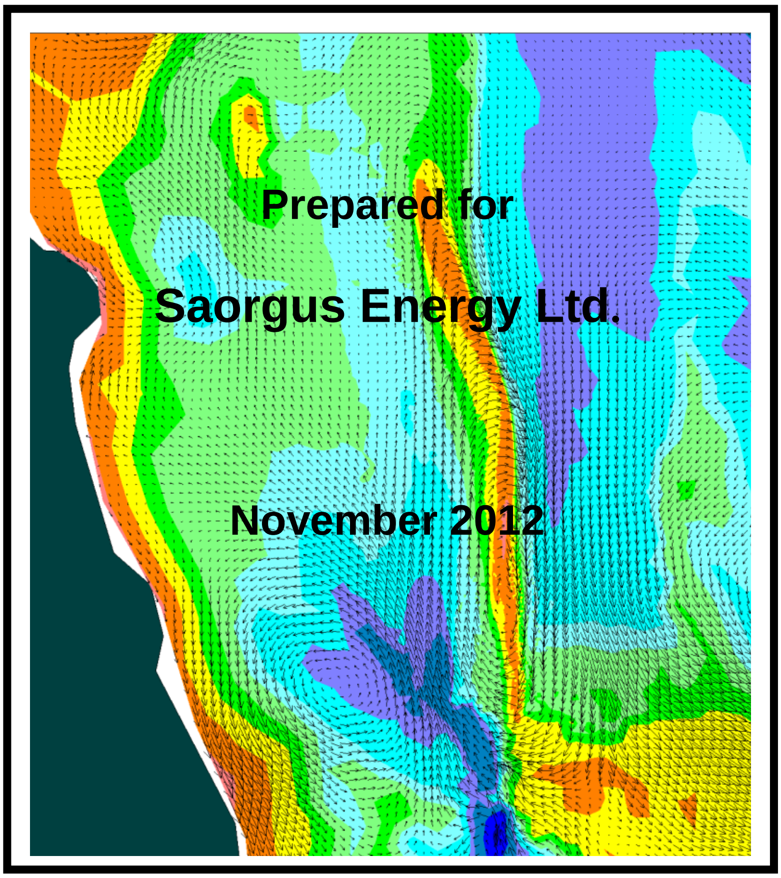
Report No. HEL095501 v1.1

Hydrodynamic Modelling Assessment of the Dublin Array project on the Kish and Bray Banks



Prepared for

Saorgus Energy Ltd.

November 2012

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1. INTRODUCTION

1.1 Background

Hydro Environmental Ltd was commissioned by Saorgus Energy Ltd. to investigate the potential hydrodynamic impact from the proposed Dublin Array Wind Farm on the Kish and Bray Sand Bank, off the east coast of Dublin and Wicklow in the Irish Sea. This report attempts to quantify the hydrological and sedimentological impacts of the proposed 145 turbine windfarm development on the Kisk and Bray banks through a calibrated hydrodynamic model of the subject waters.

The study area for the Dublin Array Wind Farm along the Kish and Bray Sand Banks extends 18km north-south and 3km east-west in relatively shallow waters ranging from 4.5m to 31.5m below mean sea level. These banks are described as submarine banks trending north-south parallel to the coastline with NNE-SSW trending bedforms consisting primarily of sand and some gravel.

1.2 Description of Proposed development

The key components of the Dublin Array are 145 offshore wind turbines of 3 to 6 MW including associated scour protection spaced at approximately 500m, refer to figure 1 for location map. The turbine hub heights will be between 85m and 100m above sea level. The turbine blades maximum vertical heights will be no more than 160m above sea level and no lower than 30m above mean high water springs. The wind turbines will be supported on a foundation consisting of a steel monopile and a transition piece. A monopile is a long cylindrical steel tube with a diameter ranging between 4m and 6.5m and will be driven into the seabed to a depth of between 20m and 40m depending on the bearing capacity. Once the monopile is installed a transition piece is lifted on to the top of the pile and grouted in place. It is envisaged that rock armour protection will be placed locally on the seabed around the base of each monopile to minimise the effects of scour. The turbines within the wind farm will be connected to each other in groups by buried submarine cables connecting to an offshore substation, to be located towards the middle of the array. This substation is likely to be supported on a multiple foundation piled structure. From this substation an undersea high voltage export cable will connect to the landfall site at Shanganagh Co. Dublin (approx. 2km north of Bray). From the landfall site at Shanganagh underground cables will connect to the National grid at the ESB Carrickmines substation. Two offshore meteorological masts will also be associated with the proposed development.

1.3 TELEMAC Hydraulic Software System

The TELEMAC system and specifically TELEMAC 2D is the software of choice for modelling the complicated hydrodynamics of the Irish Sea coastal waters off the Wicklow and Dublin coastline. Particularly given the very high computation refinement required to model the 145 Turbine monopiles within an array area of 54km^2 and along the Kish and Bray Sand Banks. TELEMAC is a software system designed to study environmental processes in free surface transient flows. It is therefore applicable to seas and coastal domains, estuaries, rivers and lakes. Its main fields of application are in hydrodynamics, water quality, sedimentology and water waves.

TELEMAC is an integrated, user friendly software system for free surface waters. TELEMAC was originally developed by Laboratoire National d'Hydraulique of the French Electricity Board (EDF-LNHE), Paris. It is now under the directorship of a consortium of organisations including EDF-LNHE, HR Wallingford, SOGREAH, BAW and CETMEF. It is regarded as one of the leading software packages for free surface water hydraulic applications and with more than 1000 Telemac Installations Worldwide.

The TELEMAC system is a powerful integrated modelling tool for use in the field of free-surface flows. Having been used in the context of very many studies throughout the world (several thousand to date), it has become one of the major standards in its field. The various simulation modules use high-capacity algorithms based on the finite-element method. Space is discretised in the form of an unstructured grid of triangular elements, which means that it can be refined particularly in areas of special interest. This avoids the need for systematic use of embedded models, as is the case with the finite-difference method. Telemac-2D is a two-dimensional computational code describing the horizontal velocities, water depth and free surface over space and time. In addition it solves the transport of several tracers which can be grouped into two categories, active and passive, with salinity and temperature being the active tracers which alter density and thus the hydrodynamics.

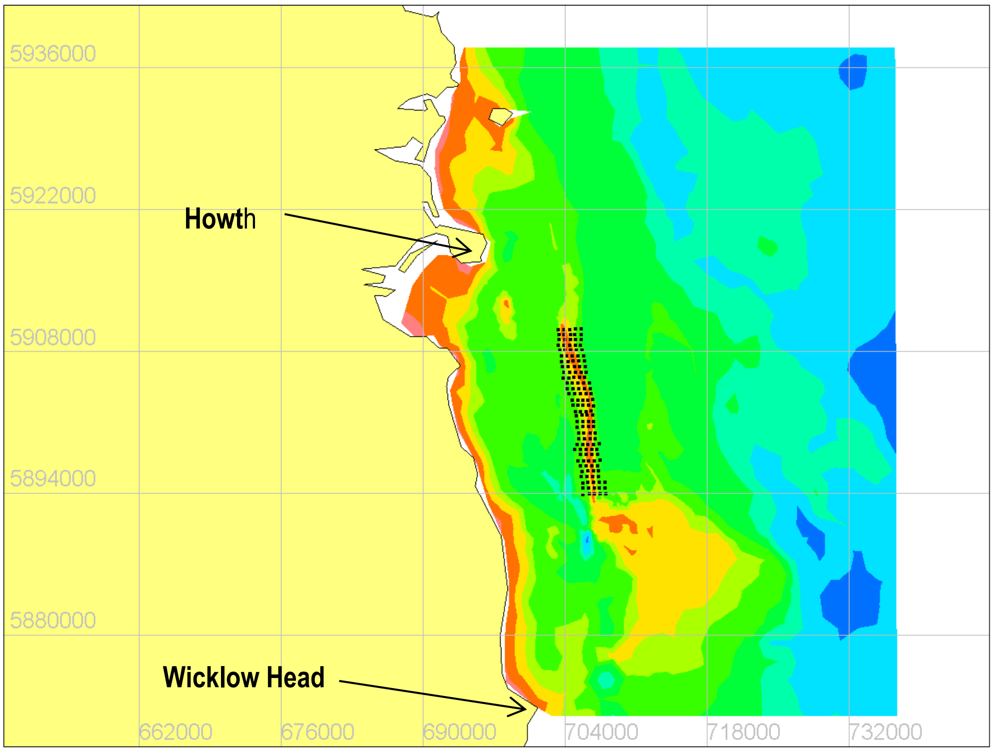


Figure 1 Location of proposed turbine windfarm (145 no Turbines) within Model Domain

1.4 Data Sources

Bathymetric

Saorgus Energy Ltd. commissioned a bathymetric and geophysical survey of the banks in 2008 (Hydrographic surveys Ltd., 2009) providing 145 bathymetric transverse profiles across the sands banks. The Geological survey of Ireland (GSI) Informar Study produced highly refined seabed lidar survey for much of the domain which included the north and middle section of the Kish and Bray Sand Banks. The hydrographic survey and infomar surveys are to chart datum (lowest astronomical tide). The BODC (British Oceanographic Data Centre) GEBCO_08 Grid is a global bathymetric grid at 30 arc second intervals (released January 2009 and updated Nov 2009 and Sept 2010) and relates to local mean sea water. The GEBCO_08 Grid was largely generated by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data.

Comparison of the present day bathymetry with historical Admiralty bathymetry (Adm Chart 1468 produced between 1843 and 1911 would suggest moderately stable conditions along the bank.

Sea Bed Geotechnical Investigations

A preliminary site investigation was carried out by Glovers on the north end of the Kish Bank in September 2008. This involved drilling 3 No. shell and auger boreholes 20m through the bed stratum at 200mm diameter. This investigation tested the consolidation and distribution and bearing capacity of the sediment.

Description of Sediments encountered

The description of the soil encountered by Glovers is a lightly silty, predominantly fine to medium Sand (94% sand and 6% silt), which is a loose to medium deposit in the upper 2.5m to 6m, medium dense deposit from 6m to 12m and a dense deposit below 12m.

Other information on sediment distribution along the bank can be deduced from the EcoServe Grab samples (2008). The Ecoserve report indicated that the shallower parts of the Kish Bank consisted of fine sand with some shell, along the western edge the seabed was predominantly coarse shell with sand which graded into shell and pebbles and gravel and stones along the west of the Bray Bank and larger cobbles and stones at the southern end of the Bray Bank. This distribution indicates stronger velocities to the south which is confirmed by the Aquafact hydrometric survey and the hydrodynamic modelling.

