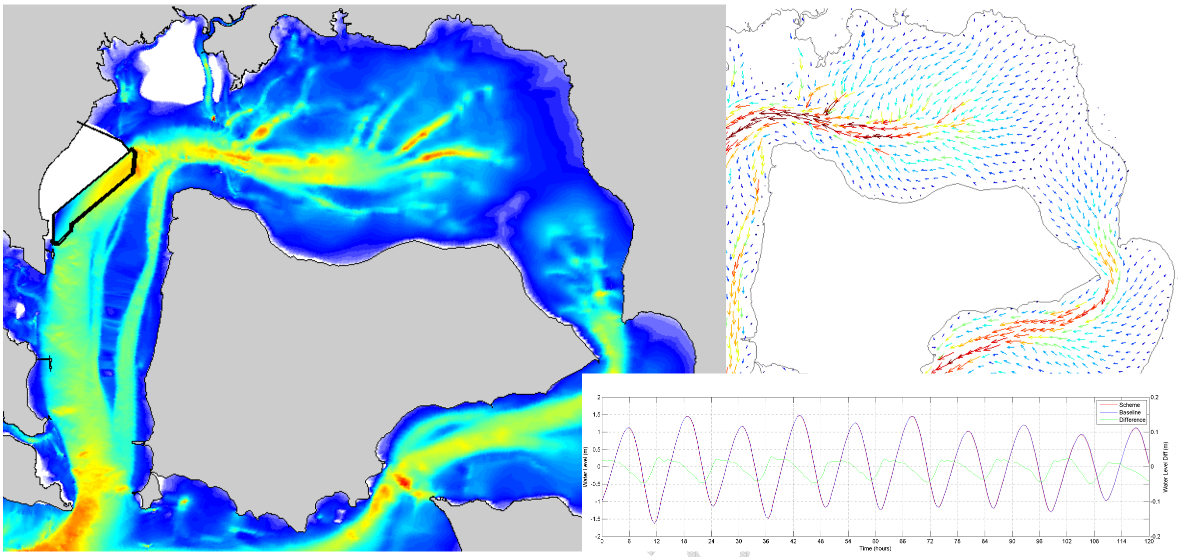

Early Hydrodynamic Modelling for Port of Hastings Development Project

Port of Hastings Development Authority

28 February 2017

Final Draft (Issue D)

HAS-CEP0-HY-REP-0012-D

HASKONING AUSTRALIA
a company of Royal HaskoningDHV

Suite 5, Level 5
100 Walker Street
NORTH SYDNEY NSW 2060
T: +61 (0) 2 8854 5000
F: +61 (0) 2 9929 0960
www.royalhaskoningdhv.com
ABN 66 153 656 252

Document title	Early Hydrodynamic Modelling for Port of Hastings Development Project
Document short title	Early Hydrodynamic Modelling
Status	Final Draft (Issue D)
Date	28 February 2017
Project name	Port of Hastings Development Project
Reference	HAS-CEP0-HY-REP-0012-D
Client	Port of Hastings Development Authority
Project number	8A0300

Issue History

Issue	Status	Drafted by	Checked by	Approved by	Date
A	Preliminary Draft for discussion purposes (Section 3 only)	Rohan Hudson	Andy Symonds	n/a	28/11/2014
B	Preliminary Draft for discussion purposes (includes Section 2)	Rohan Hudson	Ben Patterson / Nick Lewis	n/a	9/12/2014
C	Final Draft (includes Section 4 and revised Sections 1, 2 & 3)	Rohan Hudson	Chris Kuczera	n/a	19/12/2014
D	Final Draft (includes final internal review)	Rohan Hudson	Peter Horton	n/a	31/03/2015

CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

1.1 Hydrodynamics Work Stream

The Port of Hastings Development Authority (the Authority) is responsible for the facilitation of the development of the Port of Hastings (in Western Port, Victoria, Australia) into a world-class competitive container port, along with subsequent management and operation. The Port of Hastings Development Project (denoted as the 'Project' herein) includes all the activities which would be required to achieve the proposed development of the port. The Authority has appointed a team of consultants to conduct scoping studies, establish project planning tools and undertake business case and environmental assessments, culminating in the completion of a Comprehensive Impact Statement (CIS) to support the Project's development.

Haskoning Australia Pty Ltd (a company of Royal HaskoningDHV) has been appointed to undertake the Hydrodynamics Work Stream. The objectives of this Work Stream are to:

- develop baseline understanding of coastal and estuarine physical processes in the marine and intertidal environment of Western Port through data collection, observations and numerical modelling that reproduces existing conditions;
- provide information to the Project Team to assist in defining the preferred port design, layout and dredging strategy; and
- detailed assessment of potential impacts of the preferred Project option on physical processes in Western Port, and provision of this information to the wider Project Team for assessment of ecological impacts.

1.2 Brief Project Description

To develop Port of Hastings into a world-class competitive container port, dredging of new berths and swing basins, as well as existing channels will be required to facilitate access for larger draft vessels. A proportion of the dredged material would be used to construct a reclamation area to the north of Long Island Point for development of the container terminal. Material unsuitable for reclamation or excess to reclamation requirements would need to be placed in one or more locations offshore of Western Port (in State or Commonwealth Waters), within Western Port, or on land within the Special Use Zone.

1.3 Geographical Setting

The Port of Hastings is located in Western Port, Victoria, Australia. The geographical setting of Western Port is provided in Figure 1, along with discretisation into segments based on physical characteristics as derived from Marsden et al (1979).

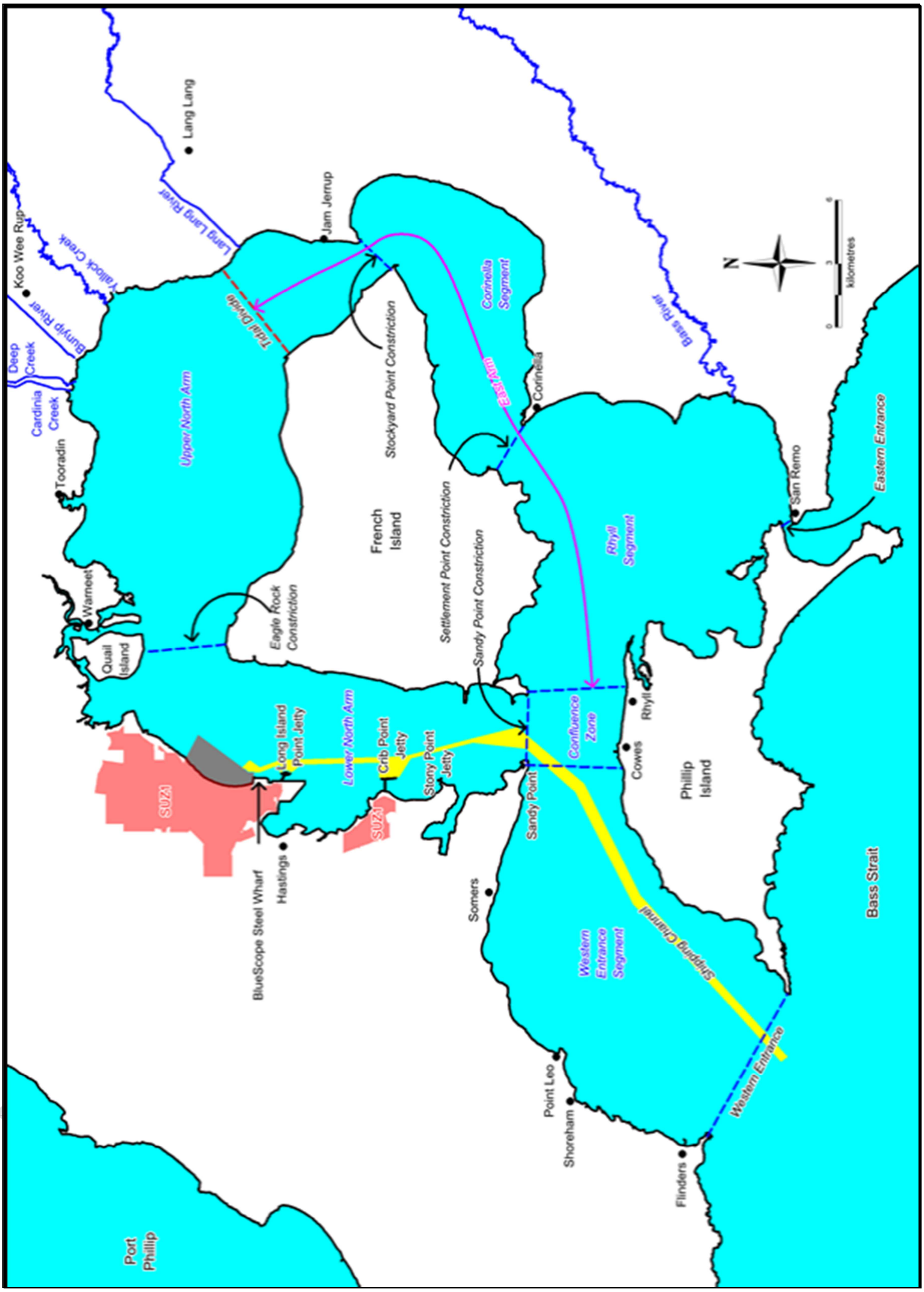

Figure 1: Geographical setting of Western Port, Victoria (after: Marsden et al 1979)

1.4 Purpose of this Report

This report provides details of the Early Hydrodynamic Modelling Investigations undertaken for the Project. The Early Hydrodynamic Modelling Investigations have been undertaken to inform the Design and Engineering (D&E) prime consultant with information to assist option development and design. Two discrete modelling tasks have been undertaken:

1) Hydrodynamic sensitivity testing of a number of development scenarios; and
2) Hydrodynamic and wave modelling to provide Metocean conditions to inform the design of the channel and port environs.

The investigation also includes an initial assessment of long waves in the Port and channel areas.

Due to time constraints, these Early Hydrodynamic Modelling Investigations make use of an existing hydrodynamic model developed by Cardno Pty Ltd for the Authority during the Preliminary Business Case studies. While preliminary model calibration of the Cardno model was undertaken, the short project timeframes meant that a detailed calibration and verification process could not be undertaken resulting in a reduced level of certainty that can be associated with model output using the current model setup.

A more comprehensive suite of models is currently planned for development. These models will be used to further inform the project, after more extensive development calibration and verification.

1.5 Outline of Report

Section 2 provides information regarding the hydrodynamic sensitivity testing of a number of development scenarios.

Section 3 provides information regarding the hydrodynamic and wave modelling to provide 12 months of simulated metocean conditions to inform the design of the channel and port environs.

Section 4 provides information regarding an initial assessment of long waves in the Western Port.

2 HYDRODYNAMIC SCENARIO MODELLING (TIDAL DIVIDE SENSITIVITY)

2.1 Objective and Methodology

Section 2 of this report is provided to satisfy the objectives of Task 1 of the early hydrodynamic modelling scope (WP-HY-13), which includes providing information on the hydrodynamic impacts of a number of preliminary port design scenarios. Of particular interest are potential impacts to the location of the tidal divide in Western Port. The information is intended to inform the iterative options development and assessment process.

To meet these objectives the existing DELFT-3D hydrodynamic model (developed during Preliminary Business Case Studies by Cardno has been used to undertake an initial assessment of a number of design scenarios. A range of model outputs have been analysed and are presented to determine the impact of the port scenarios.

2.1.1 Description of Hydrodynamic Model

To calculate the impact of different port design scenarios, a suitable hydrodynamic model was required. The dual domain, DELFT-3D model previously developed by Cardno used a 20m fine grid in the Lower North Arm (the location of the proposed Port Development) and a 150m coarse grid for the remainder of Western Port and offshore area. This model was provided to Haskoning Australia by the Authority and found to be suitable for this investigation, as it was able to resolve key processes and was of suitable resolution to model the different design scenarios. The model bathymetry and extent is presented in Figure 2.

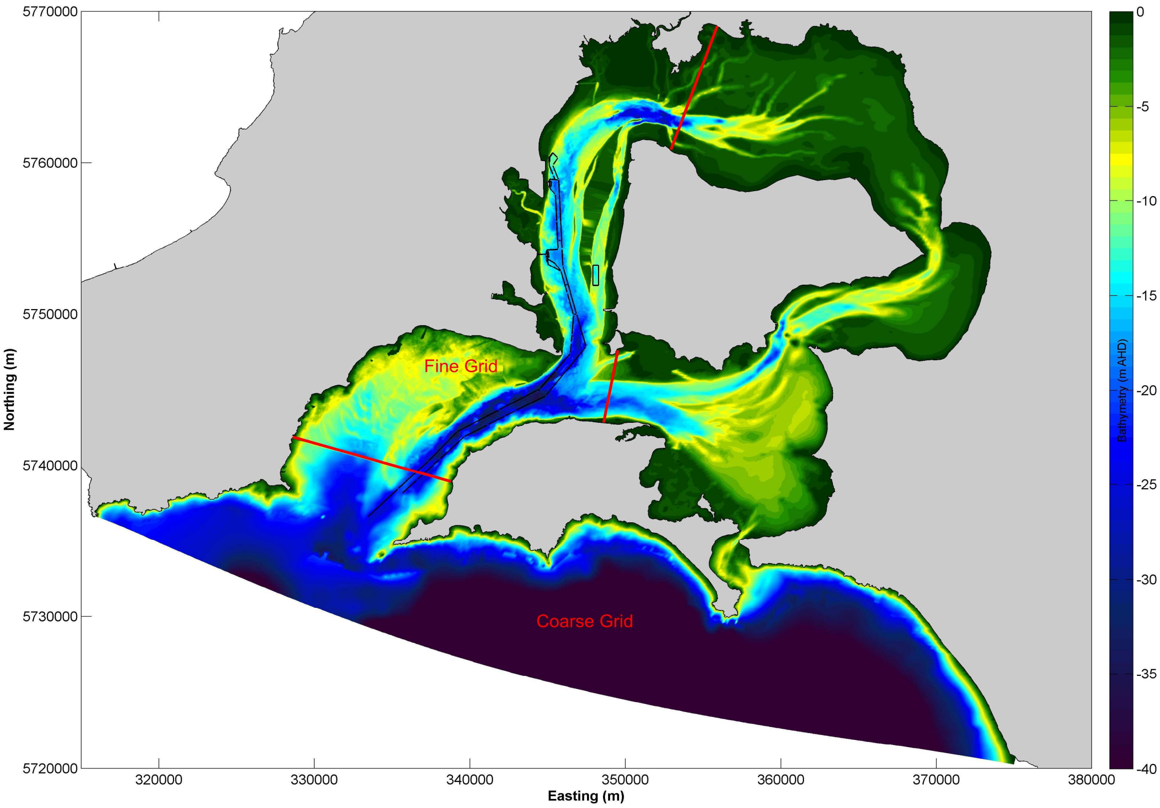

Figure 2: Model Bathymetry and Extent

The model was used to simulate a one-month period (15 December 2012 to 16 January 2013) using the boundary conditions previously defined by Cardno. A review of the achieved model calibration undertaken by Cardno indicated that the model was able to closely reproduce observed water levels

within Western Port and velocity measurements at two locations within the Lower North Arm. However, a review of the tidal boundary condition (as presented in Section 3.1.3) indicated that the adopted tidal lag across the offshore water level boundary produced unrealistic lateral currents to the south of Phillip Island, though this is considered to not significantly affect the assessment of design scenarios within Western Port.

2.1.2 Description of Design Scenarios

In addition to the base case (existing condition (EXST), see Figure 3) three initial port design scenarios have been assessed to gain an understanding of how the proposed port development may influence hydrodynamic processes within Western Port. The port design scenarios considered as part of this assessment comprised:

- Close to shore (CTS) alignment;
- Far out from shore (FOFS) alignment;
- Alternate (ALT) alignment.

The close to shore port alignment is presented in Figure 4 and includes dredging to a depth of -15.6 m CD. The far out from shore port alignment is presented in Figure 5 and includes dredging to a depth of -17.6 m CD. These two scenarios are likely to provide "book end" (i.e. provide upper and lower bound) impacts to the range of hydrodynamic impacts of alignments that fall between these two scenarios. However, further detailed testing is still recommended due to the possibility of unforseen or non-linear impacts. The alignment of the alternate scenario is presented in Figure 6 and two (-15.6 m CD (ALT156) and -17.6 m CD (ALT176)) dredge depth options have also been assessed as part of this configuration.

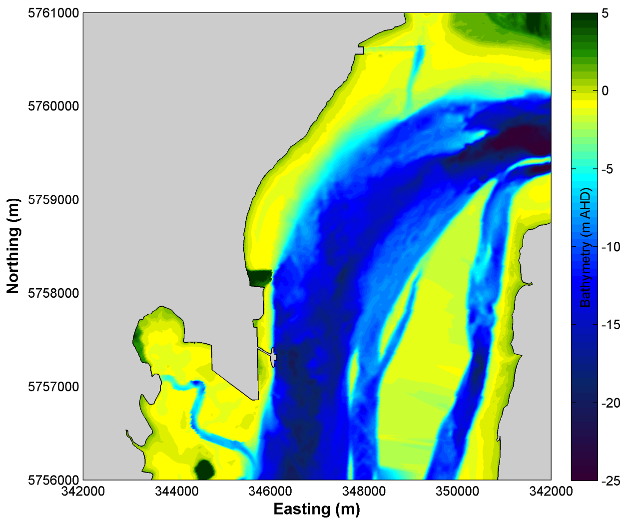

Figure 3: Existing Scenario

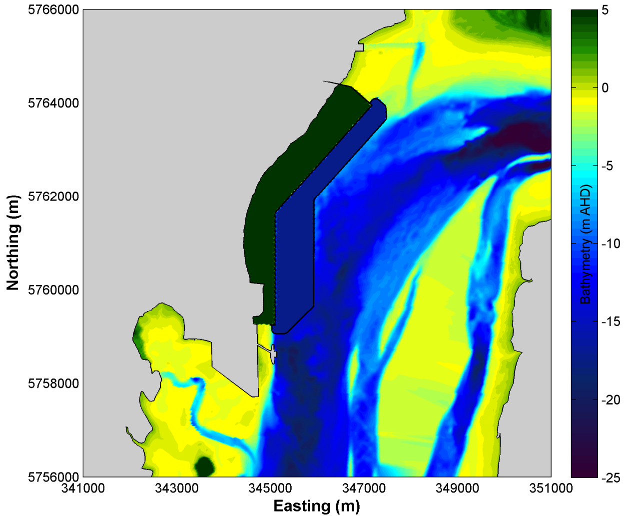

Figure 4: Close To Shore (CTS) Scenario

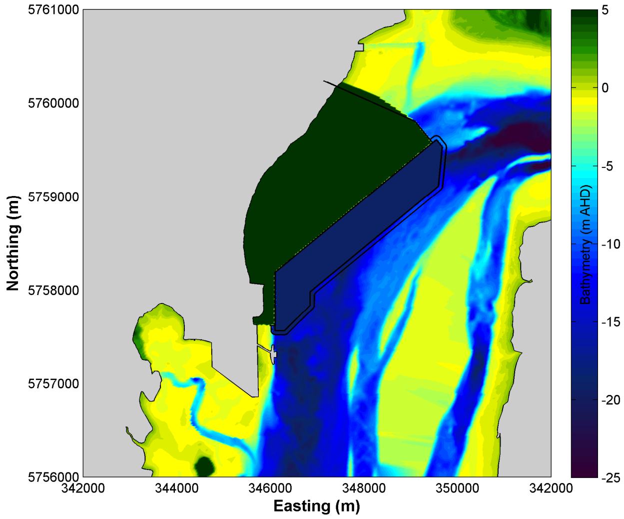

Figure 5: Far Out From Shore (FOFS) Scenario

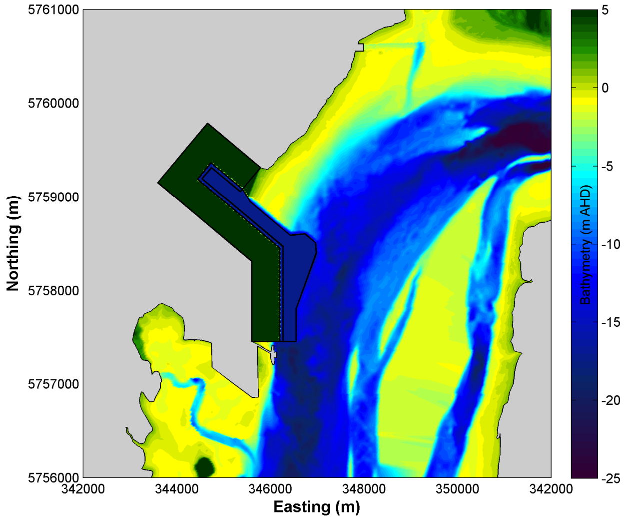

Figure 6: Alternate (ALT) Scenario

2.2 Model Results

A range of model outputs have been generated to assist in providing an improved understanding of the existing Western Port hydrodynamics and to help quantify the potential changes associated with each of the design scenarios.

2.2.1 Plots of Water Level Exceedance

Plots of water level exceedance have been generated based on the results of the one month simulation. Figure 7 presents the modelled 90th percentile water level exceedance value for the existing conditions. Tidal amplification around both sides of French Island is evident. The equivalent plots for each of the port scenarios are presented in Figure A-1 to Figure A-4 (in Appendix A) and show that the proposed port scenarios would have minimal impact on the general pattern of water levels within Western Port.

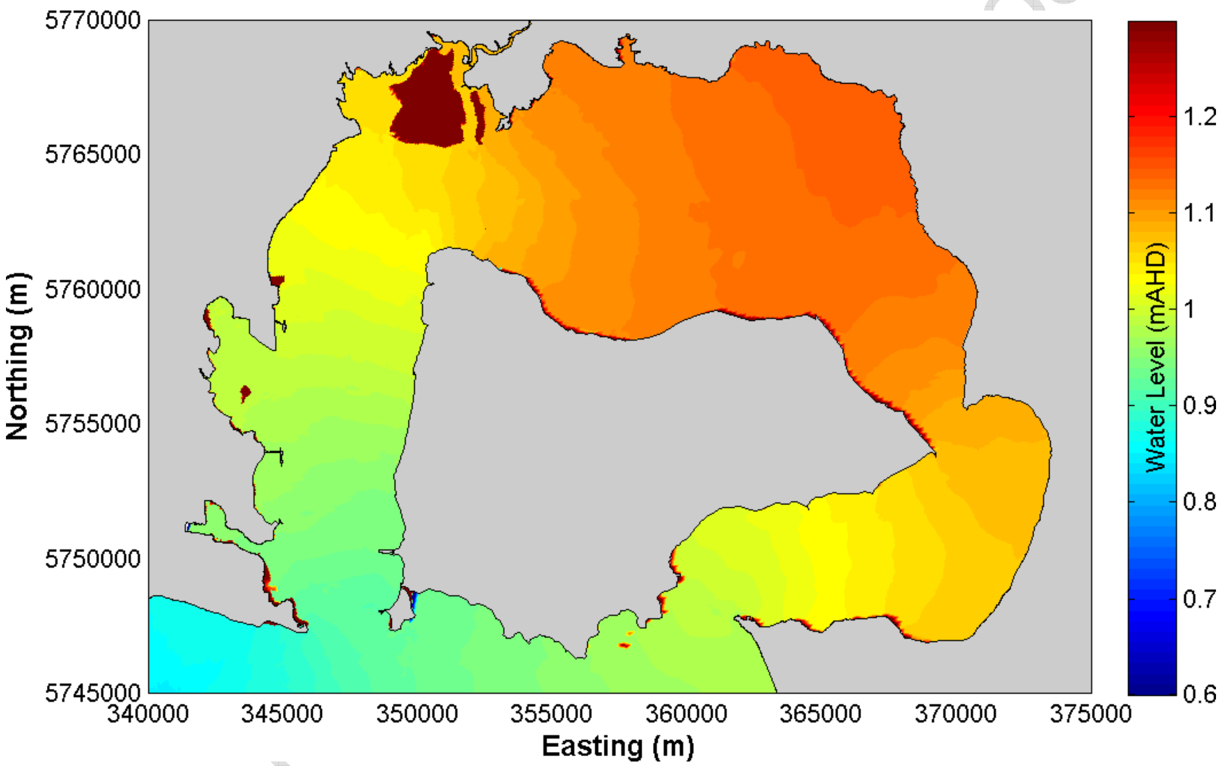

Figure 7: 90th Percentile Water Level Exceedance for Existing Scenario

2.2.2 Plots of Current Speed Exceedance

Plots of current speed exceedance have been generated based on the results of the one month simulation. Figure 8 presents the modelled 90th percentile current speed exceedance value for the existing conditions. The figure indicates that higher current speeds typically occur in the deeper channels (refer Figure 2). The approximate location of the tidal divide, characterised by significantly lower tidal velocities, is evident in the north eastern area of Western Port (this is further discussed in Section 2.2.6).

The equivalent plots for each of the port scenarios are presented in Figure A-5 to Figure A-8 (in Appendix A) and show that outside of the immediate vicinity of the port development, the proposed scenarios would have minimal impact on the general pattern of current speeds within Western Port. From the four figures (Figure A-5 to Figure A-8) it is evident that, with the exception of the FOFS

scenario, the current speed at the berth face would be below 0.5 m/s for 90% of the time. In the FOFS scenario (Figure A-6), because the berth face is located in the main channel and the channel width has been restricted, current speeds above 0.8 m/s would be experienced for 10% of the time.

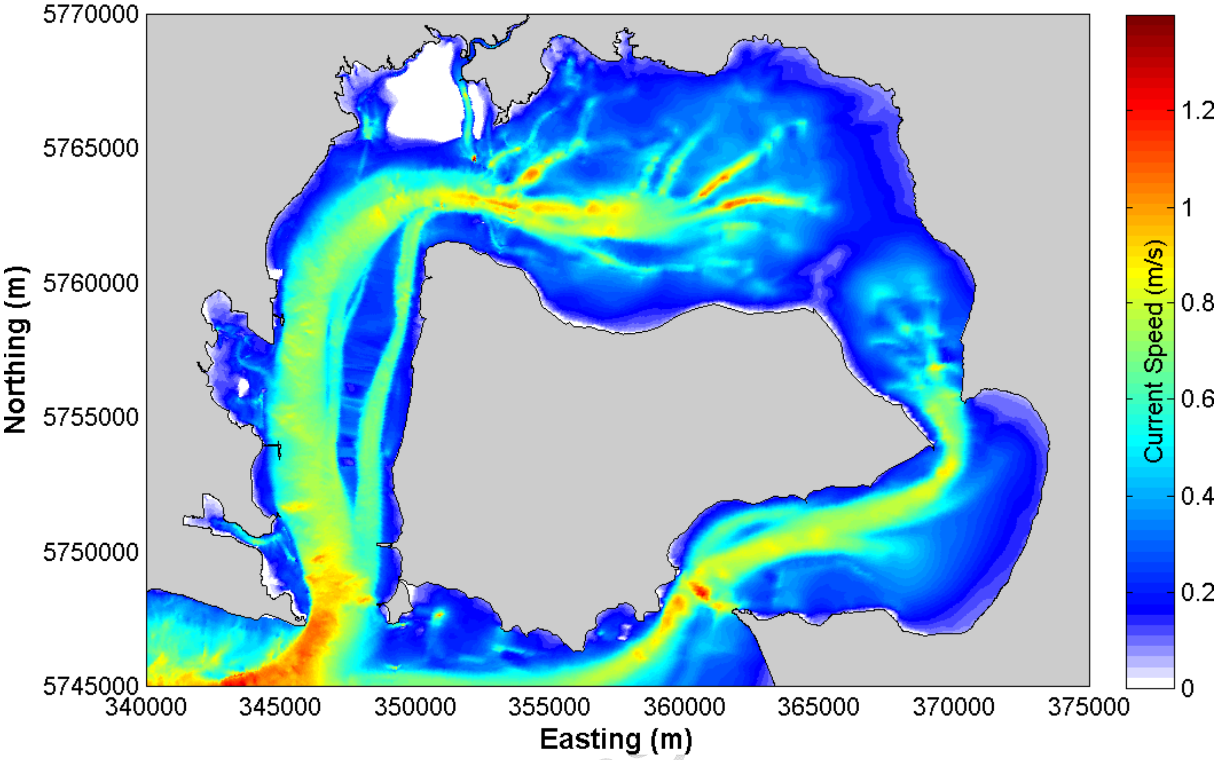

Figure 8: 90th Percentile Current Speed Exceedance for Existing Scenario

2.2.3 Assessment of Changes to Tidal Discharges and Net Circulation

An assessment of the impact of different scenarios on changes to tidal discharges and net circulation in Western Port has been made, focussing on tidal discharge into the Lower North Arm (western side of French Island) and into the Corinella Segment (eastern side of French Island), refer Figure 9. Tidal discharge can be calculated by the DELFT3D model at any predefined cross-section along a model grid line.

Instantaneous tidal discharge in the Lower North Arm is presented in Figure 10 and shows that for a 5 day period of spring tides, flood and ebb flows of +/- 30,000 to 40,000 m^3/s occur in the base-case (existing) scenario and proposed scenarios. Note that ALT176 results have been omitted due to the insignificant difference to ALT156. The difference in discharge for each scenario, compared to the existing condition, is presented in Figure 11 and shows that during a flood tide the FOFS peak discharge is 1,000 m^3/s (~3-4%) lower than the existing condition, due to the proposed reclamation associated with the scenario reducing the available channel width and cross-sectional area. For the CTS scenario there is also a reduced flood tide inflow in the order of 400 m^3/s, however, there is also a difference in timing (phase) of the difference in discharge. For the two alternative scenarios (ALT156 & ALT 176) there is minimal difference in discharge into the Lower North Arm.

Cumulative discharge into the Lower North Arm is presented in Figure 12 and indicates a spring tidal prism in the order of 500,000-600,000 ML, while the neap tidal prism is 300,000-400,000 ML at this location. The presence of a residual net circulation, in the order of 300,000 ML/month, clockwise around French Island is also evident in Figure 12. Figure 13 presents the difference in cumulative discharge into the Lower North Arm for each of the scenarios, compared to the existing condition. The graph shows that the CTS scenario enhances the clockwise net circulation around French Island by ~15,000 ML/month (an increase of ~5%). The FOFS scenario reduces the net clockwise circulation by ~7,500 ML/month (a reduction of ~2-3%). The alternative scenarios (ALT156 & ALT176) have minimal impact on net circulation.

Discharge data into the Corinella Segment has also been analysed to further assess potential changes to tidal discharge and net circulation. From Figure 14 it is evident that at this location, peak tidal discharge is approximately half of that into the Lower North Arm. The impact of the scenarios on changes to tidal discharge is also considerably smaller and less in phase (Figure 15). At this location the tidal prism (see Figure 16) is also much smaller, though the monthly net clockwise circulation in the order of 300,000 ML/month is evident. At this location the net clockwise circulation is expressed as a negative net circulation and also there is a different start point to the calculation of net discharge.

Figure 17 presents the difference in cumulative discharge into the Corinella Segment for each of the scenarios compared to the existing condition. At this location the CTS scenario enhances the clockwise net circulation around French Island by ~10,000 ML/month, while the FOFS scenario reduces the net clockwise circulation by ~7,500 ML/month. Again the alternative (ALT156 & ALT176) scenarios are shown to have minimal impact on net circulation.

The stage - volume relationship of the Lower North Arm (up to the tidal divide) for the existing situation and scenarios are presented in Figure 18. The Figure shows how much available waterway volume has changed due to each Port development scenario. It is evident for the FOFS scenario, that reclamation has reduced the available tidal waterway volume by ~2 GL. This accounts for some but not all of the difference in cumulative discharge (Figure 13). The remaining difference is attributed to changes in conveyance.

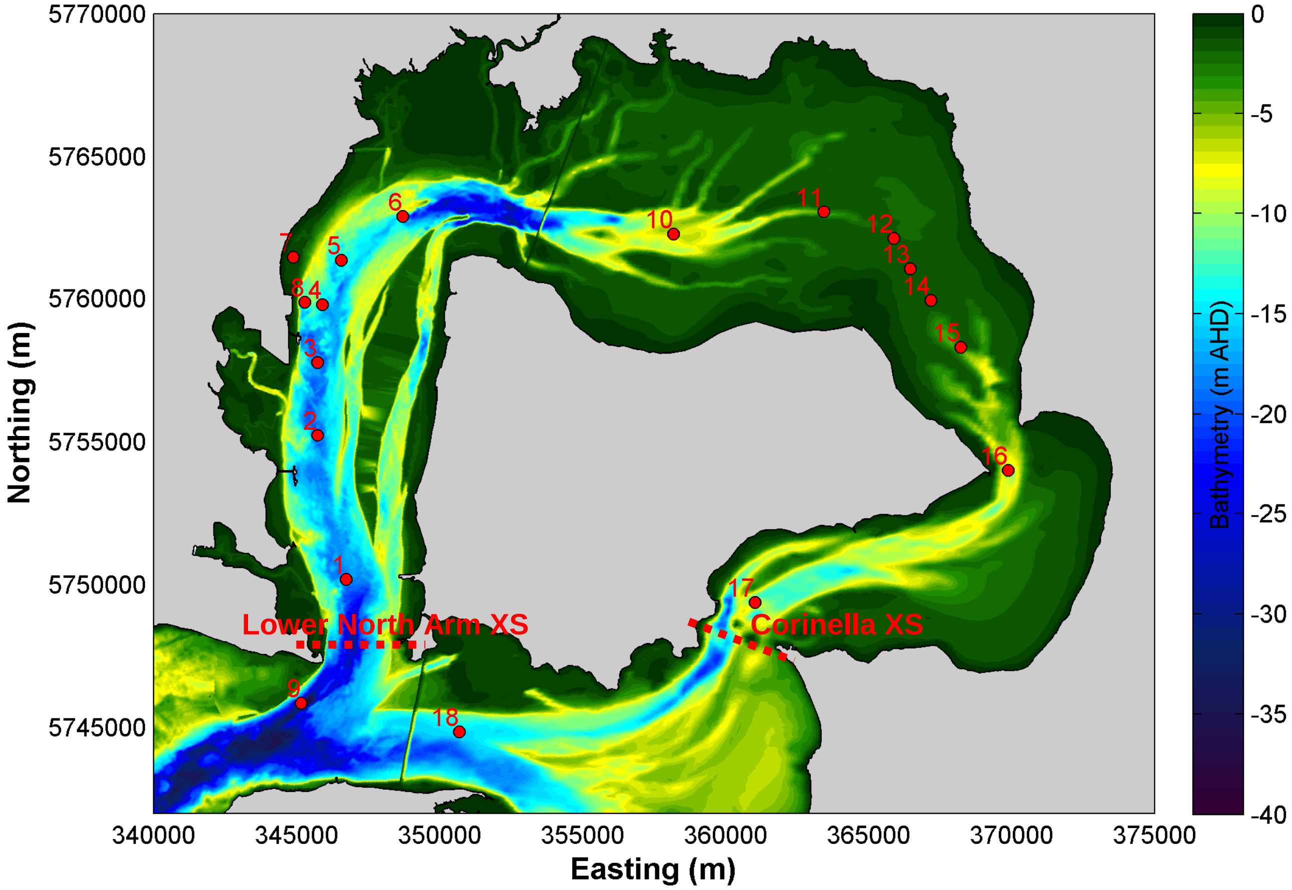

Figure 9: Location of Output Points and Cross-Sections

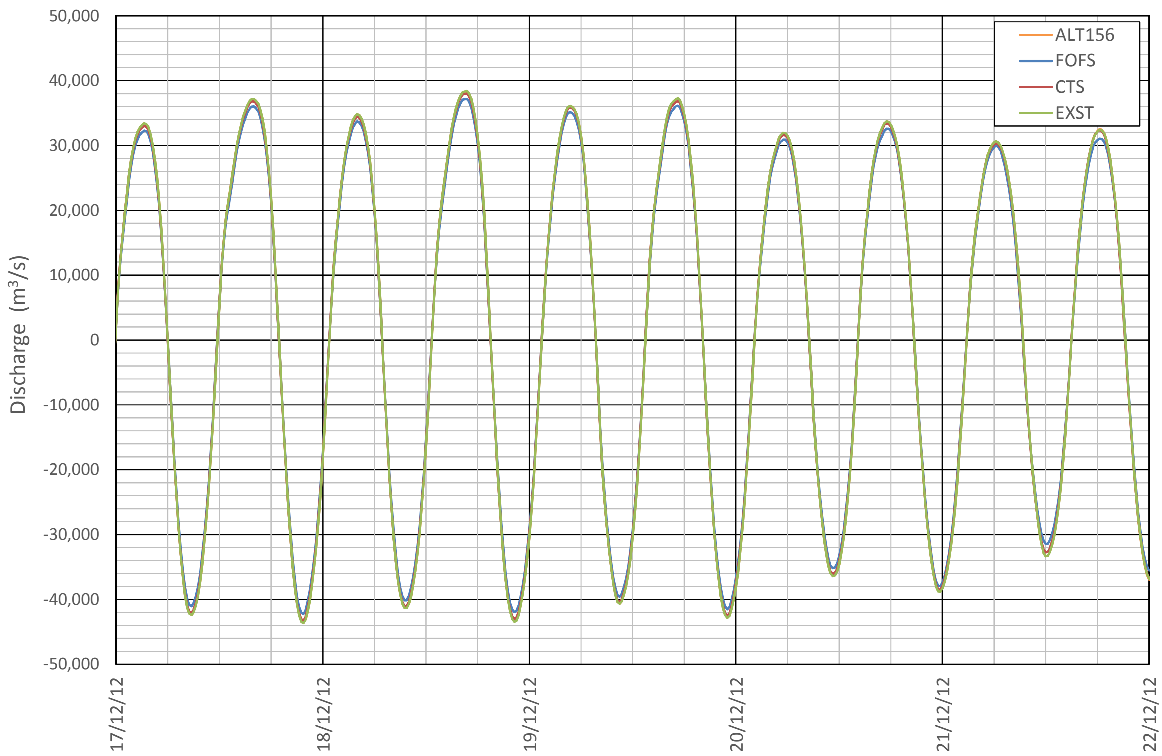

Figure 10: Tidal Discharge into the Lower North Arm

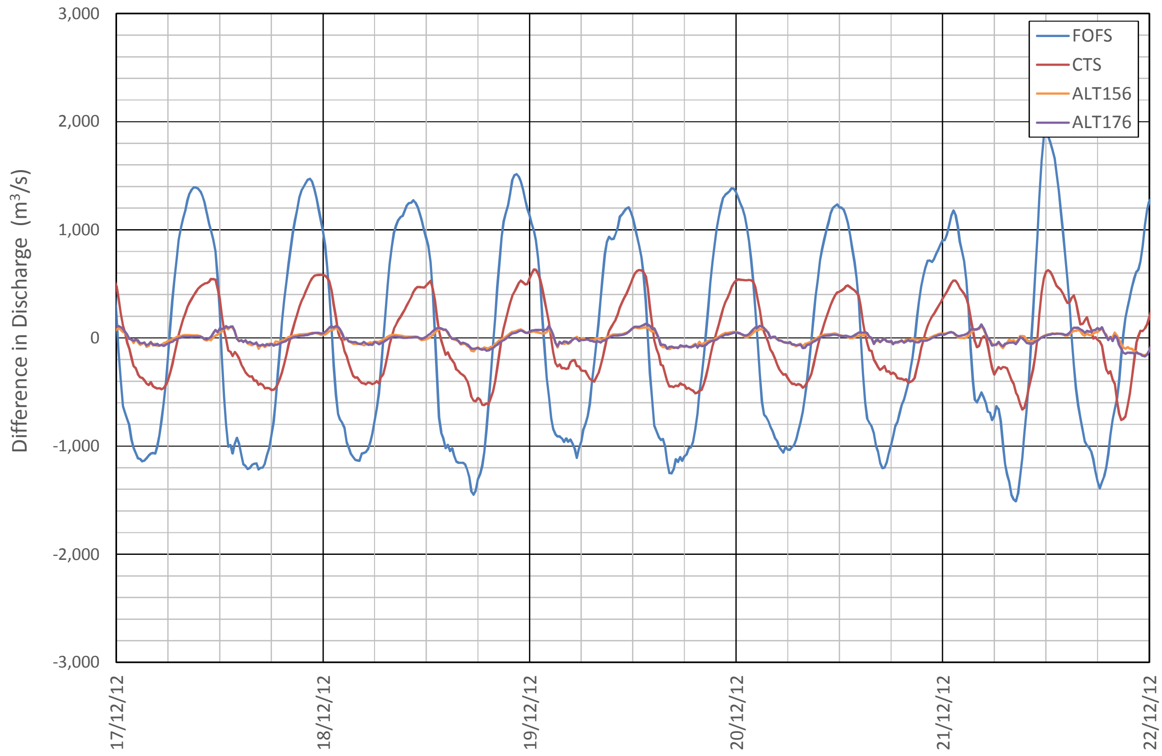

Figure 11: Differences in Tidal Discharge Compared to EXST Scenario into the Lower North Arm

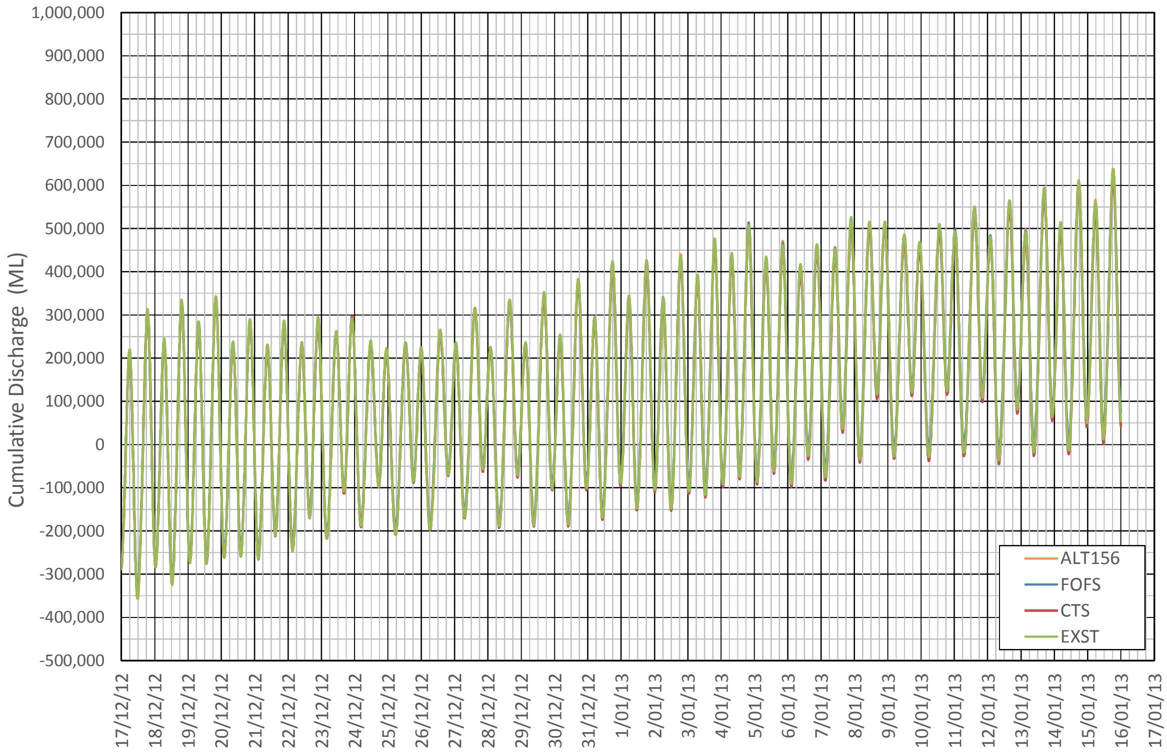

Figure 12: Cumulative Tidal Discharge into the Lower North Arm

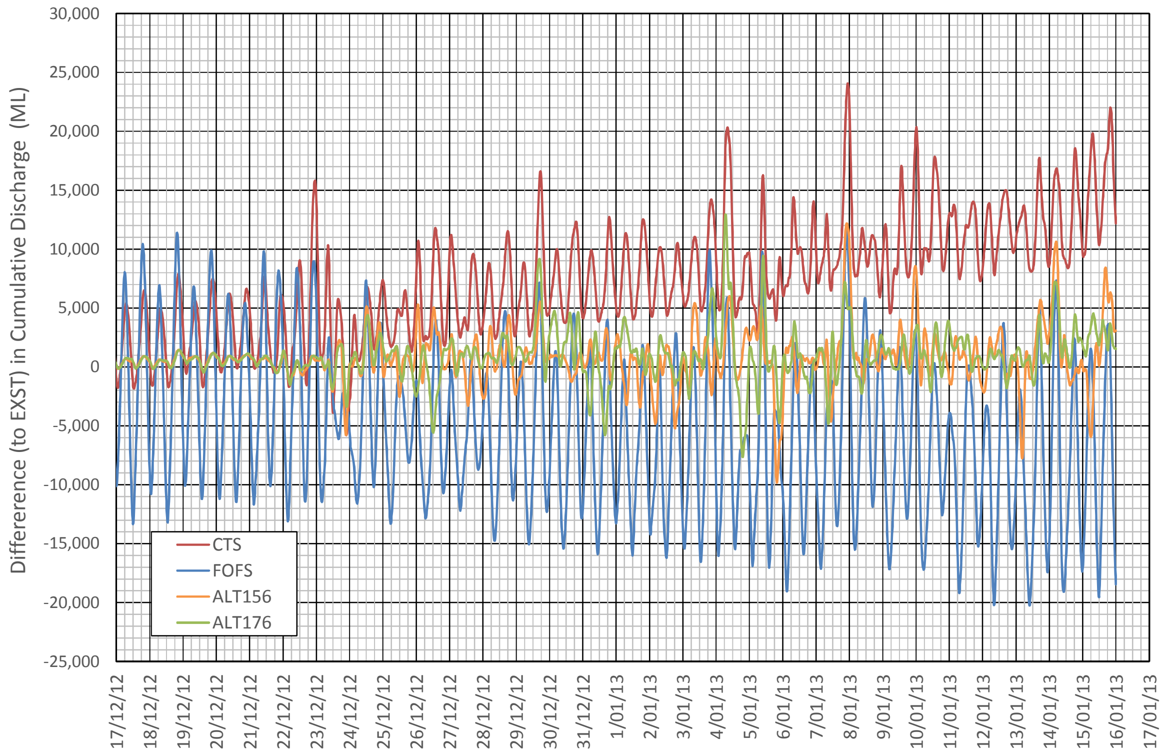

Figure 13: Difference in Cumulative Tidal Discharge (Compared to EXST Scenario) into the Lower North Arm

