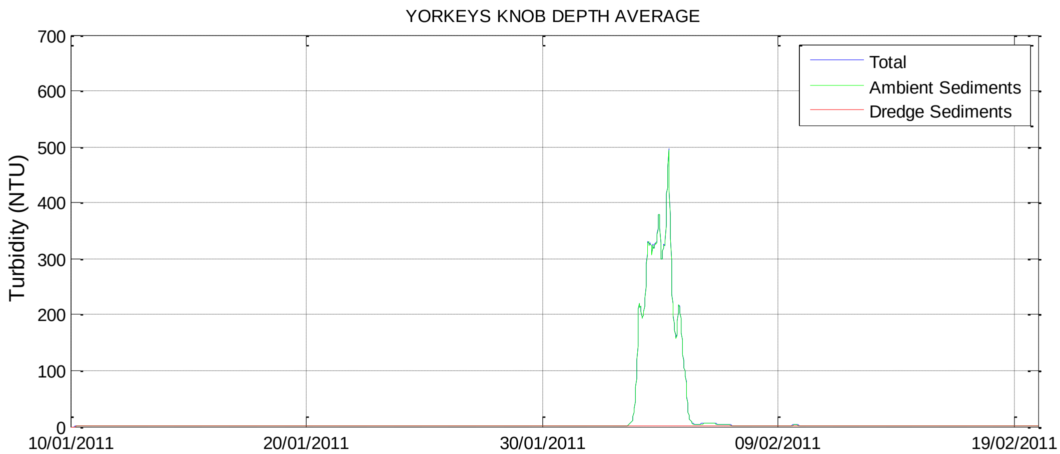


Figure I-23 "Worst Case" DMPA Re-suspension Depth Average Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