Table 1 Average Sediment distribution based on the three test Boreholes, refer to Figure 2

% passing	Diameter (mm)
100	3.35
99.9	2
99.1	1.18
96.0	0.6
90.8	0.425
79.3	0.3
55.4	0.212
26.5	0.15
4.1	0.063

% passing	Diameter (mm)
90	0.415
80	0.306
50	0.197
20	0.143
10	0.089

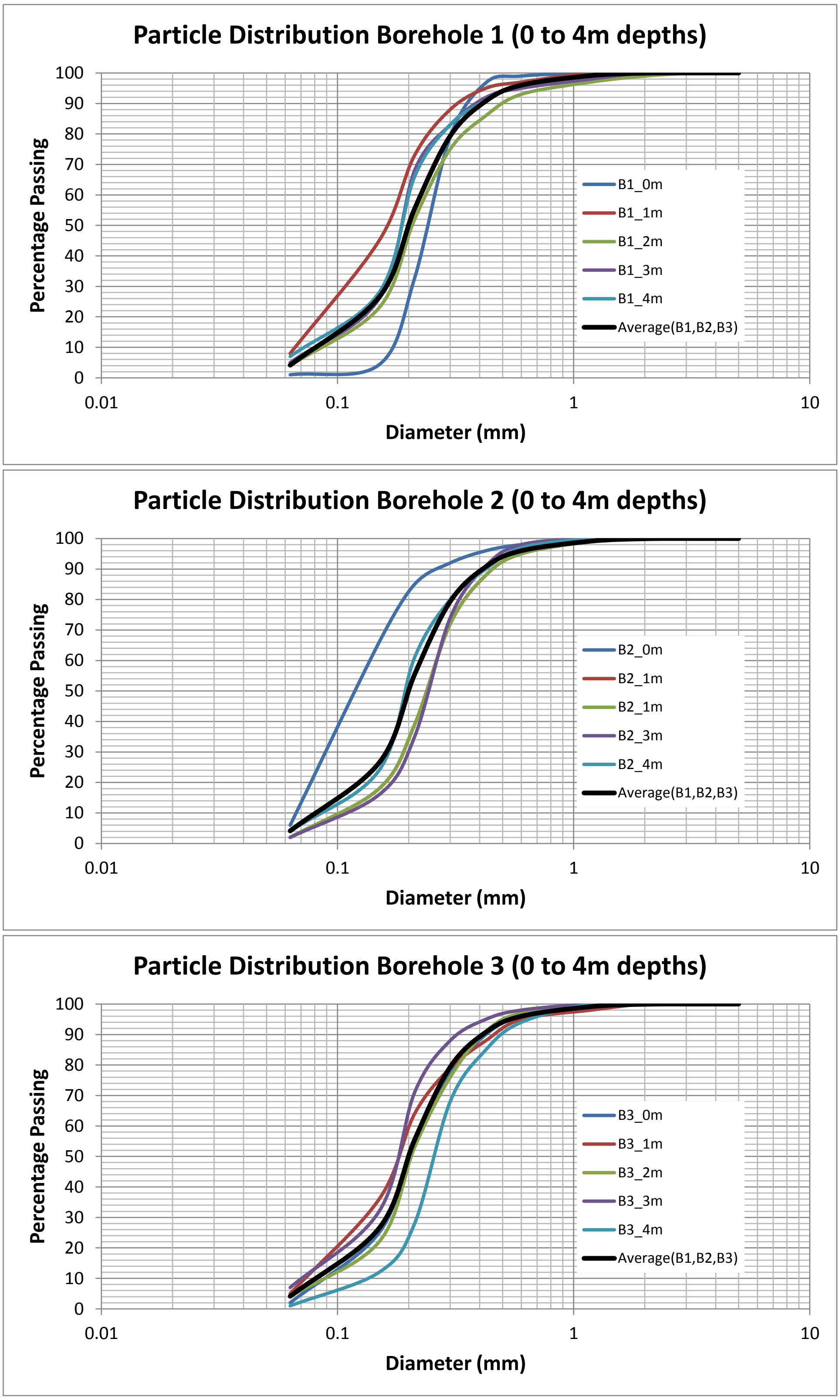


Figure 2   Sediment Distribution Results Offshore Boreholes into Kish Sand Bank (refer to figure 3 for locations).

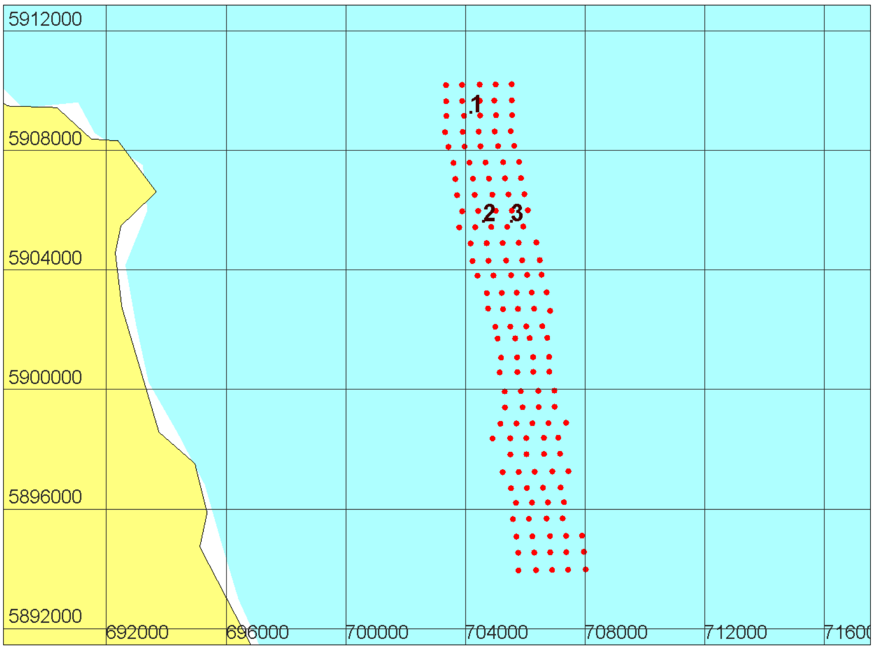


Figure 3 Location of Site Investigation Boreholes (20m deep) BH 1 to 3

Hydrometric Survey by Aquafact (August-September 2012).

In order to provide baseline information on the tidal regime along the banks and to provide a data set for model calibration and validation, a detailed hydrographic survey as input to this study was carried out by Aquafact International. This survey measured the vertical varying currents and water depths from 23rd August to the 19th September 2012 at two sites, one located on the northern end of the Kish Bank and the second on the southern end of the Bray Bank. Two other locations (C1 and C2) at mid-distance along the bank were monitored for 24hours from 19th to 20th of September (2012). Refer to Figure 10 for the locations of these survey points. This hydrographic survey is presented in a separate report entitled “Marine Hydrographic Survey of the Kish Bank Co. Wicklow – August September 2012”, included in Appendix 1 of this report.

2. HYDRODYNAMIC MODELLING

2.1 Finite Element Model Structure

The total model domain extends from Skerries near Rush North Dublin 66km south to Wicklow Head and extends from the Irish shoreline 43km eastward into the Irish Sea, Refer to Figure 4. The model domain area is 2,786km^2 with the immediate Dublin Array area at 54km^2. An unstructured mesh of triangular elements was fitted to the domain with a total of 101,820 elements for the existing (pre-development) case and 101,100 triangular elements for the proposed development case.

The unstructured mesh varies from 2,000m triangular element lengths along the south east and north open sea boundaries to minimum element edge lengths of 2.4m in the vicinity of the Turbine Piles. An element growth ratio of 1.2 from the high refined area of the Turbine Piles to larger boundary elements was specified. The overall mesh is shown in Figure 5 and an example of the mesh refinement in the vicinity of the Turbine Piles is presented in Figure 6.

To ensure similarity in mesh structure for comparison between the existing and proposed case and to eliminate any potential numerical noise produced by different mesh structures the same mesh was used with the elements located inside the pile diameter removed and the pile set as a circular island boundary for the proposed case. The element and node numbering of the meshes was optimised so as to minimise band width and improve speed of solution. The bathymetry within the domain area was produced by triangulation of the HSL (2008) survey, GSI Informar Lidar Surveys and the BODC European Shelf 0.5minute bathymetry and mapped onto the computation mesh nodes, refer to Figures 7 and 8. The Irish Coastline was modelled relatively coarsely as it is sufficiently remote from the area of interest not to influence the computation and thus tidal flats and wetting/drying areas were not modelled by assuming a minimum depth below mean sea level of 2.5m. The domain projection for model was set to UTM 29 North and this assists extrapolating boundary and initial conditions from European shelf global solutions. The vertical datum for all the data sets input inputted to the model was converted to mean Sea level.