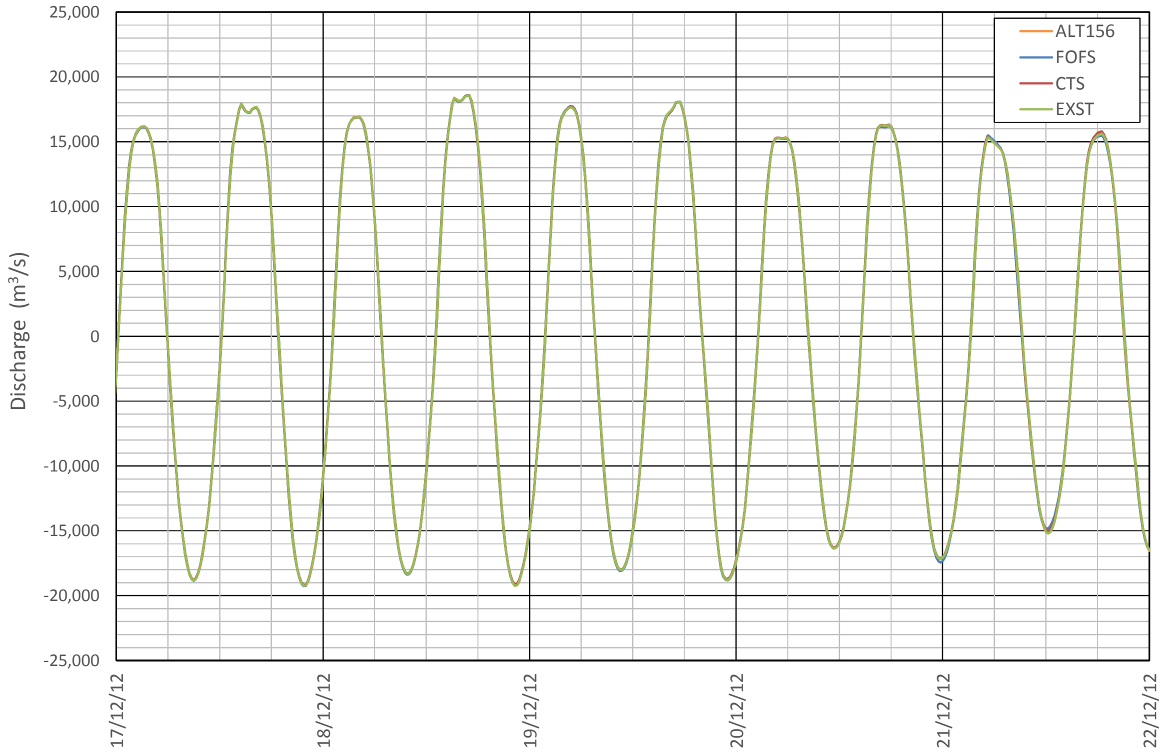

Figure 14: Tidal Discharge into the Corinella Segment

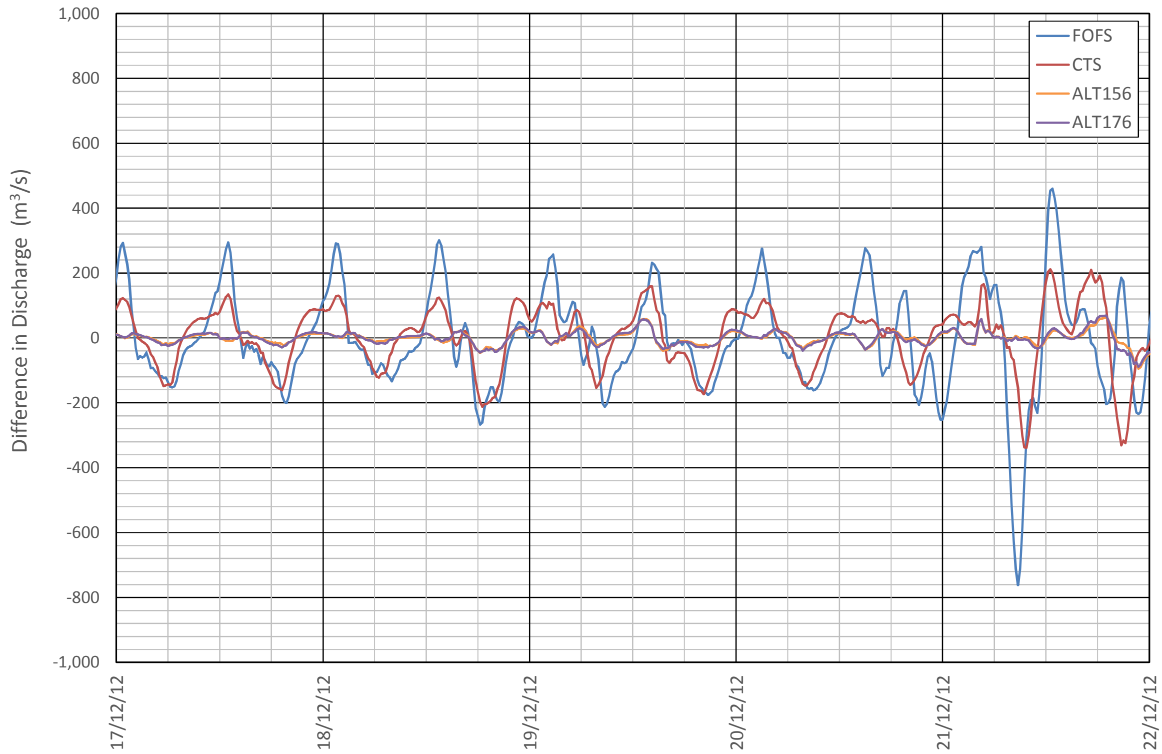

Figure 15: Differences in Tidal Discharge Compared to Existing Scenario into the Corinella Segment

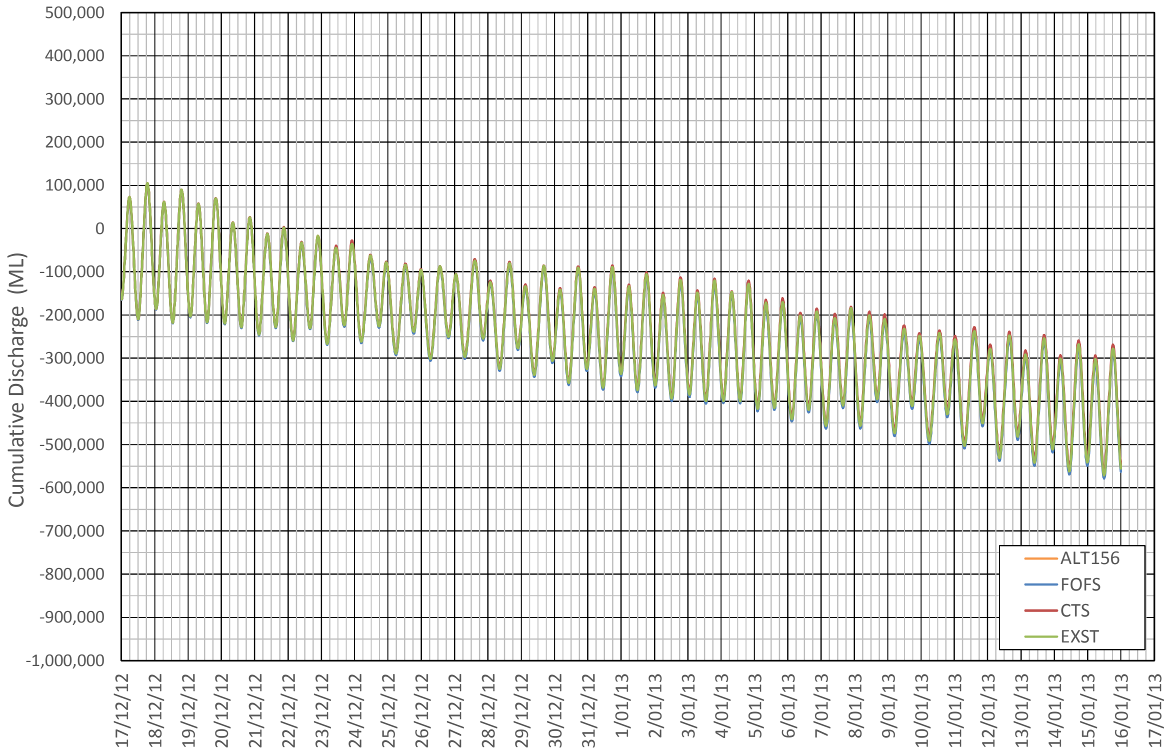

Figure 16: Cumulative Tidal Discharge into the Corinella Segment

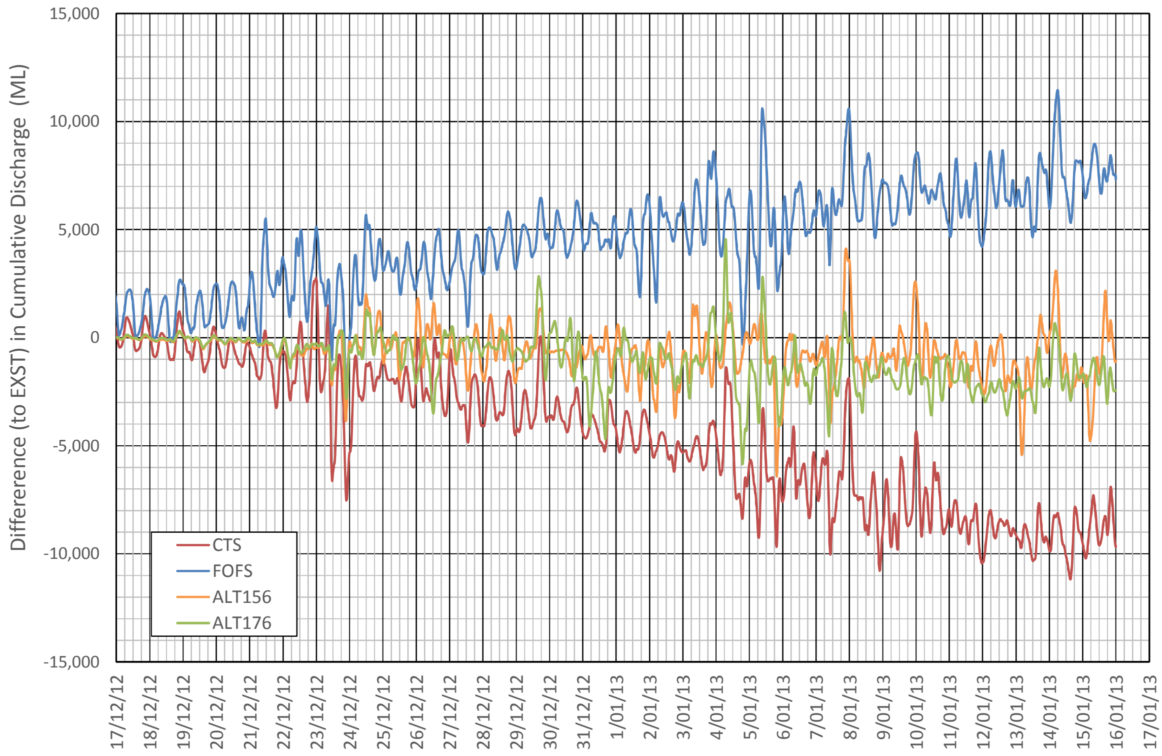

Figure 17: Difference in Cumulative Tidal Discharge (Compared to EXST Scenario) into the Corinella Segment

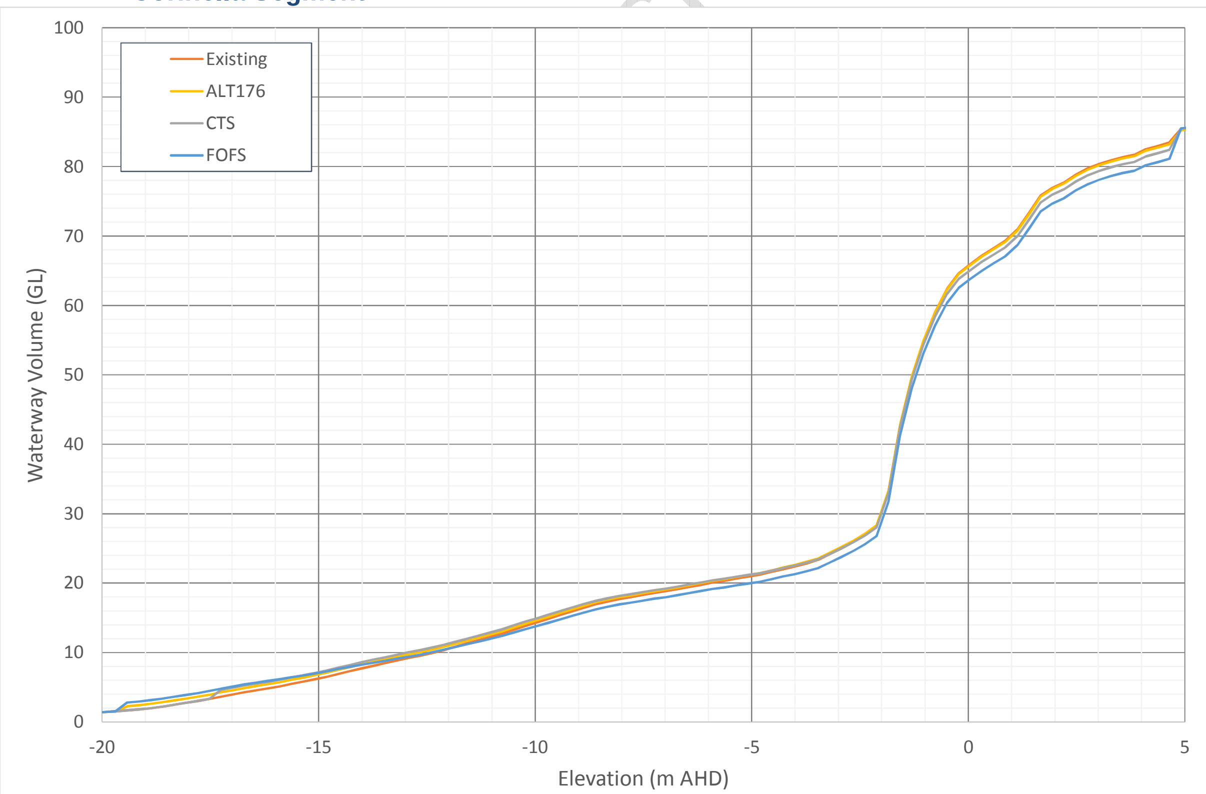

Figure 18: Scenario Stage - Volume Relationship for Lower North Arm to Tidal Divide Compartment

2.2.4 Temporal Assessment of Design Scenario Changes to Water Levels and Current Speeds

Temporal changes to water levels and current speeds caused by the four design scenarios have been assessed as described below.

A time-series of water levels and current speed at each of the 18 locations presented in Figure 9 has been extracted. Graphs for the existing case and four scenarios at three key locations are presented in Appendix B. The time-series graphs present both the existing and scenario modelled water levels and currents for five days (00:00 17th December to 00:00 22nd December, 2012) and also show the difference compared to the existing scenario.

The three selected sites (as presented in Appendix B) include:

- Site 5 – Near the Proposed Port Site;
- Site 1 – Entrance to Lower North Arm; and
- Site 13 – Approximate Location of the Tidal Divide.

Comments on each of the 12 graphs (Figure B-1 to Figure B-12) are provided in Table B-1.

Key points include:

- The temporal analysis indicates that the FOFS scenario will have the greatest impact on water levels and currents in the vicinity of the proposed port (i.e. Site 5).
- At Site 13, the approximate location of the tidal divide, the scenarios cause minimal (< 1 mm/s) change in current speed, however, both the FOFS and CTS scenario result in a +/- 2-3 cm water level change.
- Because of spatial variations in ebb and flood currents, point current speed data cannot be used to infer total discharge.

2.2.5 Spatial Assessment of Scenario Changes to Water Levels and Current Speeds and Directions

Spatial changes to water levels and current speeds and directions caused by the scenarios have been assessed as described below.

The impact of the design scenarios on water levels (WL) and currents within Western Port have been assessed by calculating the differences in water levels, current speed and current direction (vectors) between the existing condition and each of the four port development scenarios. WL and current speed differences have been calculated for a Peak Ebb (PE), Low Water (LW), Peak Flood (PF), and High Water (HW) conditions for the spring tidal cycle occurring on 17th December 2012. The time of each tide stage is:

- Peak Flood (17 Dec 16:00);
- High Water (17 Dec 18:30);
- Peak Ebb (17 Dec 22:30);
- Low Water (18 Dec 00:30).

<u>Spatial Change in Current Speed</u>

The spatial impact (difference) of the design scenarios on current speed compared to the existing scenario is presented in Figure C-1 to Figure C-16 and summarised in Table C-1.

Spatial Change in Water Levels

The spatial impact (difference) of each design scenario on water levels (WL) compared to the existing scenario is presented in Figure C-17 to Figure C-32 and summarised in Table C-2. It is important to note that some differences in water level are due to changes in the timing of the tide.

Spatial Change in Current Direction (Vector)

The spatial impact (difference) of each design scenario on current direction compared to the existing scenario is presented in Figure C-33 to Figure C-48 and summarised in Table C-3. Blue vector arrows represent the currents for the existing scenario, while red vector arrows represent the scenarios.

2.2.6 Assessment of Potential Change to Location of Tidal Divide

The tidal divide in Western Port is the location in the north east of the bay separating the area where the rising tide brings water from the west, via the North Arm, from that where the water comes from the east, via the East Arm. The tidal divide is characterised as a location of relatively low velocities, as rising, inflowing water meets rising, inflowing water from the other direction and accordingly the hydrodynamics result in primarily water level fluctuations only (see Figure B-9 to Figure B-12). A change in the position of the tidal divide may have consequences for sediment transport in this portion of the bay. The text below describes how the location of the tidal divide has been calculated and defined, and how the four port scenarios may cause a change to the location of this low velocity environment.

In this investigation the one month simulation of hydrodynamics has been used to calculate a map of the current speed exceeded 90% of the time (see Section 2.2.2). Figure 8 presents the modelled 90th percentile current speed exceedance value for the existing conditions, while the equivalent plots for each of the port scenarios are presented in Figure A-5 to Figure A-8 (in Appendix A). The location of the area of low velocity, characteristic of the tidal divide, is evident in each figure.

To quantify the location of the tidal divide, a digital surface map (DSM) of the 90th percentile exceedance current speed was produced and the location of the 0.2 m/s contour defined (as presented in Figure 19) to provide an indication of the location of the tidal divide in Western Port. A review of vector and contour maps over a number of tidal cycles, indicates that this approach provides a suitable indication of the tidal divide. To further define hydrodynamic behaviour and quantify movement in the tidal divide a long-section of lateral variation (along the long-section defined as an orange line in Figure 19) of the 90th percentile current speed is presented in Figure 20.

Investigation of the Figure 19 and Figure 20 indicates that there is an approximate 1 km reach where for 90% of the time (over a one month period) tidal currents are below 0.2 m/s. In the middle of this area, velocities reach a local minima where they are a maximum of 0.1 m/s for 90% of the time. In this area, low current speeds will result in an area where sediment deposition is favoured and erosion (i.e. re-suspension) is less likely. The figures show that for the FOFS and alternate (ALT156 & ALT176) scenarios there is minimal change in position (compared to the existing scenario) of this low velocity area (i.e. the tidal divide). For the CTS scenario there is a minor change in the location of the tidal divide, with an approximate 50 m eastward (i.e. clockwise) movement in location of the low velocity environment.

Figure 19: Location of Tidal Divide for Existing and Three Port Scenarios
Note: Tidal Divide defined using 30 day modelled 90%ile current speed 0.2 m/s contour
KEY: Dark Blue=EXST, Red = FOFA, Green = CTS, Light Blue ALT156, Orange = Long-Section

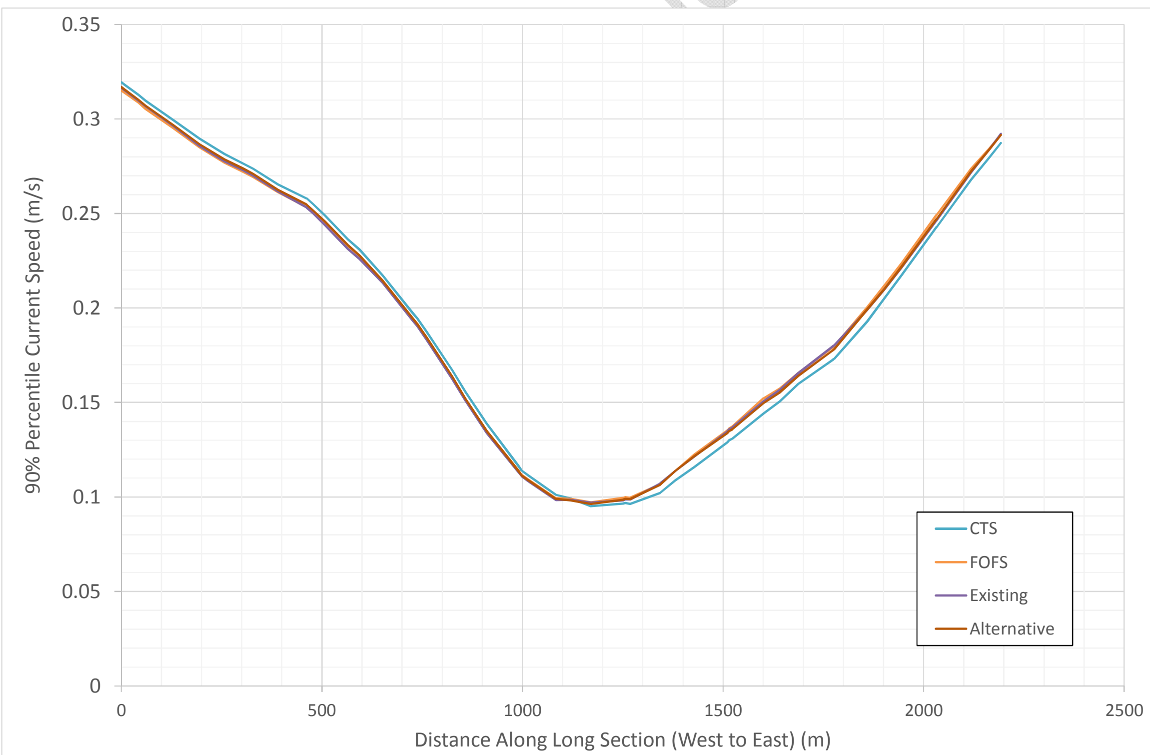

Figure 20: Long Section Presenting Variation of 90%ile Current Speed at The Tidal Divide for Existing and Three Port Scenarios

2.3 Summary, Discussion and Limitations

The existing DELFT-3D hydrodynamic model developed during the Preliminary Business Case study has been used to undertake an initial assessment of the existing condition and four preliminary design scenarios comprising:

- Close to shore (CTS) alignment;
- Far out from shore (FOFS) alignment;
- Alternate (ALT156) alignment dredged to -15.6 m CD.
- Alternate (ALT176) alignment dredged to -17.6 m CD

The model was used to simulate a one-month period using boundary conditions described defined by Cardno.

Model output presented in this Section has included:

- maps of 90th percentile exceedance water level and current speed;
- tidal discharge and tidal volume analysis;
- time-series of water levels and currents at three key location in Western Port;
- spatial impact (scenario compared to existing case) for water levels, current speed and current directions for a peak ebb, low water, peak flood, and high water condition; and
- an assessment of location and change to the tidal divide.

Key findings of the assessment include:

- During a flood tide, for the FOFS scenario, the peak discharge into the Lower North Arm is 1,000 m/s (~3-4%) lower than the existing condition, due to the quay reducing the available channel width and cross-sectional area.
- For the CTS scenario there is also a reduced flood tide inflow in the order of 400 m^3/s (~1-2%), however, there is also a difference in timing (phase) of the difference in discharge. Adjusting for the phase difference would reduce the magnitude of the difference in discharge.
- For the two alternative scenarios (ALT156 & ALT 176) there is minimal difference in discharge into the Lower North Arm.
- An analysis of cumulative discharge (tidal volume) into the Lower North Arm, indicates that the spring tidal prism is the order of 500,00-600,000 ML, while the neap tidal prism is 300,000-400,000 ML at this location. The presence of a residual net circulation, in the order of 300,000 ML/month, clockwise around French Island is also evident.
- The analysis shows that the CTS scenario enhances the clockwise net circulation around French Island by ~15,000 ML/month (an increase of ~5%), while the FOFS scenario reduces the net clockwise circulation by ~7,500 ML/month (a reduction of ~2-3%). The alternative scenarios (ALT156 & ALT176) have minimal impact on net circulation.
- The temporal and spatial analysis indicates that the FOFS scenario will have the greatest impact on water levels and currents in the vicinity of the proposed port.
- At the approximate location of the tidal divide, the scenarios cause minimal (< 1 mm/s) change in current speed, however, both the FOFS and CTS scenario result in a +/- 2-3 cm water level change.
- The 90th percentile exceedance current speeds were calculated from the results of the one month hydrodynamic simulations and used to quantify the location of the tidal divide. Mapping of the 90th percentile, 0.2 m/s current speed contour, indicates that with the exception of the CTS scenario, there was an insignificant change in the location of the tidal divide for the four scenarios assessed. A long-section of the 90th percentile current speed, running perpendicular

to the tidal divide, indicated that for the CTS scenario the tidal divide would shift approximately 50m to the east.

The impacts of a number of design scenarios have been initially assessed using the DELFT3D model produced during the Preliminary Business Case study by Cardno. A model verification exercise undertaken by Cardno showed that the model could reliably reproduce observed water levels and currents in the Lower North Arm. Based on this verification exercise, the model should be able to reliably predict the hydrodynamic impacts of a range of port design scenarios. It is important to note that a review of the tidal boundary condition (as presented in Section 3.1.3) indicates that the adopted tidal lag across the offshore water level boundary will produce unrealistic lateral currents to the south of Phillip Island. However, this should not significantly affect the assessment of design scenarios within Western Port due to the comparative nature of the analysis and means that the use of the existing model is suitable to meet the objectives. Ongoing data collection and modelling exercises are being used to progressively improve confidence in model studies used by the Authority to assess the potential impact of the proposed port development.

3 12 MONTHS OF METOCEAN CONDITIONS FOR CHANNEL DESIGN

3.1 Objectives and Methodology

Section 3 of this report is provided to satisfy the objectives of Task 2 of the early hydrodynamic modelling scope (WP-HY-13) which comprises providing simulated time series data concerning wave, currents and water levels to inform channel design.

12 months of metocean parameters including: water velocities, water levels, water depths, wind and wave conditions were required to inform channel design including Under Keel Clearance (UKC) analysis. A review of available data and numerical modelling has been undertaken to provide this information.

3.1.1 Description of Hydrodynamic Model

To appropriately calculate the influence of tidal currents on swell propagation a combined wave and hydrodynamic model was required. The Cardno coarse (150m) DELFT3D model grid was found to be suitable for this purpose, as it was able to resolve key processes and could be run in a suitable time frame. The wave and hydrodynamic models were coupled (i.e. run together) to represent the influence of tidal currents on wave conditions. The model was configured to represent the existing (i.e. 2013) bathymetric conditions in Western Port.

The model bathymetry and extent is presented in Figure 21.

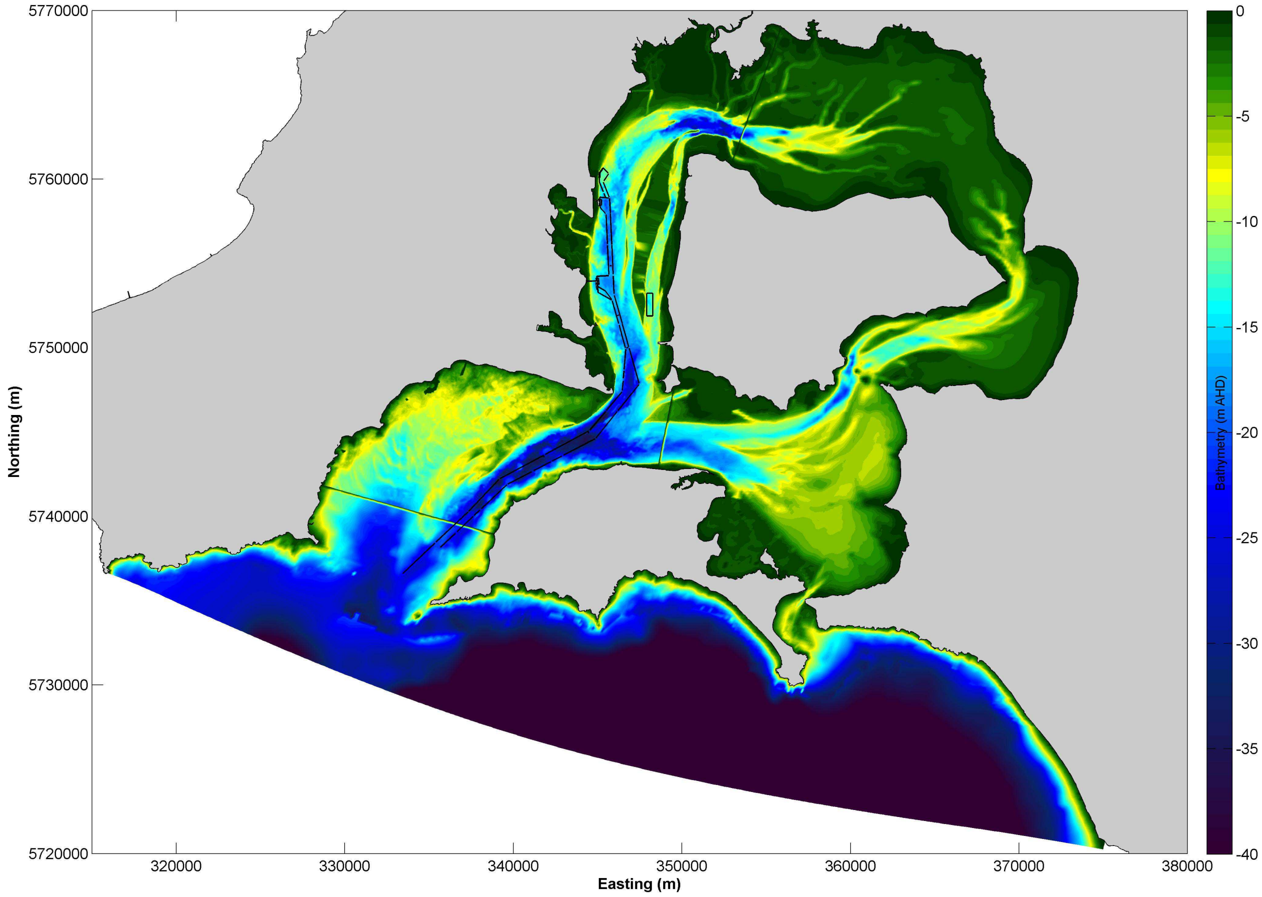

Figure 21. Model Bathymetry and Extent

3.1.2 Assessment of Wave, Tide and Wind Conditions

Ten years (from 2003 to 2012) of wave, tide and wind data was assessed to determine annual variability and determine an appropriate (representative) year of conditions to model the wave and hydrodynamic parameters required to inform channel design and UKC investigations.

Wave Conditions

Wave data has been collected to the south of Point Nepean by Port of Melbourne Corporation (PoMC) since 2003. Annual wave exceedance statistics were calculated to assist in determination of a representative year of conditions as presented in Figure 22 and summarised in Table 1. Differences in annual statistics compared to the 10 year statistics are presented in Table 2 and show that with the exception of the maximum wave height and the 99%ile exceedance height, all annual statistics are within 0.12m of the 10 year value. This indicates that there is minimal difference in terms of inter-annual wave variability and that any year (with perhaps the exception of 2007 or 2012) could be considered a “typical” year in terms of wave conditions (significant wave height). Wave data for 2006 was selected based on it being the most complete data set available.

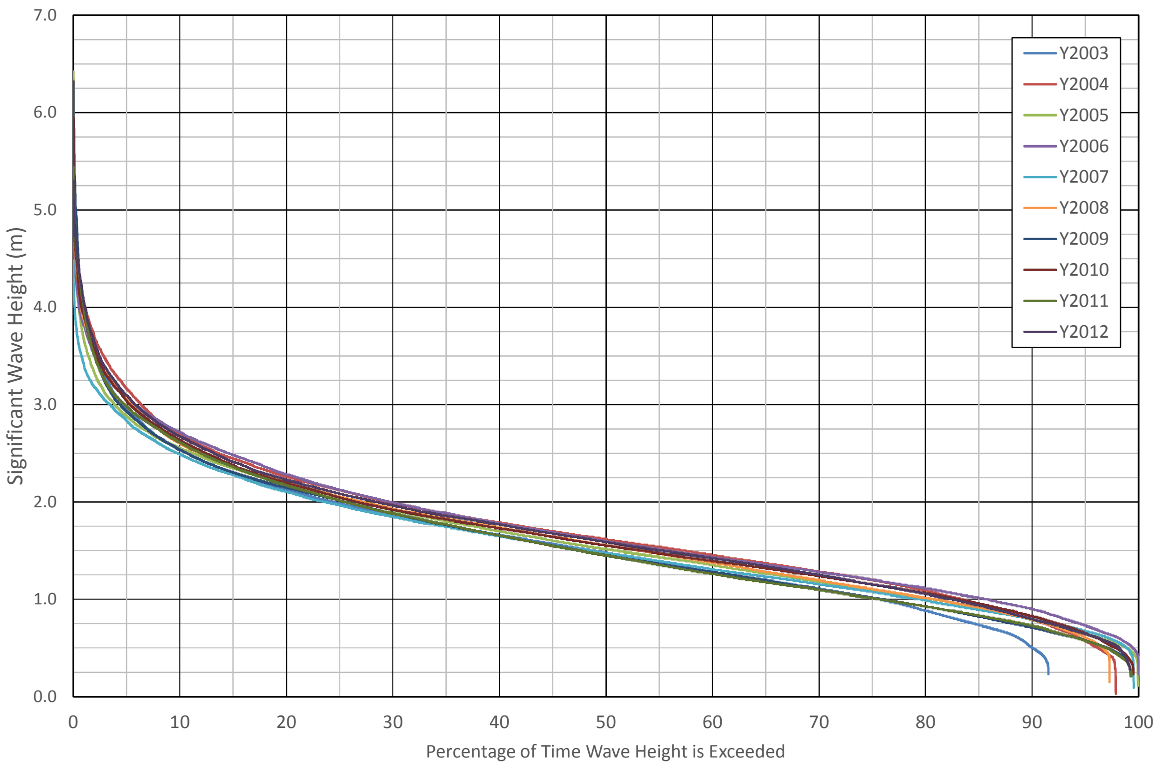

Figure 22: Point Nepean Annual Wave Height Exceedance (2003 to 2012)

Table 1: Annual Wave Height Statistics (2003 to 2012)

Hsig (m)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	10 Years
Max	6.35	5.86	6.42	5.16	4.48	6.33	6.32	5.95	5.44	5.30	6.42
Average	1.65	1.74	1.62	1.72	1.58	1.68	1.58	1.67	1.59	1.70	1.65
25%ile	1.13	1.23	1.09	1.20	1.08	1.14	1.03	1.16	1.02	1.17	1.12
50%ile	1.56	1.63	1.52	1.60	1.47	1.58	1.46	1.56	1.46	1.60	1.55
75%ile	2.04	2.14	2.04	2.12	1.97	2.07	2.02	2.05	2.02	2.09	2.06
90%ile	2.59	2.70	2.55	2.72	2.49	2.62	2.54	2.64	2.62	2.68	2.61
99%ile	3.95	4.04	3.67	3.81	3.41	3.88	3.96	3.92	3.98	4.04	3.87
Days data missing	30.92	7.77	0.27	0.00	1.67	9.92	2.77	1.75	2.46	2.98	60.50

Table 2: Differences in Annual Wave Height Statistics relative to the 10 year

Hsig (m)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Max	-0.07	-0.56	0.00	-1.26	-1.94	-0.09	-0.10	-0.47	-0.98	-1.12
Average	0.00	0.08	-0.03	0.07	-0.08	0.03	-0.07	0.02	-0.06	0.04
25%ile	0.01	0.11	-0.03	0.08	-0.04	0.02	-0.09	0.04	-0.10	0.05
50%ile	0.01	0.08	-0.03	0.05	-0.08	0.03	-0.09	0.01	-0.09	0.05
75%ile	-0.02	0.07	-0.02	0.06	-0.09	0.01	-0.04	-0.01	-0.04	0.03
90%ile	-0.02	0.09	-0.06	0.11	-0.12	0.01	-0.07	0.03	0.01	0.07
99%ile	0.08	0.17	-0.20	-0.06	-0.46	0.01	0.09	0.05	0.11	0.17

Tidal (Water Level) Conditions

Tidal water level data is collected at Stony Point by the National Tidal Centre (NTC) as part of the Australian Baseline Sea Level Monitoring Project (ABSLMP). Annual water level exceedance statistics for eleven years, 2003 – 2013 (as presented in Table 3) were calculated to assist in quantifying the variability in tidal conditions at Stony Point.

Differences in annual statistics compared to the 11 year statistic are presented in Table 4 and show that with the exception of the minimum water level, all annual statistics are within 0.1 m of the 11 year value. This indicates that there is minimal difference in terms of inter-annual water level variability. Water level data for 2006 was used in the model to match the adopted 2006 wave conditions as metocean conditions drive both wave conditions and water level anomalies and as such it is advisable to use a concurrent period of water level, wind and wave boundary conditions in the model simulation.

Table 3: Annual Water Level Statistics (2003 to 2013) for Stony Point

WL(mAHD)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	11 Years
max	1.64	1.62	1.58	1.62	1.64	1.60	1.64	1.63	1.62	1.62	1.62	1.64
99%ile	1.26	1.27	1.30	1.22	1.34	1.30	1.35	1.30	1.36	1.32	1.33	1.31
90%ile	0.84	0.86	0.88	0.81	0.87	0.88	0.91	0.89	0.92	0.92	0.95	0.89
50%ile	-0.05	-0.02	-0.01	-0.07	-0.02	-0.01	0.01	-0.03	0.00	0.02	0.05	-0.01
10%ile	-1.06	-1.02	-1.00	-1.06	-0.99	-0.98	-0.98	-1.00	-0.98	-0.97	-0.94	-1.00
1%ile	-1.54	-1.49	-1.49	-1.52	-1.49	-1.49	-1.46	-1.46	-1.42	-1.40	-1.39	-1.48
min	-2.06	-1.90	-1.83	-1.99	-1.94	-1.84	-1.87	-1.83	-1.79	-1.77	-1.69	-2.06
average	-0.08	-0.05	-0.03	-0.09	-0.04	-0.02	-0.01	-0.03	-0.01	0.00	0.03	-0.03
% missing data	3.9	2.8	0.3	0.0	2.0	0.0	0.0	0.0	0.9	0.0	0.0	0.89

Table 4: Differences in Annual Water Level Statistics relative to the 11 year average for Stony Point

WL(m)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
max	0.00	-0.02	-0.06	-0.02	0.00	-0.04	0.00	-0.01	-0.02	-0.02	-0.02
99%ile	-0.05	-0.04	-0.01	-0.09	0.04	-0.01	0.04	-0.01	0.05	0.01	0.02
90%ile	-0.05	-0.02	-0.01	-0.07	-0.01	0.00	0.02	0.00	0.03	0.04	0.07
50%ile	-0.04	-0.01	0.00	-0.06	-0.01	0.00	0.02	-0.02	0.01	0.03	0.06
10%ile	-0.06	-0.02	0.00	-0.06	0.00	0.02	0.02	-0.01	0.02	0.03	0.06
1%ile	-0.06	-0.01	-0.01	-0.04	-0.01	-0.01	0.02	0.01	0.06	0.07	0.08
min	0.00	0.16	0.23	0.07	0.13	0.22	0.19	0.23	0.27	0.29	0.37
average	-0.05	-0.02	0.00	-0.06	-0.01	0.01	0.02	-0.01	0.02	0.03	0.06

Wind Conditions

Wind data is collected at Stony Point by the Bureau of Meteorology (BoM) as part of the Australian Baseline Sea Level Monitoring Project (ABSLMP). Annual wind speed exceedance statistics for eleven years, 2003 – 2013 (as presented in Table 5) were calculated to assist in quantifying the variability in wind conditions at Western Port. It is important to note that data was missing for over 50% of the time in 2010 and 2011, and significant (i.e. > 15%) data was missing in 2003, 2004 and 2005. While 11.7% of data was originally missing from the 2006 Stony Point this data set was in-filled with data from the nearby Cerberus wind gauge.

Differences in annual statistics compared to the 11 year statistic are presented in Table 6 and show that with the exception of the maximum wind speed, all annual statistics are within 1.4 m/s of the 11 year value. This indicates that there is minimal difference in terms of inter-annual wind speed variability. Wind data for 2006 was used in the model to match the adopted 2006 wave and water level conditions.

Table 5: Annual Wind Speed Statistics (2003 to 2013) for Stony Point

Speed (m/s)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	11 Years
max	15.80	14.10	17.00	15.60	15.60	16.80	21.30	12.90	17.50	18.60	18.60	21.30
99%ile	11.72	11.40	10.90	10.40	11.00	10.00	11.50	10.76	10.80	12.40	12.14	11.40
90%ile	8.20	7.40	7.30	7.20	7.70	7.20	7.70	7.10	7.70	7.80	8.40	7.70
50%ile	4.90	4.30	4.00	3.60	4.10	4.00	4.10	4.90	4.20	4.10	4.40	4.17
10%ile	1.70	1.50	1.40	0.56	1.50	1.50	1.50	1.80	1.50	1.40	1.50	1.40
1%ile	0.10	0.10	0.10	0.00	0.60	0.50	0.50	0.80	0.40	0.30	0.40	0.10
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
average	4.94	4.41	4.26	3.79	4.40	4.18	4.40	4.75	4.39	4.46	4.71	4.39
% missing data	22.5	25.3	17.9	0.0	1.9	0.0	0.0	91.2	66.8	2.9	0.0	20.8

Table 6: Differences in Annual Wind Speed Statistics relative to the 11 yr average for Stony Point

Diff (m/s)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
max	-5.5	-7.2	-4.3	-5.7	-5.7	-4.5	0.0	-8.4	-3.8	-2.7	-2.7
99%ile	0.3	0.0	-0.5	-1.0	-0.4	-1.4	0.1	-0.6	-0.6	1.0	0.7
90%ile	0.5	-0.3	-0.4	-0.5	0.0	-0.5	0.0	-0.6	0.0	0.1	0.7
50%ile	0.7	0.1	-0.2	-0.6	-0.1	-0.2	-0.1	0.7	0.0	-0.1	0.2
10%ile	0.3	0.1	0.0	-0.8	0.1	0.1	0.1	0.4	0.1	0.0	0.1
1%ile	0.0	0.0	0.0	-0.1	0.5	0.4	0.4	0.7	0.3	0.2	0.3
min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
average	0.5	0.0	-0.1	-0.6	0.0	-0.2	0.0	0.4	0.0	0.1	0.3

3.1.3 Development of Model Boundary Conditions

Review of Tidal Boundary Conditions used in previous modelling by Cardno

A suitable water level boundary condition (BC) was required for the 12 month simulation. As there were no suitable offshore water levels measured offshore of Western Port, Stony Point tidal data was adopted to “drive” the offshore tidal boundary. A review of the model boundary definition by Cardno was undertaken to determine if the methodology previously used would be suitable for this modelling exercise.