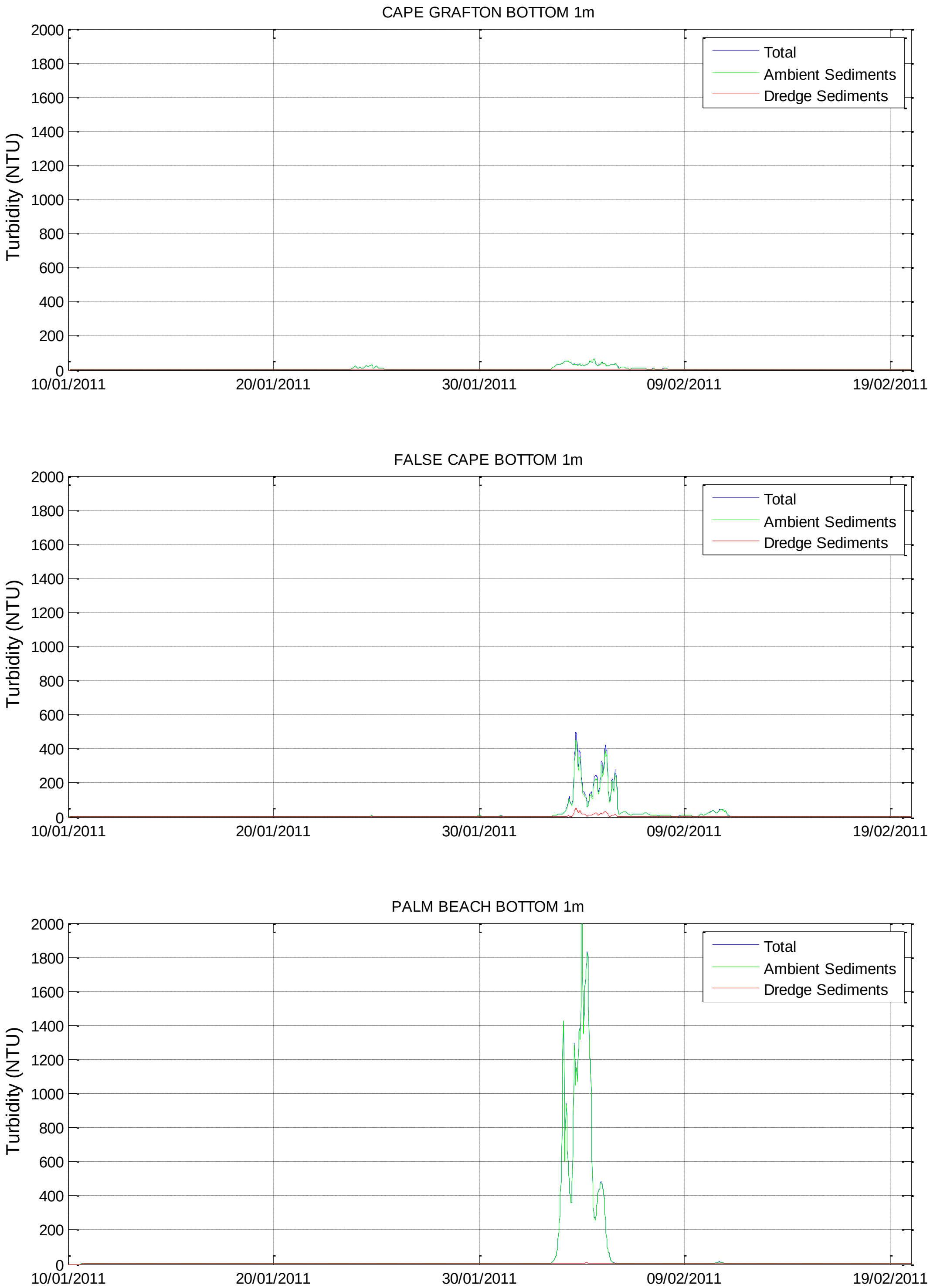


Figure I-24 “Worst Case” DMPA Re-suspension Bottom 1m Turbidity: Cape Grafton (top); False Cape (middle); Palm Beach (bottom)