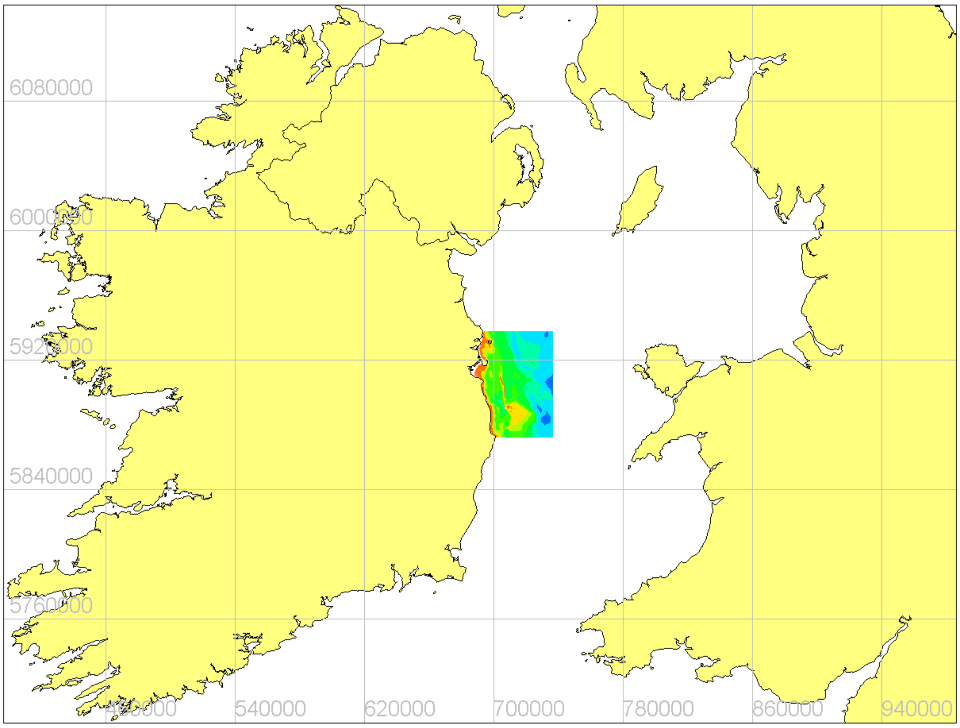


Figure 4 Model Domain Area for Dublin Array Model

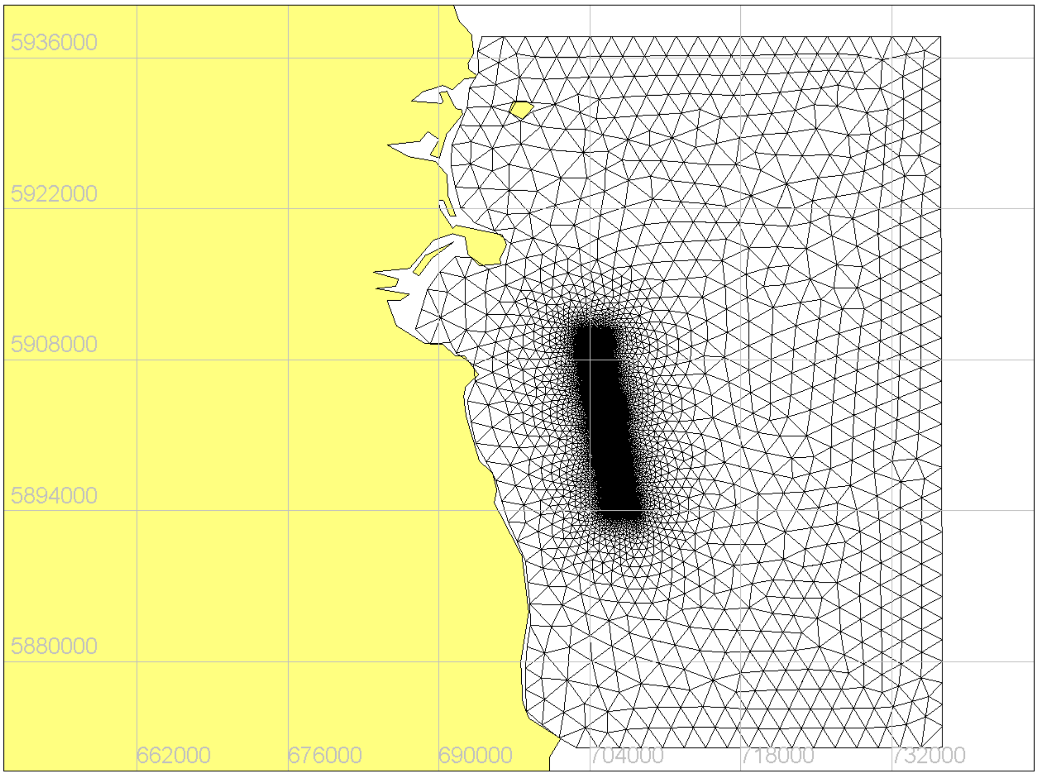


Figure 5 Finite element Domain with high refinement surrounding Turbine Piles

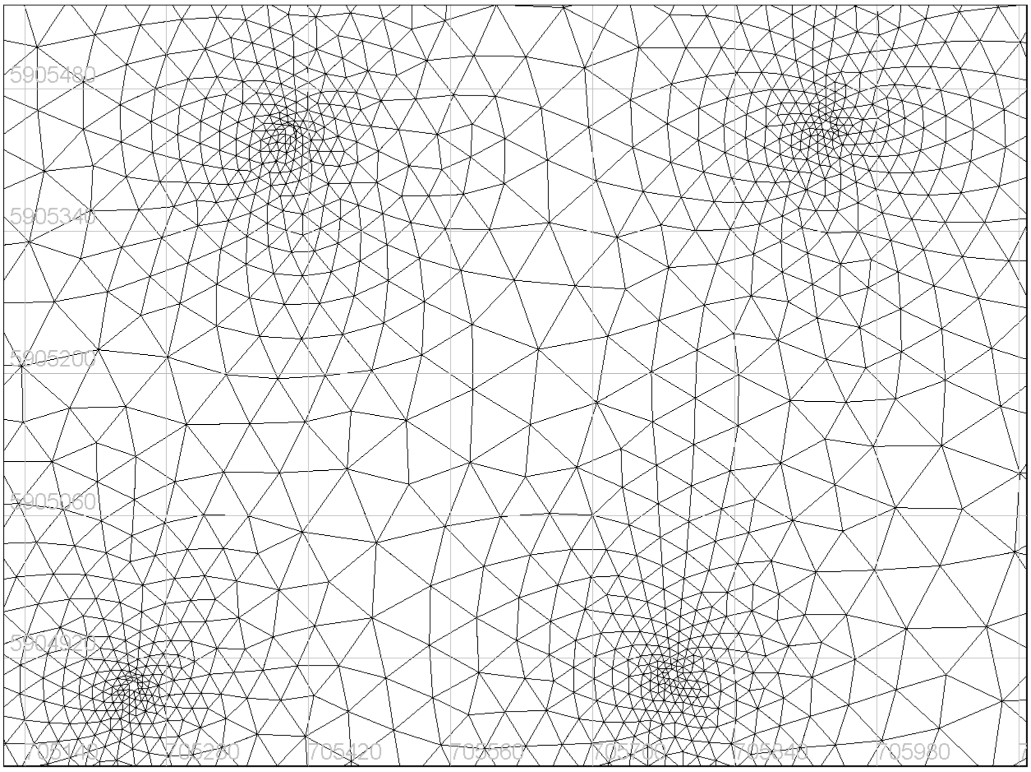


Figure 6 Mesh Refinement in vicinity of 4 No. Turbine Piles (pattern repeated for all 145 piles)

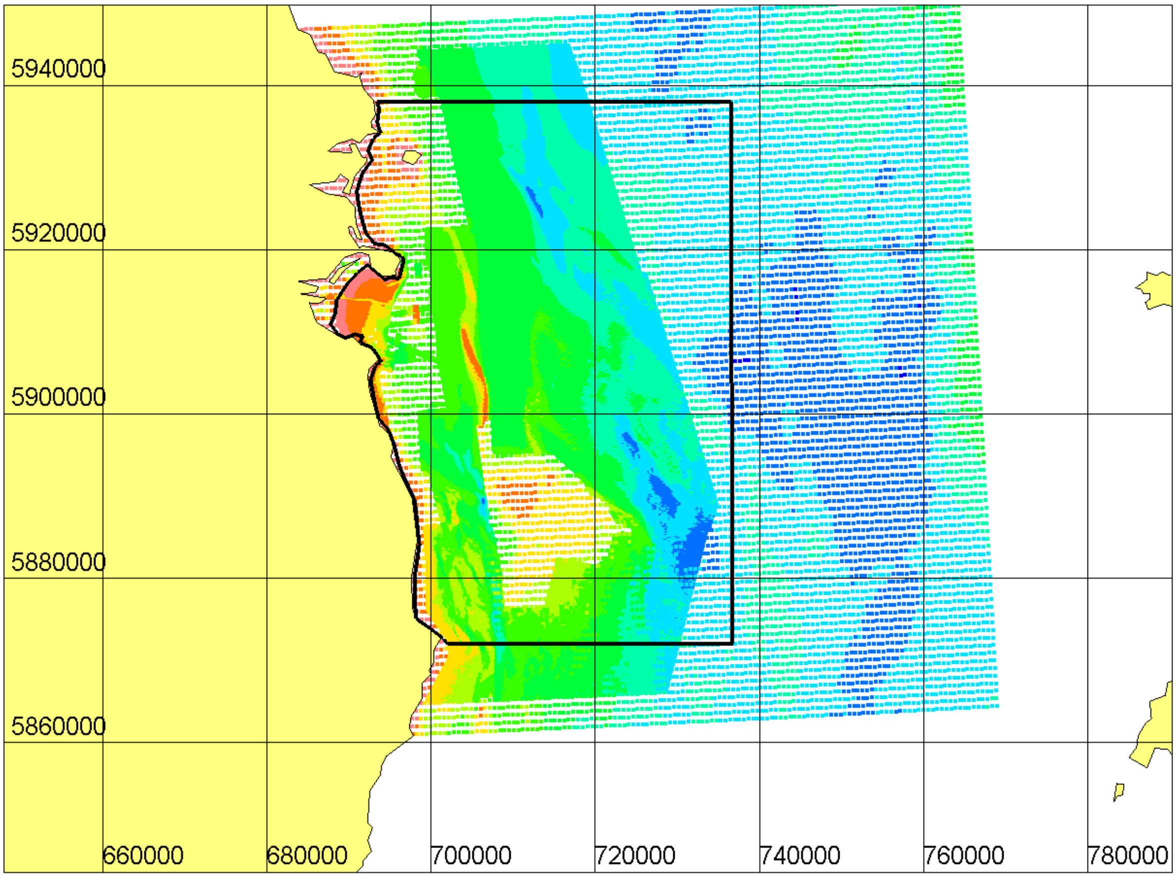


Figure 7 Modelled Irish Sea Domain off Bray Head with available bathymetry data (infomar, BODC European Shelf 0.5minute,Admiralty Chart and HSL 2008 survey of Kish and Bray banks) (note projection to UTM 29N)

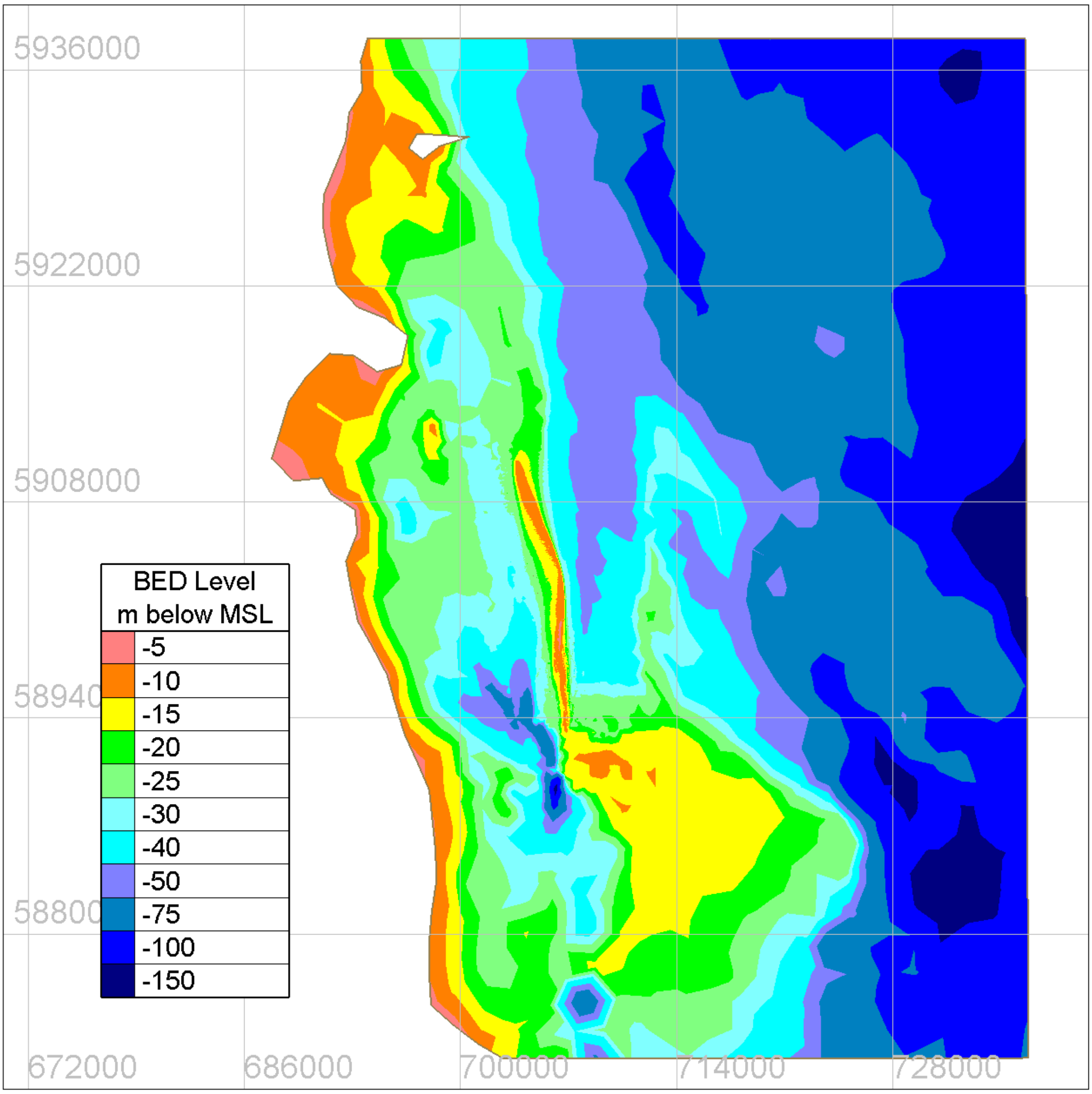


Figure 8 Modelled Bathymetry

2.2 Boundary and Initial conditions Specification

Boundary conditions driving the Dublin Array Hydrodynamic Model were generated from regional/local tidal solutions by OSU (Oregon State University). The regional solution was derived from the European Shelf structured grid Barotrophic tidal model that covers the North-East Atlantic Ocean with 11 harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4 and MN4), refer to Figure 9 for extent of the European Shelf Model coverage. The solution gives amplitudes and phases for tidal elevation and transport from which two horizontal components of the current can be deduced (by dividing transport by water depth). The resolution of the local European Shelf solution is 1/30 degree and is referenced to mean sea level. The harmonic constants from the ES model were interpolated on to the relevant boundary nodes of the local model. These harmonic constants were also used to reconstruct the initial conditions within the domain at simulation commencement and to define the time varying boundary conditions at each boundary node and at each time step.