The Cardno water level boundary used in the Preliminary Business Case is presented in Figure 23 and comprises measured tides for Stony Point but applied 30 minutes earlier at the western offshore boundary (approximately Cape Schanck). At the eastern end of the offshore boundary (approximately Cape Patterson) a water level based on the Lorne residual with an (undisclosed) time lag was added to the predicted tide using constituents from Waratah Bay (taken from the Australia National Tide Tables (2013)). Waratah Bay is located approximately 65 km to the east of the eastern edge of the model boundary, which means that the tidal timing will not be correct. It should be noted that the model applies a linearly interpolated water level along the model boundary between the eastern and western time series.

An analysis of the BC data indicates that the eastern WL data is applied 2 hours earlier than the western BC. This produces a WL gradient along the boundary that is greater than 0.69 m for 50% of the time and is greater than 1.0 m for 15% of the time. This high water level gradient along the boundary drives a strong lateral (i.e. east to west and west to east) current. The magnitude of these

currents are far greater than initial measurements of current speed in this area (i.e. at the Cape Woolamai ADCP).

The 2 hour tide lag along the boundary also reduces the average instantaneous water level at the boundary by approximately 20%, which results in the Western Port only experiencing approximately 0.8 times the tidal range of the applied boundary condition data. However, as discussed below, there is some amplification of tides travelling into Western Port, so water levels measured within the estuary should be scaled downwards if they were to be applied at an offshore water level boundary.

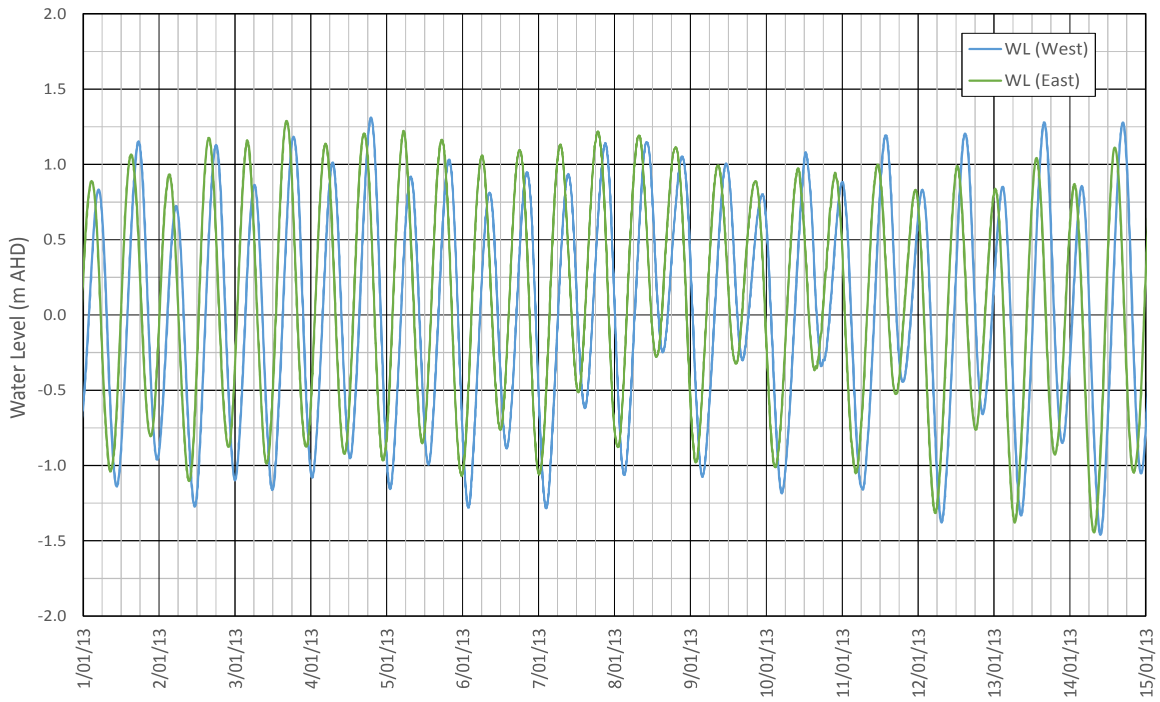

Figure 23: Tidal Boundary Conditions applied in the Previous Model by Cardno

Generation of Appropriate Tidal Boundary Conditions

As there were no suitable measured data sets of water levels offshore of Western Port, Stony Point data tidal data was adopted to “drive” the offshore tidal boundary. However, given the location of the Stony Point gauge within Western Port and the alongshore length of the offshore boundary and distance offshore, a suitable lag (for both the western and eastern boundary) and scale factor was required.

Tidal data given in Shapiro (1975) indicates that there was a tidal amplification factor of 1.147 (inverse = 0.88) between Flinders and Stony Point. The study also indicated that between these two locations there was a tidal lag of 53 minutes at low water and 56 minutes at high water. Given the tidal boundary condition is further offshore than Flinders, a -60 minute lag (i.e. the tide was applied 60 minutes earlier) at the western model boundary was adopted.

An initial assessment of water levels collected by a recent ADCP deployment offshore of Phillip Island (Cape Woolamai) as part of the data collection work for the Hydrodynamics Work Stream indicates that the ratio of Stony Point to offshore water levels is typically 0.86 for neap tides and 0.94 for spring tides. Based on this information a scale factor of 0.9 was applied to the observed Stony Point water level data to generate an appropriate offshore tidal boundary condition, that would account for tidal amplification into Western Port.

In the absence of observed water levels at the eastern end of the tidal boundary a tidal celerity (wave speed) calculation was used to estimate an appropriate tidal lag along the offshore boundary. For a boundary length of 62 km and a depth of 70 m the shallow water wave assumption indicates a tidal lag of 39 minutes is appropriate. However, as this assumes the tide propagates purely along the boundary it may over-estimate the lag if the tidal front approaches the shore at a more perpendicular angle as indicated in Figure 24. Based on the celerity calculation and information presented in Figure 24 a tidal lag of 30 minutes was adopted along the offshore boundary (i.e. the eastern WL is applied 30 minutes after the western WL). The final adopted tidal boundary included:

- Western BC = Observed Stony Point WL x 0.9 applied 60 minutes earlier
- Eastern BC = Observed Stony Point WL x 0.9 applied 30 minutes earlier

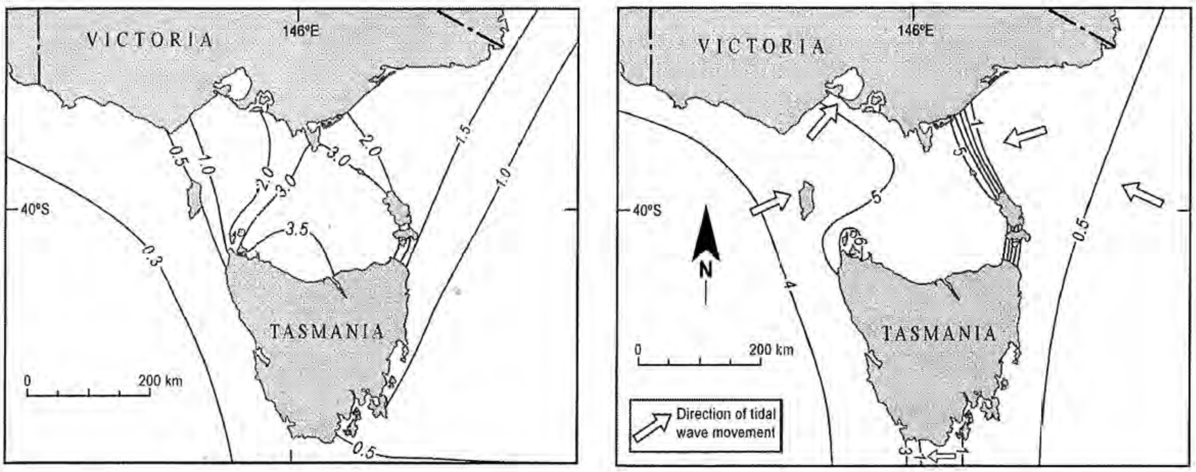

Figure 24: The behaviour of Bass Strait tides. (Source: Short, 2006)

Showing co-range (left) and co-tidal (right) lines, where: co-range lines indicates the variation in spring tide range in metres; and co-tidal lines indicate the relative time of arrival. Note how: the tidal range is significantly amplified in Bass Strait with the gradient greatest in the far souththwest; and the tide moves clockwise around Tasmania to enter Bass Straight in the west 5 hours later than in the east

It is important to note that there is a degree of uncertainty regarding this boundary condition which will be addressed in future data and model investigations. It is intended to reduce this uncertainty in future modelling by ensuring the hydrodynamic model extent is sufficiently far offshore that tidal conditions from global tidal models can reliably be adopted. The adopted BC was checked by comparing the model's ability to reproduce the observed water levels at Stony Point as presented in Section 3.2.1.

Discussion of Swell Wave Boundary Conditions

Swell wave modelling undertaking during the Authority's Preliminary Business Case Phase by Cardno applied a +18% scale factor to measured wave conditions at Point Nepean to produce an offshore wave boundary condition for Western Port. An initial review comparing 34 days of recently measured wave data at Cape Woolamai to Point Nepean data (Draft TechNote_009, dated 21/11/2014, see Appendix D) indicated that a fixed scale factor did not appropriately represent all wave conditions. However, for longer period waves (T>14s) the 18% scale factor is likely to be conservative and so was adopted for this investigation as these longer period waves are more important for the UKC investigations.

Proposed regional wave modelling will assist in the development of more accurate offshore wave conditions in subsequent stages of the project.

3.2 Model Results

3.2.1 Sensitivity Testing and Checking of Tidal Boundary Conditions

A number of different tidal lags and scale factors were applied to observed Stony Point water level data and modelled to determine the best available boundary conditions.

Using the adopted model boundary conditions (as presented in Section 3.1.3) the model was able to reasonably match the measured water levels at Stony Point as presented in Figure 25. Using the adopted BC conditions with a 0.9 scale factor, the model was able to closely match observed high tides although it slightly over-predicted (predicted lower than the measured) the measured low tides. The adopted tidal lags at the boundary resulted in the model being able to closely match the timing of the measrued tides at Stony Point.

A comparison of the modelled to observed tidal currents at the South ADCP site is presented in Figure 26. Using the adopted tidal lags and a 0.9 scale factor the model was able to closely reproduce the observed tidal velocities at this location.

Modelled velocity magnitudes using the adopted BC's and the previous Cardno BC's, at the approximate location of the Cape Woolamai ADCP deployed during July 2014, is presented in Figure 27. The use of a 30 minute lag across the model boundary reduced peak tidal velocities from above 2 m/s (due to a 2 hour tidal lag) to closer to 0.5 m/s. An initial analysis of the Cape Woolamai ADCP data from June/July 2014 indicated that tidal currents were typically below 0.2 m/s, though current speeds of up to 0.4 m/s were observed during storm events. The data indicated that to accurately simulate the current field to the south of Phillip Island the model boundary would need to be extended significantly further offshore or used in conjunction with a regional Bass Strait model.

<u>Sensitivity Testing Of Current Speeds at Selected UKC Output Locations</u>

A comparison of simulated current speeds for three different tidal boundary conditions, at four locations are presented in Figure 28 (MP17), Figure 29 (MP13), Figure 30 (MP07) and Figure 31 (MP03). The locations of the four points are presented in Figure 32. The three different boundary conditions simulated comprised:

- The Observed Stony Point WL x 0.9 with a 30 minute lag across the WL boundary (i.e. the Adopted BC used in the 12 month simulation).
- The Observed Stony Point WL x 0.9 with no lag across the WL boundary.
- The boundary condition used in the Preliminary Business Case Simulations by Cardno. This simulation has an approximate 2 hour lag across the WL boundary.

An assessment of influence of the tidal lag at the model BC at the four points is outlined below:

- At MP17 in the Lower North Arm, the difference between the adopted 30 minute lag and no lag cases was insignificant, while the 2hr lag case had typically ~0.1 m/s (~10%) lower current speeds on the Ebb tide and 0.05 m/s lower on the Flood tide.
- At MP13 (to the north of Phillip Island), there was a small (~1-2 cm/s) difference in current speeds between the adopted 30 minute lag and no lag cases, while the 2hr lag case had typically ~0.1 m/s (~10%) lower for both the Ebb tide and Flood tide.

- At MP07 (to the west of Phillip Island), there was a small (~1 cm/s) difference in current speeds between the adopted 30 minute lag and no lag cases on the Ebb Tide and a larger ~0.1 m/s difference in current speed at the Peak Flood tide. For the 2hr lag case the difference in current speed ws typically ~0.15 m/s lower for both the Ebb tide and ~0.2 m/s lower Flood tide.
- At MP03 (to the south west of Phillip Island), there was a ~0.1 m/s difference in current speeds between the adopted 30 minute lag and no lag cases for both the Ebb and Flood tide. For the 2hr lag case, the difference in current speed was very large > 1 m/s and the timing was also different.

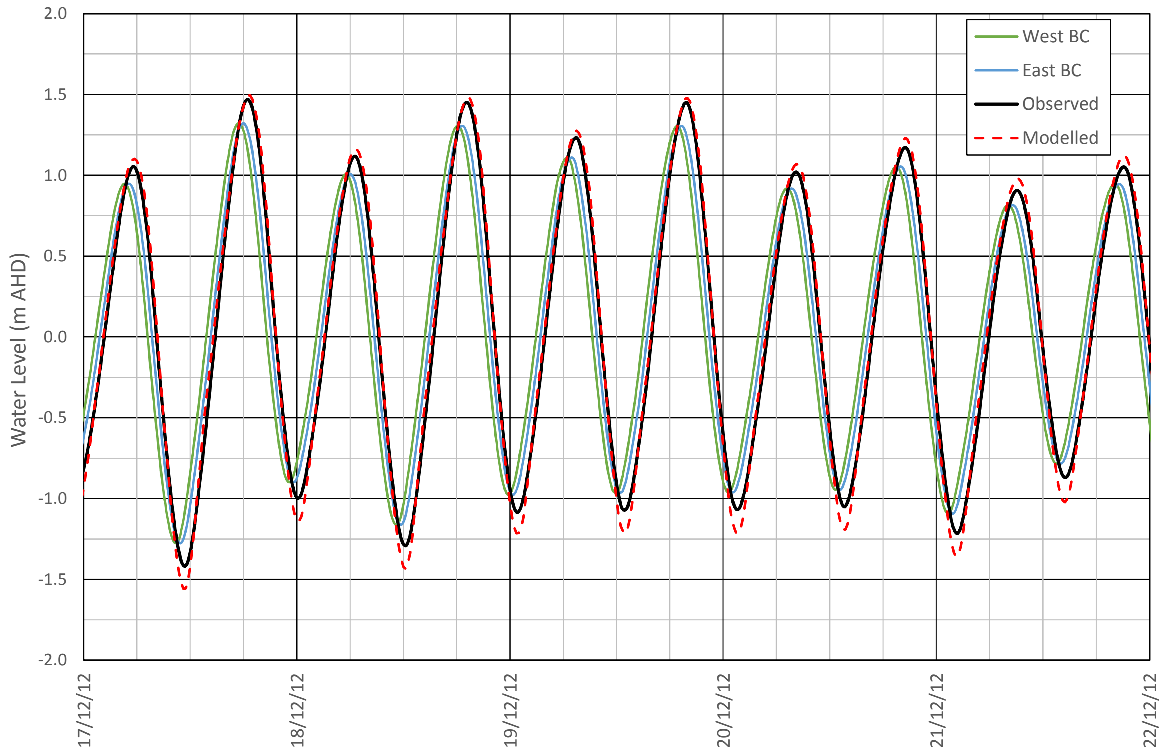

Figure 25: Adopted WL BC and Stony Point Observed and Modelled Water Levels

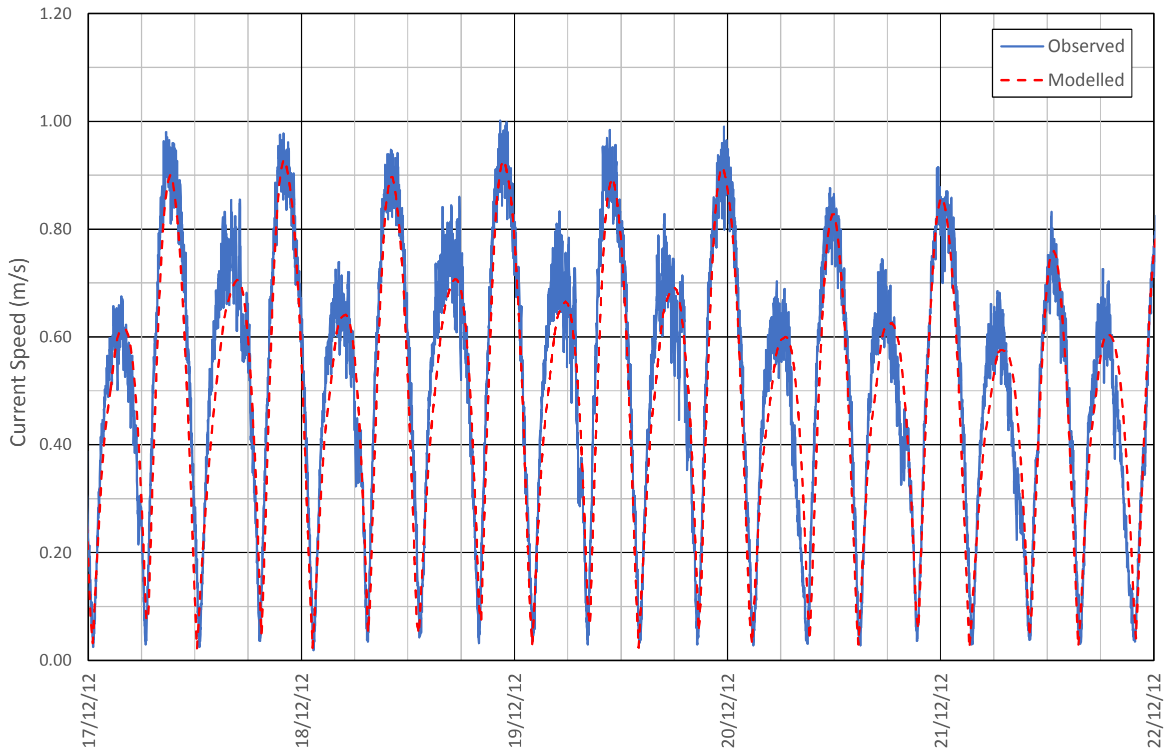

Figure 26: Observed and Modelled Velocity Data for South ADCP Site

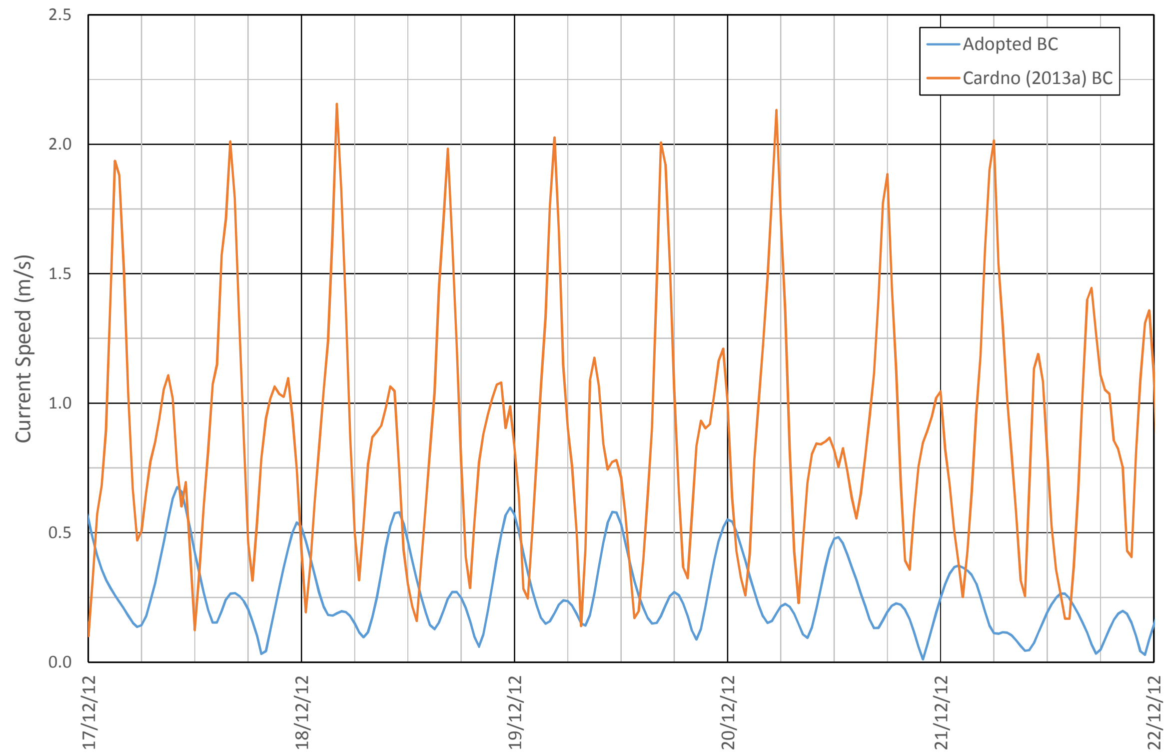

Figure 27: Modelled Velocity Magnitude at Cape Woolamai (ADCP) for two Different BC Cases

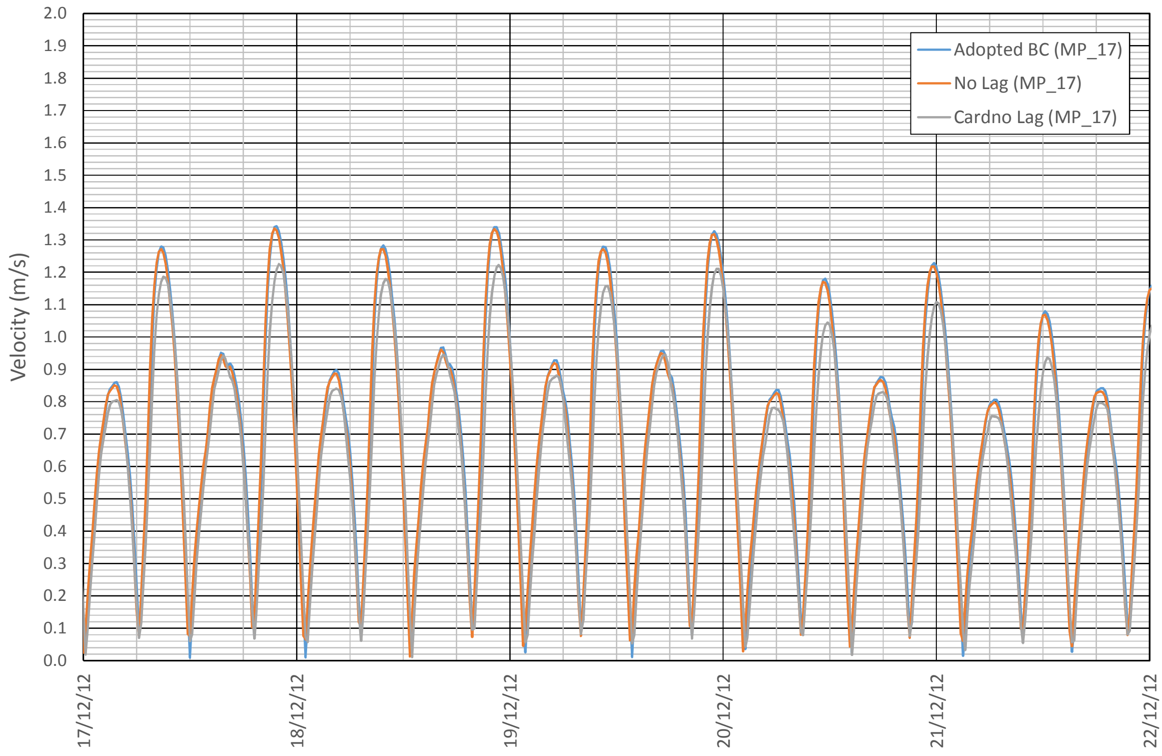

Figure 28: Modelled Current Speeds at MP17 for Three BC Tidal Lags

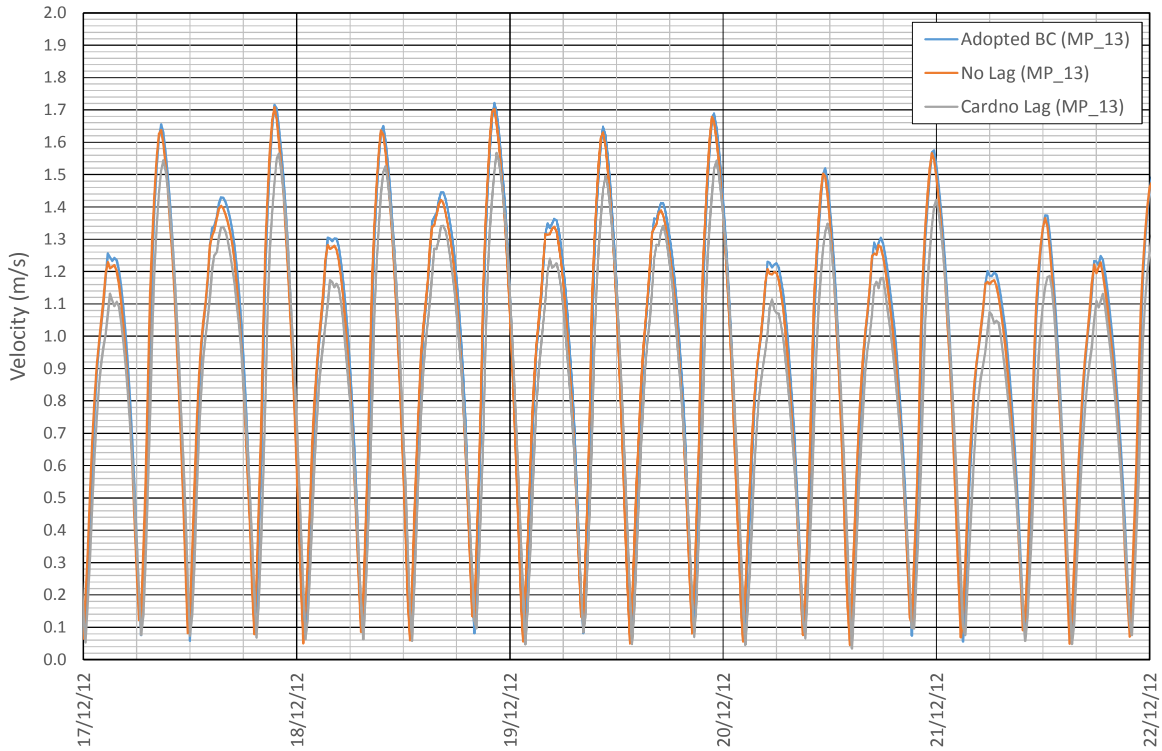

Figure 29: Modelled Current Speeds at MP13 for Three BC Tidal Lags

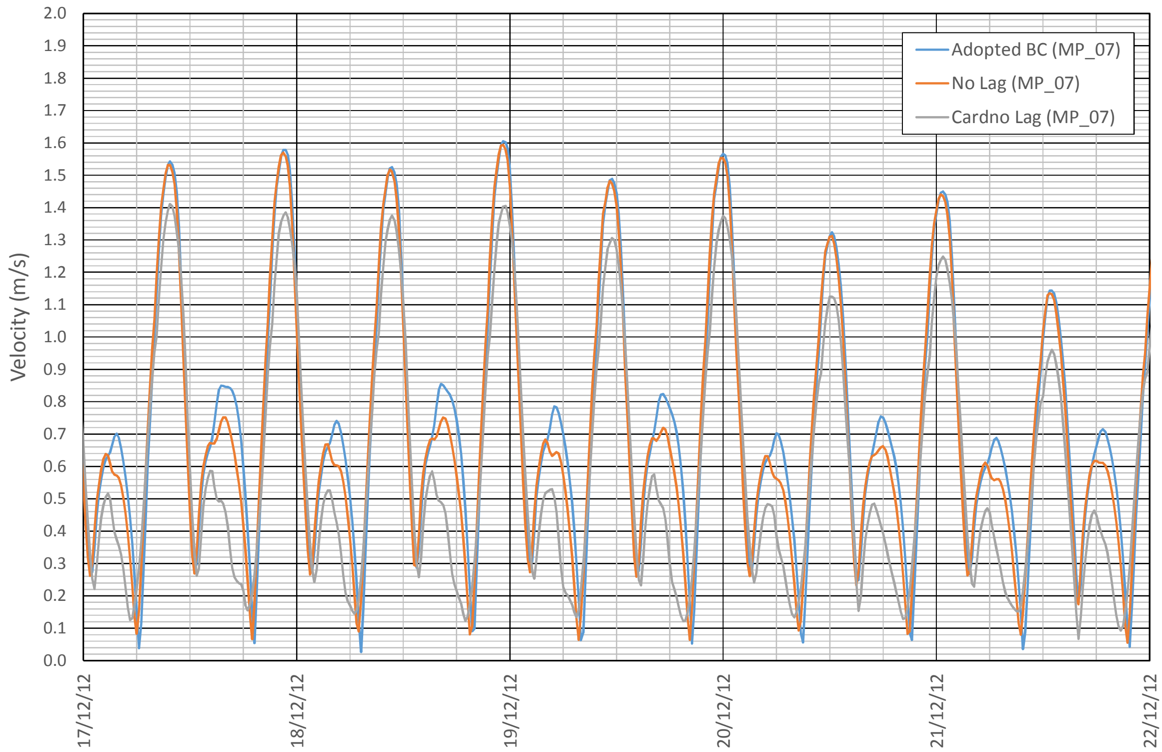

Figure 30: Modelled Current Speeds at MP07 for Three BC Tidal Lags

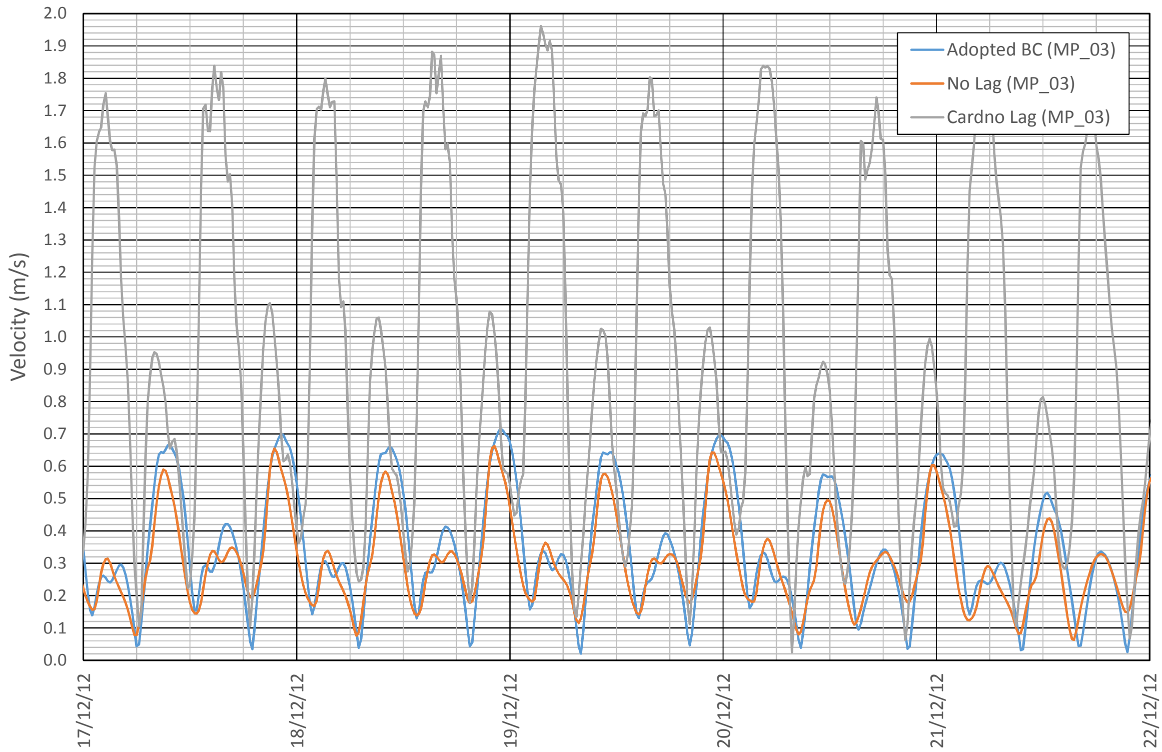

Figure 31: Modelled Current Speeds at MP03 for Three BC Tidal Lags

3.3 Model Output

Time series of the hydrodynamic and wave parameters defined in Table 7 have been extracted from the models at the 33 locations defined in Table 8 and presented in Figure 32. The files have been provided separately to PoHDA for use in the channel design and Under Keel Clearance (UKC) studies.

A summary of wave statistics for the output locations is provided in Table 9 (wave height) and

Table 10 (peak wave period).

A summary of water level statistics for the output locations is provided in

Table **11**, while a summary of current speed statistics is provided in

Table **12**.

Table 7: Model Output Parameters

Phenomena	Parameters	Time Intervals
Waves	significant wave height, peak spectral wave period, peak wave direction mean wave period, mean wave direction	Hourly
Currents and water levels	water level, water depth, current speed (depth averaged) current direction	6 minutes

Table 8: Model Output Locations for UKC Study

Output Point	Easting	Northing	Adopted Grid Position (M,N)
MP01	328479	5731682	86, 3
MP02	330069	5733176	91, 12
MP03	331384	5734441	96, 20
MP04	332587	5735527	101, 27
MP05	333529	5736440	105, 32
MP06	334974	5737781	111, 41
MP07	336467	5739176	118, 51
MP08	337467	5740135	123, 58
MP09	338482	5741086	128, 65
MP10	339390	5742047	132, 73
MP11	340555	5742682	140, 79
MP12	341849	5743349	150, 86
MP13	343021	5744013	159, 94
MP14	344416	5744707	170, 102
MP15	345330	5745646	177, 111
MP16	346378	5746911	184, 123
MP17	346973	5747893	187, 133
MP18	346872	5748659	185, 139
MP19	346868	5749371	184, 145
MP20	346724	5750110	181, 151
MP21	346506	5750818	177, 157
MP22	346291	5751653	173, 164
MP23	346072	5752434	169, 170
MP24	345889	5753096	165, 176
MP25	345831	5753809	162, 182
MP26	345784	5754578	159, 189
MP27	345783	5755208	157, 195
MP28	345713	5756096	153, 204
MP29	345614	5756920	149, 212
MP30	345635	5757774	145, 222
MP31	345517	5758536	141, 229
MP32	345900	5759644	141, 243
MP33	346241	5760418	141, 252

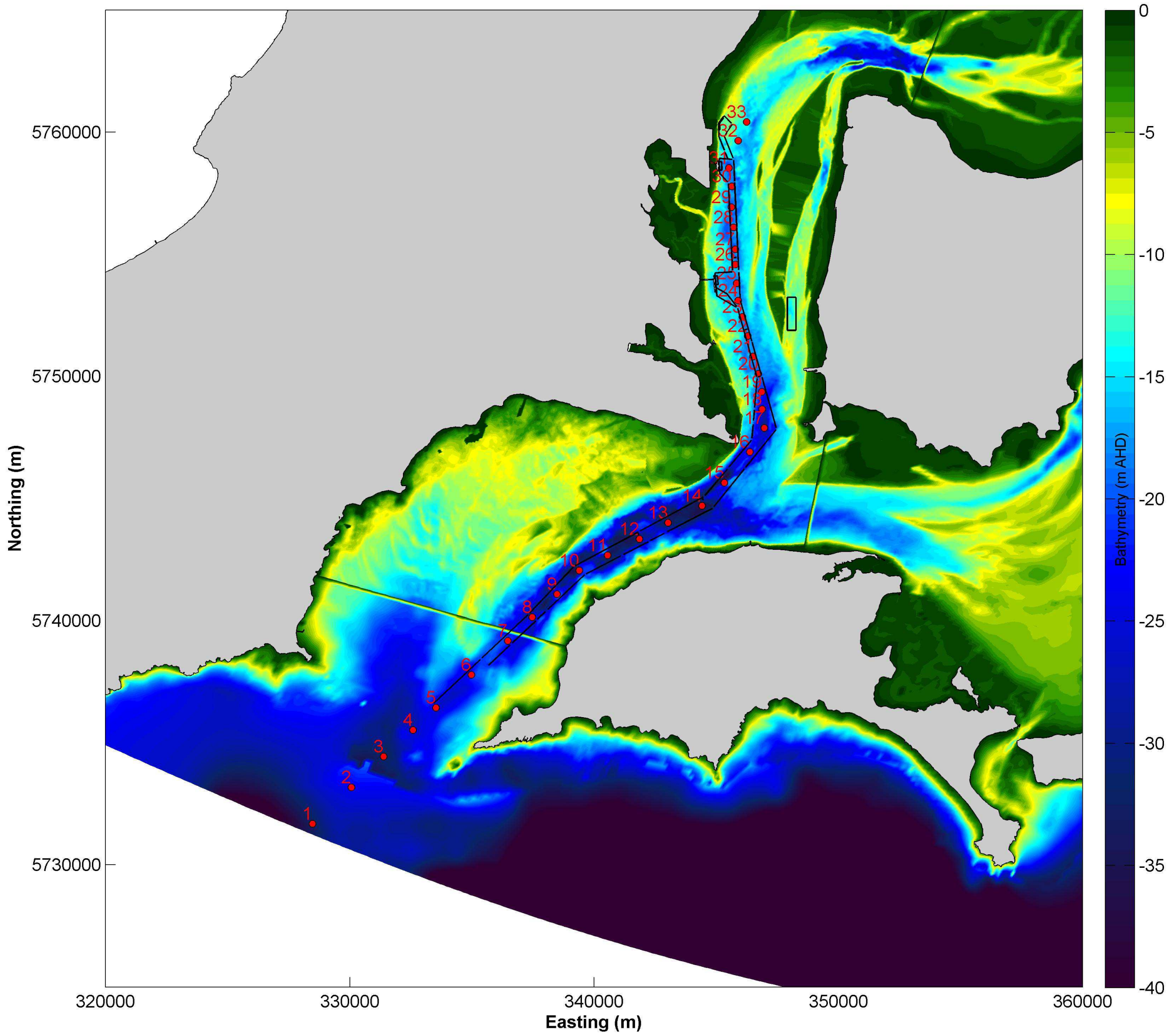

Figure 32: Location of Model Outputs underlain by Model Bathymetry

Table 9: Summary of Significant Wave Height (H_s (m)) Statistics

Output Point	Average	Max	Min	95%ile	90%ile	75%ile	50%ile	25%ile	10%ile
MP01	2.04	5.86	0.00	3.65	3.24	2.52	1.90	1.43	1.07
MP02	2.11	6.40	0.00	3.79	3.37	2.61	1.96	1.48	1.09
MP03	2.15	6.30	0.00	3.84	3.43	2.65	2.00	1.50	1.12
MP04	2.16	7.28	0.00	3.96	3.48	2.68	1.99	1.49	1.09
MP05	2.05	6.67	0.00	3.77	3.31	2.56	1.91	1.41	1.02
MP06	1.44	4.54	0.00	2.64	2.33	1.81	1.34	0.99	0.70
MP07	1.04	3.48	0.00	1.94	1.68	1.31	0.96	0.70	0.49
MP08	0.94	3.79	0.00	1.89	1.59	1.19	0.83	0.60	0.43
MP09	0.74	3.38	0.00	1.72	1.39	0.92	0.60	0.42	0.30
MP10	0.57	2.84	0.00	1.39	1.13	0.74	0.44	0.30	0.21
MP11	0.44	2.09	0.00	0.98	0.81	0.56	0.36	0.26	0.18
MP12	0.36	1.75	0.00	0.85	0.71	0.47	0.27	0.19	0.13
MP13	0.33	1.44	0.00	0.68	0.56	0.39	0.28	0.21	0.15
MP14	0.26	1.13	0.00	0.53	0.44	0.32	0.23	0.16	0.12
MP15	0.26	1.31	0.00	0.58	0.47	0.33	0.22	0.16	0.11
MP16	0.14	0.65	0.00	0.33	0.27	0.19	0.11	0.08	0.05
MP17	0.08	0.36	0.00	0.19	0.15	0.10	0.06	0.04	0.02
MP18	0.05	0.29	0.00	0.14	0.12	0.07	0.04	0.02	0.02
MP19	0.05	0.27	0.00	0.13	0.10	0.06	0.03	0.02	0.01
MP20	0.04	0.25	0.00	0.12	0.09	0.05	0.03	0.02	0.01
MP21	0.03	0.24	0.00	0.11	0.09	0.05	0.02	0.01	0.01
MP22	0.03	0.25	0.00	0.12	0.09	0.04	0.02	0.01	0.01
MP23	0.03	0.24	0.00	0.11	0.09	0.04	0.01	0.01	0.00
MP24	0.03	0.23	0.00	0.11	0.09	0.04	0.01	0.01	0.00
MP25	0.03	0.22	0.00	0.10	0.08	0.04	0.01	0.01	0.00
MP26	0.03	0.21	0.00	0.10	0.08	0.04	0.01	0.00	0.00
MP27	0.02	0.18	0.00	0.09	0.07	0.03	0.01	0.00	0.00
MP28	0.02	0.19	0.00	0.09	0.07	0.03	0.01	0.00	0.00
MP29	0.02	0.21	0.00	0.09	0.07	0.03	0.01	0.00	0.00
MP30	0.02	0.19	0.00	0.09	0.07	0.03	0.01	0.00	0.00
MP31	0.02	0.15	0.00	0.07	0.05	0.03	0.01	0.00	0.00
MP32	0.02	0.13	0.00	0.06	0.05	0.02	0.01	0.00	0.00
MP33	0.02	0.13	0.00	0.06	0.05	0.02	0.01	0.00	0.00