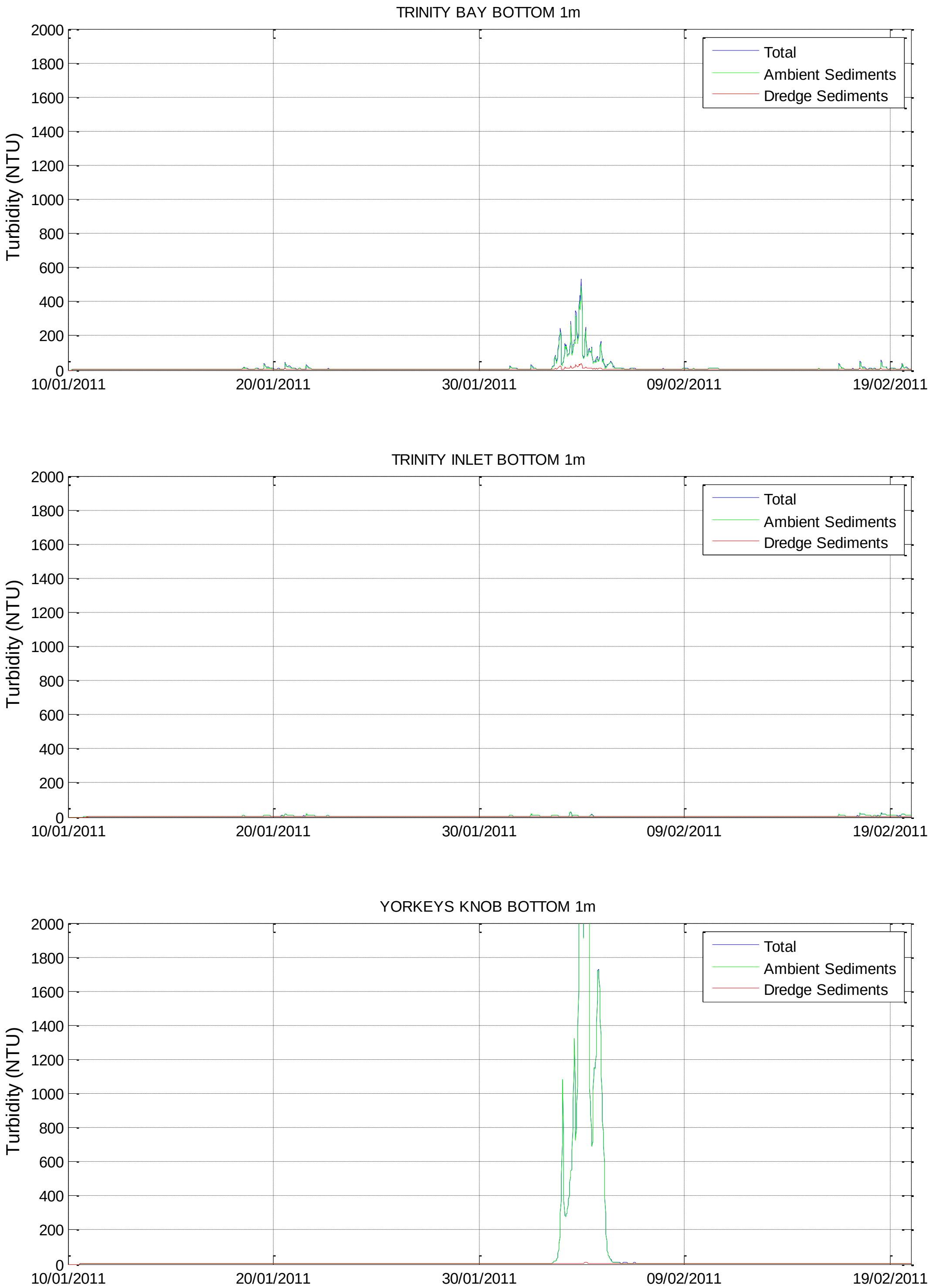


Figure I-25 "Worst Case" DMPA Re-suspension Bottom 1m Turbidity: Trinity Bay (top); Trinity Inlet (middle); Yorkeys Knob (bottom)

BRW.
CLIENT
CHOICE
AWARDS
2013
WINNER

BMT WBM

BMT WBM Bangalow	6/20 Byron Street Bangalow 2479 Tel +61 2 6687 0466 Fax +61 2 66870422 Email bmtwbm@bmtwbm.com.au Web www.bmtwml.com.au
BMT WBM Brisbane	Level 8, 200 Creek Street Brisbane 4000 PO Box 203 Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email bmtwbm@bmtwbm.com.au Web www.bmtwml.com.au
BMT WBM Denver	8200 S. Akron Street, #B120 Centennial Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtwbm.com Web www.bmtwbm.com
BMT WBM London	1st Floor, International House St Katherine's Way London E1W1TW Email london@bmtwbm.co.uk Web www.bmtwbm.com.au
BMT WBM Mackay	Suite 1, 138 Wood Street Mackay 4740 PO Box 4447 Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Melbourne	Level 5, 99 King Street Melbourne 3000 PO Box 604 Collins Street West VIC 8007 Tel +61 3 8620 6100 Fax +61 3 8620 6105 Email melbourne@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Newcastle	126 Belford Street Broadmeadow 2292 PO Box 266 Broadmeadow NSW 2292 Tel +61 2 4940 8882 Fax +61 2 4940 8887 Email newcastle@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Perth	Suite 6, 29 Hood Street Subiaco 6008 Tel +61 8 9328 2029 Fax +61 8 9486 7588 Email perth@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Sydney	Level 1, 256-258 Norton Street Leichhardt 2040 PO Box 194 Leichhardt NSW 2040 Tel +61 2 8987 2900 Fax +61 2 8987 2999 Email sydney@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Vancouver	Suite 401, 611 Alexander Street Vancouver British Columbia V6E 3W1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtwbm.com.au Web www.bmtwbm.com