For this study the south, east and north boundaries were specified as imposed U, V and H (velocity and depth boundaries) and the west boundary (Irish Shoreline) as a land boundary (zero normal Flux boundary). Given the imposed / clamped nature of the open sea boundaries, a radiation condition at these boundaries using the

Thompson Method was necessary to allow numerical noise to propagate freely out of the computational domain rather than becoming trapped and oscillating unrealistically within the domain.

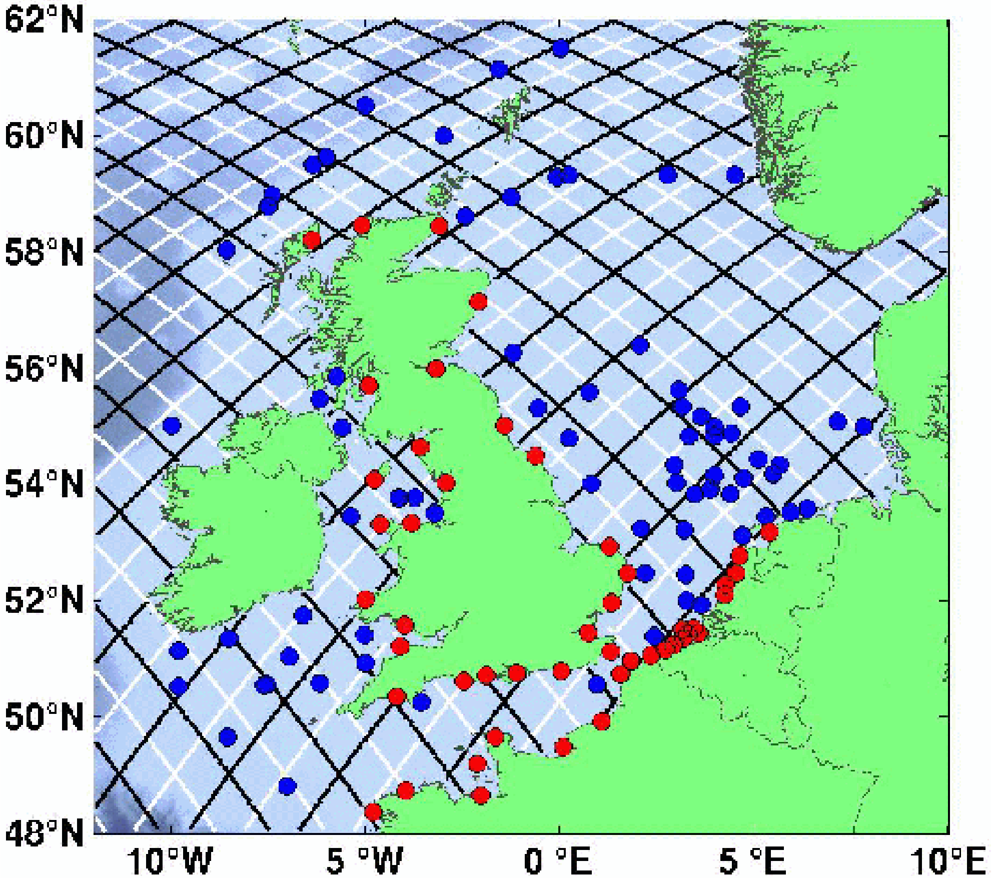


Figure 9 NOA European Shelf Model

2.3 Model Calibration and Verification

The hydrodynamic model was calibrated and validated against the tidal velocity and depth measurements performed by Aquafact (August-September 2012). Four measurement locations were available along the Kish–Bray sand bank as shown in Figure 10. Two locations (north and south) had 27days of continuous ADCP recordings providing near bed, mid-depth and near surface velocity magnitudes and directions and water depth. Two locations C1 and C2, mid-way along the bank, provided a 24hour data set coinciding with spring tides. These measurements provided an excellent data set to calibrate and validate the hydrodynamic model.

The hydrodynamic model was run for a start date of 23/08/2012 00:00 to the 20/09/2012 23:50 for a computational time step of 30seconds and simulation results were output every 10min's for the complete model domain and stored in a binary results database. Time series of water depths and depth averaged velocities were generated for each of the measurement points from this results database. A final calibrated manning's roughness of 0.018 was used with a full k-ε turbulence model to simulate eddy viscosity / turbulence and accurately produce the observed hydrodynamics.

An option for scaling (increasing/decreasing) the magnitudes of the specified boundary tidal heights and velocities from the European Shelf Tidal Solution was not required for this application with the ES tidal solution generating realistic results without modification.

The time series comparisons between the measured and modelled hydrodynamics (velocity magnitude, direction and tidal water depth) are presented in Figures 11 to 14 for each of the observation sites. The North and South sites have measured time series data for 27 complete days, measured at 10m intervals through the water column and Sites C1 and C2 have a 24hour monitoring period also measured at 10minute intervals and for different vertical depths. At all of the measurement sites the computed and measured data agree well with each other, in particular the timing of peak and slack velocities, the tidal heights being extremely consistent over the measurement period and the magnitude and direction of tidal flows. The variation in tidal range is also well demonstrated by the model with the tidal range decreasing significantly from north to south as it approaches the amphidromic point off Arklow. The results presented in Figures 11 to 14 clearly demonstrate that the hydrodynamic model for the study area is suitably robust and accurate and replicates extremely well the complex tidal regime in the vicinity and across the Kish-Bray Sand Banks. It is concluded that the Dublin Array Hydrodynamic Model is fit for purpose in quantifying the baseline hydrodynamic conditions and in measuring / quantifying the potential hydrodynamic impact of the Turbine Piles locally and on the far field.

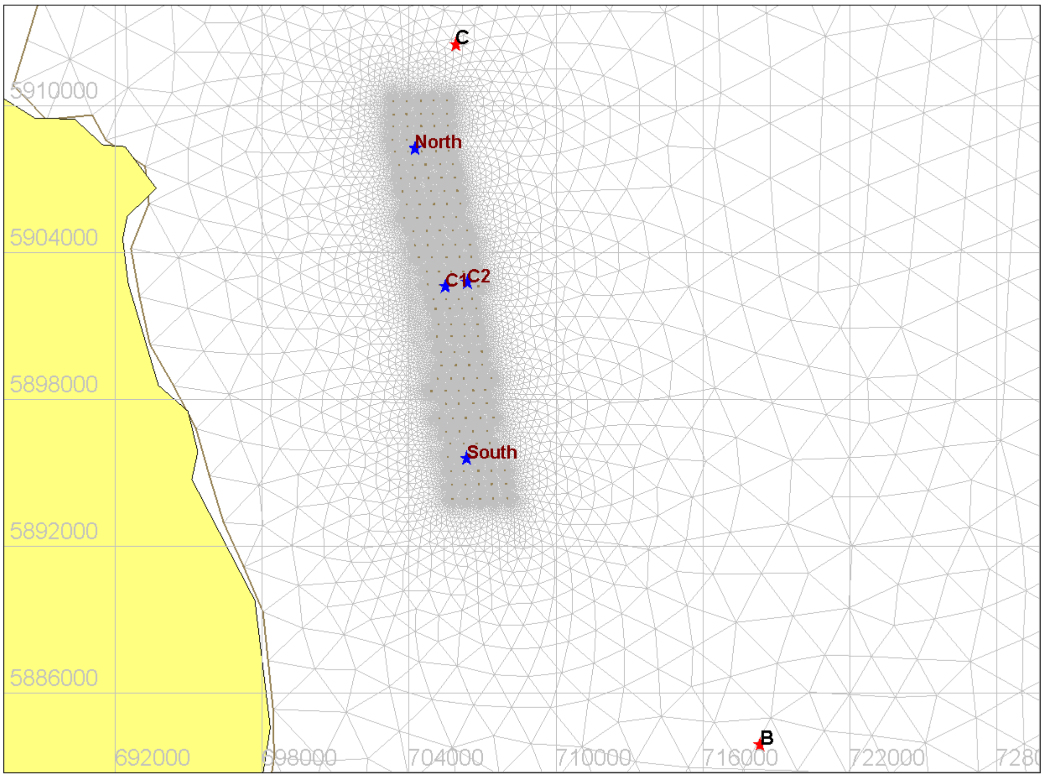


Figure 10 Tidal Stream Survey Locations (B and C are Admiralty Chart Tidal Prism observations)