Table 10: Summary of Peak Spectral Wave Period (T_p (s)) Statistics

Output Point	Average	Max	Min	95%ile	90%ile	75%ile	50%ile	25%ile	10%ile
MP01	12.66	25.00	2.22	16.55	14.94	14.36	12.77	11.30	9.55
MP02	12.65	25.00	2.18	16.58	15.00	14.39	12.73	11.27	9.57
MP03	12.64	25.00	2.17	16.58	15.02	14.39	12.70	11.23	9.55
MP04	12.64	25.00	1.00	16.63	15.24	14.42	12.72	11.22	9.50
MP05	12.63	25.00	1.22	16.68	15.35	14.39	12.72	11.22	9.43
MP06	12.53	25.00	1.00	16.66	15.36	14.30	12.69	11.17	9.30
MP07	12.42	25.00	1.12	16.62	15.34	14.23	12.64	11.09	9.14
MP08	12.33	25.00	1.13	16.58	15.31	14.21	12.60	11.00	8.92
MP09	11.73	25.00	1.69	16.60	15.31	14.10	12.47	10.61	5.06
MP10	10.95	25.00	1.80	16.50	15.16	13.93	12.12	6.40	5.14
MP11	11.30	25.00	1.09	16.55	15.27	13.97	12.27	9.13	5.40
MP12	10.57	25.00	1.00	16.59	15.27	13.81	11.67	5.52	4.97
MP13	10.86	25.00	1.69	16.75	15.56	14.03	12.02	5.58	5.15
MP14	10.39	25.00	1.94	16.66	15.30	13.51	11.40	5.57	5.05
MP15	9.81	25.00	1.69	16.56	15.20	13.30	10.93	4.95	4.61
MP16	8.72	25.00	1.47	15.97	14.64	12.77	6.25	4.93	4.00
MP17	8.75	25.00	1.67	16.37	14.79	12.67	7.41	3.95	3.48
MP18	8.63	25.00	1.25	16.47	14.95	12.89	8.26	3.31	2.79
MP19	8.39	25.00	1.35	16.52	15.08	12.92	6.75	3.19	2.71
MP20	8.48	25.00	1.34	16.39	14.93	12.84	8.87	3.10	2.63
MP21	7.91	25.00	1.24	16.29	14.84	12.76	5.39	2.97	2.48
MP22	7.46	25.00	1.27	16.09	14.73	12.52	5.50	2.96	2.45
MP23	6.21	25.00	1.32	15.11	14.18	6.72	5.17	2.92	2.41
MP24	5.03	25.00	1.36	14.71	6.48	5.30	4.91	2.92	2.37
MP25	4.25	22.72	0.00	5.88	5.55	5.14	4.86	3.05	2.46
MP26	4.38	25.00	0.00	5.97	5.62	5.17	4.88	3.04	2.45
MP27	4.45	25.00	0.00	6.06	5.68	5.22	4.87	2.94	2.20
MP28	4.18	25.00	0.00	5.69	5.47	5.08	4.81	2.77	2.05
MP29	4.07	25.00	0.00	5.50	5.29	5.02	4.79	2.78	2.11
MP30	4.01	25.00	0.00	5.35	5.15	4.94	4.73	2.87	2.28
MP31	3.97	25.00	0.00	5.13	5.01	4.89	4.70	2.97	2.31
MP32	4.04	25.00	0.00	5.49	4.79	4.58	4.09	2.94	2.18
MP33	4.44	25.00	0.00	6.40	6.01	5.31	3.90	2.84	2.17

Table 11: Summary of Water Level (m AHD) Statistics

Output Point	Average	Max	Min	Range	95%ile	90%ile	75%ile	50%ile	25%ile	10%ile	5%ile
MP01	-0.12	1.42	-1.82	3.24	0.82	0.68	0.41	-0.10	-0.62	-0.98	-1.16
MP02	-0.12	1.42	-1.83	3.25	0.83	0.68	0.41	-0.10	-0.62	-0.99	-1.17
MP03	-0.12	1.42	-1.83	3.26	0.83	0.69	0.42	-0.10	-0.62	-0.99	-1.17
MP04	-0.13	1.41	-1.84	3.26	0.82	0.68	0.40	-0.11	-0.63	-1.00	-1.18
MP05	-0.14	1.40	-1.85	3.26	0.81	0.67	0.40	-0.11	-0.64	-1.01	-1.19
MP06	-0.13	1.40	-1.87	3.27	0.82	0.68	0.41	-0.11	-0.65	-1.02	-1.21
MP07	-0.13	1.44	-1.92	3.36	0.85	0.70	0.43	-0.10	-0.66	-1.04	-1.24
MP08	-0.14	1.45	-1.92	3.37	0.85	0.71	0.44	-0.11	-0.68	-1.07	-1.26
MP09	-0.15	1.46	-1.95	3.41	0.85	0.71	0.43	-0.12	-0.70	-1.09	-1.27
MP10	-0.14	1.47	-1.92	3.39	0.86	0.72	0.44	-0.12	-0.68	-1.06	-1.25
MP11	-0.14	1.47	-1.94	3.41	0.86	0.71	0.44	-0.11	-0.68	-1.06	-1.25
MP12	-0.13	1.49	-1.96	3.45	0.87	0.73	0.46	-0.10	-0.68	-1.07	-1.27
MP13	-0.13	1.50	-1.98	3.47	0.88	0.74	0.46	-0.11	-0.69	-1.09	-1.28
MP14	-0.13	1.51	-2.00	3.51	0.89	0.75	0.48	-0.09	-0.69	-1.09	-1.29
MP15	-0.13	1.52	-2.02	3.54	0.90	0.76	0.48	-0.09	-0.70	-1.11	-1.31
MP16	-0.13	1.54	-2.05	3.59	0.92	0.78	0.50	-0.09	-0.71	-1.12	-1.33
MP17	-0.12	1.56	-2.06	3.63	0.94	0.79	0.51	-0.08	-0.70	-1.12	-1.33
MP18	-0.12	1.57	-2.08	3.64	0.94	0.80	0.51	-0.08	-0.71	-1.13	-1.34
MP19	-0.12	1.58	-2.09	3.66	0.95	0.80	0.52	-0.08	-0.71	-1.13	-1.35
MP20	-0.12	1.59	-2.10	3.68	0.96	0.81	0.53	-0.07	-0.71	-1.14	-1.35
MP21	-0.11	1.60	-2.11	3.71	0.96	0.82	0.53	-0.07	-0.71	-1.14	-1.36
MP22	-0.11	1.61	-2.12	3.73	0.97	0.82	0.54	-0.07	-0.71	-1.15	-1.36
MP23	-0.11	1.61	-2.13	3.75	0.98	0.83	0.54	-0.06	-0.71	-1.15	-1.37
MP24	-0.11	1.62	-2.14	3.76	0.98	0.84	0.55	-0.06	-0.71	-1.15	-1.37
MP25	-0.10	1.63	-2.15	3.78	0.99	0.84	0.55	-0.06	-0.71	-1.15	-1.38
MP26	-0.11	1.64	-2.16	3.80	1.00	0.85	0.55	-0.06	-0.72	-1.16	-1.38
MP27	-0.10	1.64	-2.17	3.81	1.00	0.85	0.56	-0.06	-0.72	-1.16	-1.39
MP28	-0.10	1.65	-2.18	3.83	1.01	0.86	0.56	-0.05	-0.72	-1.17	-1.39
MP29	-0.10	1.66	-2.19	3.85	1.01	0.86	0.57	-0.05	-0.73	-1.17	-1.40
MP30	-0.10	1.67	-2.20	3.87	1.02	0.87	0.57	-0.05	-0.73	-1.18	-1.40
MP31	-0.10	1.67	-2.21	3.88	1.03	0.87	0.58	-0.05	-0.73	-1.18	-1.41
MP32	-0.10	1.69	-2.22	3.90	1.04	0.88	0.58	-0.05	-0.73	-1.18	-1.41
MP33	-0.10	1.69	-2.23	3.92	1.04	0.89	0.58	-0.05	-0.74	-1.19	-1.42

Table 12: Summary of Current Speed (m/s) Statistics

Output Point	Average	Max	Min	95%ile	90%ile	75%ile	50%ile	25%ile	10%ile	5%ile
MP01	0.14	0.45	0.00	0.28	0.25	0.19	0.14	0.08	0.04	0.03
MP02	0.25	0.60	0.00	0.44	0.39	0.32	0.24	0.18	0.11	0.08
MP03	0.35	0.86	0.00	0.62	0.57	0.46	0.33	0.22	0.15	0.12
MP04	0.49	1.07	0.00	0.81	0.76	0.66	0.50	0.29	0.20	0.16
MP05	0.52	1.13	0.00	0.88	0.82	0.69	0.53	0.35	0.20	0.15
MP06	0.52	1.33	0.00	0.98	0.89	0.69	0.51	0.33	0.20	0.13
MP07	0.56	1.69	0.00	1.22	1.08	0.76	0.48	0.31	0.18	0.13
MP08	0.60	1.96	0.00	1.45	1.26	0.80	0.50	0.28	0.15	0.10
MP09	0.82	2.39	0.00	1.83	1.61	1.03	0.73	0.47	0.22	0.12
MP10	0.81	2.06	0.00	1.58	1.40	1.10	0.84	0.46	0.18	0.10
MP11	0.82	1.83	0.00	1.41	1.32	1.15	0.87	0.50	0.22	0.14
MP12	0.77	1.71	0.00	1.33	1.24	1.07	0.81	0.47	0.20	0.10
MP13	0.77	1.73	0.00	1.35	1.25	1.07	0.81	0.45	0.19	0.11
MP14	0.64	1.37	0.00	1.10	1.03	0.90	0.69	0.39	0.17	0.09
MP15	0.64	1.50	0.00	1.15	1.04	0.87	0.68	0.41	0.18	0.10
MP16	0.65	1.63	0.00	1.28	1.14	0.85	0.65	0.40	0.18	0.10
MP17	0.56	1.35	0.00	1.07	0.96	0.77	0.57	0.33	0.14	0.08
MP18	0.59	1.37	0.00	1.08	0.98	0.80	0.61	0.35	0.15	0.08
MP19	0.57	1.31	0.00	1.03	0.94	0.79	0.61	0.35	0.15	0.08
MP20	0.56	1.28	0.00	1.01	0.91	0.76	0.59	0.34	0.15	0.08
MP21	0.49	1.16	0.00	0.91	0.82	0.67	0.52	0.30	0.13	0.07
MP22	0.51	1.22	0.00	0.96	0.86	0.69	0.53	0.31	0.13	0.07
MP23	0.48	1.14	0.00	0.90	0.81	0.66	0.50	0.29	0.12	0.06
MP24	0.47	1.11	0.00	0.88	0.79	0.64	0.49	0.28	0.12	0.06
MP25	0.44	1.05	0.00	0.83	0.74	0.60	0.46	0.26	0.11	0.06
MP26	0.49	1.19	0.00	0.93	0.83	0.67	0.51	0.29	0.12	0.06
MP27	0.46	1.12	0.00	0.87	0.79	0.63	0.48	0.27	0.12	0.06
MP28	0.45	1.08	0.00	0.85	0.76	0.60	0.46	0.27	0.11	0.06
MP29	0.46	1.13	0.00	0.89	0.80	0.62	0.47	0.27	0.11	0.06
MP30	0.47	1.15	0.00	0.91	0.82	0.64	0.49	0.28	0.12	0.06
MP31	0.44	1.01	0.00	0.80	0.72	0.59	0.46	0.28	0.13	0.07
MP32	0.40	0.94	0.00	0.75	0.67	0.55	0.41	0.24	0.10	0.06
MP33	0.43	1.03	0.00	0.82	0.74	0.59	0.45	0.25	0.10	0.05

3.4 Summary and Discussion

A review and analysis of available data and numerical modelling has been undertaken to provide metocean parameters including: water velocities, elevations, depth, wind and wave conditions to inform channel design including under keel clearance (UKC) analysis.

A review of wave information indicated that data for 2006 would be best suited due to data availability. A statistical analysis of ten years of wave data (2003 to 2012) indicated that there was minimal inter-annual variation in wave conditions and 2006 appeared to be a typical year in term of wave conditions.

An existing Cardno DELFT3D model with a grid resolution of 150m was used to model the hydrodynamic and wave conditions of Western Port to determine a number of metocean conditions at 33 points within the study area. The wave and hydrodynamic models were coupled to represent the influence of tidal currents on wave conditions.

A review of tidal boundary conditions used by Cardno indicated that they may not be appropriate in some of the areas of interest. A review of data and model sensitivity testing indicated that the most appropriate tidal boundary tested was:

- Western BC = Observed Stony Point WL x 0.9 applied 60 minutes earlier
- Eastern BC = Observed Stony Point WL x 0.9 applied 30 minutes earlier

This adopted tidal boundary was able to closely match observed water levels at Stony Point and observed velocities at the South ADCP gauge. The adopted BCs also produced more realistic tidal velocities offshore of Cape Woolamai (Phillip Island).

Observed wave conditions at Point Nepean were scaled by 18% to represent offshore conditions at Western Port. While it is considered that this is a conservative scale factor for longer period waves (T>14s) it is important to note that it does not adequately represent differences in wave conditions between the two sites over the full range of wave periods. This is not possible to achieve by a simple scaling factor and additional work which is being undertaken as part of the Model Build Work Order will determine the most appropriate offshore boundary conditions to adopt.

Time series of the required hydrodynamic and wave conditions at each of the 33 points have been provided to PoHDA as separate files.

3.5 Level of Confidence and Applicability

Water Levels

The initial modelling of hydrodynamics can be used to provide a provisional 12 month time series of water levels for channel design and UKC for the proposed PoH development.

For the adopted boundary conditions (described above), a comparison of measured and simulated water levels at Stony Point (Figure 25) indicated that the model was able to simulate measured water levels to within +/- 0.2 m. The hydrodynamics of the Western Port estuary mean that there is likely to be insignificant spatial variation of the predicted accuracy of the model across the entire model domain. However, it is important to note that there is a degree of uncertainty regarding the adopted water level boundary condition that scaled observed Stony Point water levels by 0.9. Initial testing indicates that an appropriate scale factor could lie between 0.85 and 0.95. The uncertainty of this scale factor is included in the +/- 0.2 m accuracy for water levels. Ongoing data collection and model development will allow for increased confidence in model results.

Currents

The initial modelling of hydrodynamics can be used to provide a provisional 12 month time series of current speed and direction for channel design and UKC for the proposed PoH development.

For the adopted boundary conditions (described above), a comparison of measured and simulated currents at the South ADCP location (Figure 26), indicate that the model is able to simulate measured current speeds to within +/- 0.1 m/s. This gives good confidence in the models ability to simulate currents within the Lower North Arm. A lack of current velocity data outside of the Lower North Arm, means that a reliable estimate of uncertainty regarding the model simulations cannot be made. However, sensitivity testing of the influence of the adopted lag along the offshore water level boundary (see Section 3.2.1) allowed an approximation of the likely accuracy of current simulations based on the adopted BC to be made as outlined below:

- In the Lower North Arm (i.e. MP17) a reduction in the adopted tidal lag will have insignificant influence on simulated current speeds.
- At MP13 (to the north of Phillip Island), there was a small (~1-2 cm/s) difference in current speeds between the adopted 30 minute lag and no lag simulations.
- At MP07 (to the west of Phillip Island), there was up to a ~0.1 m/s difference in current speeds between the adopted 30 minute lag and no lag simulations.
- At MP03 (to the south west of Phillip Island), there was a ~0.1 m/s difference in current speeds between the adopted 30 minute lag and no lag cases for both the Ebb and Flood tide.

Due to the proximity of the model boundary to output locations M01-M05, there was limited opportunity to develop stable flow conditions and any inaccuracies in the adopted lateral lag along the offshore boundary will be more noticeable at these locations. For points M06-M33 the comparison to observed data and sensitivity testing indicated that an provisional accuracy of +/- 0.1 m/s should be associated with the current speed simulations.

Additional data from the ongoing data collection program and modelling can be used to provide additional information for these areas and will allow for improved model development, calibration and verification to be undertaken.

Wave Conditions

The initial modelling of swell waves can be used to provide a provisional estimate of the wave climate for channel design and UKC for the proposed PoH development.

Uncertainty in the scaling of wave information from Point Nepean to Western Port reduced certainty in the assessment of wave conditions undertaken during this assessment, especially for peak sprectral wave periods of less than 14 seconds. Proposed regional wave modelling will assist in the development of more accurate offshore wave conditions in subsequent stages of the project.

An accurate estimation of the level of confidence of modelled wave conditions cannot be made without access to measured inshore wave data. Until this data is collected, estimates of the level of confidence in the current modelled wave conditions can only be based on engineering judgement. Due to the significant level of uncertainty associated with the Point Nepean to Western Port wave scaling factor, the current predictions of wave heights may be inaccurate by an estimated 20%-50%. However, there is greater certainty in both wave periods (which exhibit less spatial variation) and wave direction (which is influenced by bathymetry), which are likely to be within +/- 1 to 2 s for period and +/- 5 to 10 degrees for direction, although comparisons to measured data are required to better quantify these estimates of accuracy.

It should also be noted that, with the exception of the maximum wave height, the modelled 2006 wave conditions appeared to provide a representative wave climate when compared to 10 years of available

data. Because the maximum observed wave height (H_s = 5.16 m) for 2006 is 20% lower than the maximum wave height (H_s = 6.42 m) observed in the 10 year period, if a conservative estimate of maximum wave height is required the results for maximum wave height could be scaled upwards by 20% to provide a conservative estimate for channel design. However, it is important to note that there is already a degree of uncertainty regarding the scaling (currently +18%) of Point Nepean wave heights to offshore of Western Port.

4 INITIAL ASSESSMENT OF LONG WAVES

4.1 Objectives and Introduction

Section 4 of this report is provided to satisfy the objectives of Task 2b of the early hydrodynamic modelling scope (WP-HY-13) which includes providing an initial assessment of long wave issues in the Port and channel areas.

Low frequency waves, typically known as long waves, infragravity waves or subharmonic gravity waves are a group of surface gravity waves with periods greater than that of wind generated waves (wind waves), primarily between 30 seconds and 3 – 4 minutes. These waves have effectively negligible amplitudes in deep water, however become significant and even dominate shallow water wave energy fluxes.

Low frequency waves (excluding tsunami's) are generated by wind waves and categorised in two groups, bound waves and free waves.

Bound waves are essentially developed through nonlinear interactions of two primary wind wave frequencies which theoretically force a secondary wave due to their different frequencies and they are phase-coupled with the incident wave group (Herbers et al, 1994).

Free waves are dispersive low frequency waves. Their generation mechanism is complicated and is a function of their forcing as well as local topography. On a mild sloping beach, free waves are understood to develop through continued forcing of nonlinear energy transfer from the wind waves to subharmonic frequencies as the wind waves propagate to shallow water (Masselink, 1995). They are partially reflected from the beach and are refractively trapped as edge waves or escape to the deep water as leaky waves. For a steep beach or a reef, differences in the time-varying breakpoint within the short wave group induces free waves propagating shoreward and seaward from the breakpoint (Baldock et al, 2000).

Bound waves contributions and usually more significant when energetic swell conditions exist, whereas free waves are more dominant when more moderate conditions prevail.

Relevance of low frequency waves to the project is primarily associated with ship responses and related loadings due to the long period waves. A potential source of low frequency wave energy within the Western Port site is likely due to bound wave energy entering the harbour and exciting seiche motions. Free waves would likely dominate the low frequency wave energy outside of the harbour, which is important to consider when an attempt is made to correlate low frequency waves in and outside of the port area.

In this Section, an initial investigation into the significance of low frequency waves at the Western Port site based on spectral analysis of ADCP data collected at the Cape Woolamai measurement location is presented. There are currently ongoing attempts to gain some useful analysis from two recent ADCP instrument deployments in the Lower North Arm (near Beacon 35). However, there has been some difficulties in resolving any useful information on long waves from these sources due to:

- The sampling regime of the instrument was focused on measuring currents and short period wind waves. The sampling regime included a 1,024 wave burst at 2 hertz (i.e. 1,024 samples taken at a sampling rate of 2 samples per second) every hour. This is an insufficient measurement period to complete spectral analysis for long waves unless significant burst aggregation is used.

- Difficulties in extracting raw ‘ping’ and pressure data due to some minor read errors in one of the instruments raw data files.

4.2 Data preparation

Continuous measurements of sufficient record length were unavailable as wave data was measured at 2 Hz sampling frequency in an ensemble mode of approximately 17 minutes each hourly interval. To overcome this, three ensembles were concatenated to generate an aggregated time series with sufficient duration of around 51 minutes (as measured over a 3.5 hour period).

Ad-hoc beam coherence and stationarity tests were undertaken as part of a data processing procedure as described below.

Beam Coherence

The deployment depth at Cape Woolamai was around 70 m and therefore pressure attenuation inhibited the use of the pressure spectrum for wind waves. Offshore, it is of interest to know the correlation between wind waves and long waves, as wind waves are the generating mechanism of infragravity long waves. Accordingly, the surface track spectrum was selected as the primary data source for low frequency spectral analysis.

Surface track data sets were recorded by all four beams, and vertical water column heights based on pitch and roll sensors were calculated by the RDI processing software, Wavemon.

Significant wave heights for all beams and their average value were calculated and compared. A beam array was considered coherent if absolute significant wave height differences for all sensors were within the prescribed threshold of 0.5 m. If one or more sensors consisted of difference values above the threshold, the beam with the maximum error was removed and the same process was repeated until the array was considered coherent. A minimum of two beams were required for spectral analysis, or otherwise, the time series record was discarded from further analysis.

The beam coherence test was undertaken for low frequency spectra (data translation to energy spectra is described in the following Section). For low frequency beam coherence, a sum difference energy density threshold value of 0.5 m^2/Hz was used. For the purpose of investigating significance of low frequency waves, rather than quantifying their energy, this threshold was considered appropriate.

Steady Sea State

Following the beam coherence test, a simple steady sea state test was undertaken which is one of the primary assumptions in spectral analysis. Significant wave heights derived from the aggregated time series were compared to the ensemble significant wave heights. Aggregated time series were considered stationary if absolute significant wave height differences for all three ensembles were within the prescribed threshold value of 0.5 m. Time series records exceeding the threshold were discarded from further analysis. Again, for the purpose of investigating significance of low frequency waves, rather than quantifying their energy, this threshold was considered appropriate.

Summary of Data Preparation

Using the thresholds stated above for beam coherence and stationarity, Table 13 presents data accepted following each test.

Table 13: Data capture rates for each beam

Test / Beam	Beam 1	Beam 2	Beam 3	Beam 4
Beam coherence	99%	97%	95%	94%
Steady sea state	87%	87%	86%	83%
LF beam coherence	76%	79%	69%	60%

4.3 Spectral Analysis and discussion

Surface track time series records for all valid beams were detided, overlapped and windowed, and translated to variance spectra with around 0.002 Hz resolution. This resolution gives 18 low frequency bins in the range of interest, between 0.005 and 0.04 Hz. In terms of wave period this is a range of wave period from 25 seconds to 200 seconds. Surface fluctuations with frequencies less than 0.005 Hz have coarse resolution with respect to wave period, and given the very limited samples in the record, they were not considered to be accurately resolved with this methodology and resolution.

This analysis was also undertaken for subsurface pressure data. The subsurface pressure spectra were then translated to surface elevation by applying a linear wave pressure correction factor. Note that surface fluctuations above approximately 0.1 Hz frequency are not detectable at the depth of 70 m due to pressure attenuation (Young, 1999). Furthermore, translation of depth attenuated small surface fluctuations in the low frequency range is not likely to produce accurate estimates of low frequency wave amplitudes. Nevertheless, data was used as another independent source to examine the significance of low frequency wave motions at the site.

Three hourly significant wave height (H_S) based on the aggregated time series and low frequency wave component height (H_{LW}) were calculated based on the following:

$H_S = 4\sqrt{m_0}$ where $m_0 = \int_0^{0.5\ Hz} f^0 S_\eta(f)df$ (IAHR Working Group on Wave Generation and Analysis, 1989)

$H_{LW} = 4\sqrt{m_0}$ where $m_0 = \int_{0.005 Hz}^{0.04\ Hz} f^0 S_\eta(f)df$

Figure 33 presents a snapshot of H_{LW} relative to H_S for the duration of the measurement period.

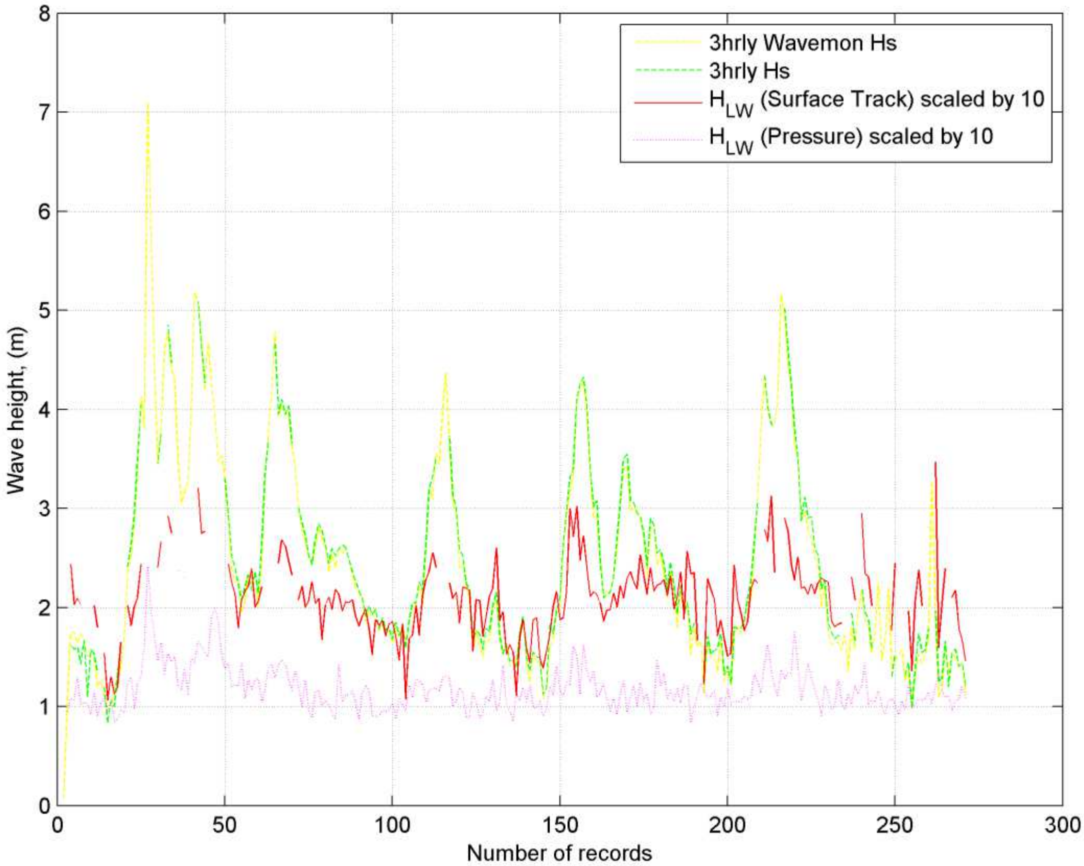

Figure 33: Time series of significant wave heights and long wave component height

There is evidence of correlation between H_{LW} and H_S. Notable increases in the pressure spectra during the first large wind wave event between record numbers 20 and 40 were a good indication of the low frequency wave presence during that particular event, which wasn't captured by the surface track spectra. However, when referring to this figure, it is important to consider that the low frequency spectra are subject to a large noise signal, which is reasonable at the depth of measurement. Rigorous filtering by assigning more realistic thresholds would likely reduce data capture rates so low that it would not be possible to draw any conclusions from the surface track analysis.

Figure 34 presents four example variance density plots from the spectral analysis. The noise referred to in the previous paragraph is evident in these figures. Further, there is a trend where variance density spectra peak (which can be considered a peak low frequency wave period) occurring at frequencies below 0.01 Hz (at a wave period of around 90 seconds). Accordingly, it is difficult to comment on the reliability of this observation, as the number of waves sampled in this range was limited and their respective wave period resolution is very coarse. It is also worthy to mention that corresponding pressure spectra did not follow this trend.

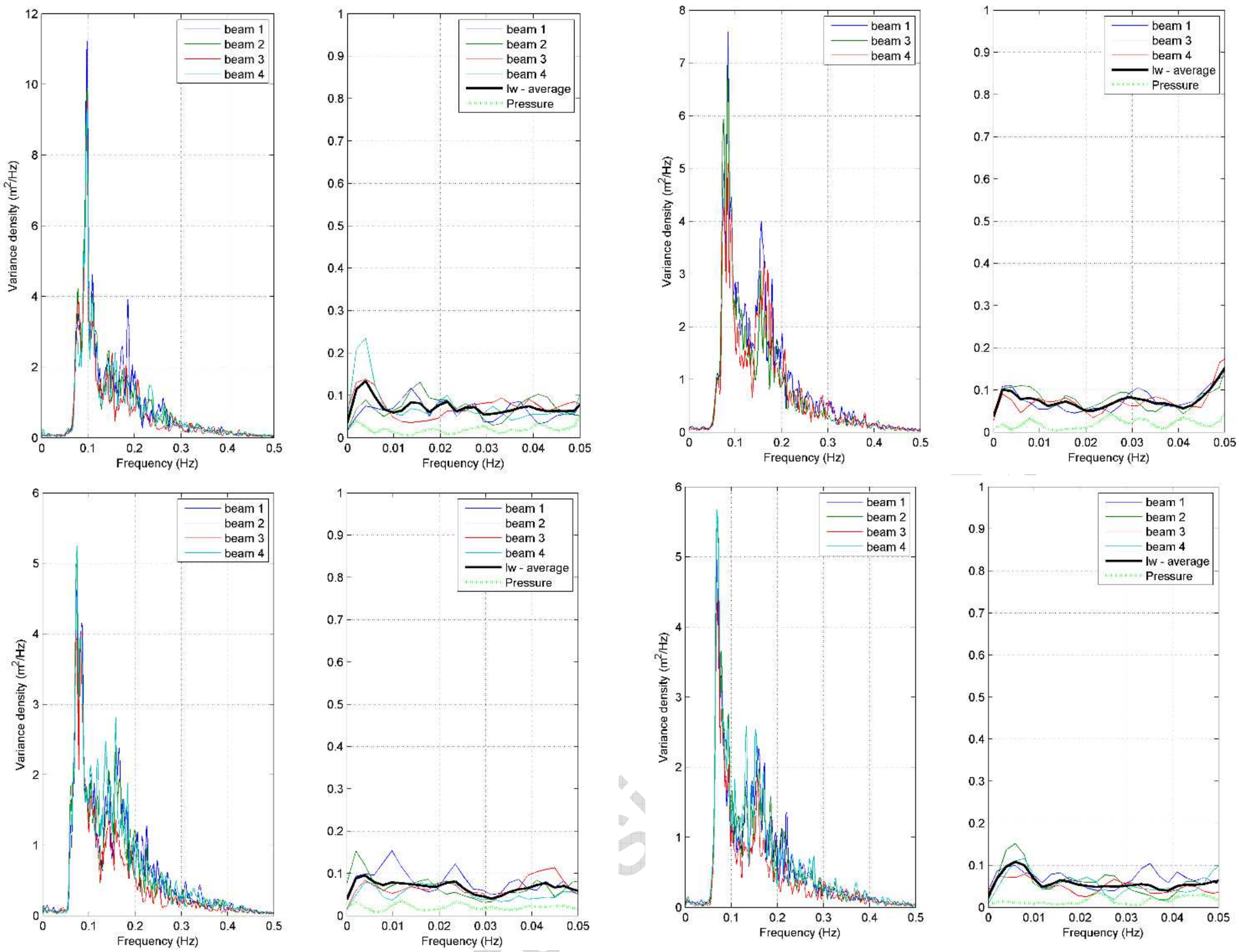

Figure 34: Four examples of 2D wave spectra, wind wave (left panel) and long wave (right panel)

4.4 Concluding Summary

There is some evidence that low frequency waves were detected by the Cape Woolamai ADCP. However, there was uncertainty associated with the data and methodology. The data collected by this instrument was not well suited to estimate low frequency wave parameters with confidence. Furthermore, indicative low frequency wave energy at Cape Woolamai does not necessarily relate to possible seiches in the Western Port as seiche is location specific. If quantifiable estimates of low frequency wave energy form an important scope of the project in the future, a measurement program specifically designed to collect low frequency wave data in the port area is recommended.

5 REFERENCES

Australian Hydrographic Office (2013), *Australian National Tide Tables 2014*, Australian Hydrographic Publication 11

Baldock, T.E., Huntley, D.A., Bird, P.A.D., O'Hare, T and Bullock, G.N. (2000). Breakpoint generated surf beat induced by bichromatic wave groups. Coastal Engineering, 39, 213-242.

Bureau of Meteorology (2014), *Monthly Data Report – May 2014, Australian Baseline Sea Level Monitoring Array*

Herbers, T.H.C., S Elgar and R.T. Guza (1994). Infragravity-frequency (0.005 – 0.05Hz) motions on the Shelf. Part I: Forced Waves. Journal of Physical Ocenography., 24, 917-927.

Masselink, G. (1985), Group bound long waves as a source of infragravity energy in the surf zone, Continental Shelf Research., 15(13), 1525-1547.

Short, A.D., 2006: *Beaches of the Tasmanian Coast and Islands: A guide to their nature, characteristics, surf and safety*. Sydney University Press, Sydney, 353 pp.

The IAHR Working Group on Wave Generation and Analysis (1989). List of Sea-State Parameters, Journal of Waterway, Port, Coastal, Ocean Engineering, 1989.