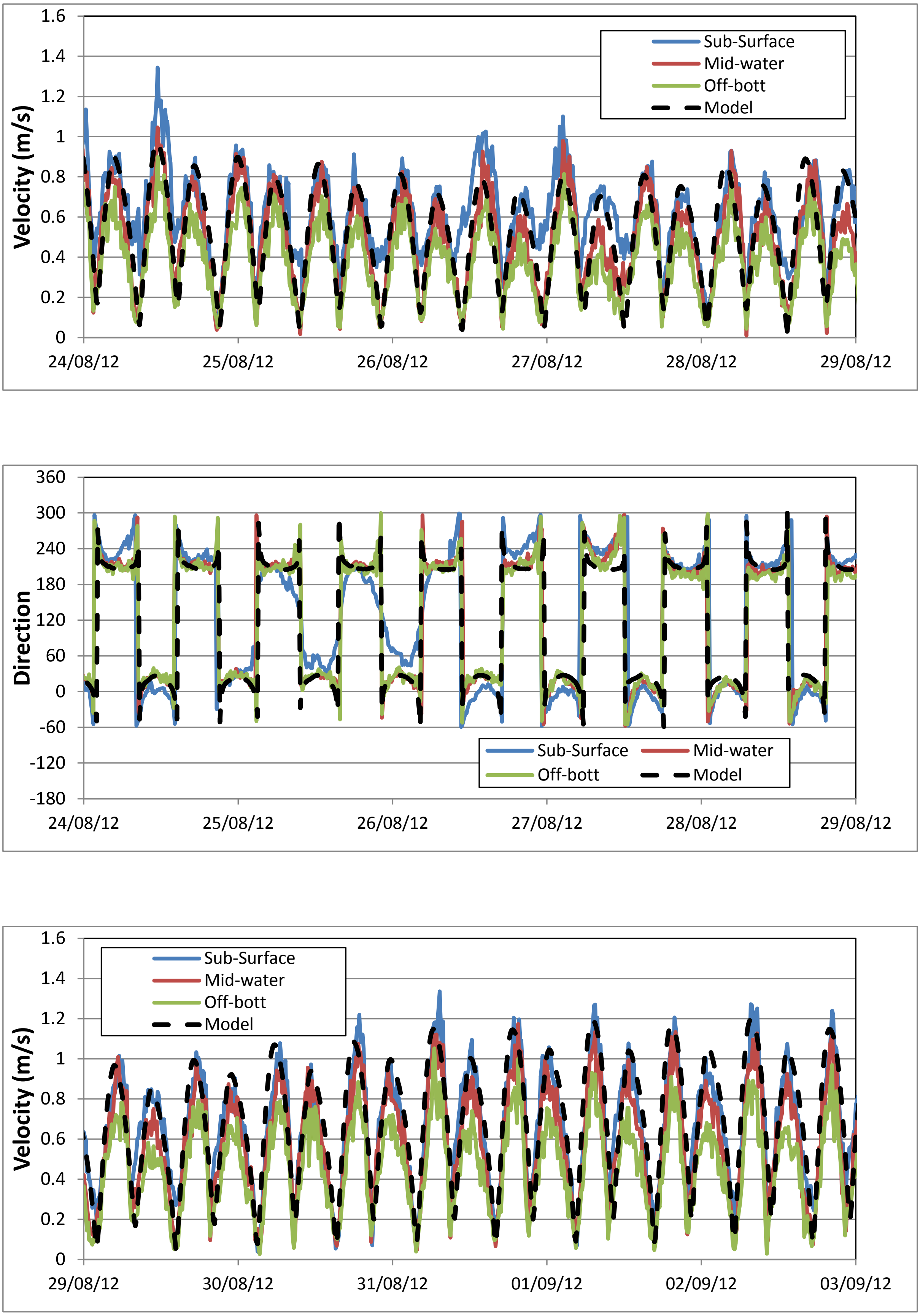
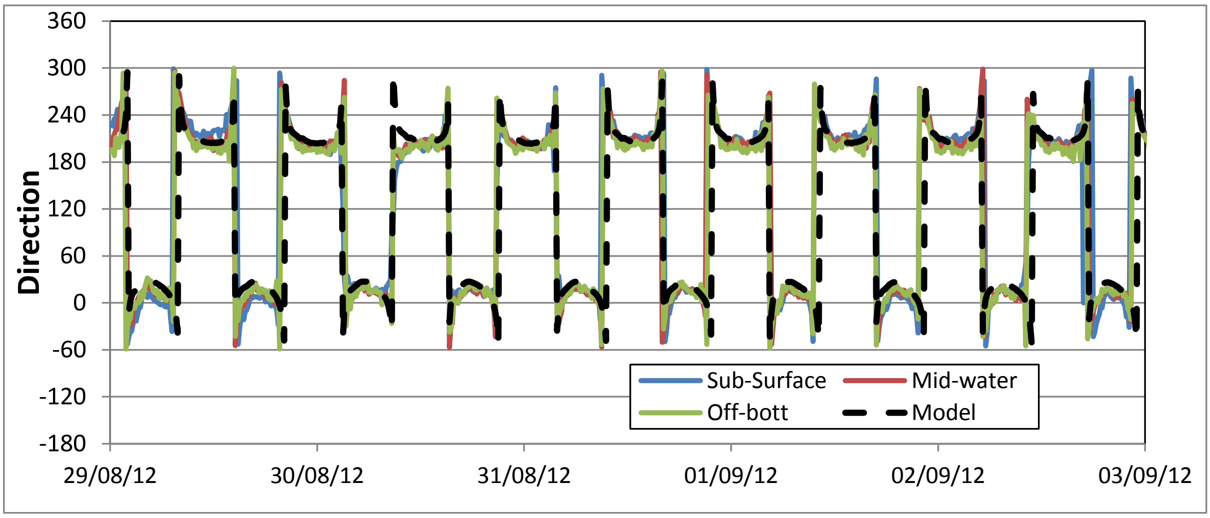
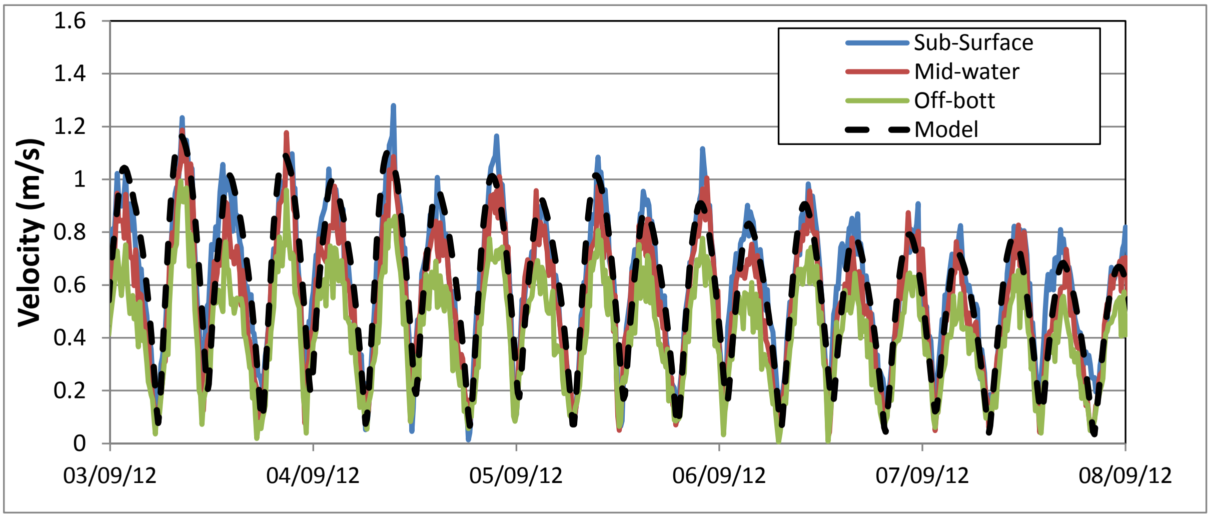


Figure 11.1 Model Calibration Results for South Kish ADCP (Tidal Speed and direction at 10minute intervals from 24 to 19th September 2012)





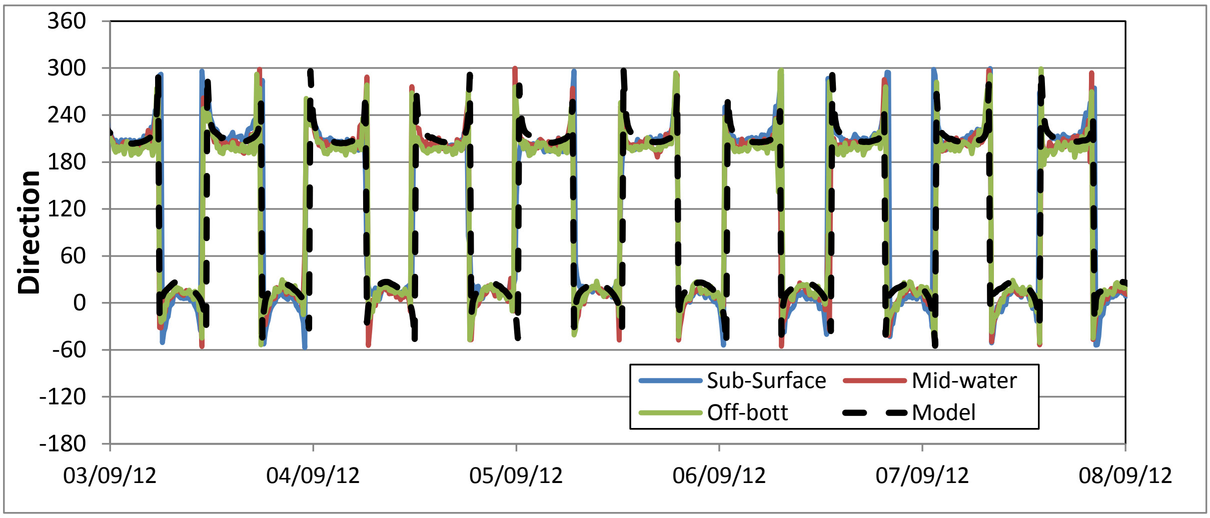
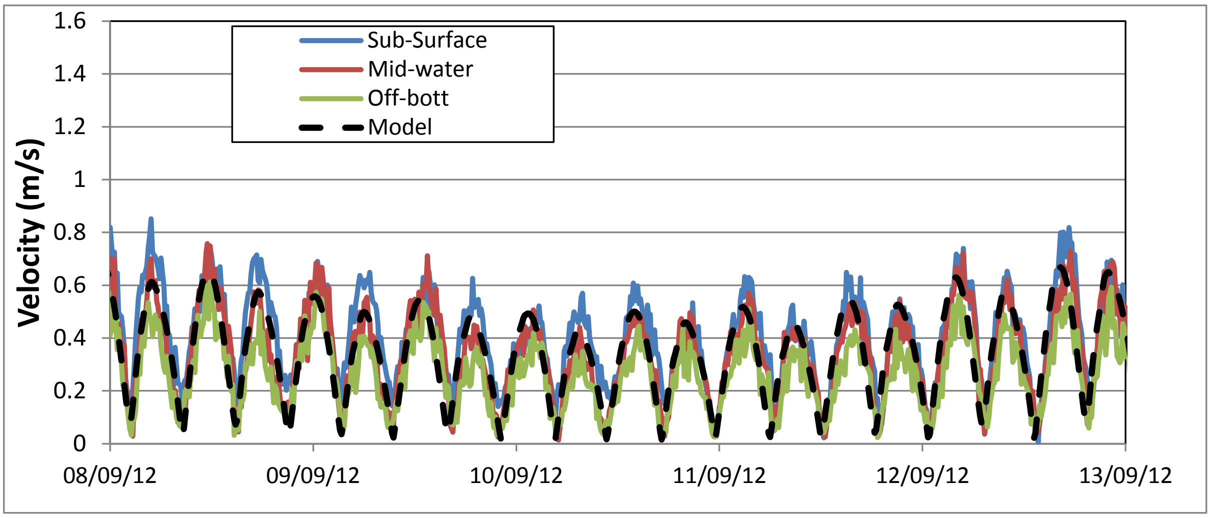
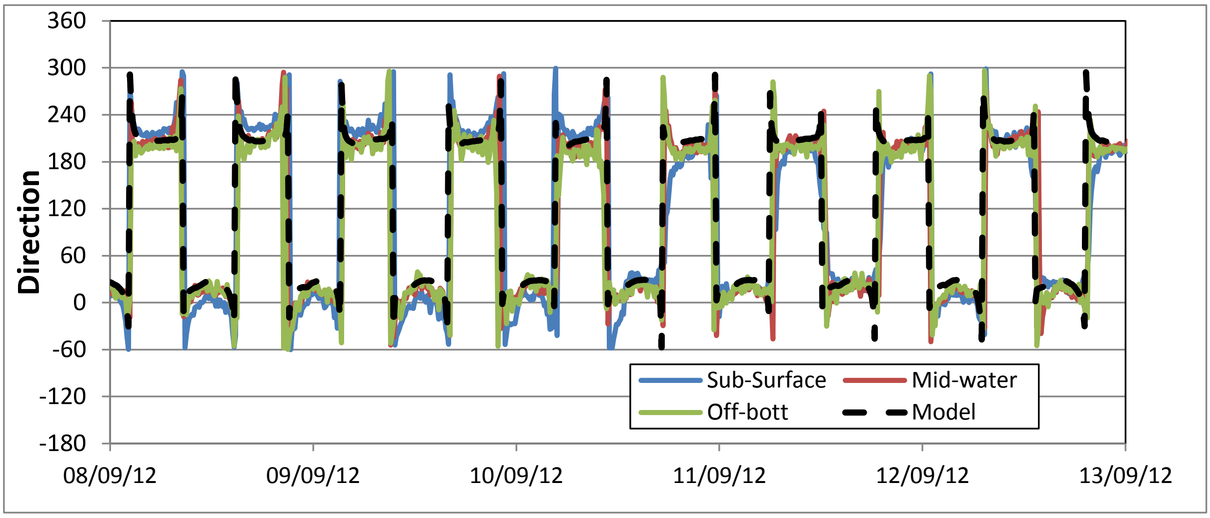


Figure 11.1 Cont'd Model Calibration Results for South Kish ADCP (Tidal Speed and direction at 10minute intervals from 24 to 19th September 2012)