Young, I.R. (1999). Wind generated ocean waves. Elsevier

Appendix A 90th PERCENTILE WL AND CURRENT SPEED FIGURES

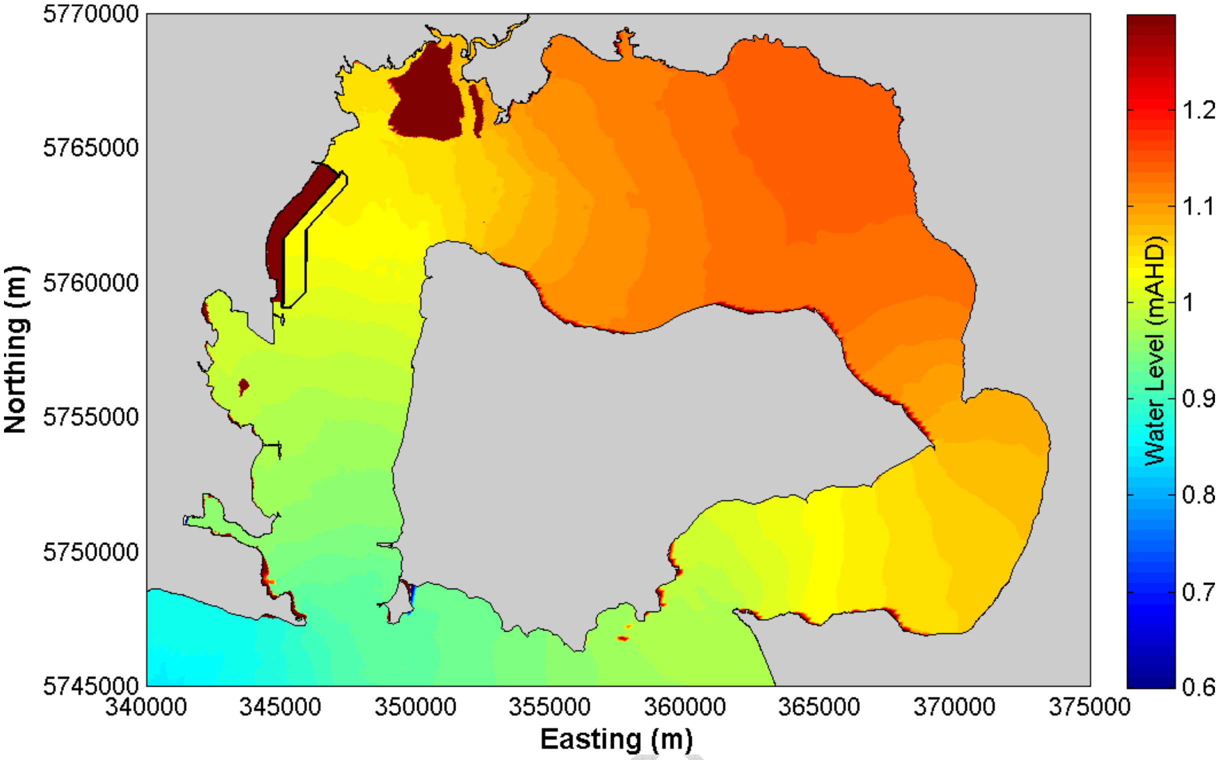

Figure A-1: 90th Percentile WL Exceedance for CTS Scenario

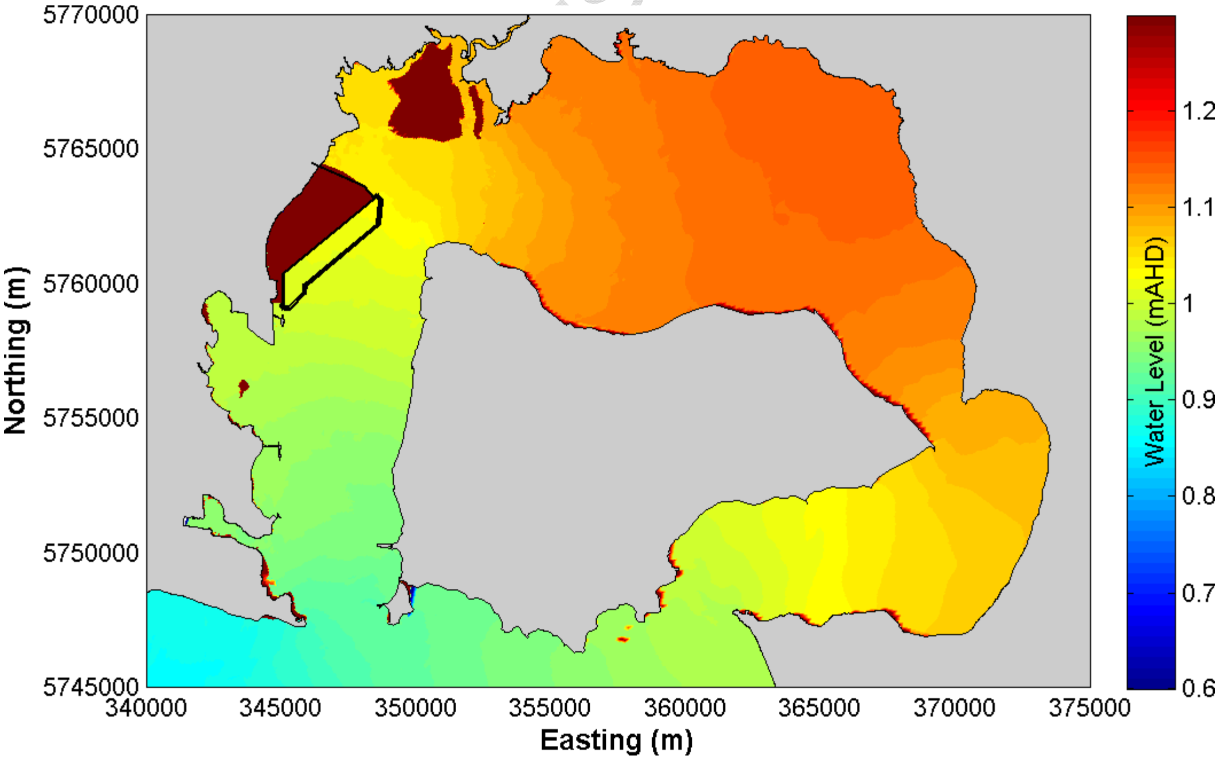

Figure A-2: 90th Percentile WL Exceedance for FOFS Scenario

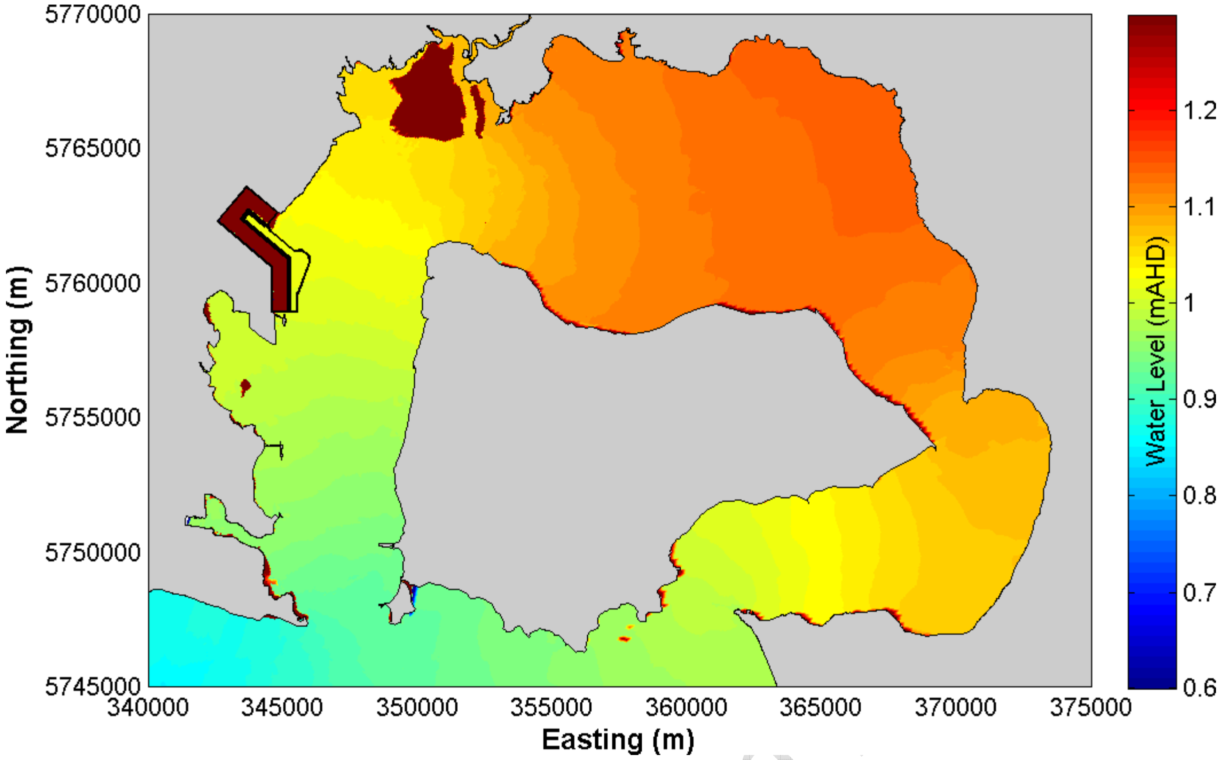

Figure A-3: 90th Percentile WL Exceedance for ALT156 Scenario

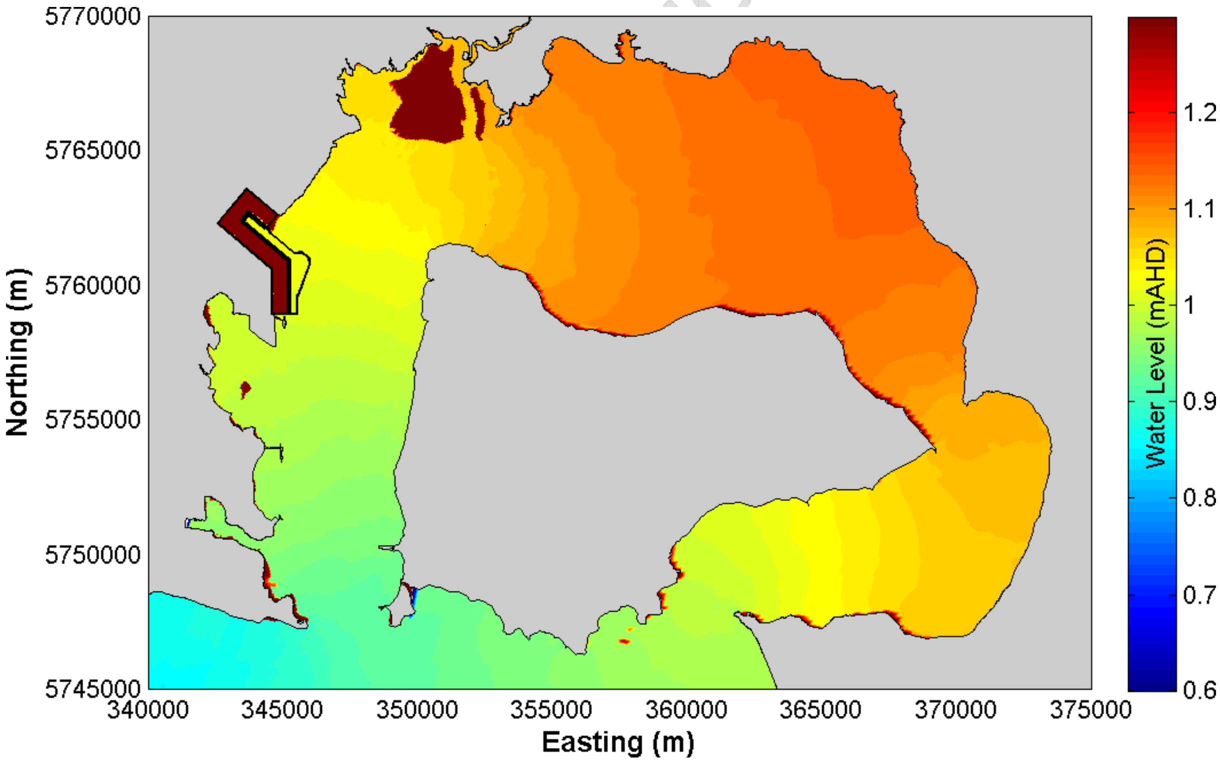

Figure A-4: 90th Percentile WL Exceedance for ALT176 Scenario

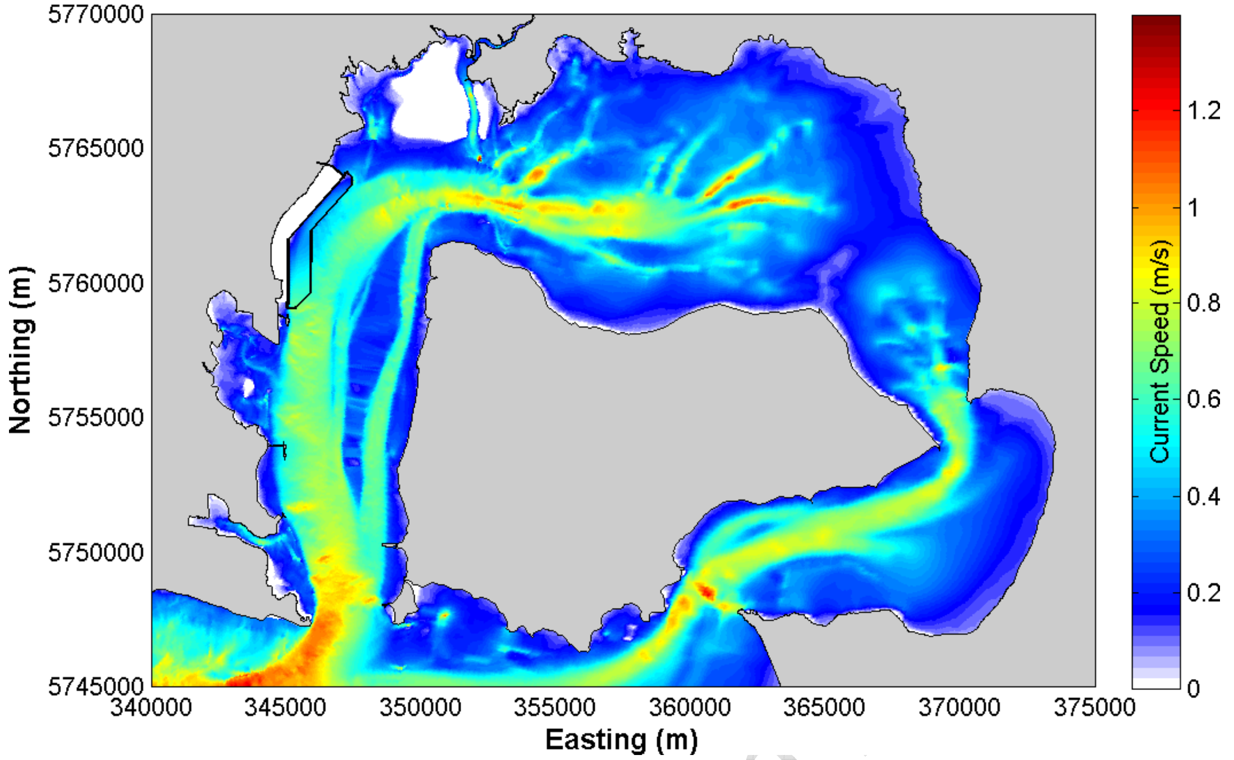

Figure A-5: 90th Percentile Current Speed Exceedance for CTS Scenario

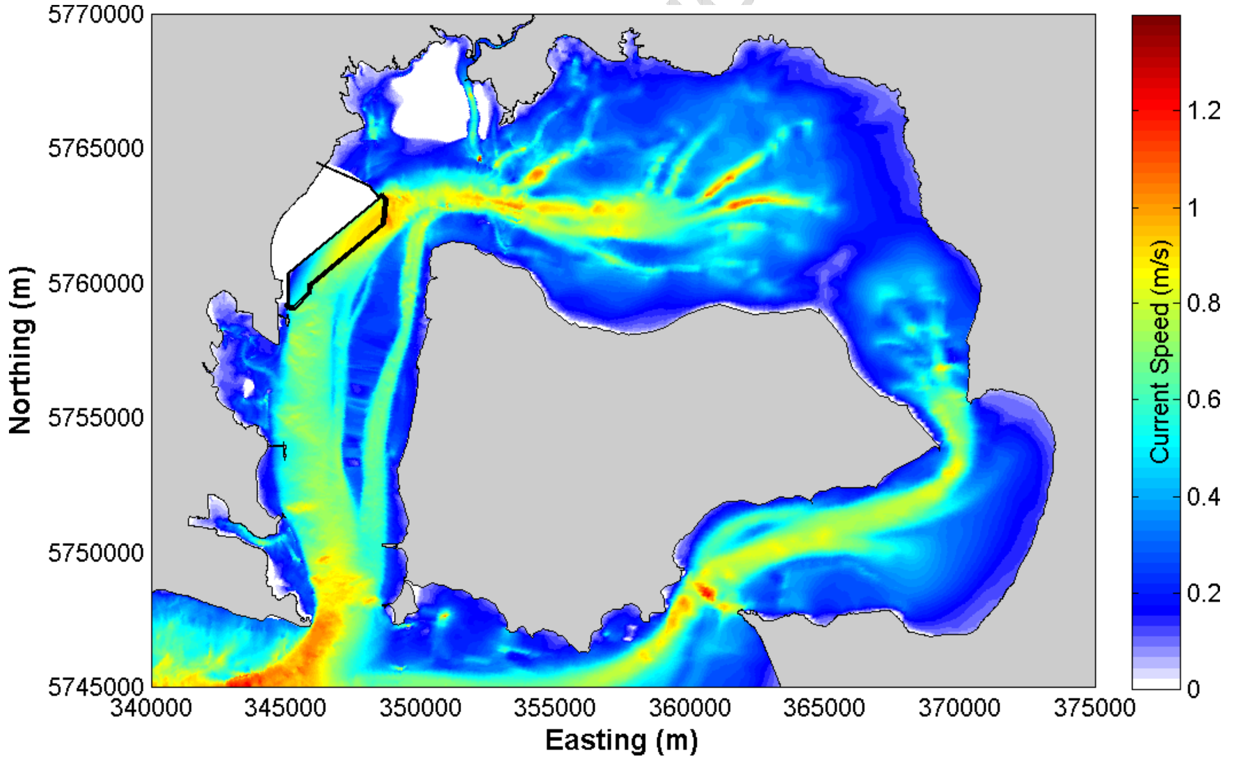

Figure A-6: 90th Percentile Current Speed Exceedance for FOFS Scenario

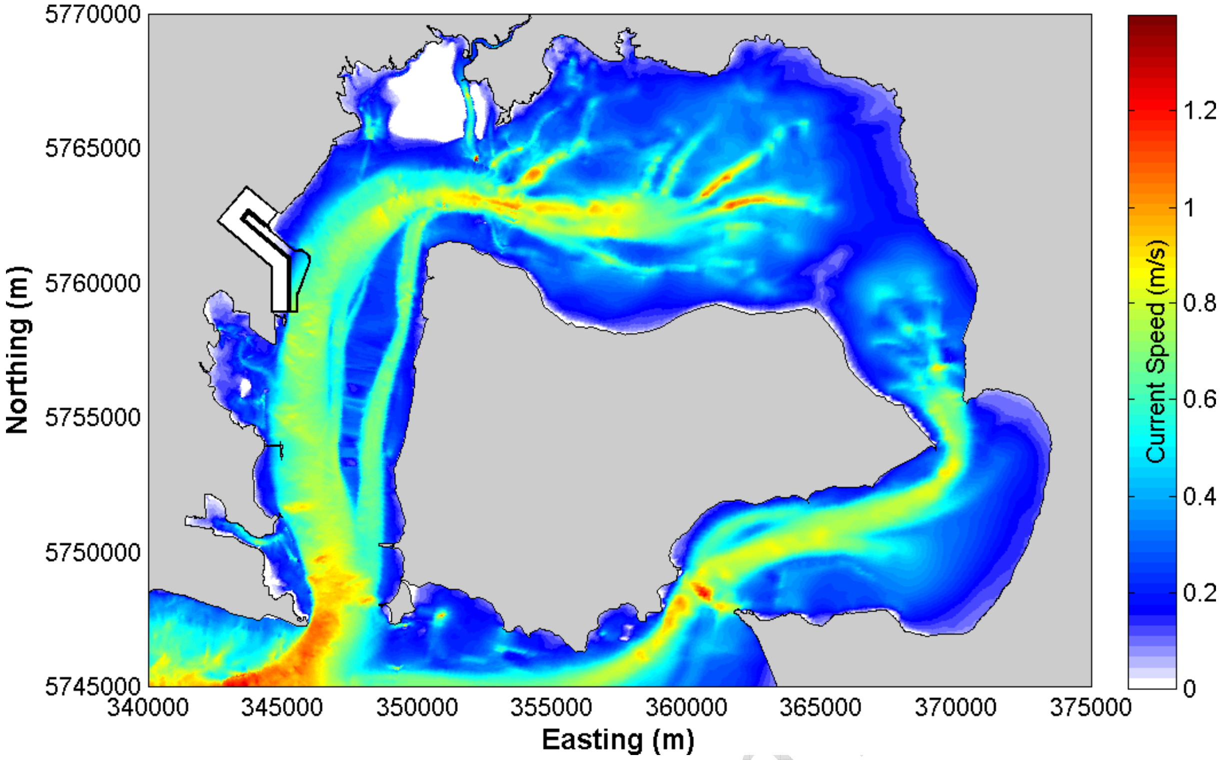

Figure A-7: 90th Percentile Current Speed Exceedance for ALT156 Scenario

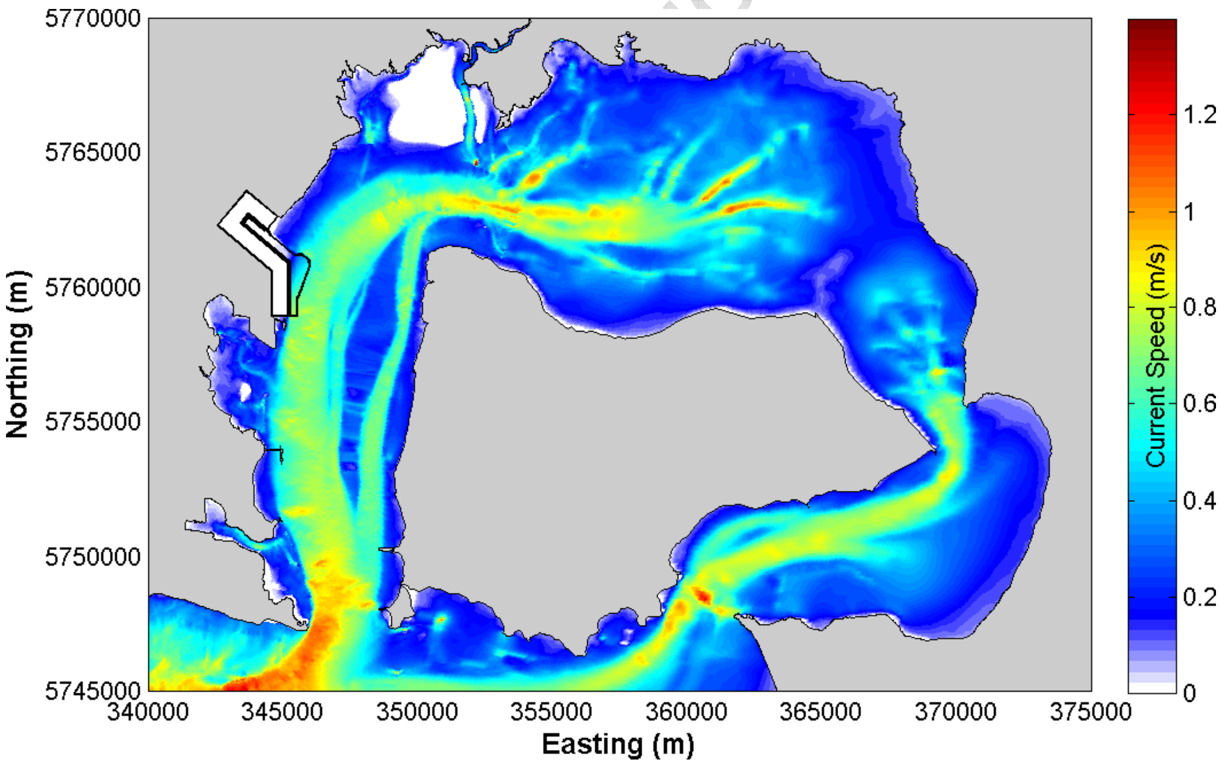

Figure A-8: 90th Percentile Current Speed Exceedance for ALT176 Scenario

Appendix B WL AND VELOCITY CHANGE TIMESERIES

Table B-1: Summary of Change in Water Level and Current Speed

Figure	Scenario	Impact	Comment
Change in Water Level and Current Speed (Site 5 – Near Proposed Port Site)			
B-1	FOFS	M	Restricted channel width increases current speeds adjacent to the quay face by up to 0.2 m/s, though at this location the increase only occurs on the flood tide. WL changes (of up to 5 cm) are mainly due to changes in the timing of the tide.
B-2	CTS	M	Increased channel cross section area reduces current speeds at this location by up to 0.1 m/s. WL changes (of up to 2.5 cm) are mainly due to changes in the timing of the tide.
B-3	ALT156	L	Minimal change to currents or WL's occur at this location.
B-4	ALT176	L	Minimal change to currents or WL's occur at this location.
Change in Water Level and Current Speed (Site 1 – Entrance Lower North Arm)			
B-5	FOFS	M	Reduced conveyance results in reduced current speeds into the Lower North Arm.
B-6	CTS	L-M	Reduced conveyance results in reduced current speeds into the Lower North Arm.
B-7	ALT156	L	Minimal change to currents or WL's occur at this location.
B-8	ALT176	L	Minimal change to currents or WL's occur at this location.
Change in Water Level and Current Speed (Site 13 – Approximate Location of Tidal Divide)			
B-9	FOFS	L-M	At this location current speeds are very low and there is only a very small change in current speed due to the scenario. WL difference of up to 2 cm due to a difference in the timing of the tide.
B-10	CTS	L-M	At this location current speeds are low and there is only a small change in current speed. WL difference of up to 2 cm due to a difference in the timing of the tide.
B-11	ALT156	L	Minimal change to currents or WL's occur at this location.
B-12	ALT176	L	Minimal change to currents or WL's occur at this location.

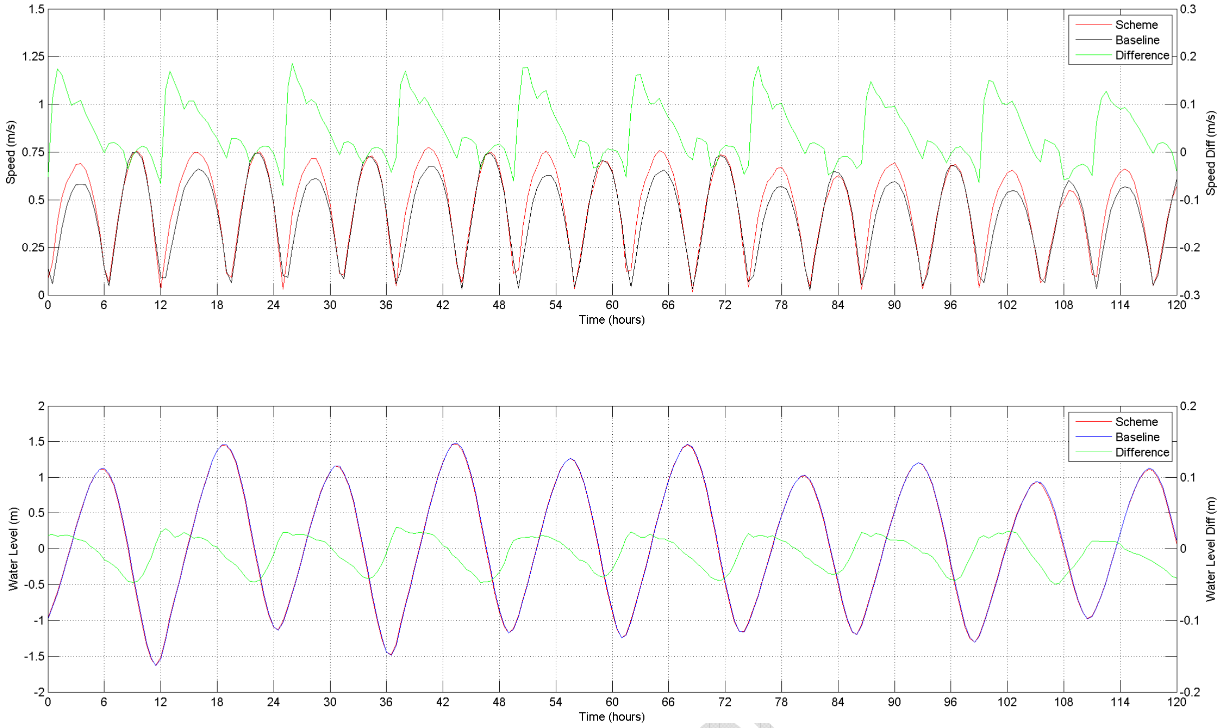

Figure B-1: Change in Water Level and Current Speed for FOFS Scenario Site 5

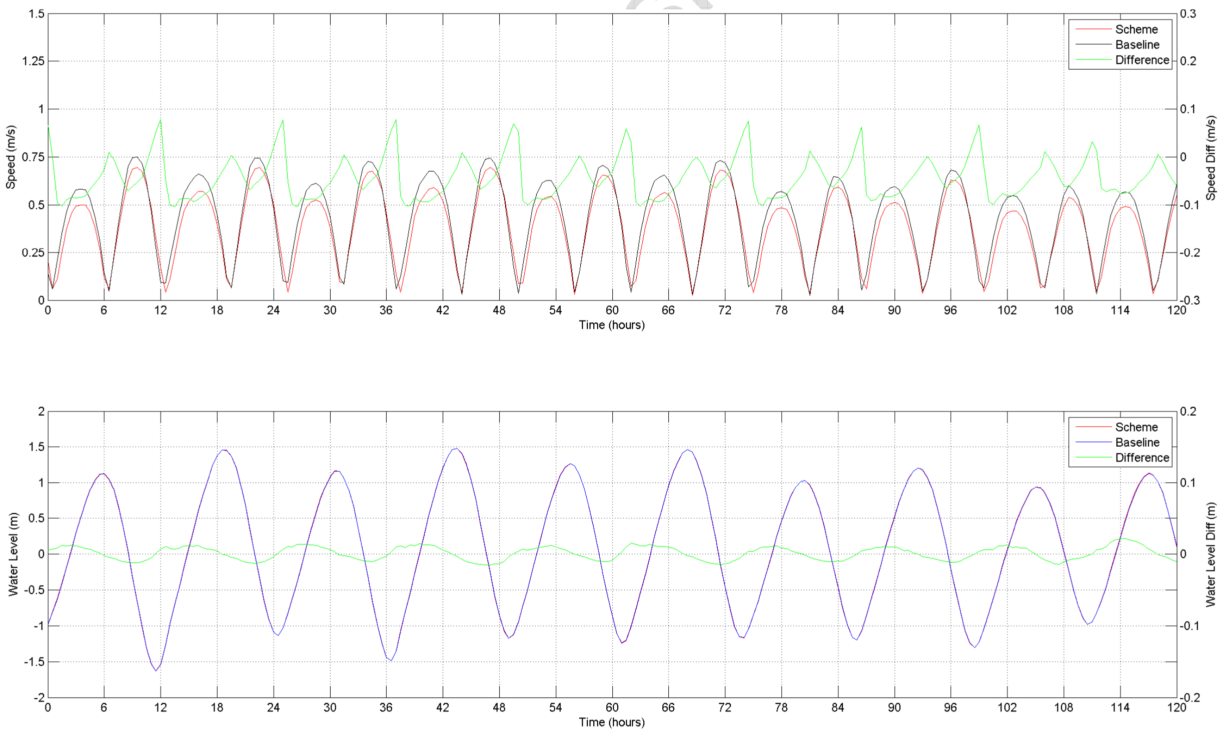

Figure B-2: Change in Water Level and Current Speed for CTS Scenario Site 5

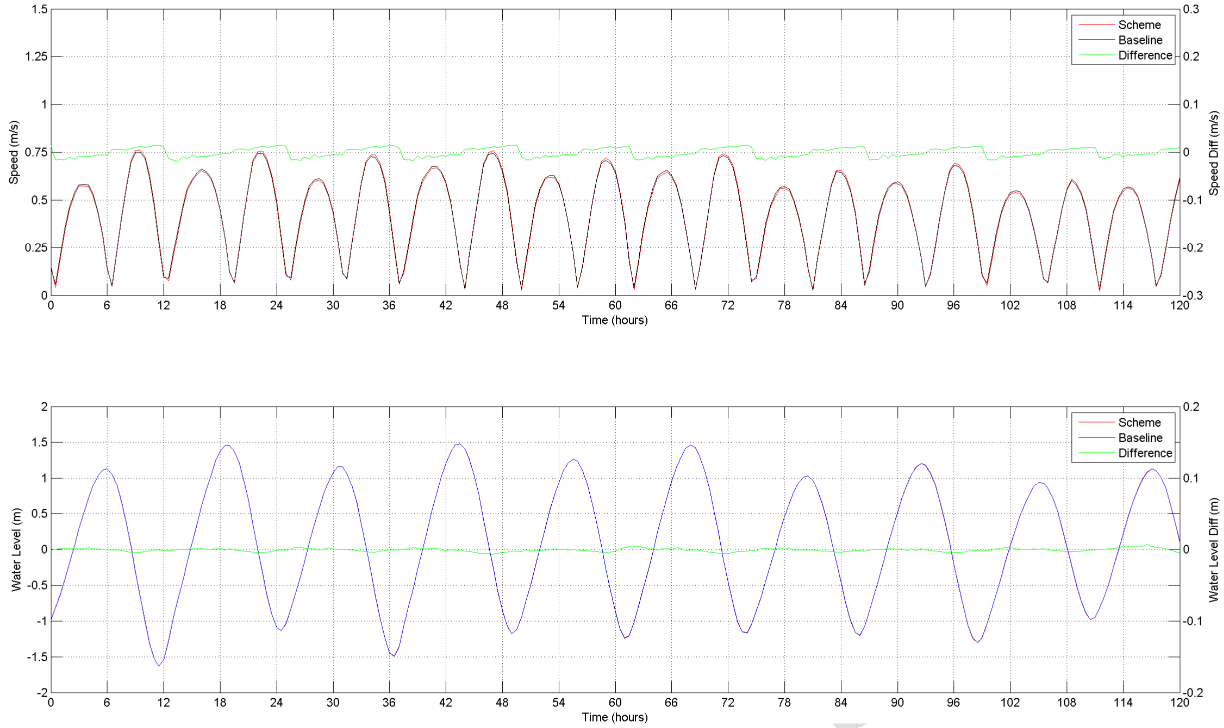

Figure B-3: Change in Water Level and Current Speed for ALT156 Scenario Site 5

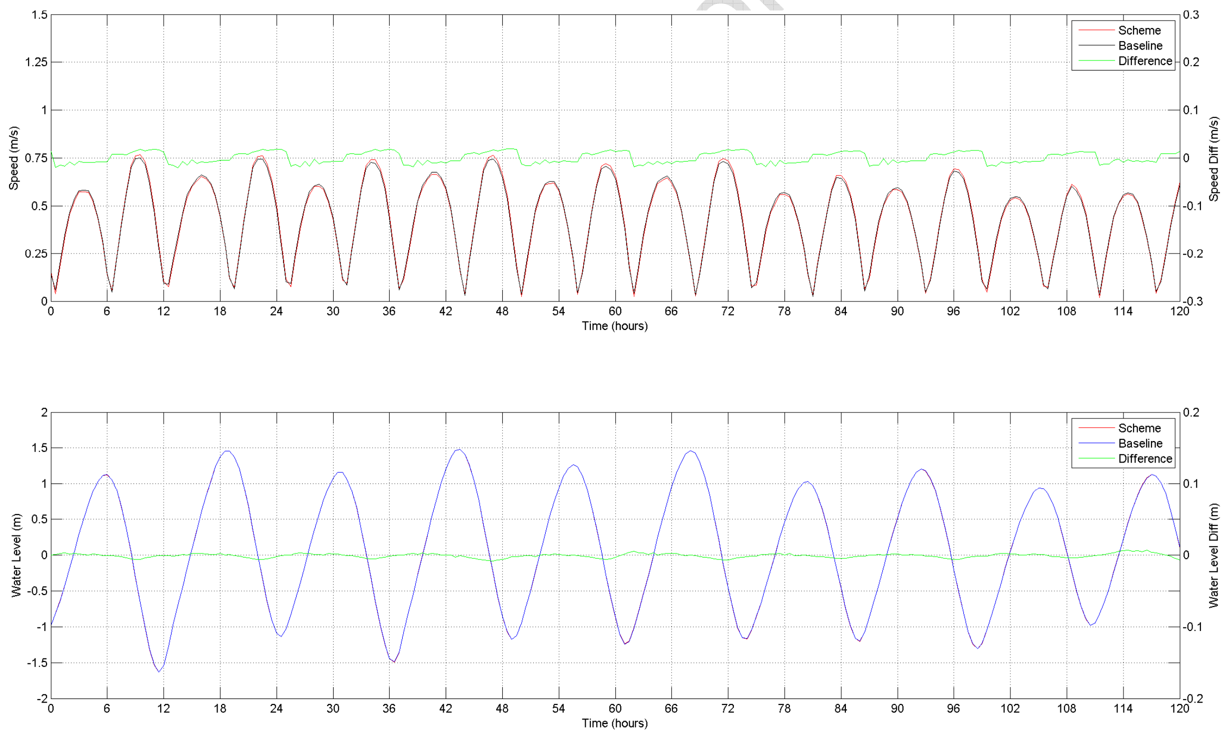

Figure B-4: Change in Water Level and Current Speed for ALT176 Scenario Site 5

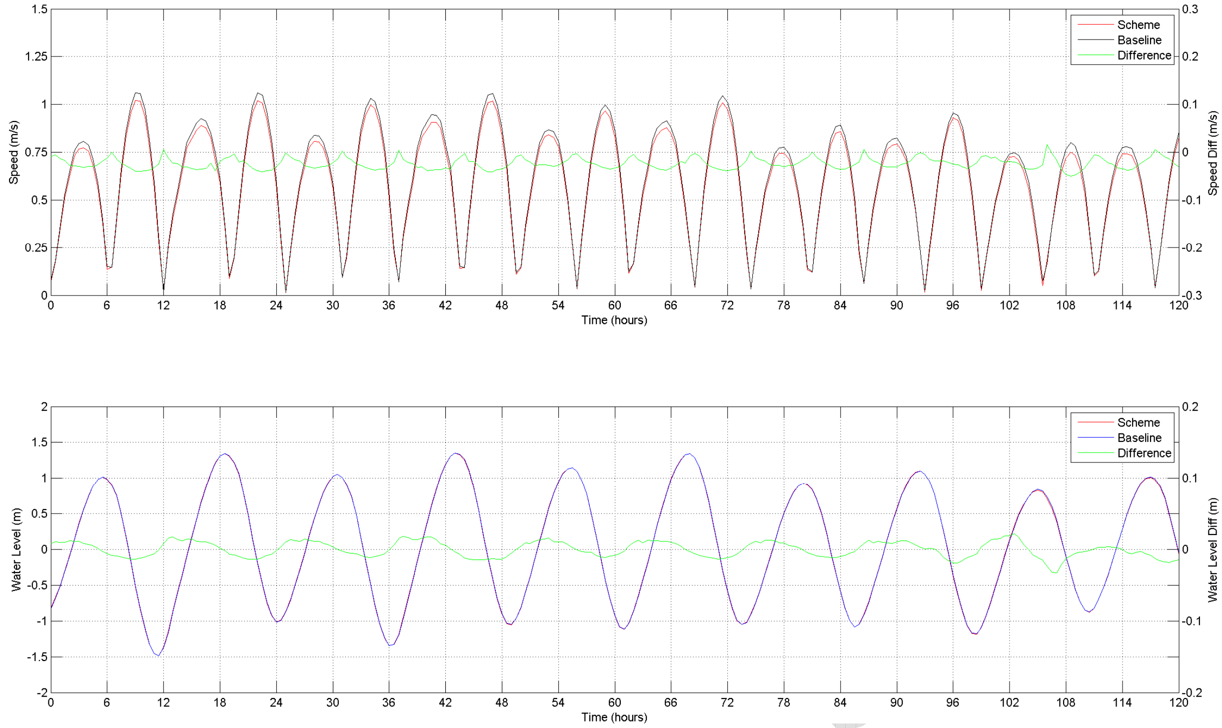

Figure B-5: Change in Water Level and Current Speed for FOFS Scenario Site 1

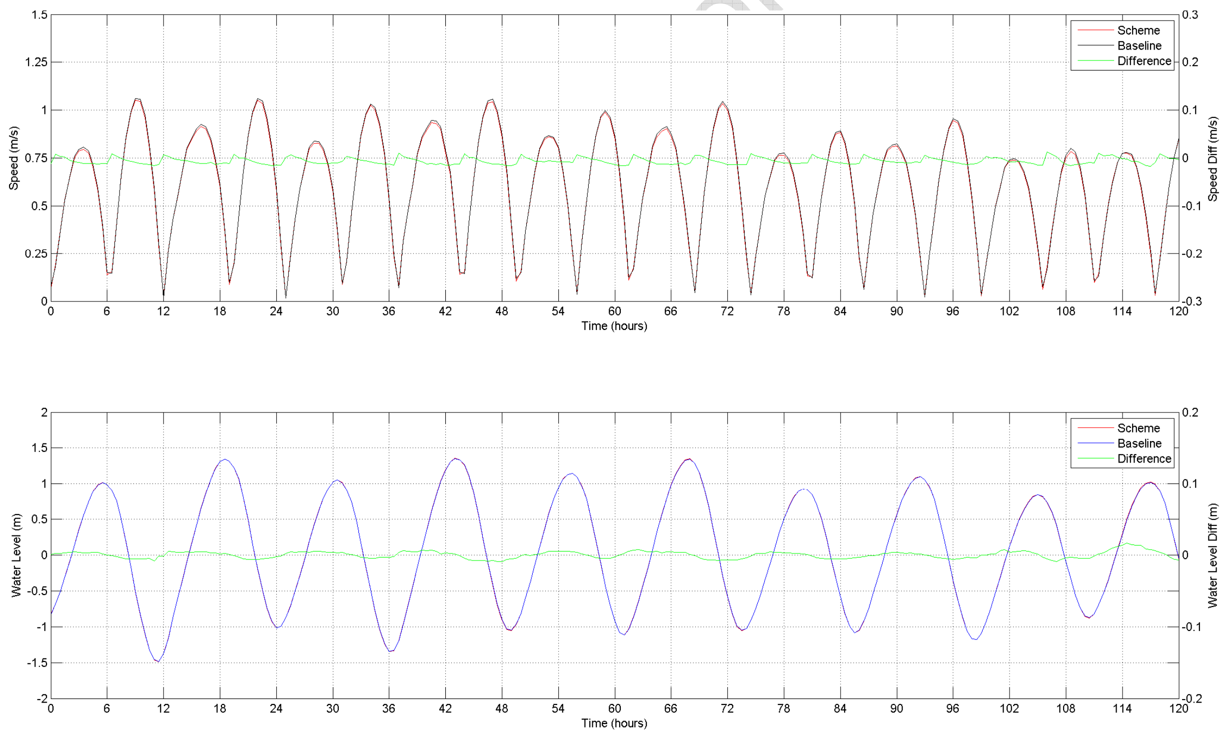

Figure B-6: Change in Water Level and Current Speed for CTS Scenario Site 1

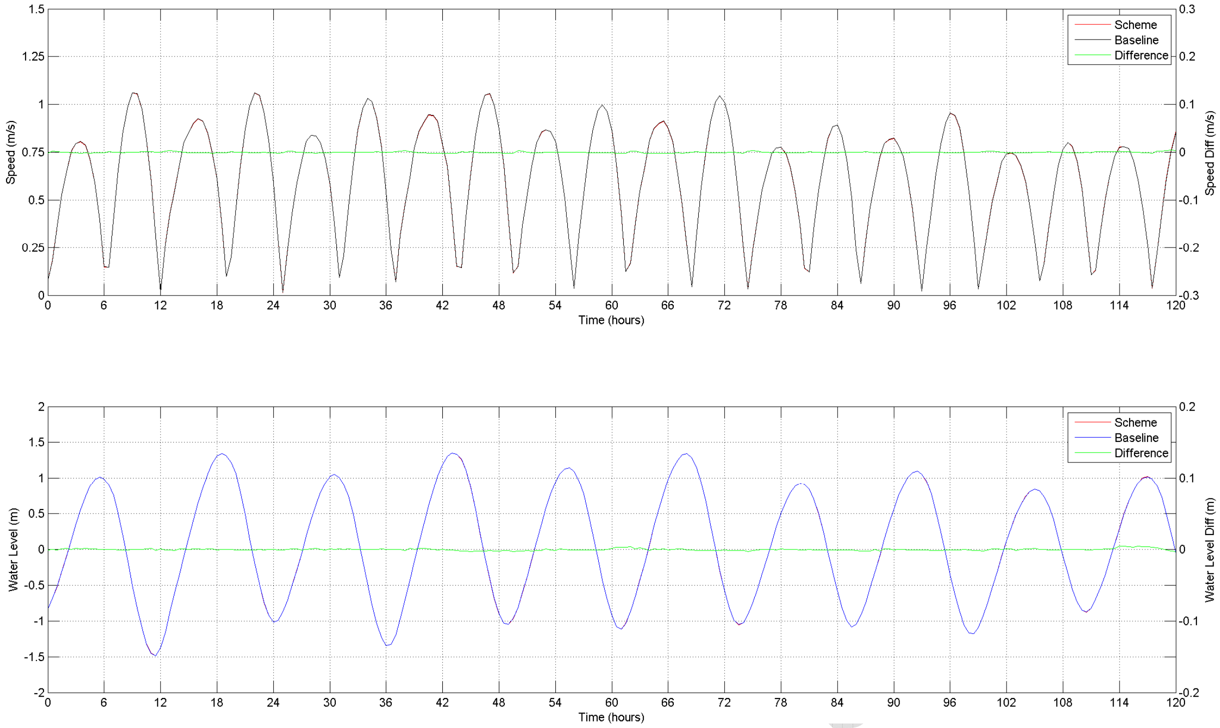

Figure B-7: Change in Water Level and Current Speed for ALT156 Scenario Site 1

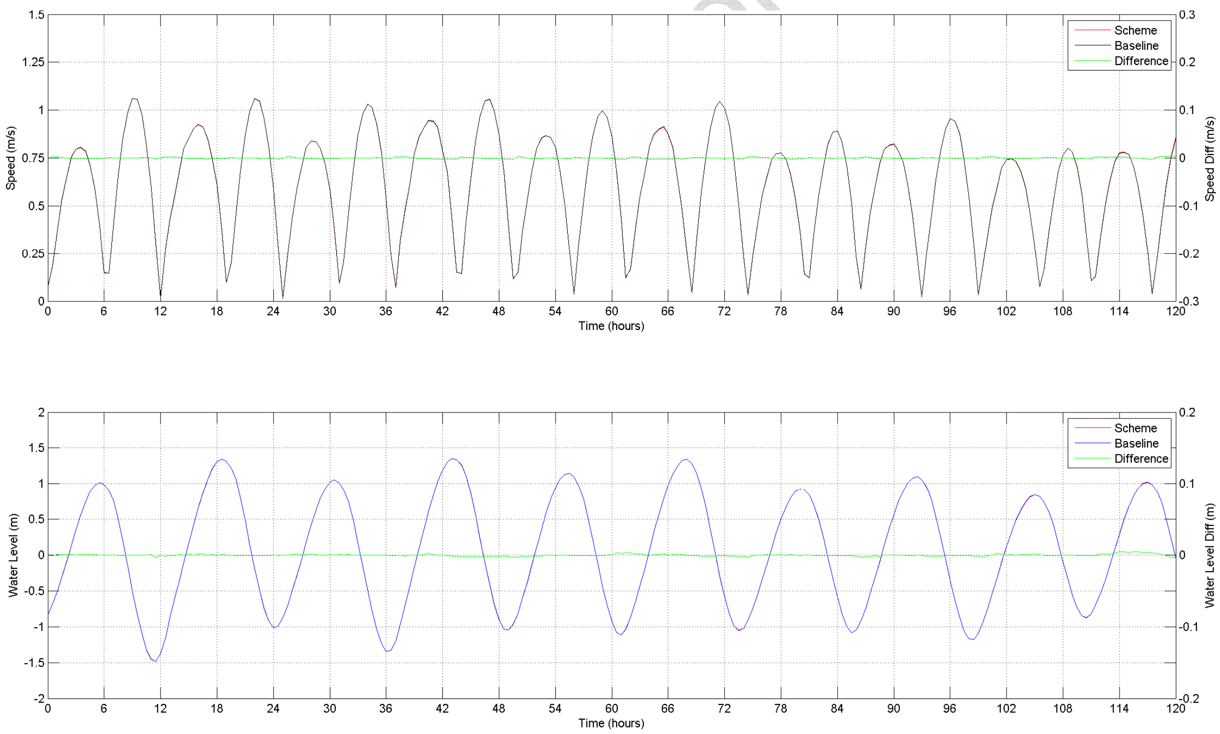

Figure B-8: Change in Water Level and Current Speed for ALT176 Scenario Site 1

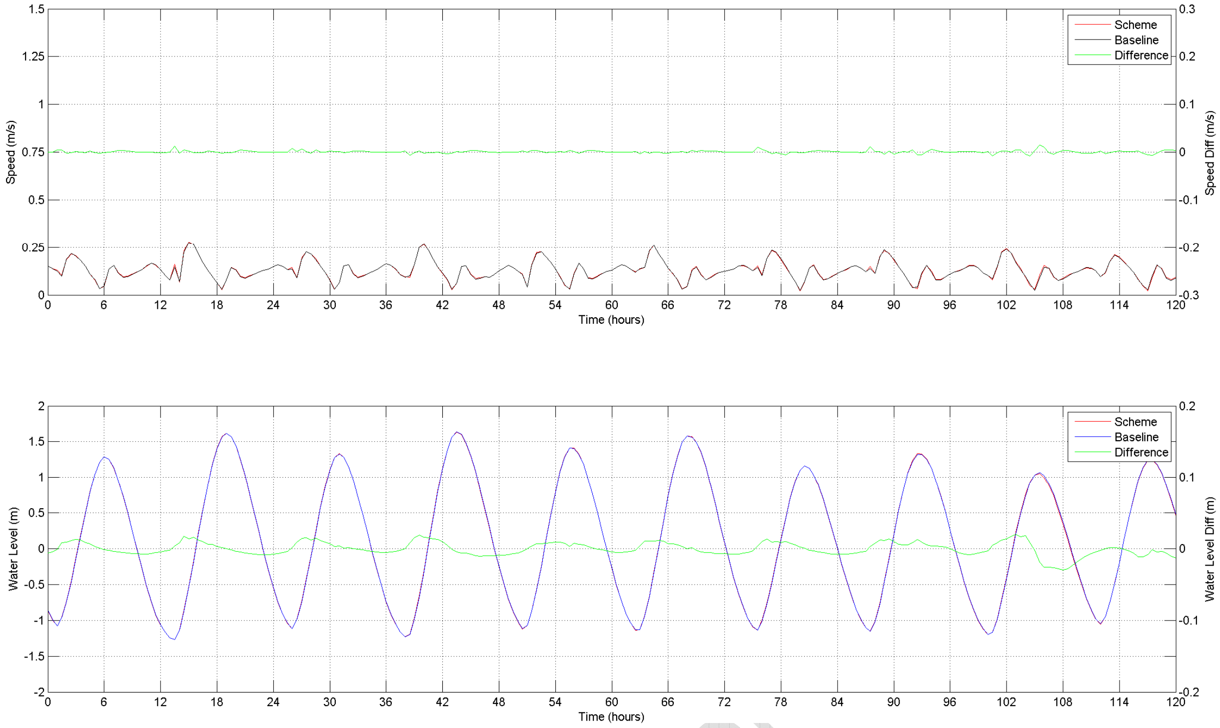

Figure B-9: Change in Water Level and Current Speed for FOFS Scenario Site 13

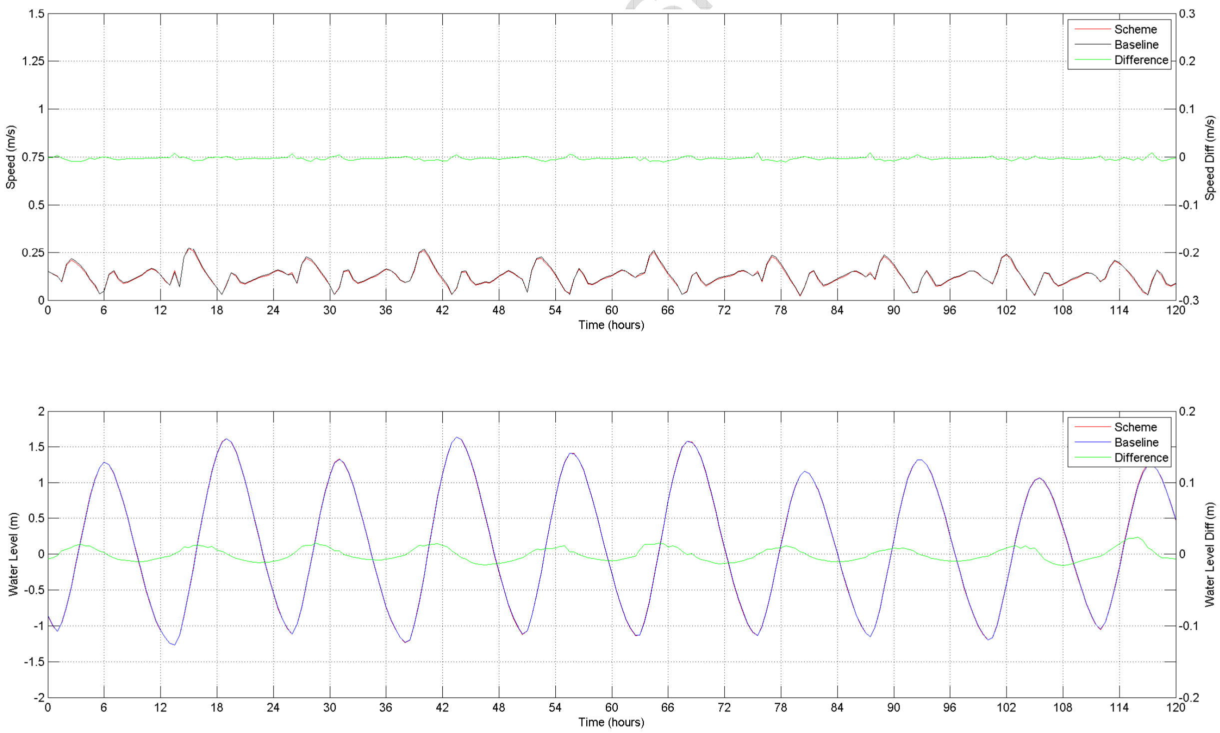

Figure B-10: Change in Water Level and Current Speed for CTS Scenario Site 13

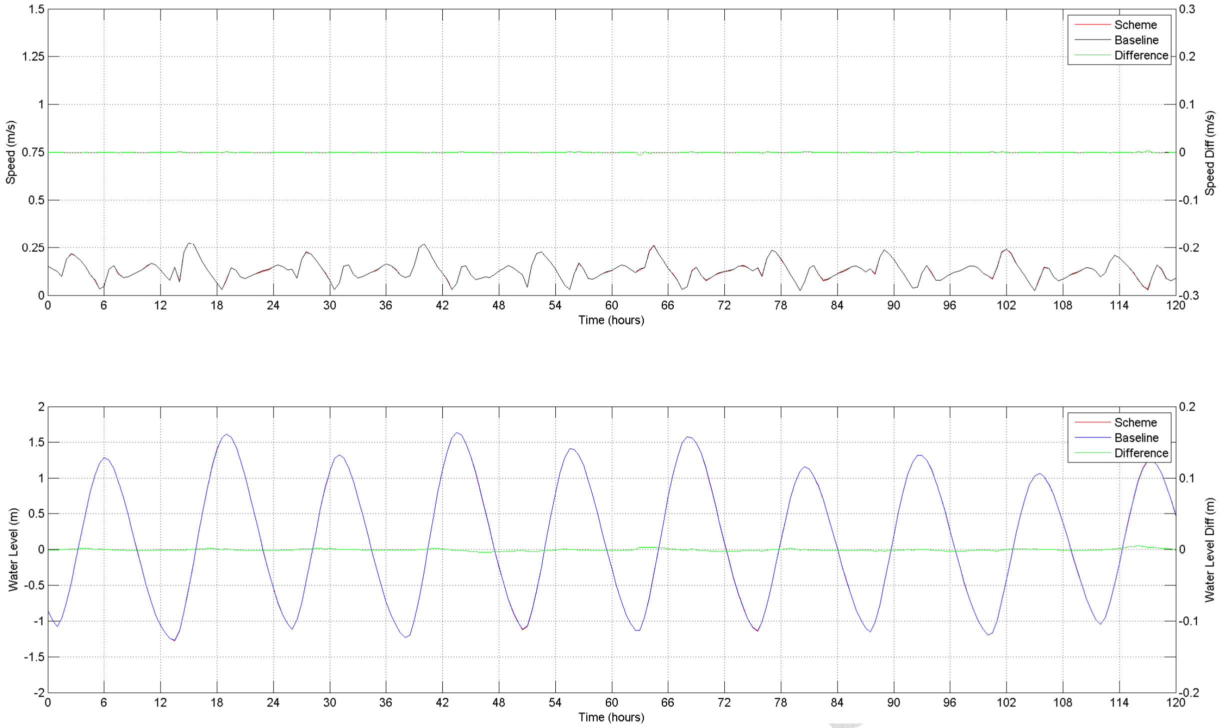

Figure B-11: Change in Water Level and Current Speed for ALT156 Scenario Site 13

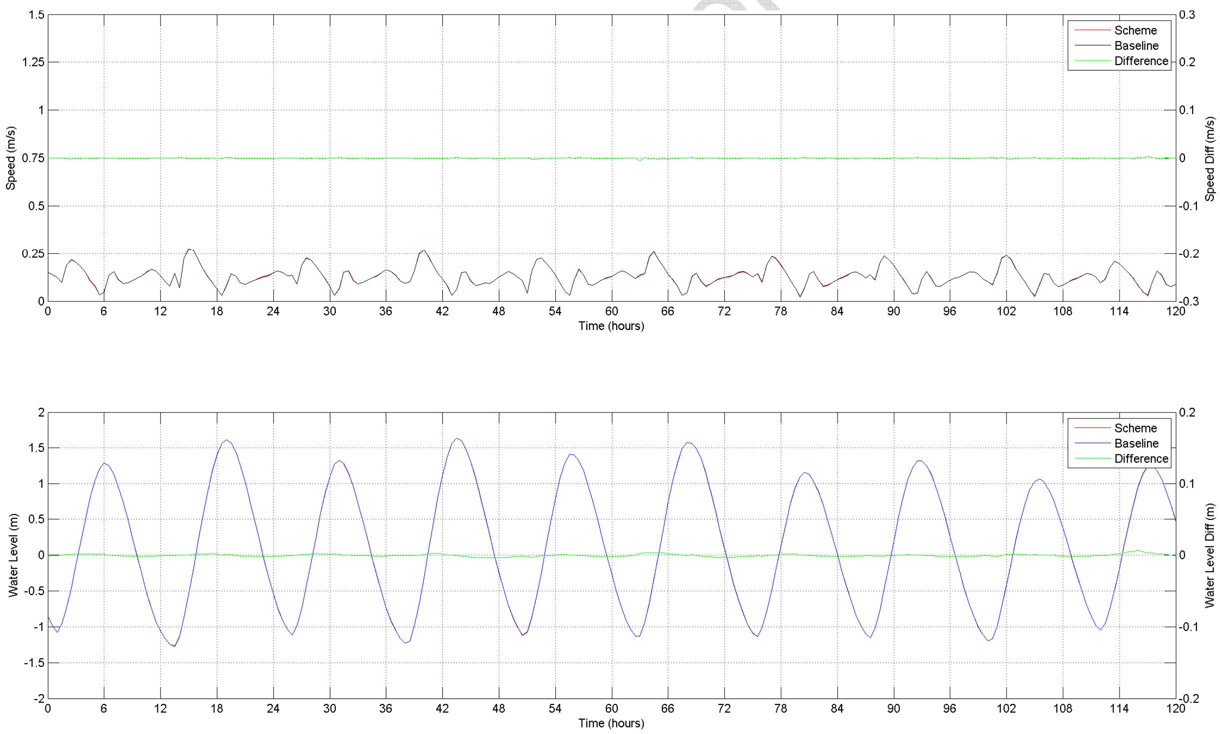

Figure B-12: Change in Water Level and Current Speed for ALT176 Scenario Site 13

Appendix C MAPS OF WL AND VELOCITY CHANGES DUE TO DESIGN SCENARIOS

Spatial changes to water levels and currents caused by the scenarios have been assessed as described below.

Spatial Change in Water Level and Currents

The impact of the design scenarios on water levels (WL) and currents within Western Port have been assessed by calculating the differences in water levels, current speed and current direction (vectors) between the existing condition and each of the four port development scenarios. WL differences have been calculated for a peak ebb (PE), low water (LW), peak flood (PF), and high water (HW) condition for the spring tidal cycle occurring on the 17th December 2012. The time of each tide stage is:

- peak flood (17 Dec 16:00);
- high water (17 Dec 18:30);
- peak ebb (17 Dec 22:30);
- low water (18 Dec 00:30).

Spatial Change in Current Speed

The spatial impact (difference) of the design scenarios on current speed compared to the existing scenario is presented in Figure C-1 to Figure C-16 and summarised in Table C-1.

Spatial Change in Water Levels

The spatial impact (difference) of the design scenarios on water levels (WL) compared to the existing scenario is presented in Figure C-17 to Figure C-32 and summarised in Table C-2. It is important to note that some differences in water levels are due to changes in the timing of the tide.

Spatial Change in Current Direction (Vector)

The spatial impact (difference) of the design scenarios on current direction compared to the existing scenario is presented in Figure C-33 to Figure C-48 and summarised in Table C-3. Blue vector arrows represent the currents for the existing scenario while red vector arrows represent the scenario options.

Table C-1: Summary of Change in Current Speed Impacts

Figure	Scenario	Impact	Comment
Change in Current Speed (Peak Flood)			
C-1	FOFS	M-H	Reduced channel width causes an increase in current speed > 0.1 m/s adjacent to the wharf. South of the wharf there is a reduction in current speed due to reduced overall conveyance in the Lower North Arm channel.
C-2	CTS	L-M	Dredging of the berths allows for increased current speeds adjacent to the berth face, however, overall there is slightly reduced conveyance in the Lower North Arm resulting in a reduced channel speed of ~0.1 m/s to the east of the quay.
C-3	ALT156	L	This scenario causes only localised impacts of below +/- 0.05 m/s.
C-4	ALT176	L	This scenario causes only localised impacts of below +/- 0.05 m/s.
Change in Current Speed (High Water)			
C-5	FOFS	M	Again the reduced channel width results in increased velocities immediately to the east of the quay, however there is an overall reduction in current velocity in the Lower North Arm for the scenario. At high water, current speeds are reduced and so is the difference between the scenario and the existing case.
C-6	CTS	L-M	Again slightly reduced conveyance in the Lower North Arm causes an overall reduction in current speed, however there are some localised increases in current speed typically < 0.05 m/s.
C-7	ALT156	L	Again there is only minimal and localised impact.
C-8	ALT176	L	Again there is only minimal and localised impact.
Change in Current Speed (Peak Ebb)			
C-9	FOFS	M-H	Reduced channel width causes an increase in current speed > 0.1 m/s adjacent to the wharf. South of the wharf there is a reduction in current speed due to reduced overall conveyance in the Lower North Arm channel.
C-10	CTS	L-M	Dredging of the berths allows for increased current speeds. This scenario results in increased channel conveyance in the Lower North Arm
C-11	ALT156	L	This scenario causes only localised impacts of below +/- 0.05 m/s.
C-12	ALT176	L	This scenario causes only localised impacts of below +/- 0.05 m/s.
Change in Current Speed (Low Water)			
C-13	FOFS	M	Reduced conveyance has overall reduced current speeds, however, there are still some areas of increased current speed.
C-14	CTS	L-M	Reduced conveyance has overall reduced current speeds, however, there are still some areas of increased current speed.
C-15	ALT156	L	This scenario causes only very localised impacts of below +/- 0.05 m/s.
C-16	ALT176	L	This scenario causes only very localised impacts of below +/- 0.05 m/s.

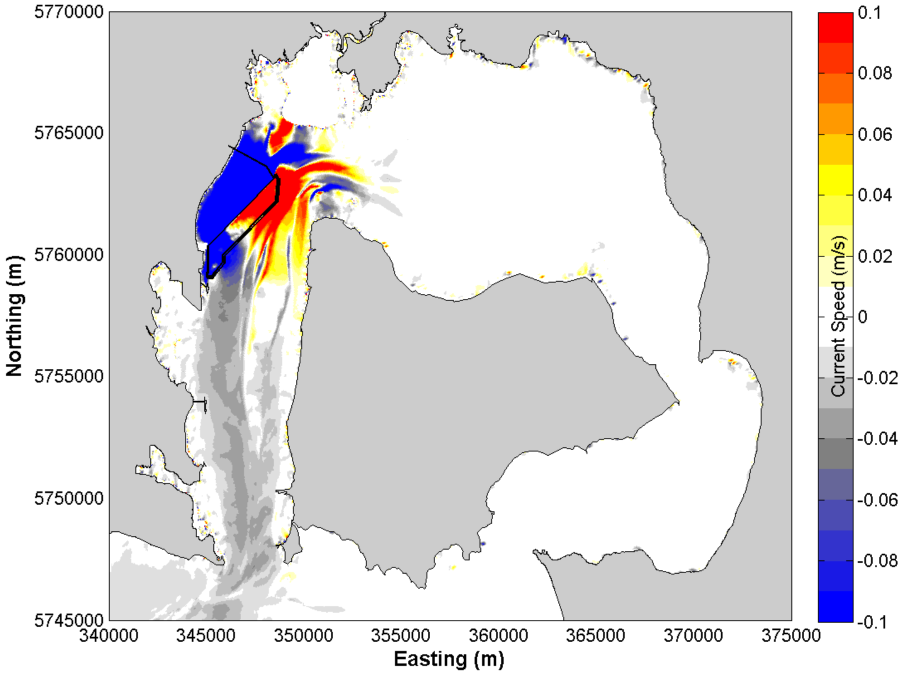

Figure C-1: Change in Peak Flood Current Speed for FOFS Scenario

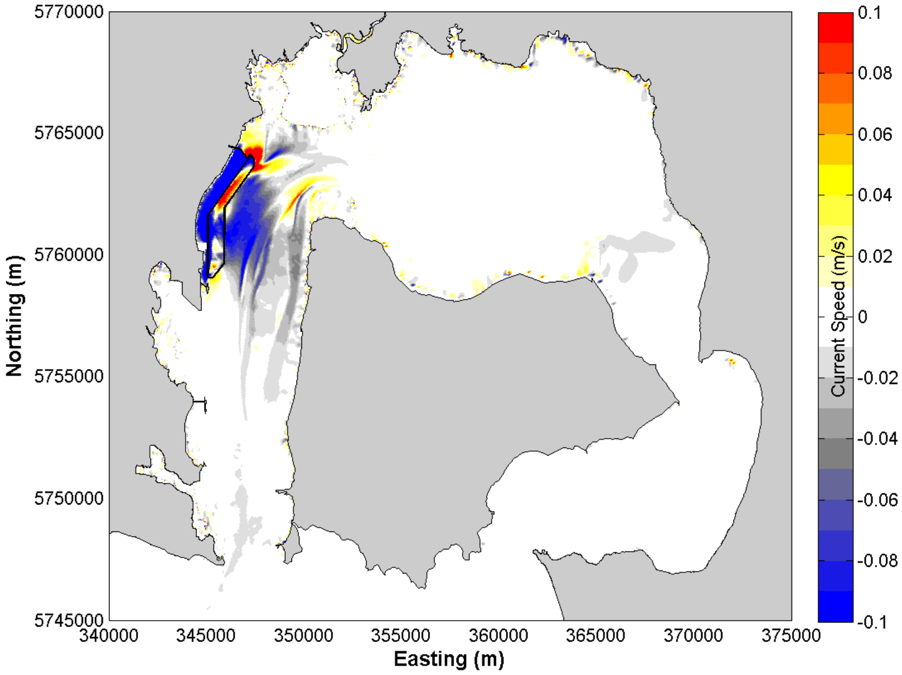

Figure C-2: Change in Peak Flood Current Speed for CTS Scenario

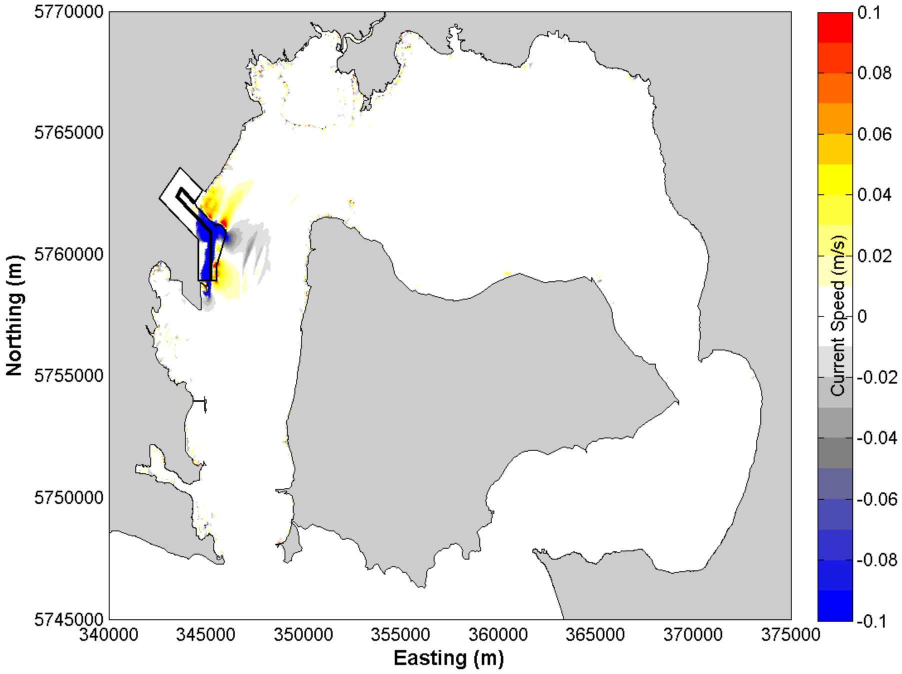

Figure C-3: Change in Peak Flood Current Speed for ALT156 Scenario

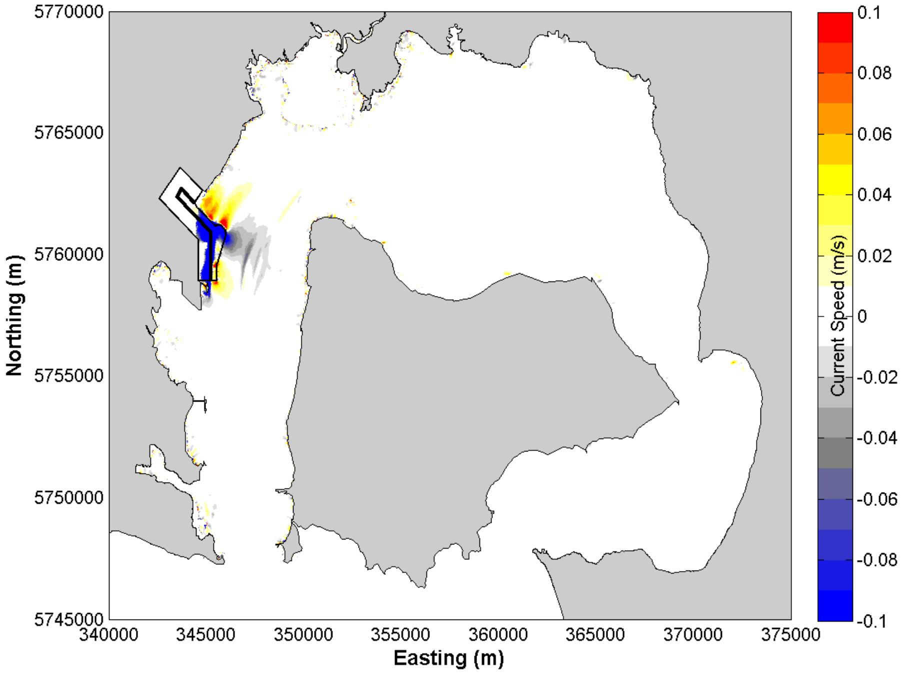

Figure C-4: Change in Peak Flood Current Speed for ALT176 Scenario

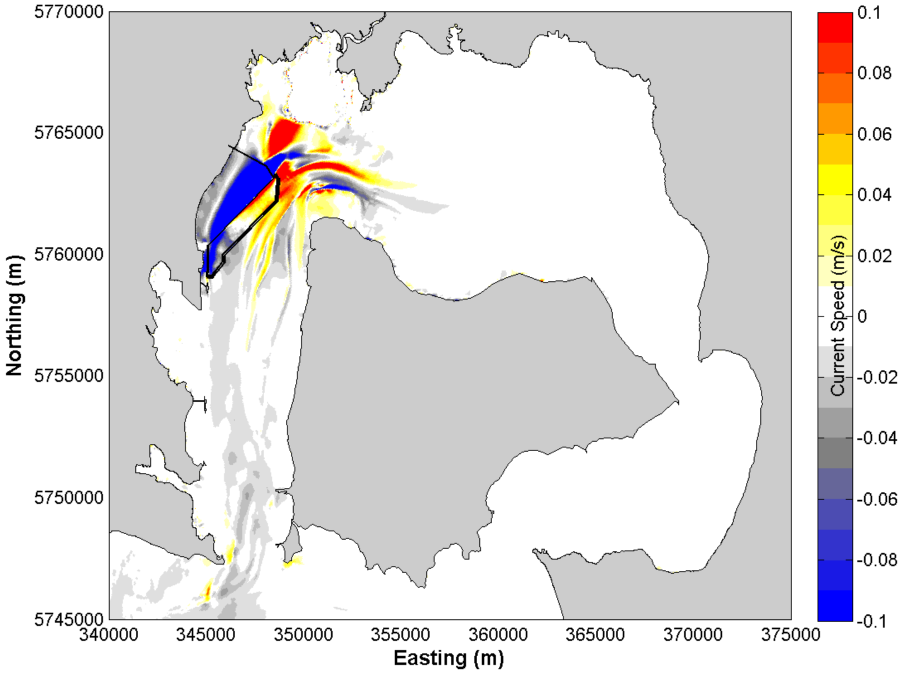

Figure C-5: Change in High Water Current Speed for FOFS Scenario

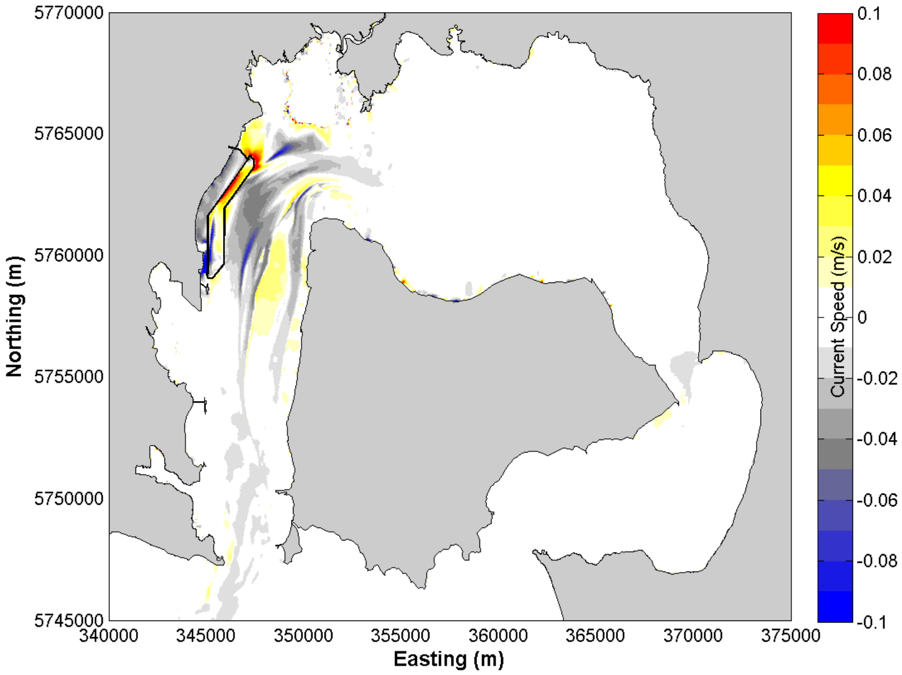

Figure C-6: Change in High Water Current Speed for CTS Scenario

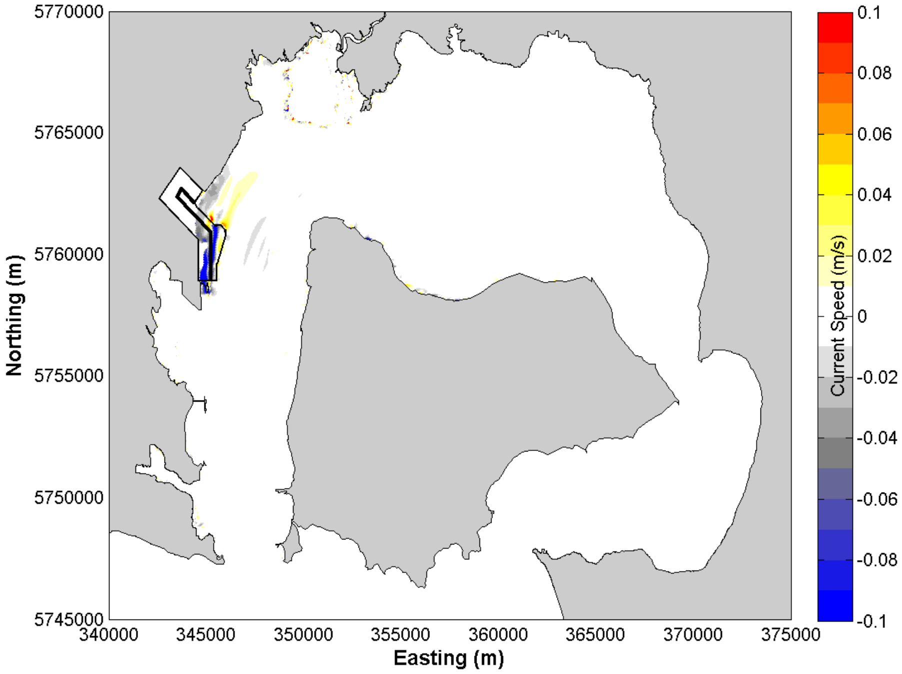

Figure C-7: Change in High Water Current Speed for ALT156 Scenario

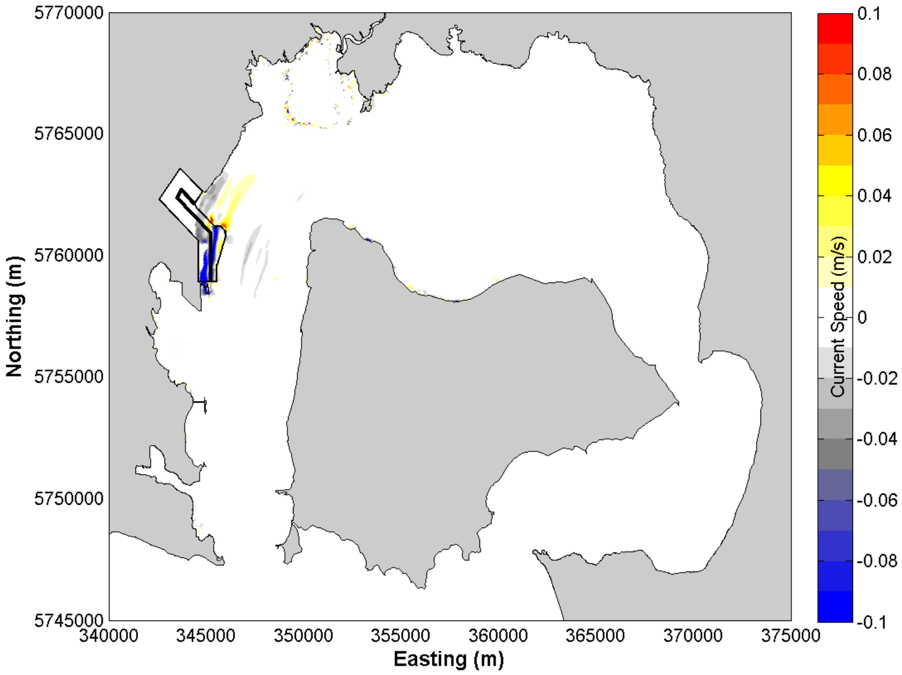

Figure C-8: Change in High Water Current Speed for ALT176 Scenario

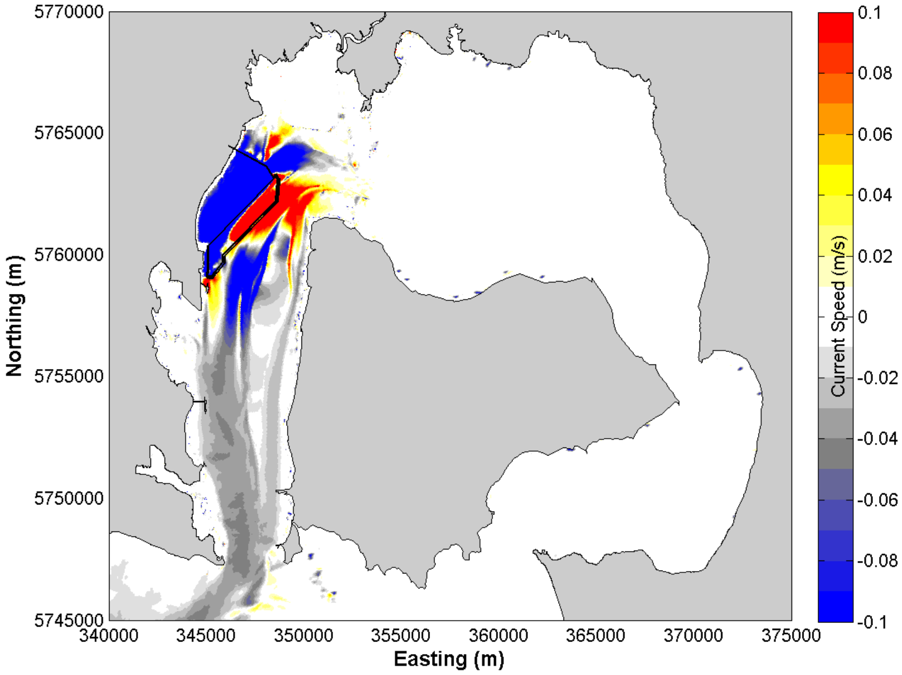

Figure C-9: Change in Peak Ebb Current Speed for FOFS Scenario

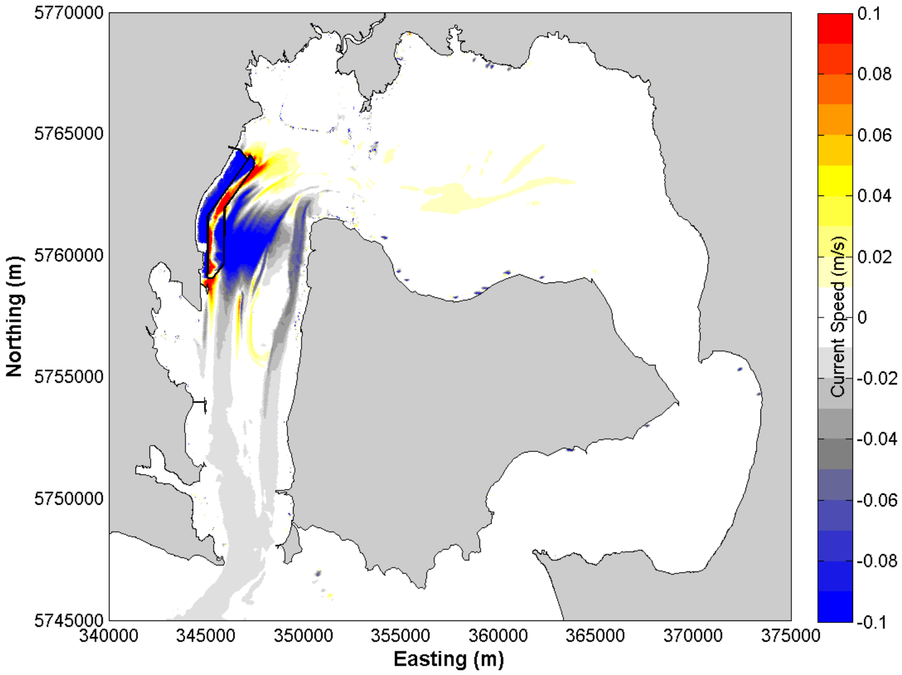

Figure C-10: Change in Peak Ebb Current Speed for CTS Scenario

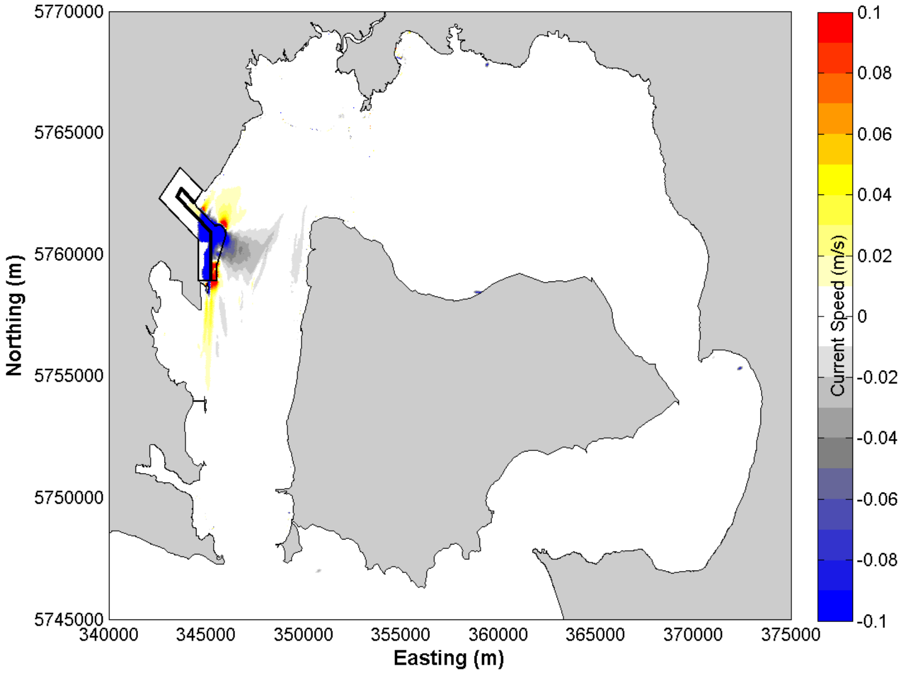

Figure C-11: Change in Peak Ebb Current Speed for ALT156 Scenario

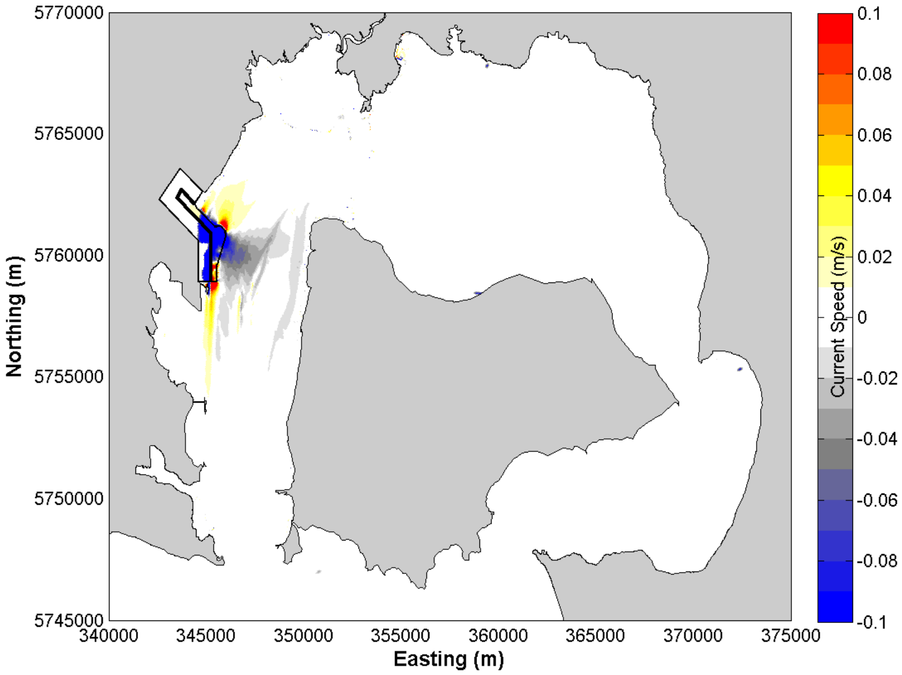

Figure C-12: Change in Peak Ebb Current Speed for ALT176 Scenario

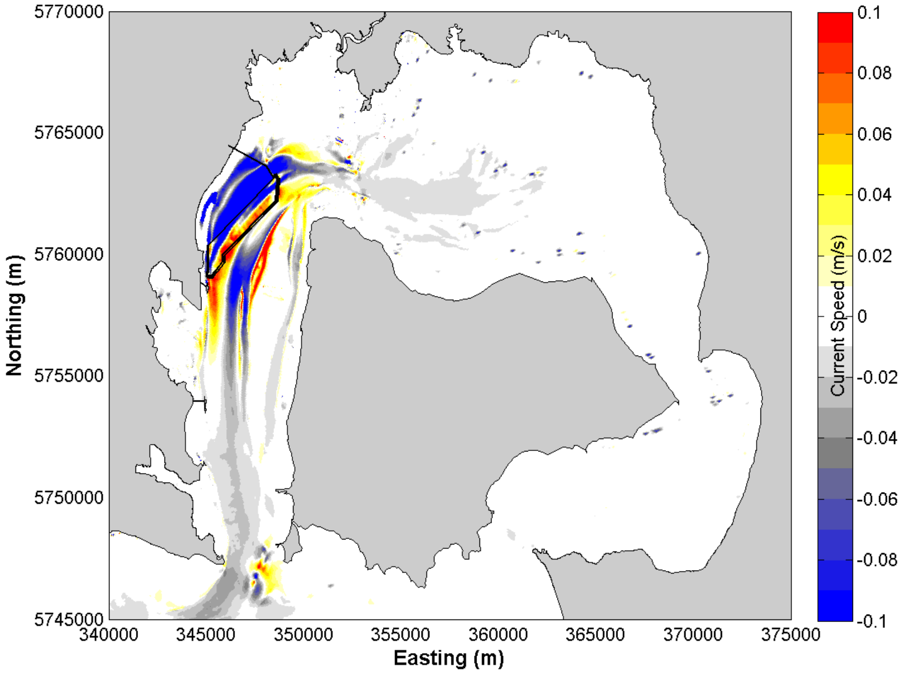

Figure C-13: Change in Low Water Current Speed for FOFS Scenario

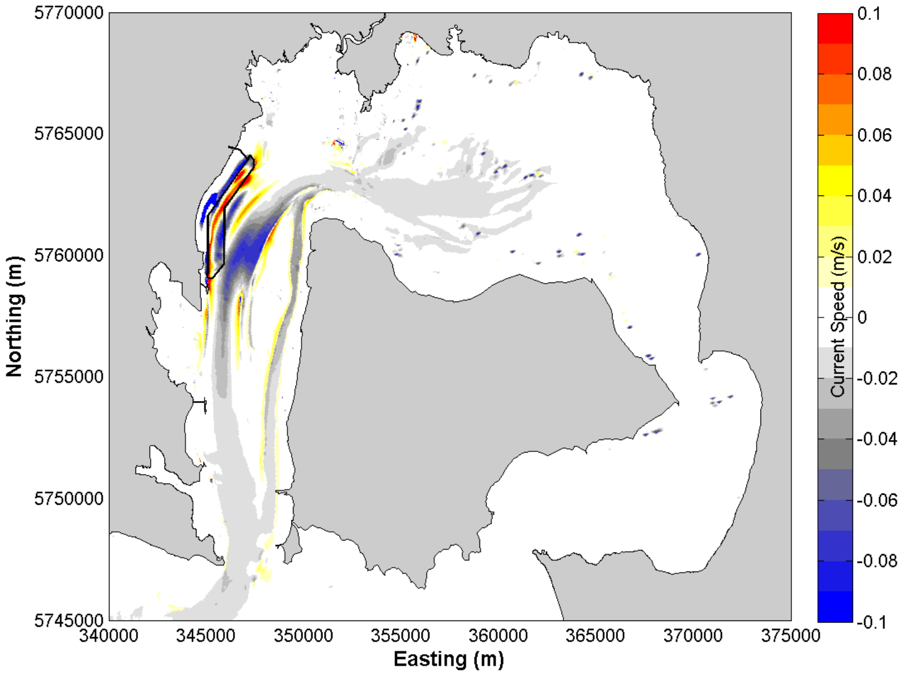

Figure C-14: Change in Low Water Current Speed for CTS Scenario

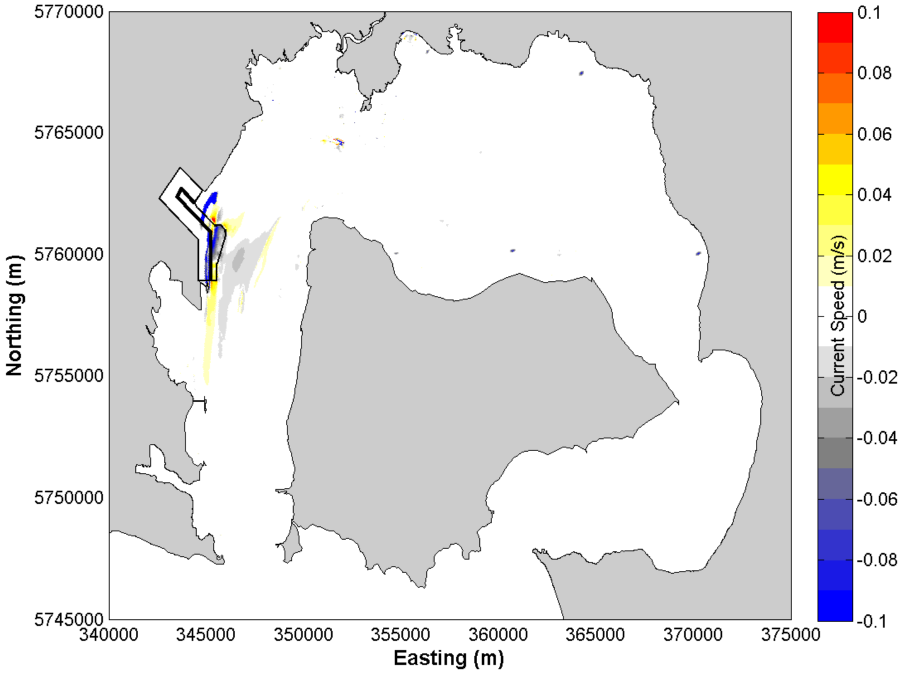

Figure C-15: Change in Low Water Current Speed for ALT156 Scenario

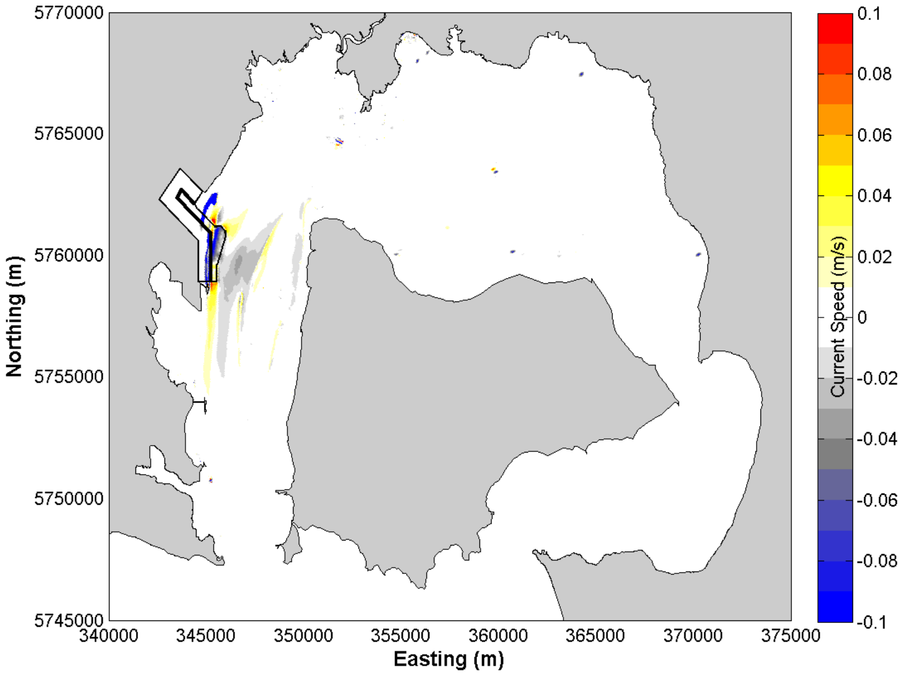

Figure C-16: Change in Low Water Current Speed for ALT176 Scenario

Table C-2: Summary of Change in Water Level Impacts

Figure	Scenario	Impact	Comment
Change in Water Level (Peak Flood)			
C-17	FOFS	M	This scenario increases WL around French Island by 0.5 to 1 cm during the peak flood tide. This is only temporary and is due to slightly different timing of the tide.
C-18	CTS	M	This scenario increases WL's around French Island by up to 1.5 cm during the peak flood tide. This is only temporary and is due to slightly different timing of the tide.
C-19	ALT156	L	This scenario causes insignificant WL change.
C-20	ALT176	L	This scenario causes insignificant WL change.
Change in Water Level (High Water)			
C-21	FOFS	L-M	WL in the Lower North Arm are slightly (~5mm) lower than the existing scenario, however for the remainder of Western Port there is minimal difference.
C-22	CTS	L-M	WL appear slightly higher in the North and East Arm (~5mm) due to a difference in timing of the tides.
C-23	ALT156	L	This scenario causes insignificant WL change.
C-24	ALT176	L	This scenario causes insignificant WL change.
Change in Water Level (Peak Flood)			
C-25	FOFS	H	At this time a WL difference of ~ 2cm is evident.
C-26	CTS	H	At this time a WL difference of ~ 2cm is evident.
C-27	ALT156	L	This scenario causes insignificant WL change.
C-28	ALT176	L	This scenario causes insignificant WL change, but slightly more change than the ALT156 scenario.
Change in Water Level (Low Water)			
C-29	FOFS	M	At this time a WL difference of ~ +/- 1cm is evident.
C-30	CTS	M	At this time a WL difference of ~ -1cm is evident.
C-31	ALT156	L	This scenario causes insignificant WL change.
C-32	ALT176	L	This scenario causes insignificant WL change.