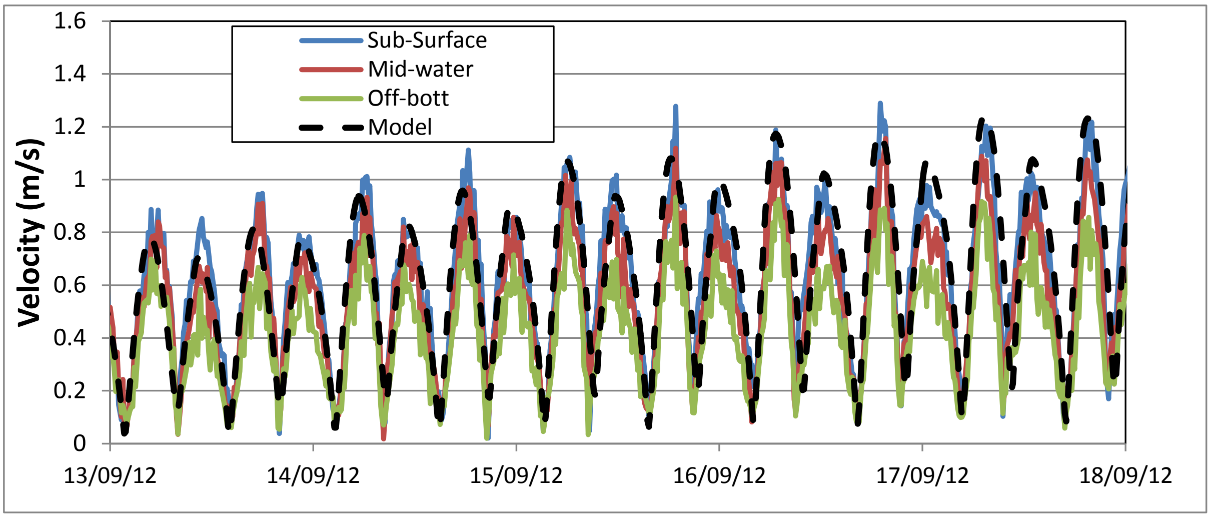
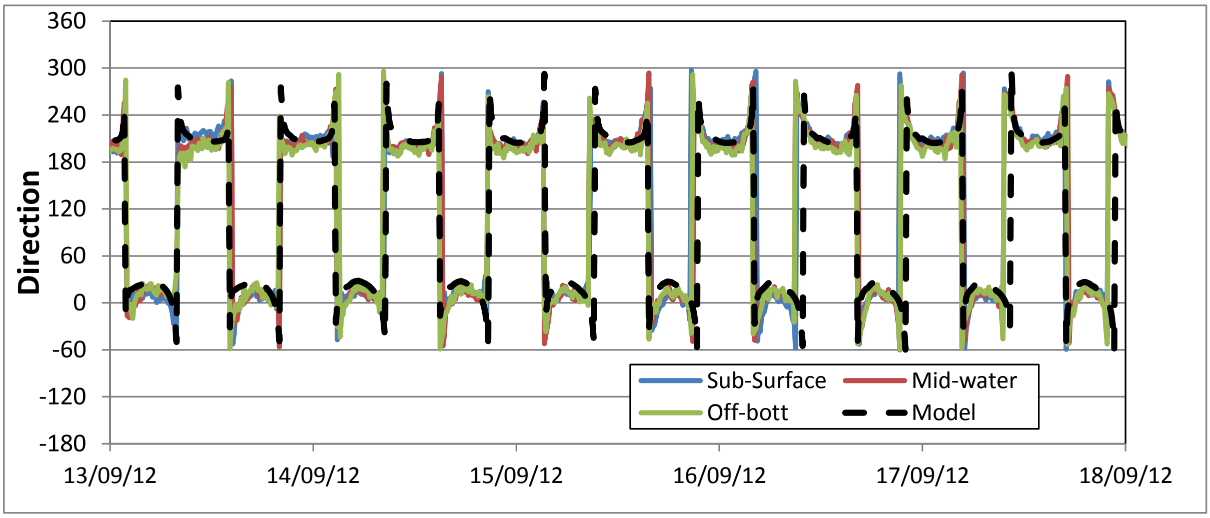


Figure 11.1 Cont'd Model Calibration Results for South Kish ADCP (Tidal Speed and direction at 10minute intervals from 24 to 19th September 2012)



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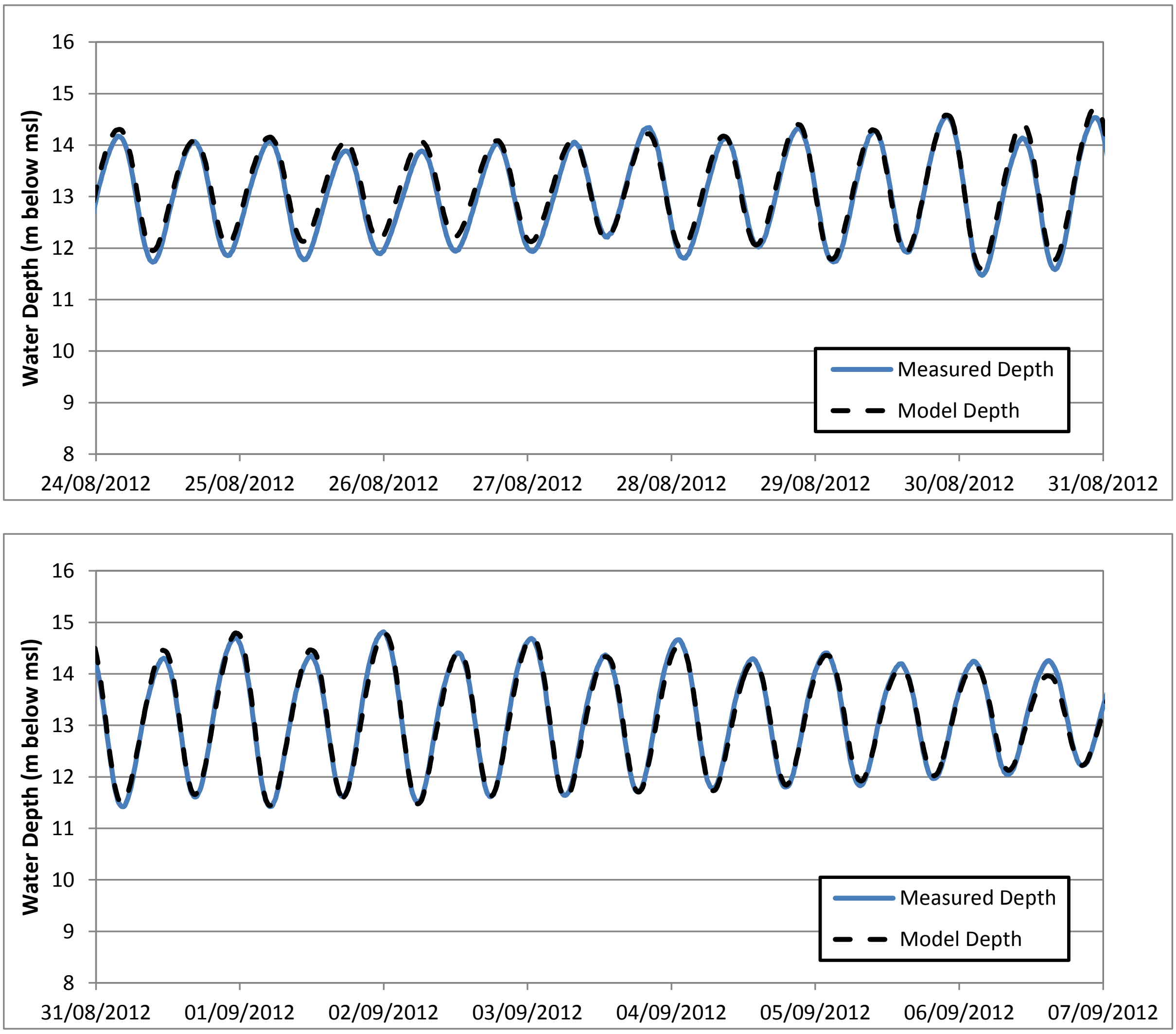
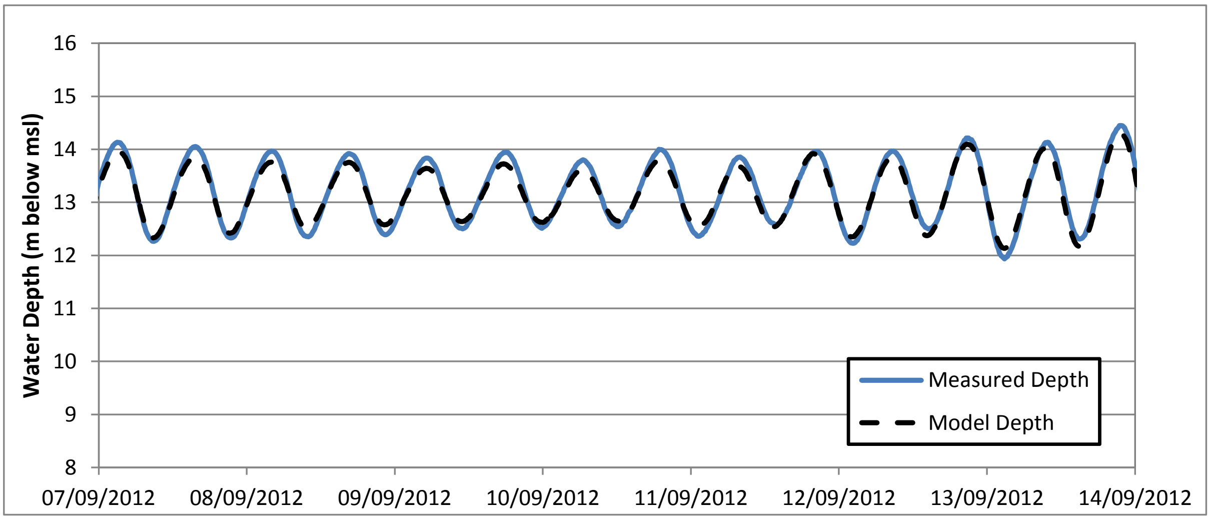


Figure 11.2 Model Calibration Results for South Kish ADCP (Tidal depths at 10minute intervals from 24 to 19th September 2012).



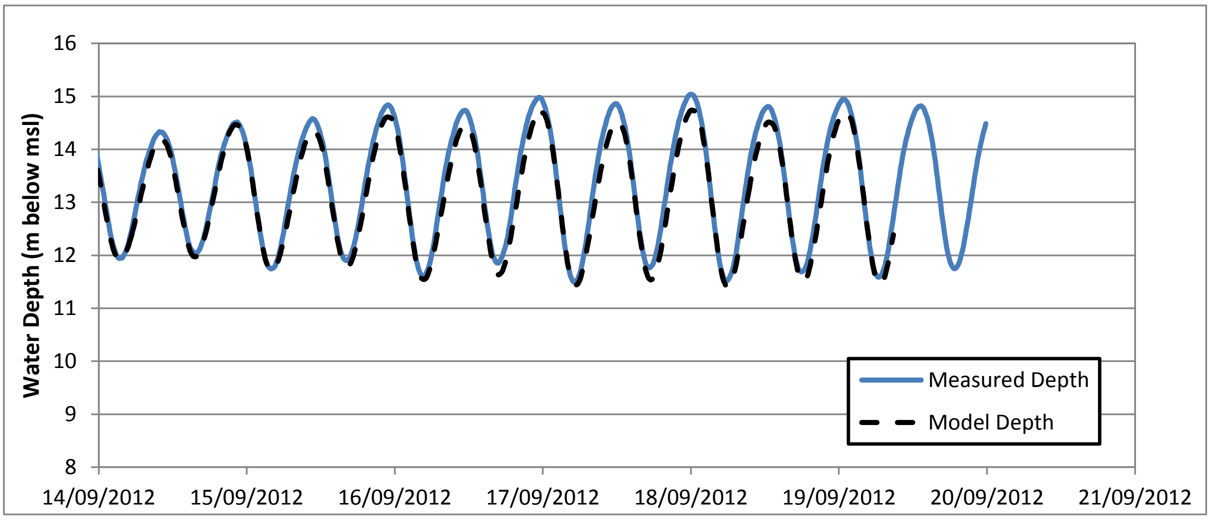
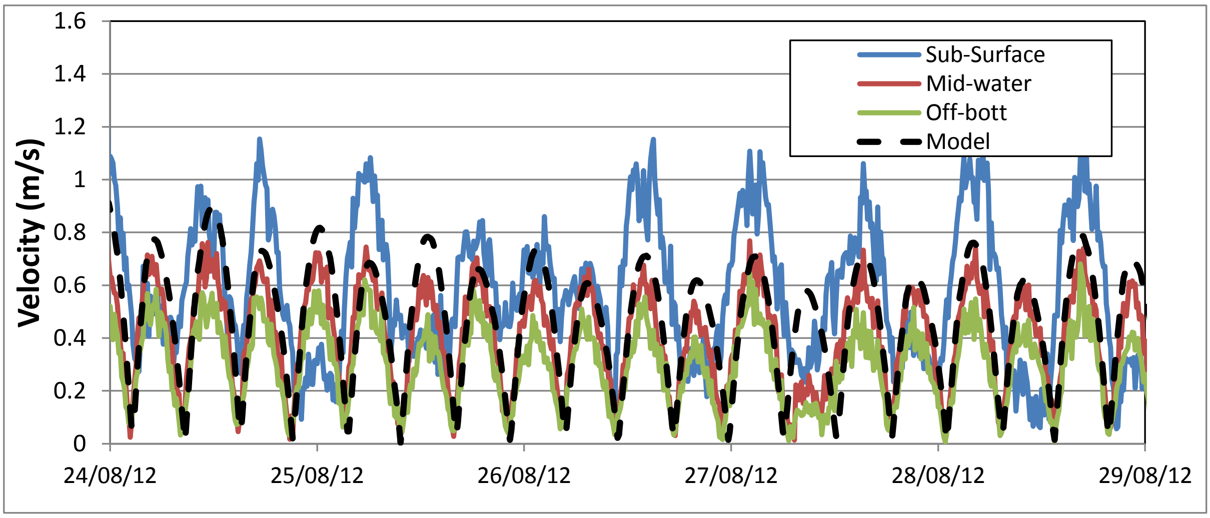
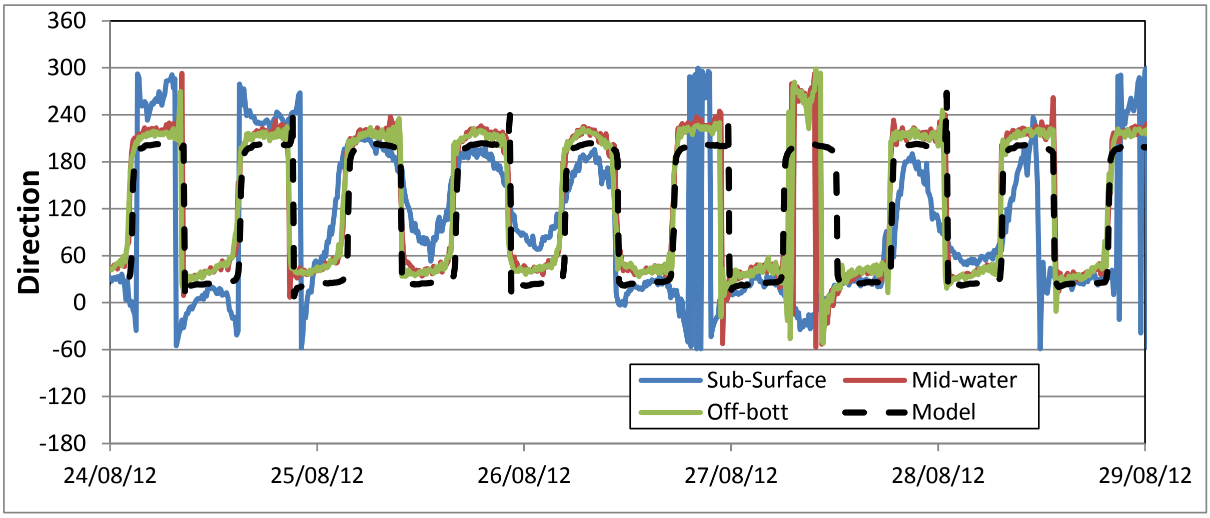


Figure 11.2 Cont'd Model Calibration Results for South Kish ADCP (Tidal depths at 10minute intervals from 24 to 19th September 2012





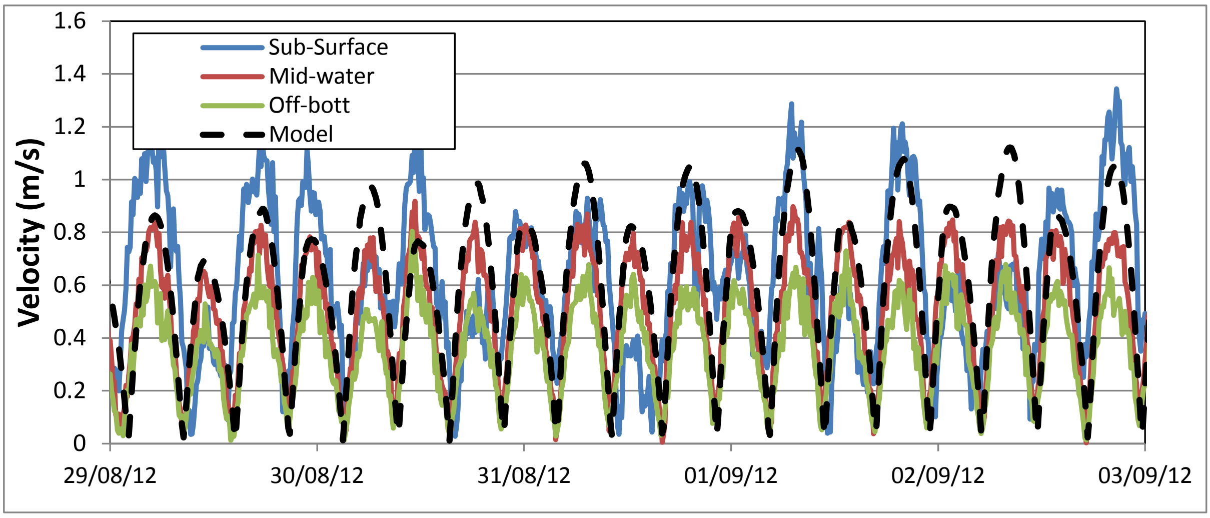
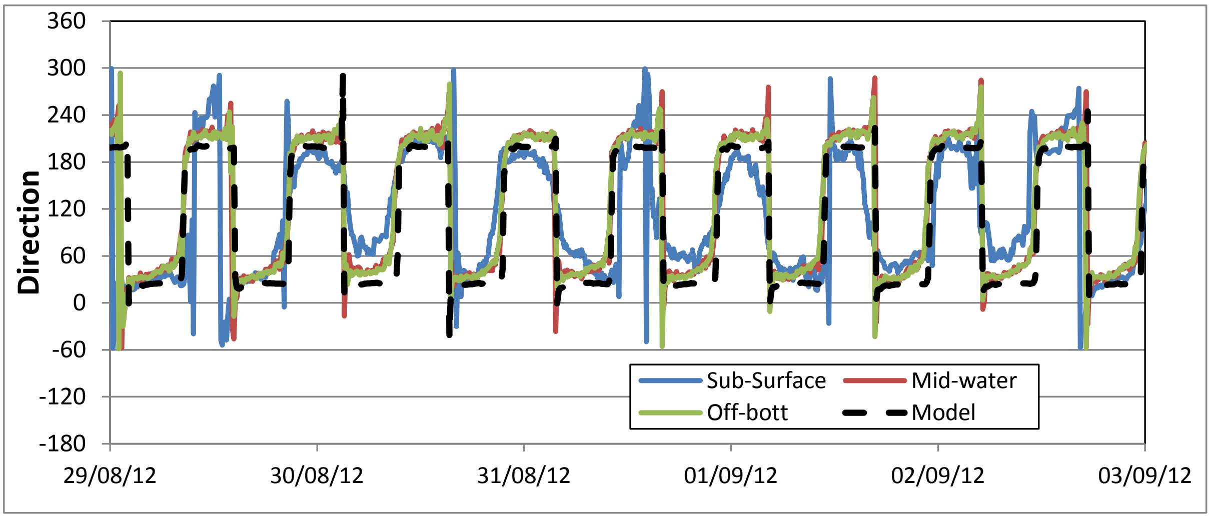
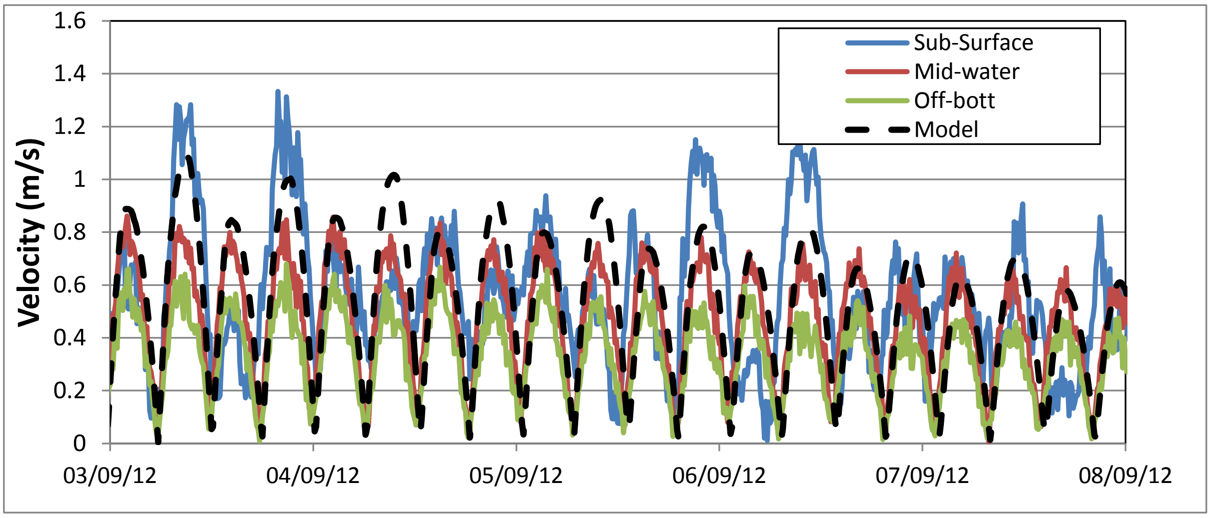


Figure 12.1 Model Calibration Results for North Kish ADCP (Tidal Speed and direction at 10minute intervals from 24 to 19th September 2012)