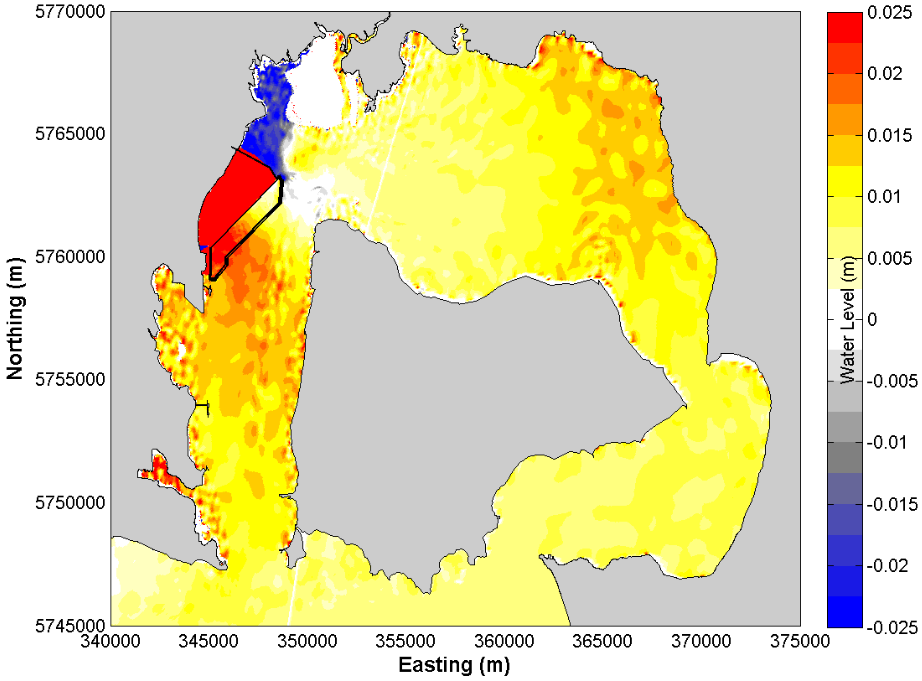

Figure C-17: Change in Peak Flood Water Level for FOFS Scenario

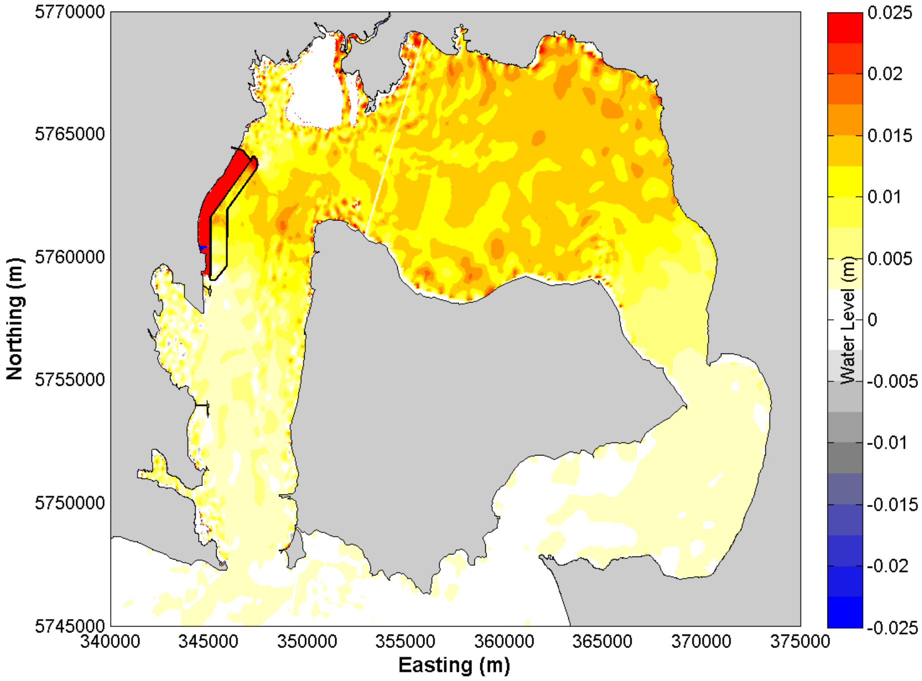

Figure C-18: Change in Peak Flood Water Level for CTS Scenario

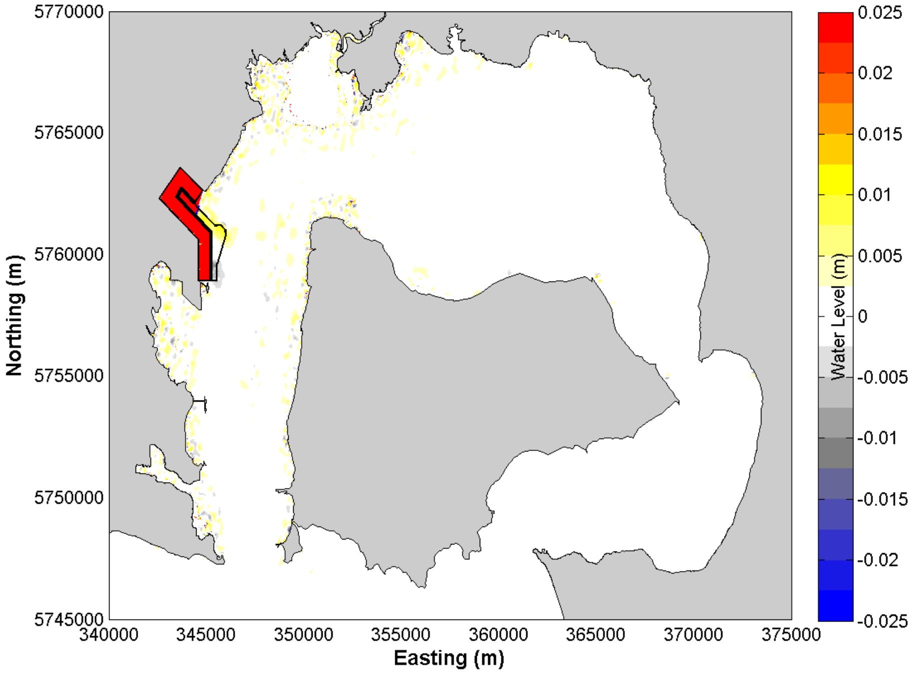

Figure C-19: Change in Peak Flood Water Level for ALT156 Scenario

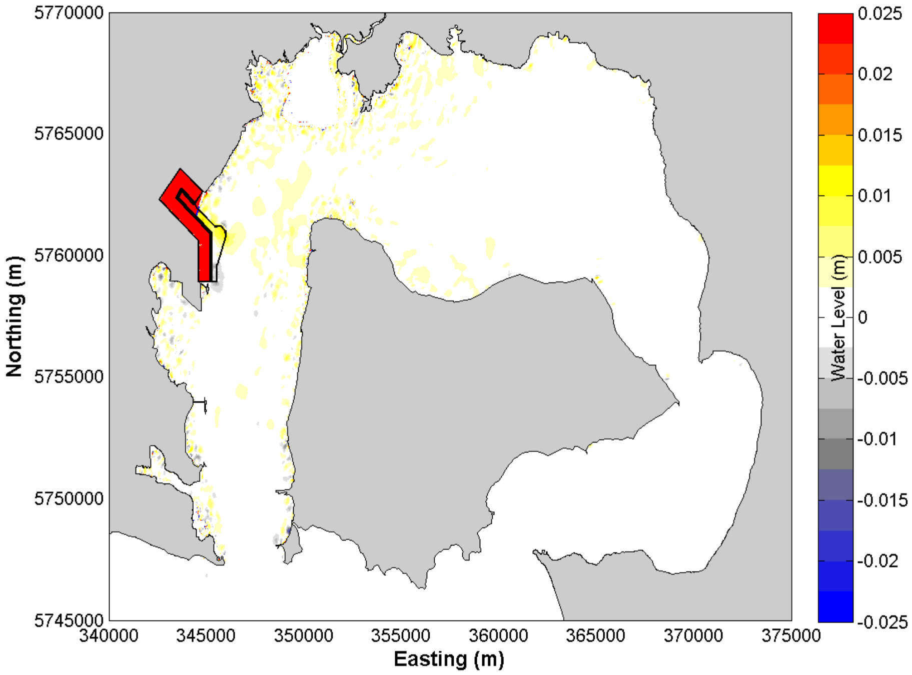

Figure C-20: Change in Peak Flood Water Level for ALT176 Scenario

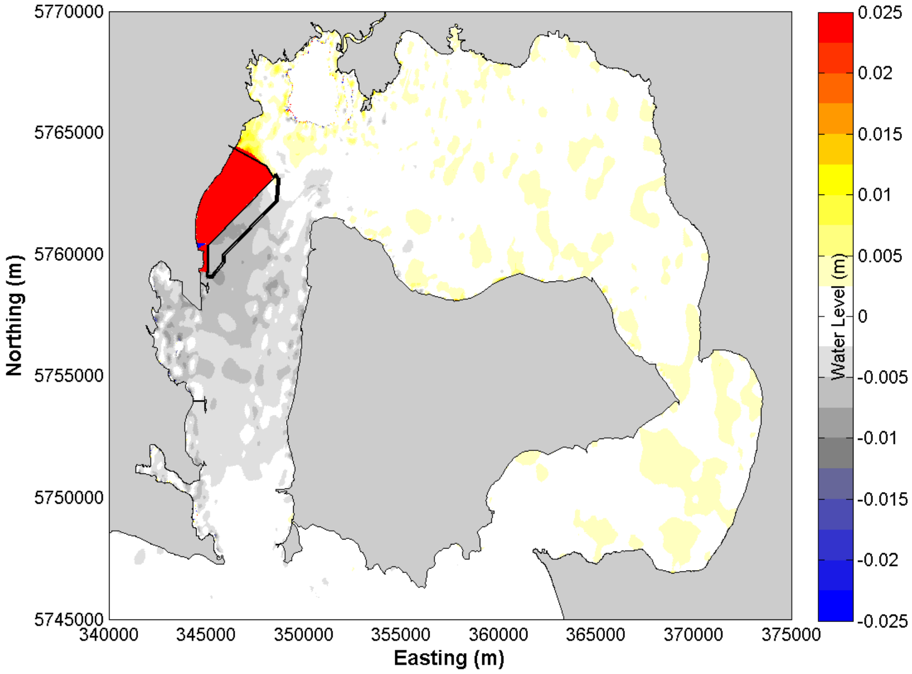

Figure C-21: Change in High Water Level for FOFS Scenario

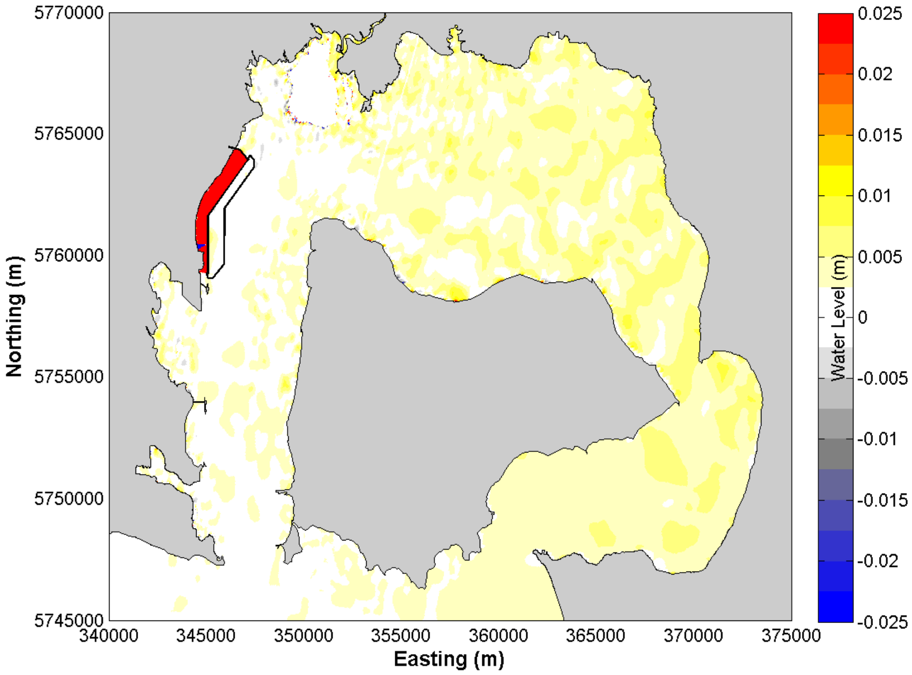

Figure C-22: Change in High Water Level for CTS Scenario

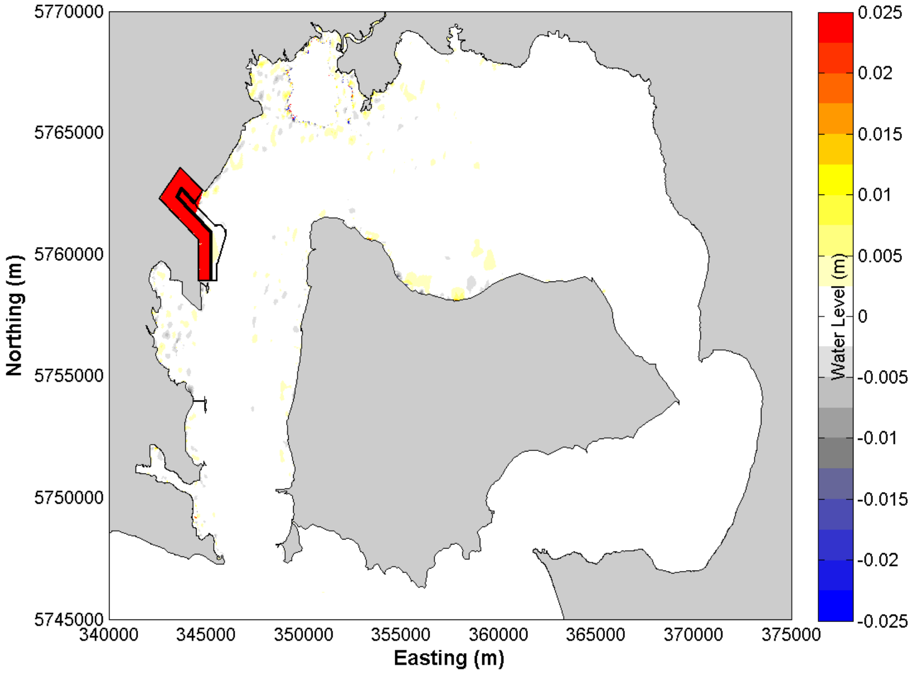

Figure C-23: Change in High Water Level for ALT156 Scenario

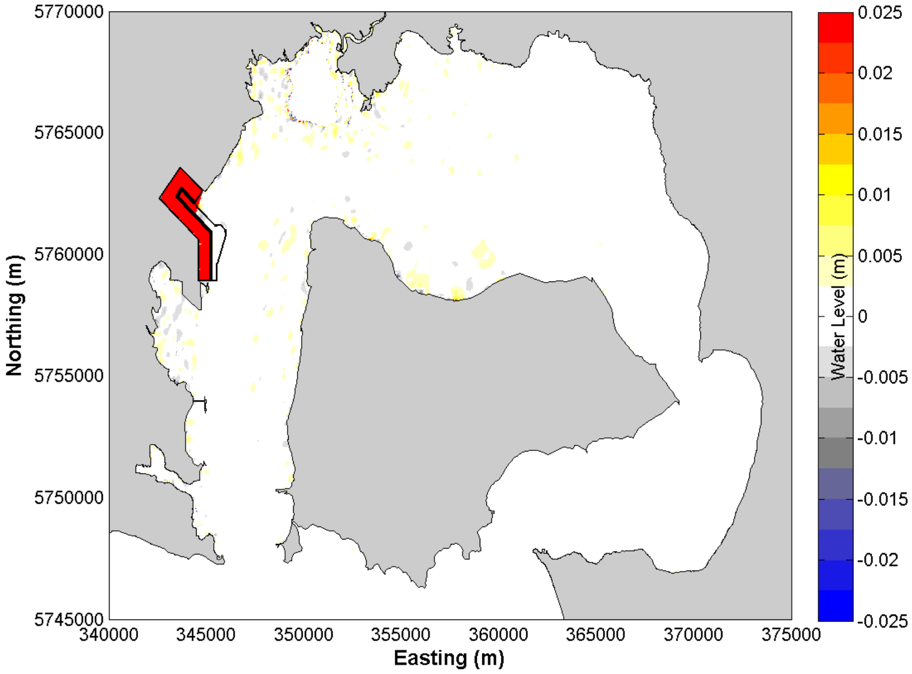

Figure C-24: Change in High Water Level for ALT176 Scenario

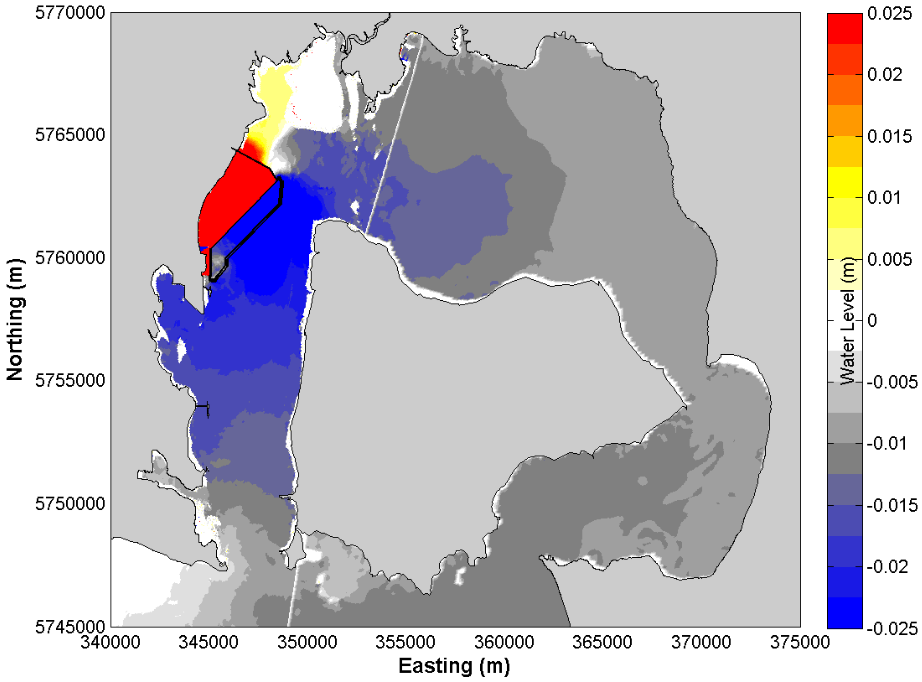

Figure C-25: Change in Peak Ebb Water Level for FOFS Scenario

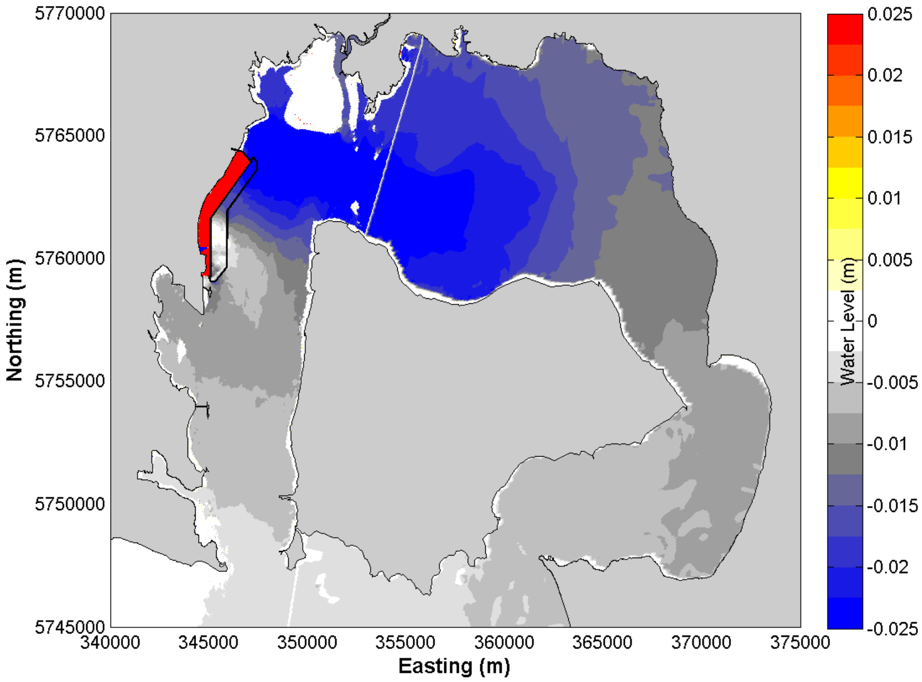

Figure C-26: Change in Peak Ebb Water Level for CTS Scenario

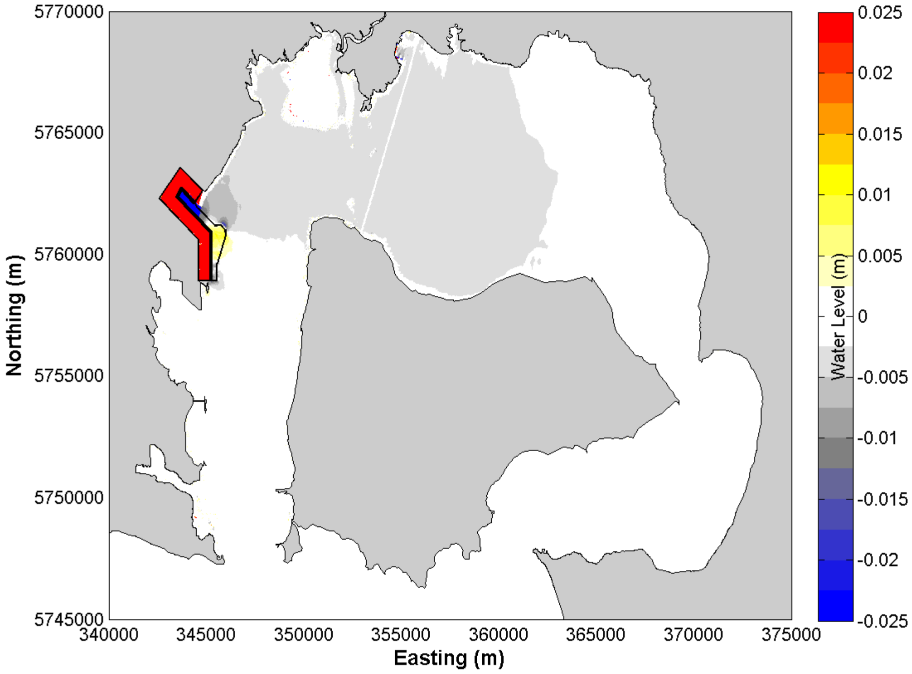

Figure C-27: Change in Peak Ebb Water Level for ALT156 Scenario

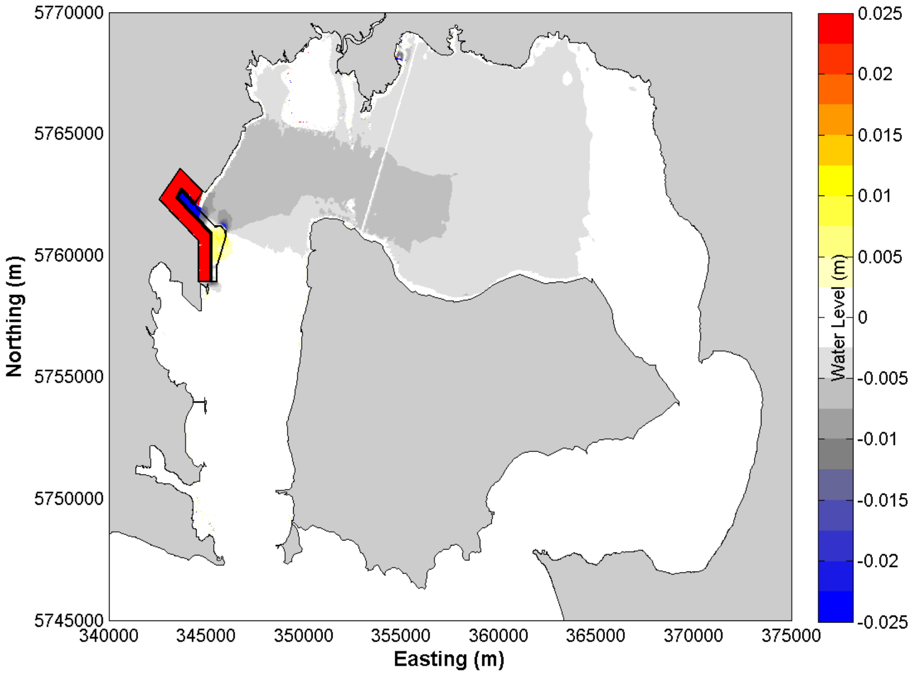

Figure C-28: Change in Peak Ebb Water Level for ALT176 Scenario

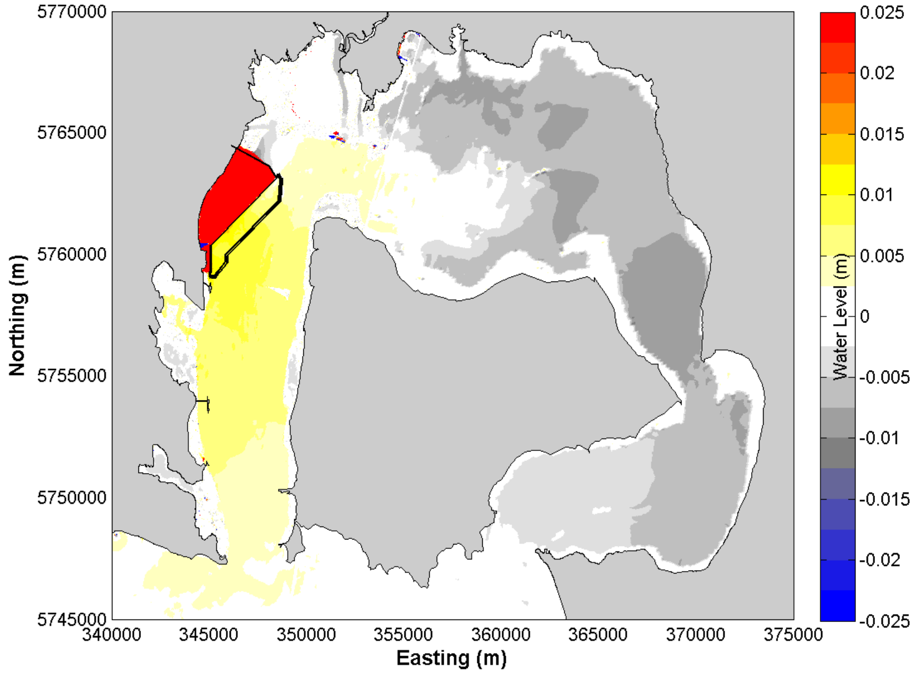

Figure C-29: Change in Low Water Level for FOFS Scenario

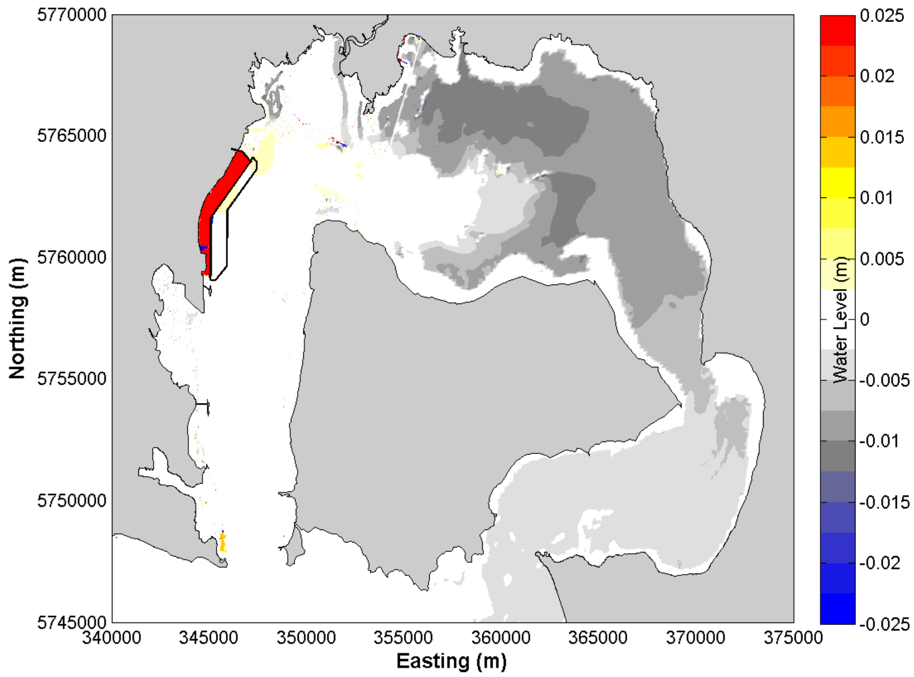

Figure C-30: Change in Low Water Level for CTS Scenario

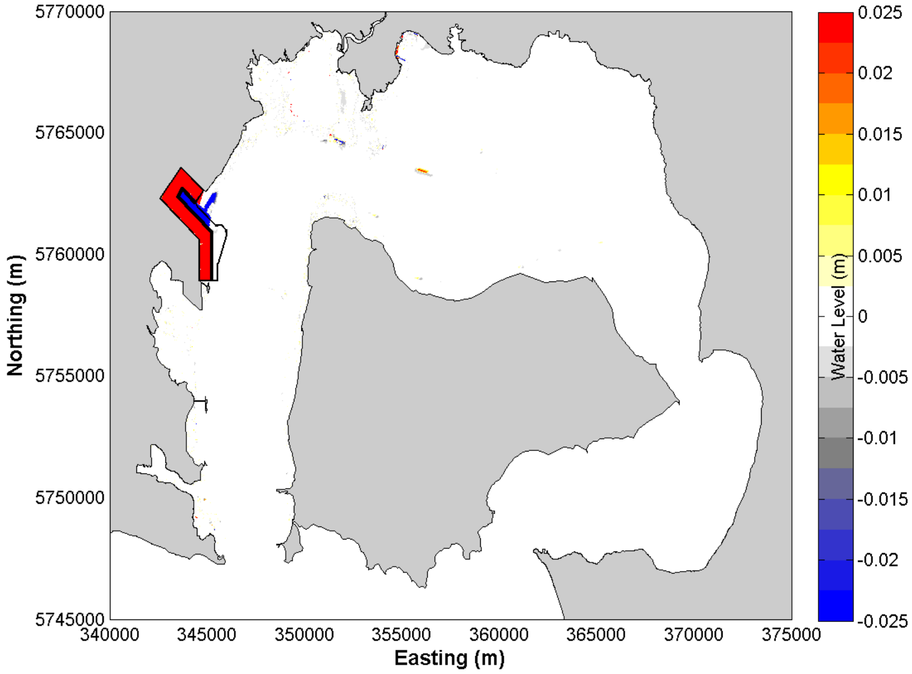

Figure C-31: Change in Low Water Level for ALT156 Scenario

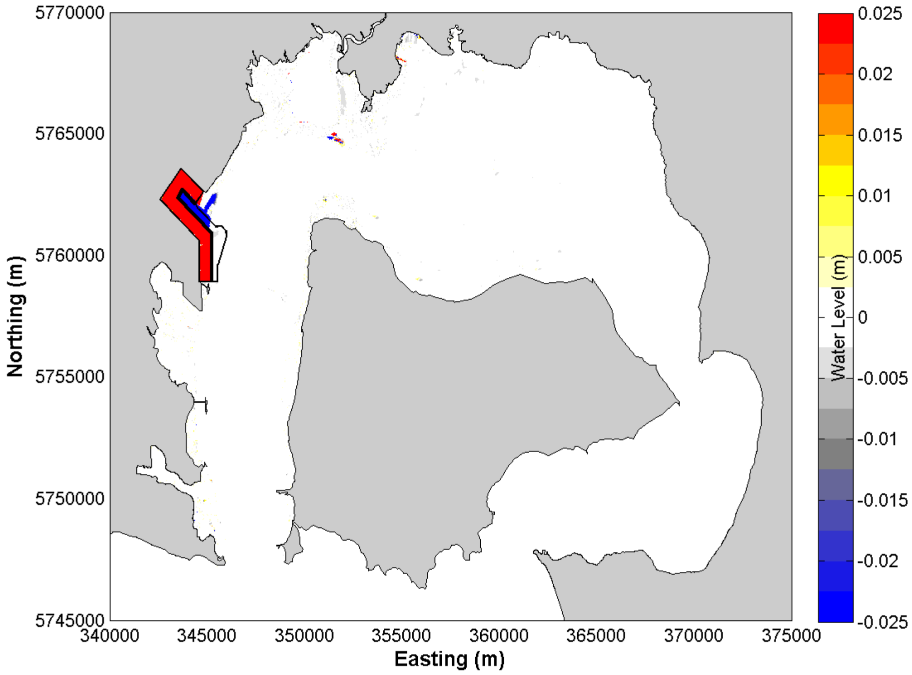

Figure C-32: Change in Low Water Level for ALT176 Scenario

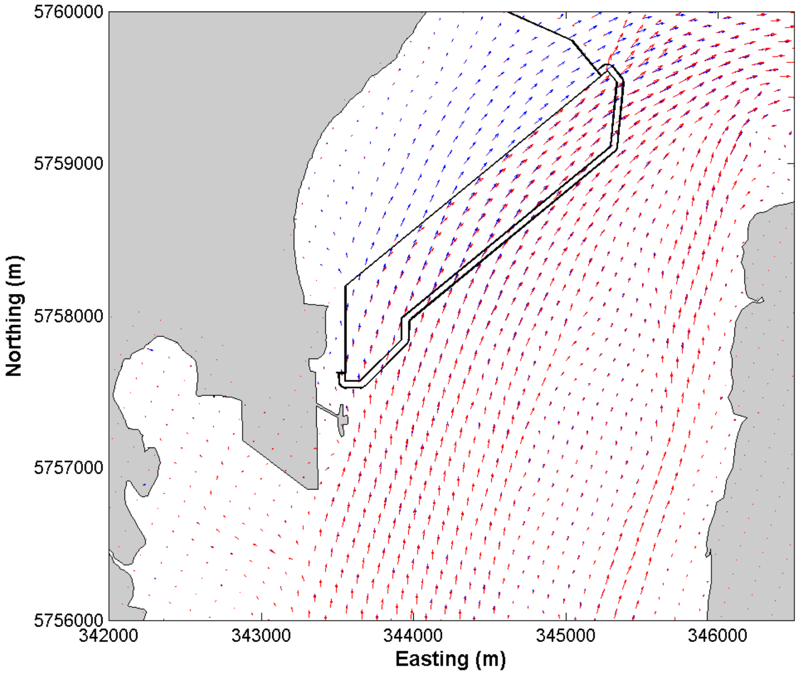

Figure C-33: Change in Peak Flood Current Direction for FOFS Scenario

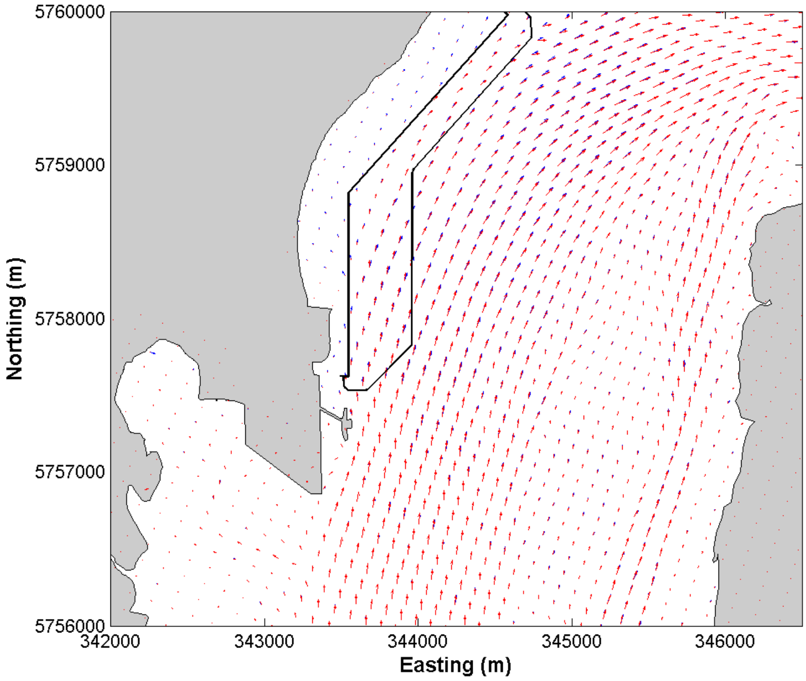

Figure C-34: Change in Peak Flood Current Direction for CTS Scenario

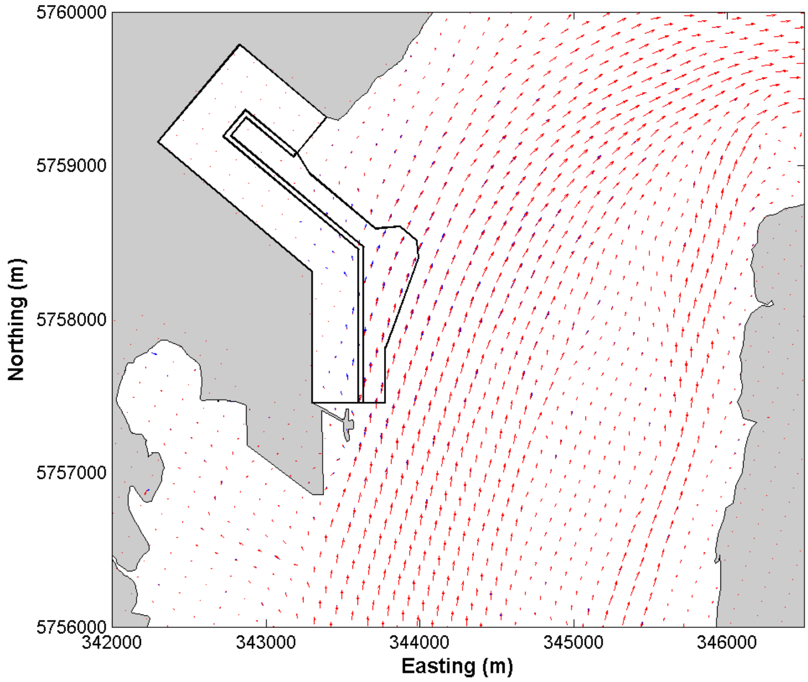

Figure C-35: Change in Peak Flood Current Direction for ALT156 Scenario

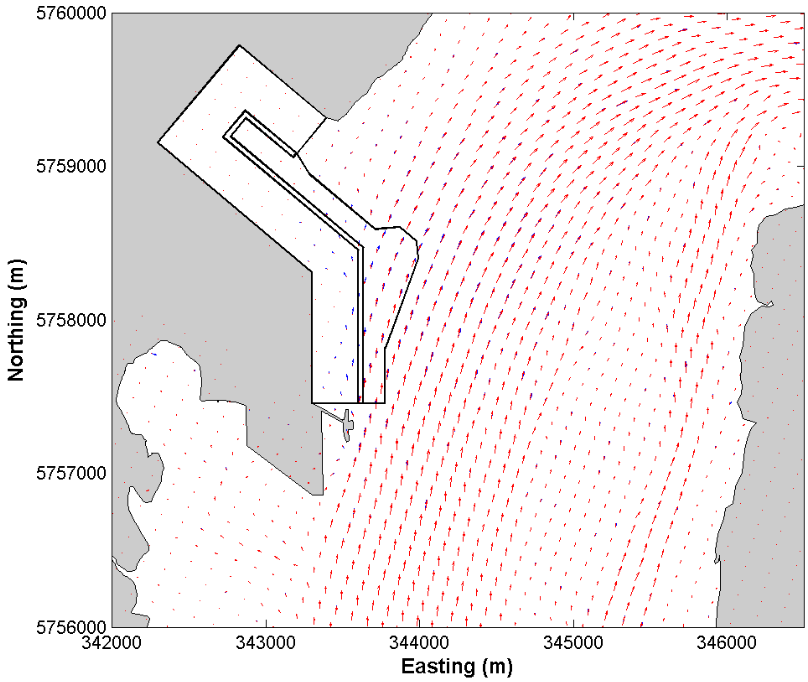

Figure C-36: Change in Peak Flood Current Direction for ALT176 Scenario

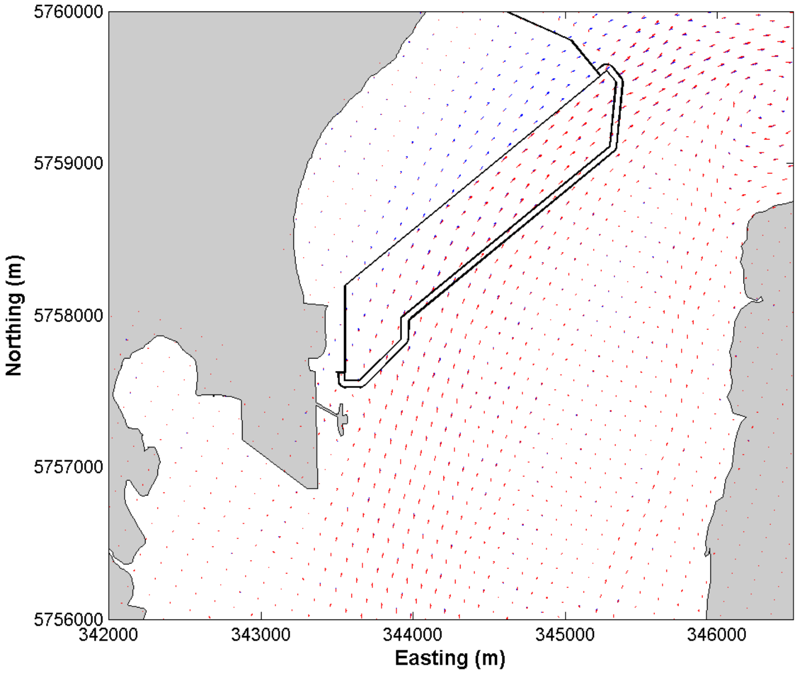

Figure C-37: Change in High Water Current Direction for FOFS Scenario

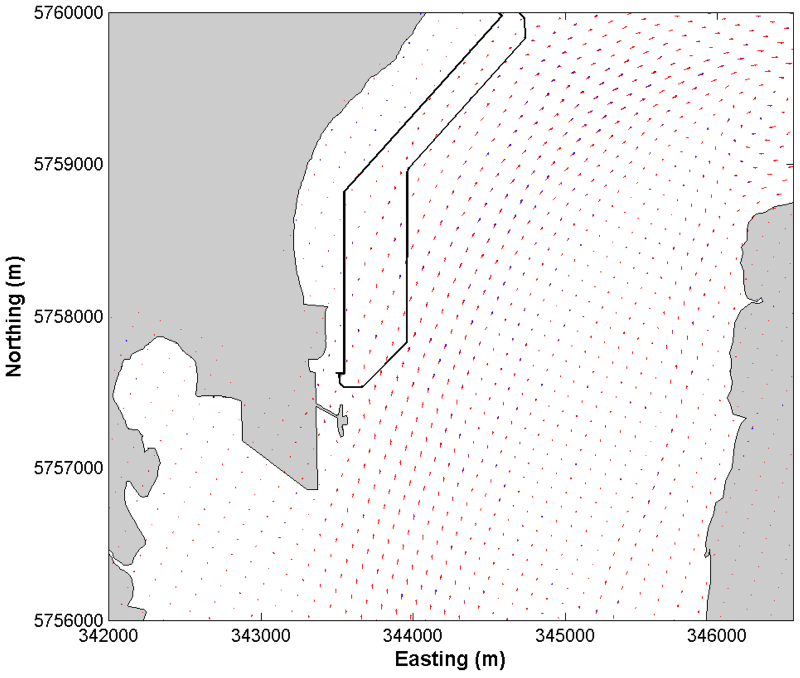

Figure C-38: Change in High Water Current Direction for CTS Scenario

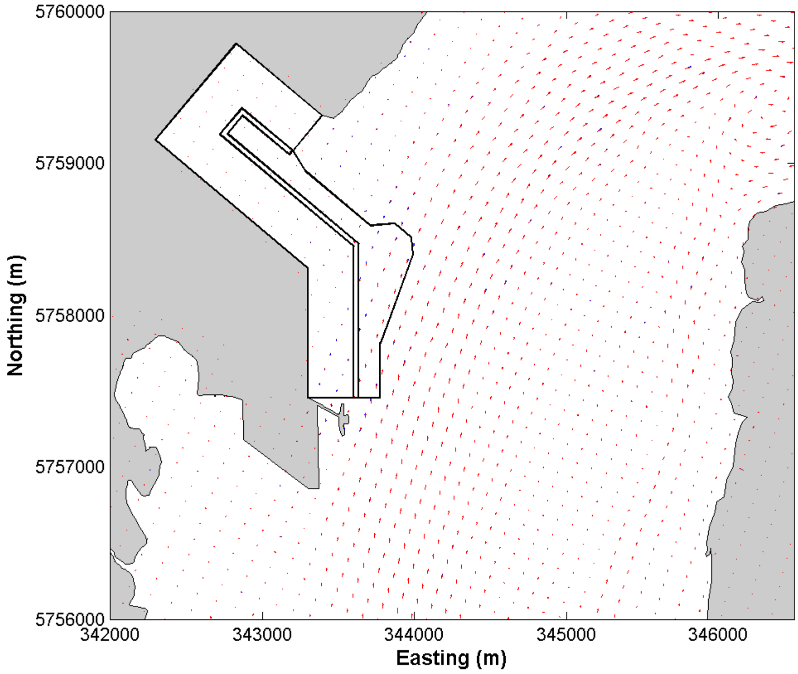

Figure C-39: Change in High Water Current Direction for ALT156 Scenario

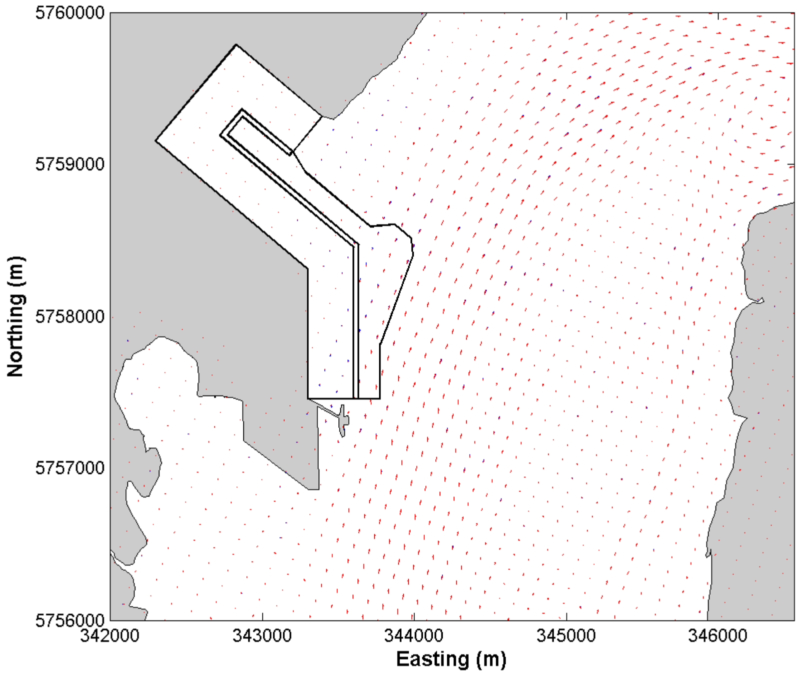

Figure C-40: Change in High Water Current Direction for ALT176 Scenario

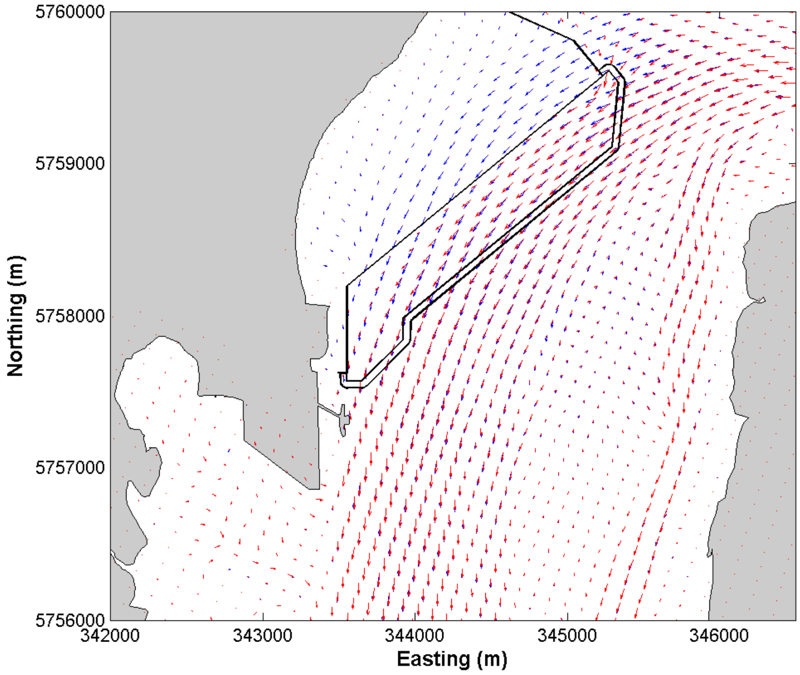

Figure C-41: Change in Peak Ebb Current Direction for FOFS Scenario

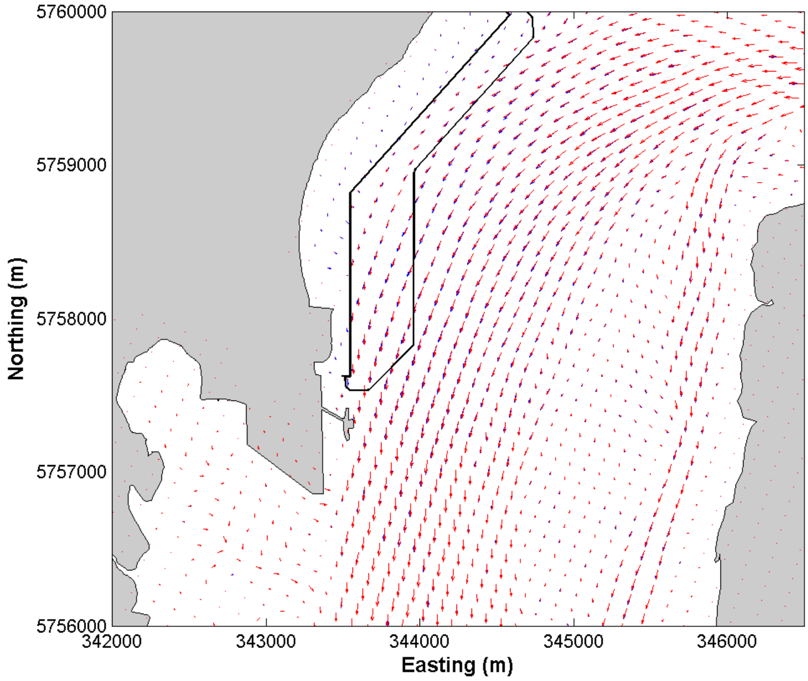

Figure C-42: Change in Peak Ebb Current Direction for CTS Scenario

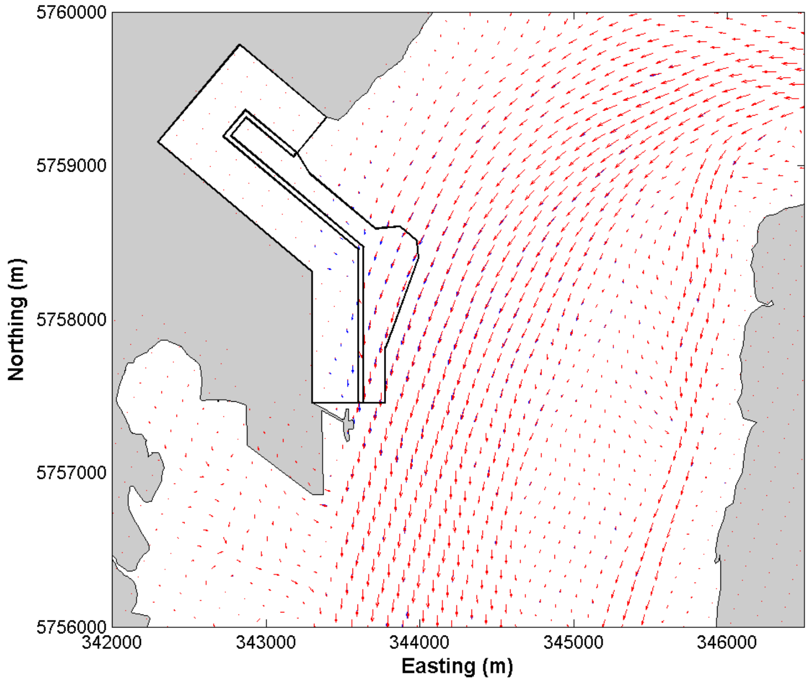

Figure C-43: Change in Peak Ebb Current Direction for ALT156 Scenario

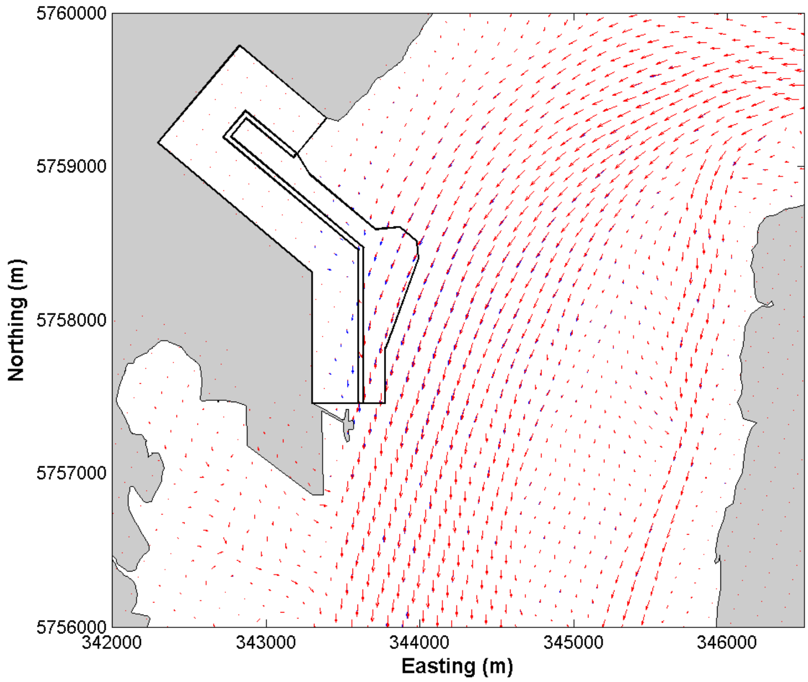

Figure C-44: Change in Peak Ebb Current Direction for ALT176 Scenario

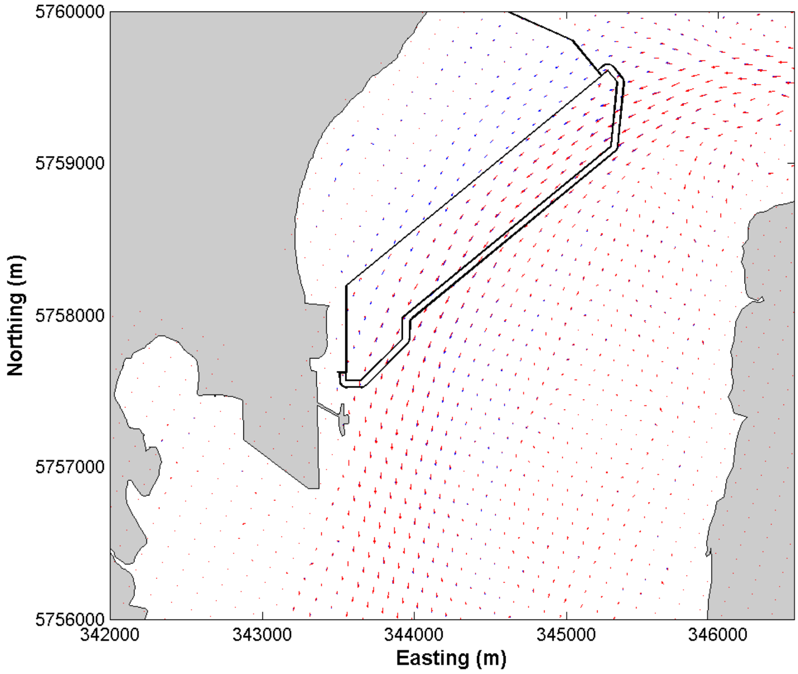

Figure C-45: Change in Low Water Current Direction for FOFS Scenario

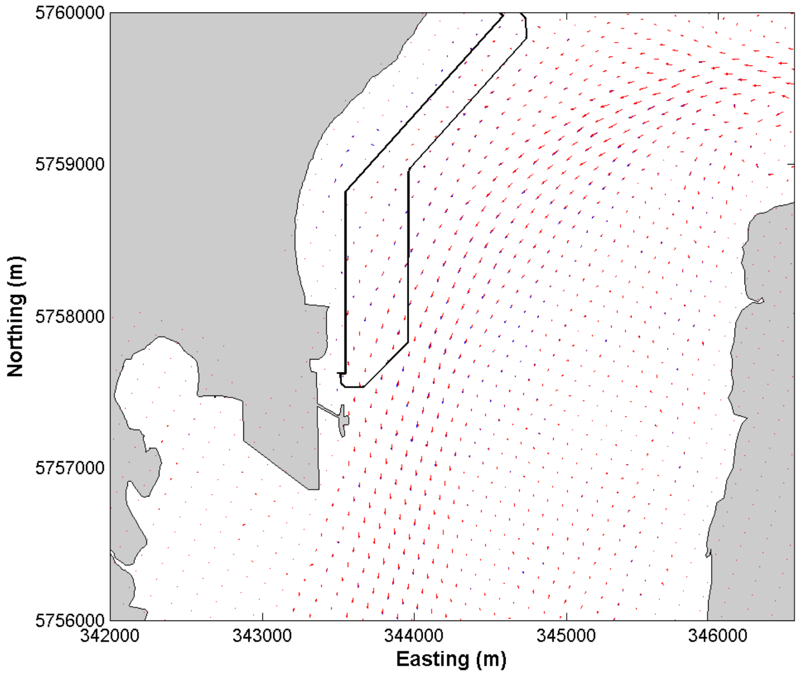

Figure C-46: Change in Low Water Current Direction for CTS Scenario

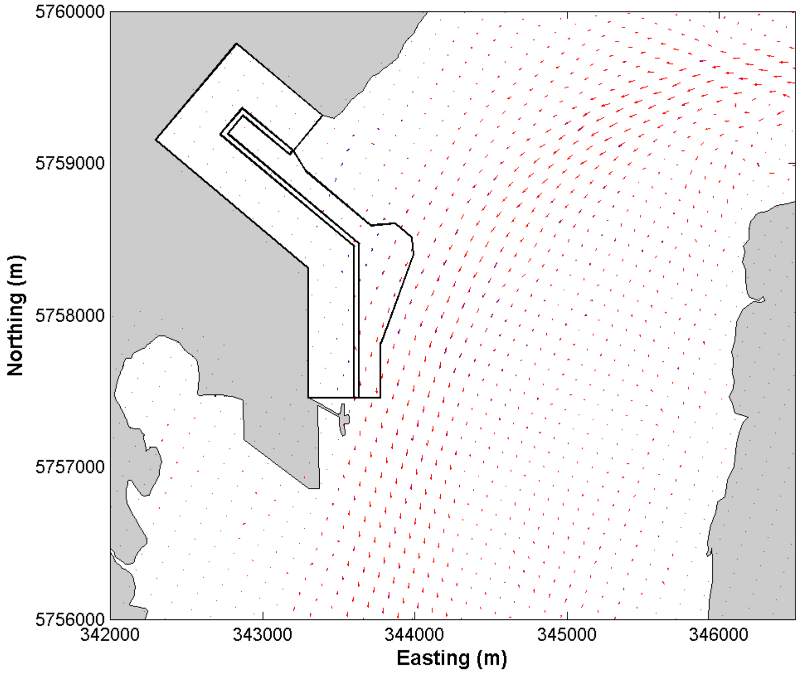

Figure C-47: Change in Low Water Current Direction for ALT156 Scenario

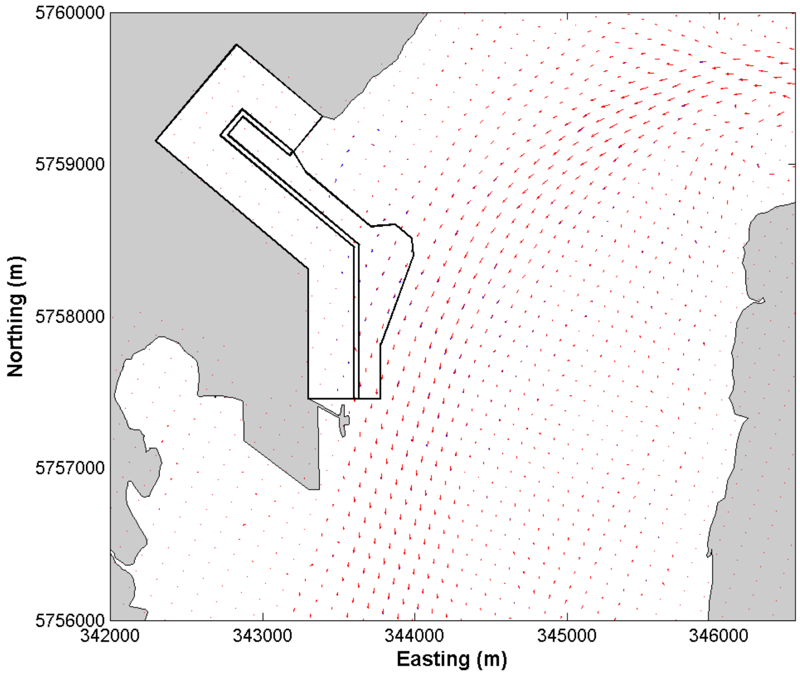

Figure C-48: Change in Low Water Current Direction for ALT176 Scenario

Appendix D WAVE COMPARISON TECHNICAL NOTE

To : Christian Taylor (PoHDA)
From : Evan Watterson; Takehiko Nose
Cc : Andrew Symonds, Rohan Hudson, Greg Britton, Nick Lewis
Date : 21/11/2014

Subject : Comparison of concurrent offshore wave record near Western Port

Introduction

The results of a preliminary comparison of a month of concurrent wave data collected in the coastal waters adjacent to the entrance of Port Phillip Bay (herein referred to as Point Nepean) and Western Port (herein referred to as Cape Woolamai) are presented below.

The Port of Melbourne Corporation (PoMC) has operated directional Waverider buoys at the Point Nepean location for about 12-years. This is the closest long-term coastal wave record to the Western Port project site. It is likely that this record will be a useful data set for the investigations into the development of a container port in Western Port. However, until recently, no concurrent wave data has been available to make a comparison between waves at the two entrances.

The objectives of the comparison were to:

- Inform the selection of appropriate wave boundary conditions for use in the early wave modelling of the Western Port's channel entrance; and
- Provide recommendations for the usefulness of the Point Nepean wave data set for the Port of Hasting Development Project.

The early wave modelling of the Western Entrance navigation channel will in turn be used to inform underkeel clearance (UKC) investigations and proposed channel design. Based on discussions with the Design and Engineering Work Stream, the principal concerns for UKC in relation to waves is the potential for 'corkscrewing' caused by wave directions quartering onto the vessel at the entrance and excess pitch from fore-aft movement of the vessel caused by waves aligned to the channel. Given the Length Overall (LOA) of the design vessel is around 300 m, the UKC investigation is predominately focused on long period swell (nominally in the wave period range 15-18 seconds).

The second objective relates to the approach adopted for further wave modelling for the Port of Hastings Development Project.

Wave Data Sets

The location of the three most relevant wave measurement sites are presented on Figure 1. A summary of the instruments used and the wave record provided at these sites is presented in Table 1. This table includes the two sites reviewed in this technical note and a third site offshore of Phillip Island referred to as Western Port Offshore. This third site is a new directional Waverider buoy recently deployed to provide representative offshore wave climate in the coastal waters adjacent to Western Port. This technical review does not include this site as sufficient concurrent data from the Point Nepean site was not available for this analysis.

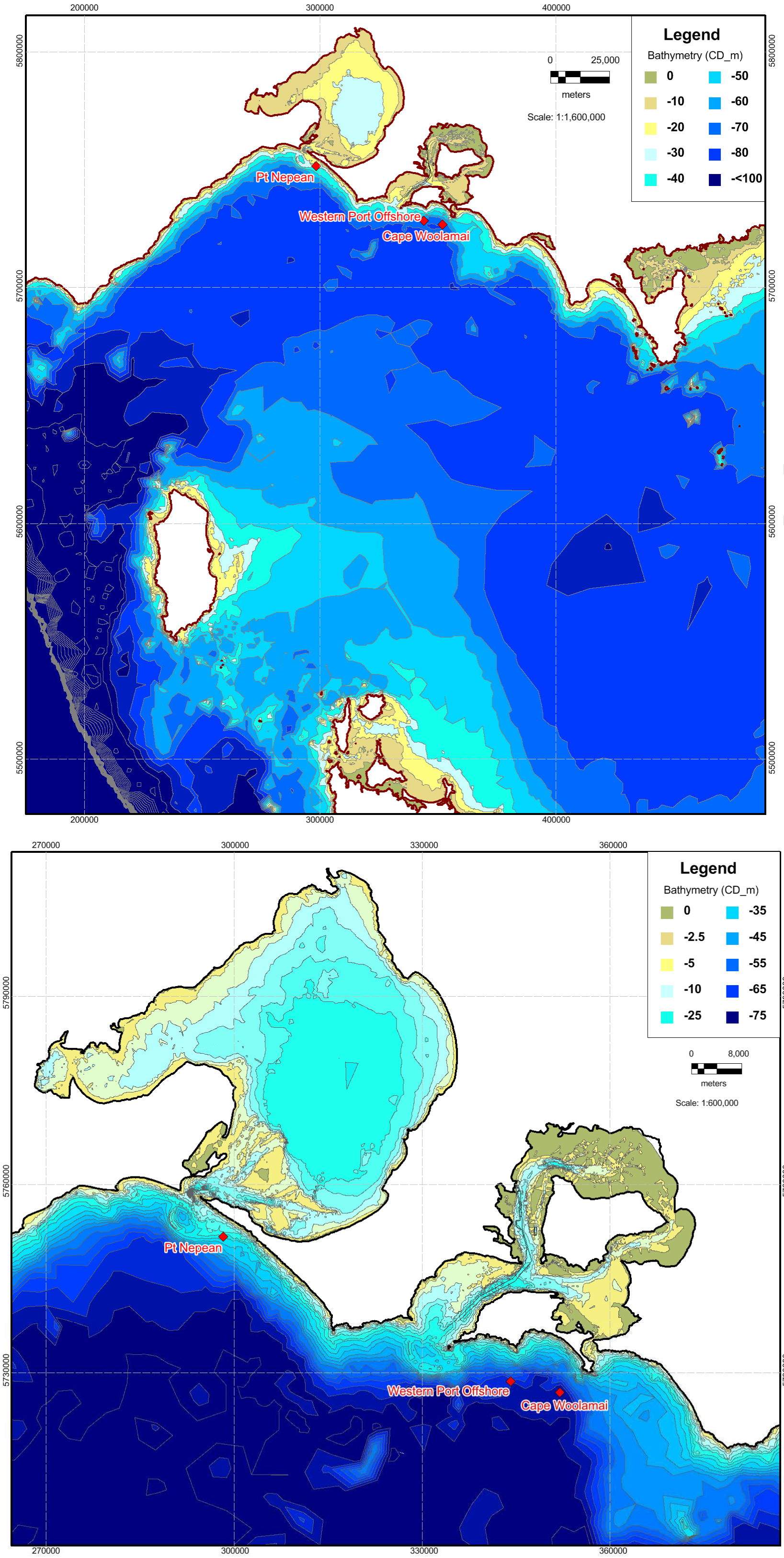

Figure 1. Location of wave measurement sites in coastal waters adjacent to Port Phillip Bay and Western Port. Regional scale (top) and local scale (bottom).

Table 1. Summary of coastal wave measurement sites

Parameter	Point Nepean	Cape Woolamai (WPO-00)	Western Port Offshore (WPO-02)

Instrument	Triaxys Directional Waverider Buoy	RDI ADCP	Datawell Directional Waverider Buoy
Type of wave measurement	Surface tracing float.	Seabed mounted instrument that uses acoustic techniques to measure velocity and track surface elevation.	Surface tracing float.
Sampling frequency	1.28 Hz	2 Hz	1.28 Hz
Nominal depth (below CD)	26 m	70 m	69 m
Start of available record	13-Jan-2003	21-Jun-2014	23-Sept-2014
End of available record[1]	30-Sept-2014	24-Jul-2014	On-going
Length of record	11.7 years	34 days	57 days

More information on the Point Nepean data set can be obtained from Port of Melbourne Corporation. It is noted that prior to the Point Nepean site, a Point Lonsdale site (further to the west) was used. A report containing a summary of the Cape Woolamai and Western Port Offshore data sets is being prepared.

Comparison of Concurrent Data

Concurrent wave data available for comparison comprises approximately one month from 21st June to 25th July, 2014. This period contained an active sea state in Bass Strait with an above average significant wave height (H_s) at Point Nepean and including five events recording significant wave heights above 4 m at Cape Woolamai. Table 2 provides a summary of basic statistics for the long-term and concurrent data sets at Point Nepean as well as the concurrent wave data at Cape Woolamai.

Table 2. Summary of long-term and concurrent wave data sets

Parameter	Point Nepean (Long-term)	Point Nepean (Concurrent = 33 days)	Cape Woolamai (Concurrent = 33 days)
Average H_s (m)	1.65	1.80	2.46
Max H_s (m)	6.70	6.70	7.78
Mean H_{max} (m)	2.69	2.93	3.83
Max H_{max} (m)	12.33	10.68	12.10
Average T_p (s)	12. 8	13.6	12.6
Average MWD (° magnetic)	200	211	221

The first of the five wave events (H_s>4m) recorded in the concurrent data period peaked at H_s of 6.7 m at the Point Nepean wave buoy on the 24th June 2014. This event represents the largest recorded H_s within the 11.7 year record at the Point Nepean wave buoy. Based on a preliminary extreme value analysis (EVA) of the Point Nepean data this event is estimated to have an average recurrence interval (ARI) of approximately 10-years (see Figure 2).

[1] The Point Nepean Waverider bouy provides an on-going record, however, a data request has to be made via the Port of Melbourne Corporation for access to this data. The last data request provided data up until 30-Sept-2014.

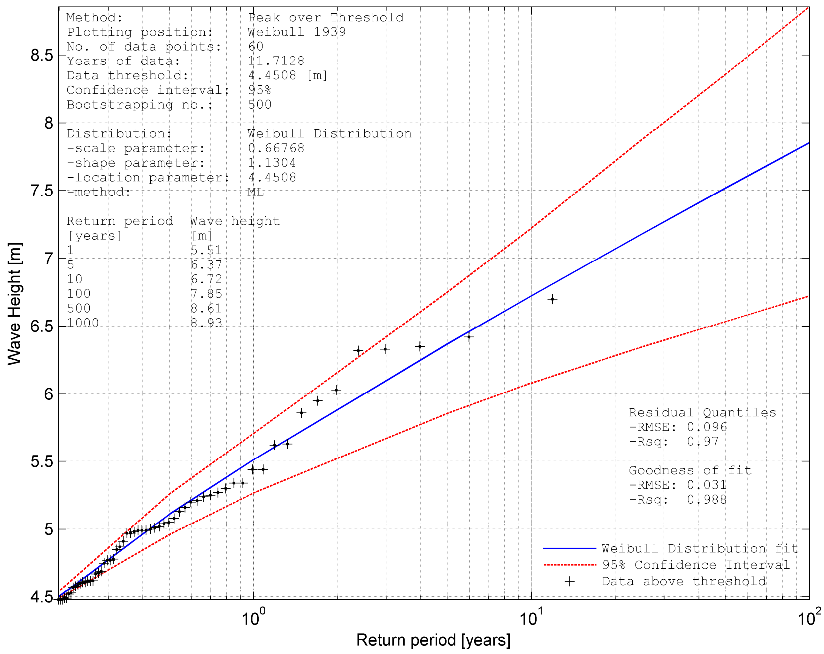

Figure 2. Preliminary EVA for Point Nepean wave data (ARI wave height values are for comparative purposes only and not intended for design purposes).

Figure 3 shows a time series comparison of the primary wave parameters (H_s, T_p and MWD) at the two sites. The following points summarise the comparisons of the two data sets in regards to primary wave parameters:

- Wave heights recorded at Cape Woolamai were generally higher than at Point Nepean. When averaged over the concurrent period, significant wave heights at Cape Woolamai were 41% larger at Point Nepean.
- There was considerable temporal variation in the magnitude of the wave height difference between the two sites. The relative percentage difference of observed wave heights was presented in the second panel of Figure 3. While the average relative difference was 41%, the relative difference ranged from -36% to 187% with a standard deviation of 28%.
- This pattern of larger but variable differences was also true for larger wave events. When the relative differences were averaged for significant wave heights greater than 4 m (based on Cape Woolamai data), Cape Woolamai significant wave heights were 46% greater than Point Nepean. The relative difference for larger waves also varied, ranging between -21% to 105% with a standard deviation of 25%.
- Peak wave period (T_p) at Cape Woolamai appeared to be slightly lower than the values at Point Nepean. The third panel of **Figure 3** shows the time series comparison of peak period. When averaged over the concurrent data period, values of T_p were 12.6s and 13.6s at Cape Woolamai and Point Nepean respectively. On the contrary, mean wave periods (T_{mean}) measured at Cape Woolamai were larger than at Point Nepean, averaging 7.8 and 6.8 seconds.

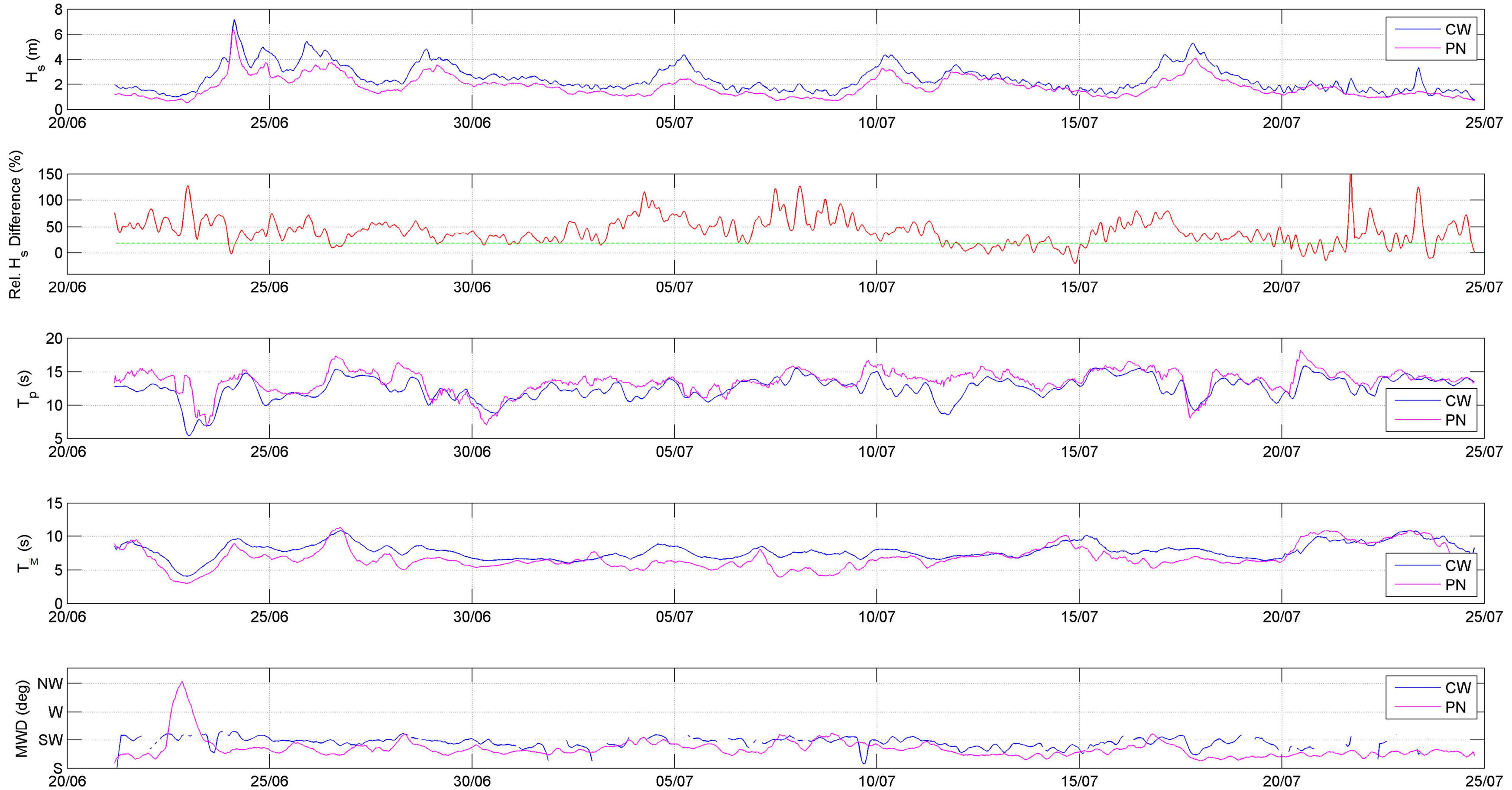

Figure 3. Comparison of Point Nepean and Cape Woolamai concurrent wave record. Top panel – H_s, second panel - relative H_s percentage difference, third panel - T_p, fourth panel - T_{mean}, and bottom panel - mean wave direction

respectively. T_{mean} is plotted in the fourth panel from the top. The variability in these wave period estimates indicated potential differences in their spectral shapes, which is expected given the location and depth differences at these measurement sites.

- Consistent with the orientation of Bass Strait, waves were dominant from the south to southwest quadrant, although a very short period of northwest waves was observed at Point Nepean preceding the storm event on 24th June. The bottom panel of Figure 3 shows the time series comparison of mean wave direction at the two sites. Cape Woolamai wave directions were generally slightly more westerly at than Point Nepean. This is likely due to wave refraction for longer period waves as discussed below. Cape Woolamai wave directions appeared more directionally spread than at Point Nepean, which may be expected in this deeper water location within Bass Strait.

Discussion of observations

To the west of Wilsons Promontory, the exposed coastline of southern Victoria is characterised by relatively high wave energy. Bass Strait is located within the Roaring Forties and adjacent to the Southern Ocean, where intense low pressure systems regularly travel in an easterly direction around the latitudes north of the Antarctic. These systems create high wave energy events that propagate towards the west coast of Tasmania and southern Victoria and get “squeezed” through the array of islands in between to enter Bass Strait. An example of this type of wave event is depicted below in Figure 4, illustrated using a forecast of significant wave heights (H_s) taken from the Australian Bureau of Meteorology (BoM) website.

Although rather coarse, the BoM wave model depicted in Figure 4 illustrates the transformation processes undertaken by high-energy waves as they enter Bass Strait. It is noted that large gradients in significant wave heights can be seen along the southern coast of Victoria. This is largely due to the wave shadowing effects of Cape Otway and King Island. The wave shadowing of Cape Otway largely explains the observation that Cape Woolamai wave heights are generally larger than at Point Nepean.

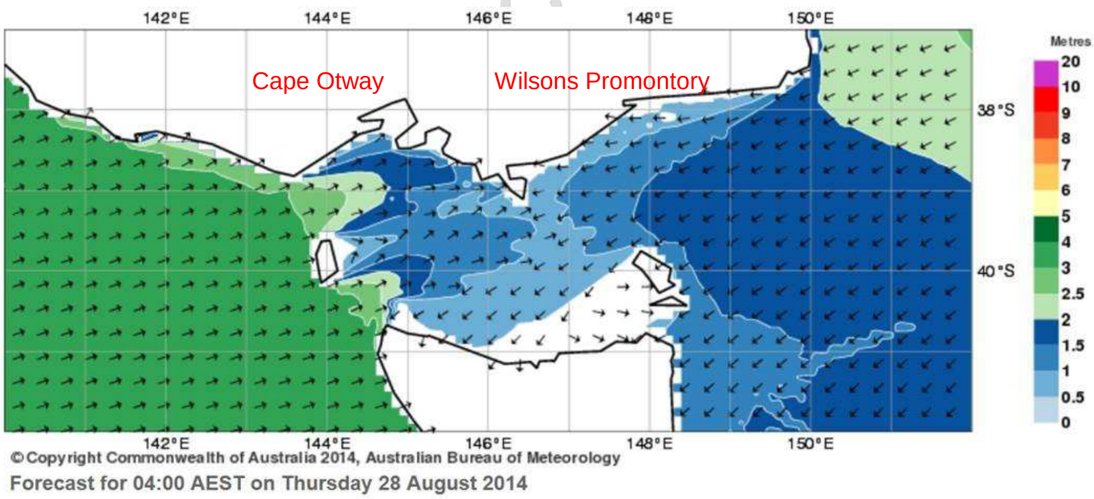

Figure 4. Example of Significant Wave Height, Hs (m) generated by a Southern Ocean low pressure system as it passes into Bass Strait. (BoM, 2014).

It is considered that the remaining observations can be explained by two key processes:

- Variation in the spectral shape of the wave events; and
- refraction of long period swells within Bass Strait.

Figure 5 provides examples of the spectral shapes of three wave events observed at Cape Woolamai and Point Nepean. Also included in Figure 5 is an estimate of the corresponding component heights for various frequency bands in this case (5-10 seconds, 10-14 seconds and 14 to 18 seconds).

- 24th June Event: broad spectrum event (periods from 6 – 18 seconds) showed moderate (~15%) significant wave height differences between the sites.
- 5th July Event: narrow spectrum event with periods in the range 10-14 second band showed a large (~70%) significant wave height differences between the sites.
- 10th July Event: dual-frequency event with spectral peaks at 16 second (major) and 10 seconds (minor) showed small (~13%) significant wave height differences between the sites. This event also showed a slightly larger 14-18s component height at Point Nepean.

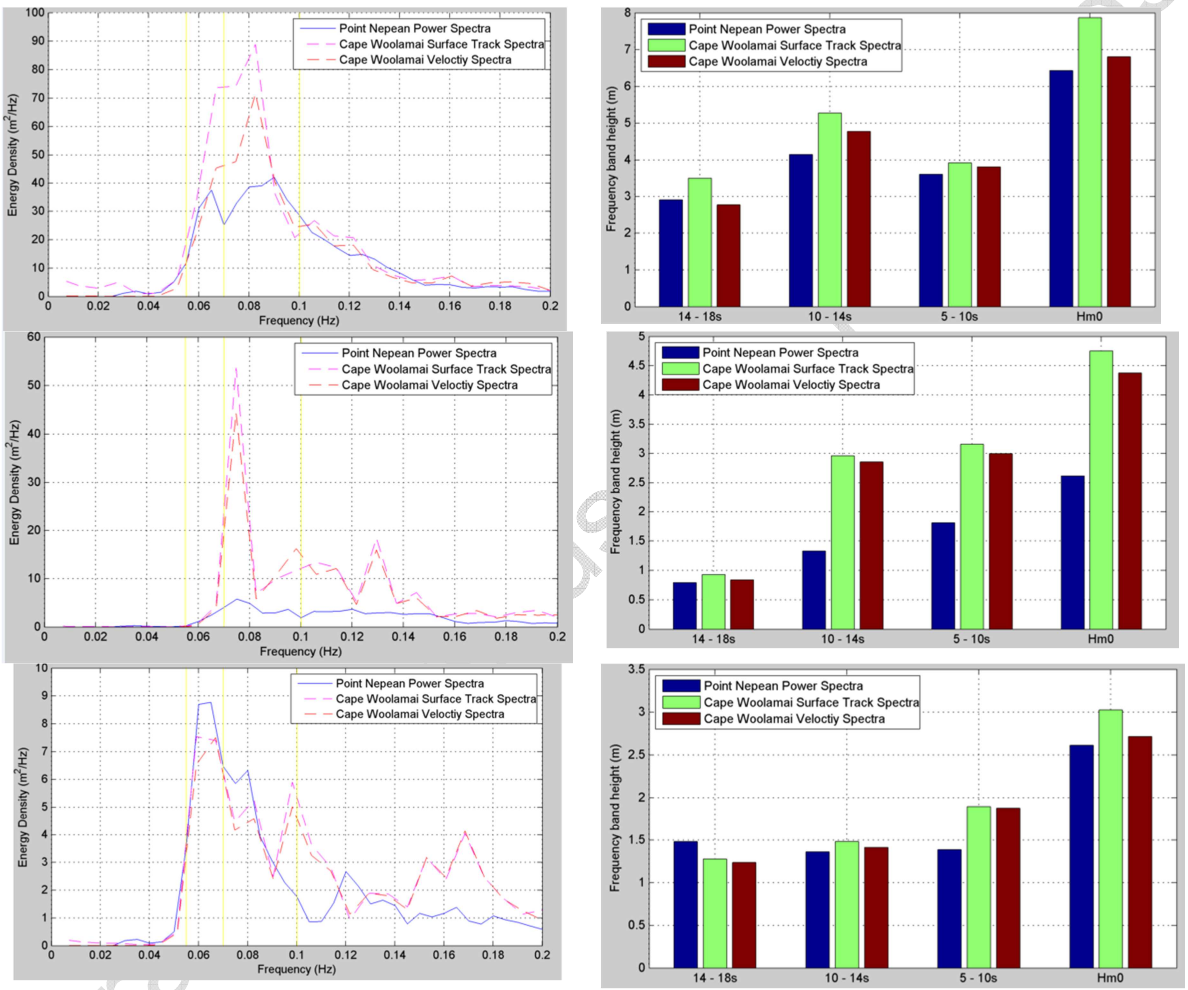

Figure 6. Wave energy spectrums (left) and component heights (right) for events on the 24th July (top), 5th July and 10th July 2014 (bottom). Spectral shapes and component heights for Cape Woolamai derived from two alternative measurement methods.

Figure 1 shows the depth range in the important area of wave propagation (offshore area east of Cape Otway) to be around 80 m. Only long period swells will “feel” the bottom in these depths and only very long period waves (i.e. T>14-16s) will undergo significant refraction. That is longer period swell waves (T~>14s) will tend to refract northward towards the southern Victorian coastline while swell waves of shorter periods (T~<14s) will tend to propagate in a more SW direction. Wave diffraction would also play a role in directing wave energy northward.

Table 3 provides a summary of the relative percentage difference in component heights between the two sites when averaged over the concurrent data period. This comparison of bands of the wave

energy spectrum explains the observed variation in wave height differences and the tendency for Cape Woolamai to show a reduced T_p and larger T_{mean}.

Table 3. Component heights over concurrent data period

Component Wave Period Range (s)	Average Relative Difference (%)	Min-Max Relative Difference (%)	Standard Deviation (%)
5 – 10	53.8	-25 to 317	42
10 - 14	32.5	-39 to 179	32
14 - 18	-11.5	-66 to 105	26

The depth at the Point Nepean site is only 26 m and this will influence the direct comparison of recorded wave data due to the wave shoaling processes.

Recommendations

Considering that UKC and channel design are predominantly concerned with longer period swells (T>14s) for the design vessels in question and that the outputs of the early wave modelling is intended primarily for UKC, adoption of the 18% increase in wave height, as recommended by Cardno is considered appropriately conservative.

While a simple transformation assumption may be considered appropriate for preliminary design estimates future wave modelling should account for the more complex underlying processes occurring. The assumption of a simple percentage transformation factor between Point Nepean and the coastal waters offshore of Western Port is a misrepresentation of the underlying processes and significantly underestimates the transformation for lower wave periods (<14s). As such, a regional wave model, either derived from a global wave model or a downscaled Bass Strait hindcast model should be consider for developed. This wave model should be shown to have good agreement with not only the primary wave parameters (e.g. H_s, T_p and *MWD*) but also the measured wave energy spectrum for a range of difference wave events. It should also be of sufficient resolution to account for wave refraction/diffraction processes in Bass Strait.

Further analysis should be undertaken that incorporates concurrent data from the Cape Sorrel Waverider buoy (west coast of Tasmania), the recently deployed Western Port Waverider buoy and the Port Nepean Waverider buoy. Future data requests should be made to PoMC for up-to-date wave data such that it can be compared to the Western Port Waverider buoy that was recently deployed. This request should extend to cover the directional wave spectrum as this has not been provided to-date. Future comparisons between Point Nepean and Western Port offshore should consider the directional spectrum.

Limitation

This analysis is on only 34 days of concurrent data. It provides a provisional indication of relative difference using the available data at the time of analysis.

The water depth at the Point Nepean site is only 26m. At this depth long period waves will be more influenced by wave shoaling than at the deeper (70 m) Cape Woolamai site. This is likely to influence the direct comparison between the two sites. The effect of wave shoaling should be further

considered when comparing the two records. Furthermore, non-linear wave theories should be used when considering the difference in wave shoaling between the two sites.

Future analysis should consider the method of spectral tracking as adopted by NOAA as documented in Tolman (2009).

References

Tolman (2009*) Under Manual and system documentation of WAVEWATCH III*, National Oceanic and Atmospheric Administration, US Department of Commerce