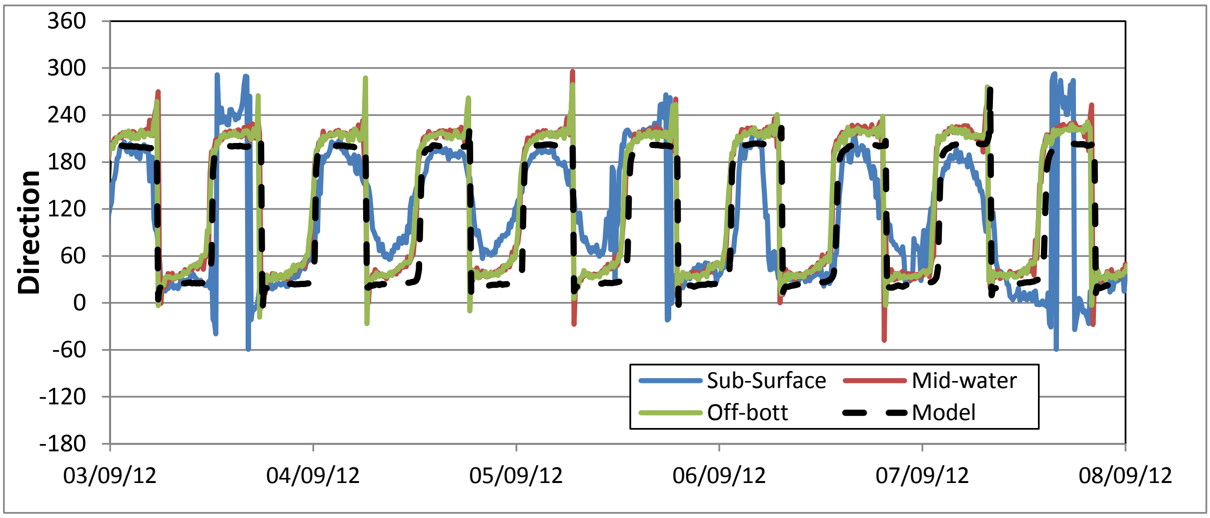
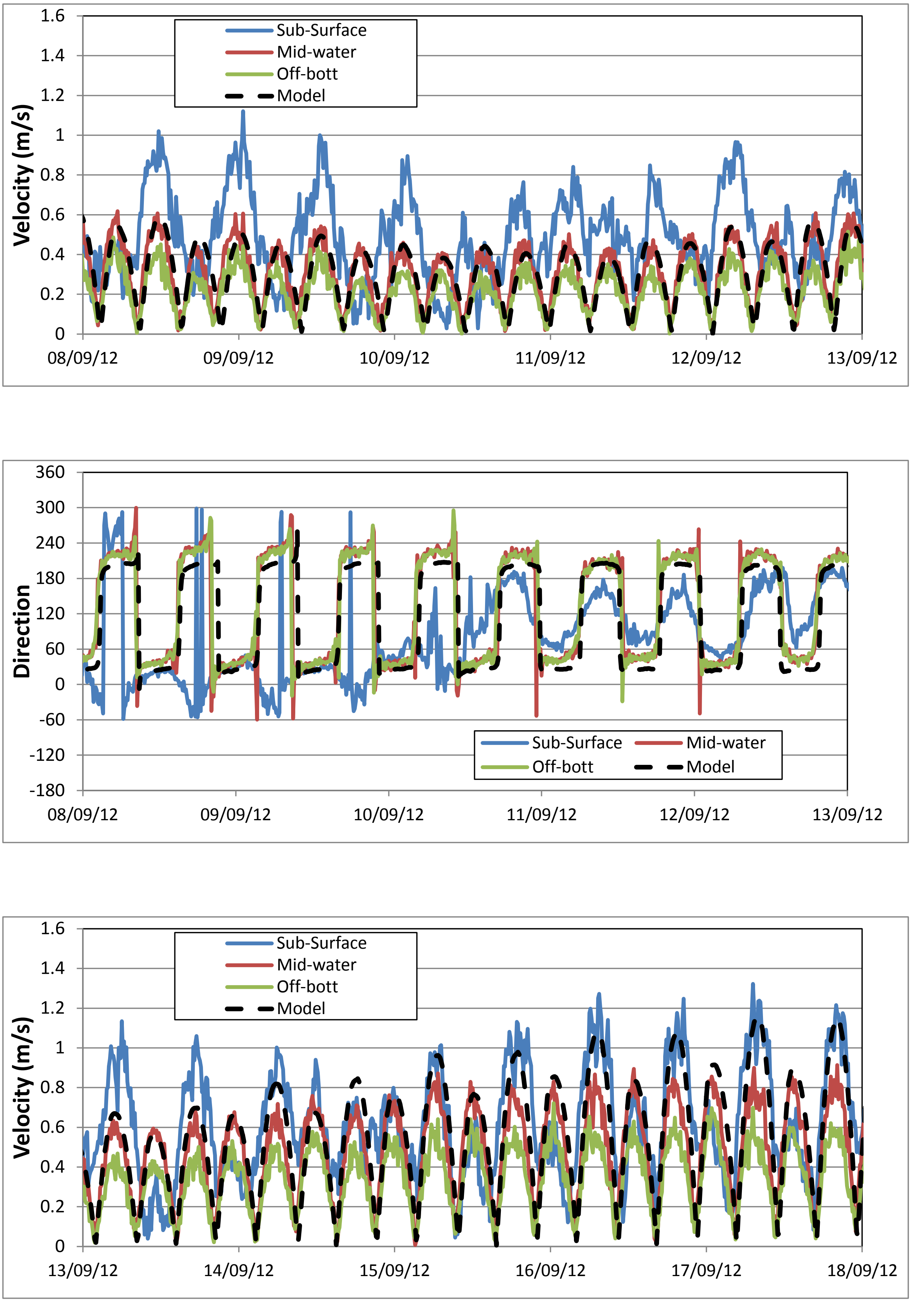


Figure 12.1 Cont'd Model Calibration Results for North Kish ADCP (Tidal Speed and direction at 10minute intervals from 24 to 19th September 2012)



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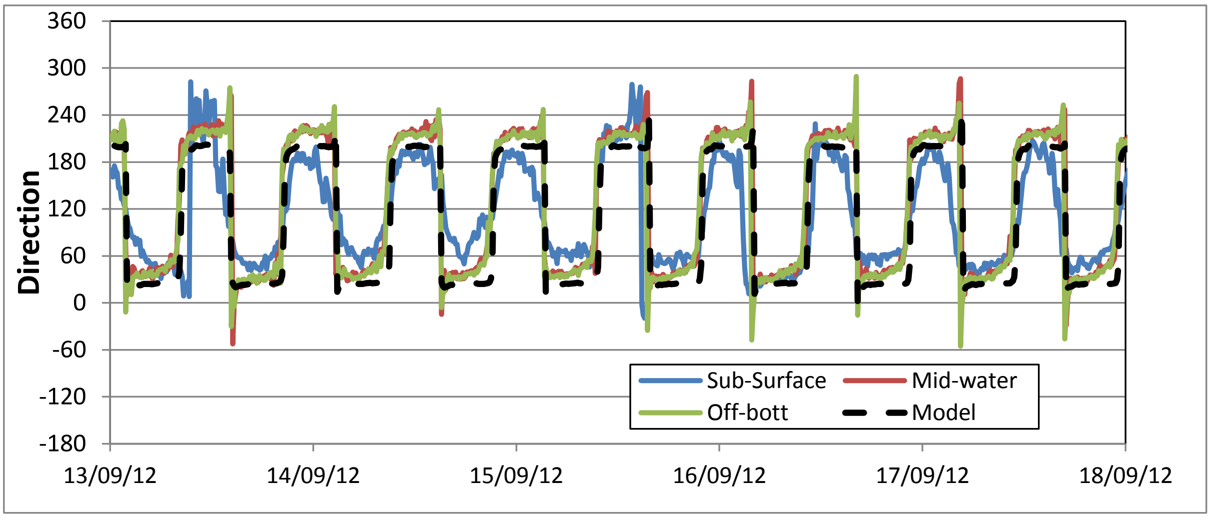
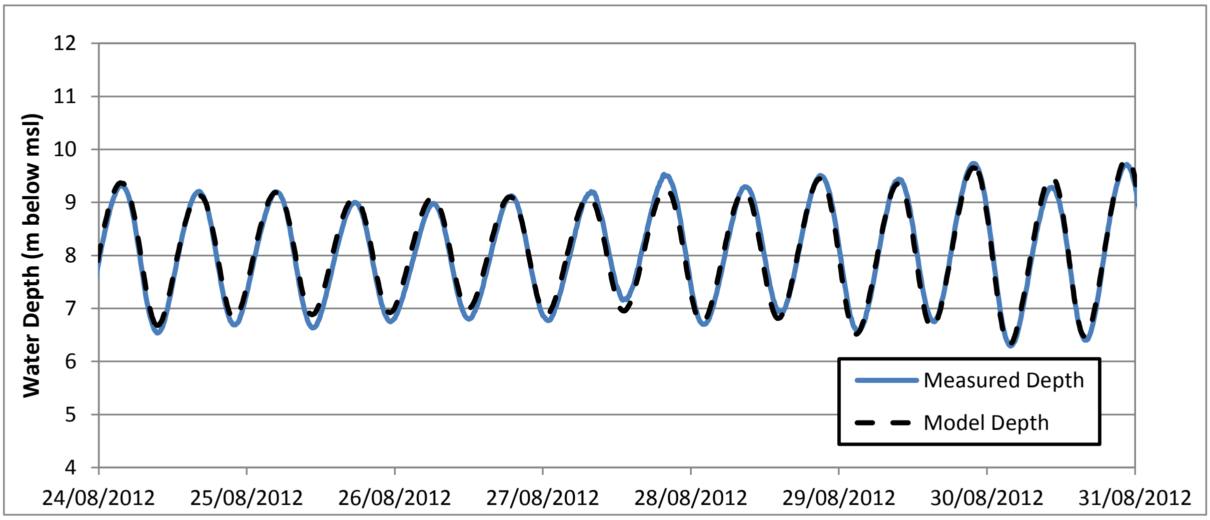


Figure 12.1 Cont'd Model Calibration Results for North Kish ADCP (Tidal Speed and direction at 10minute intervals from 24 to 19th September 2012)



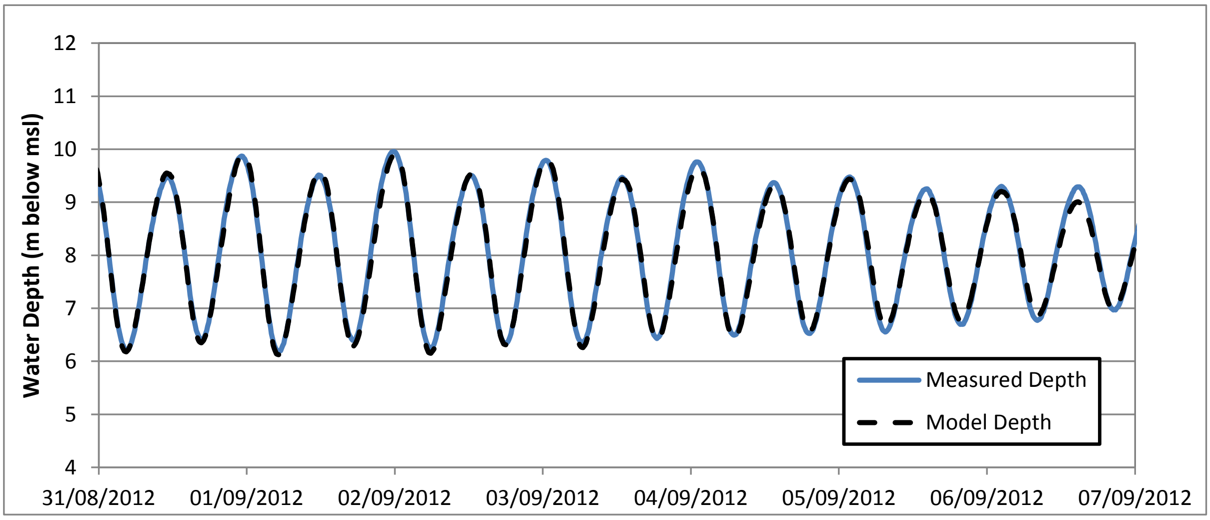
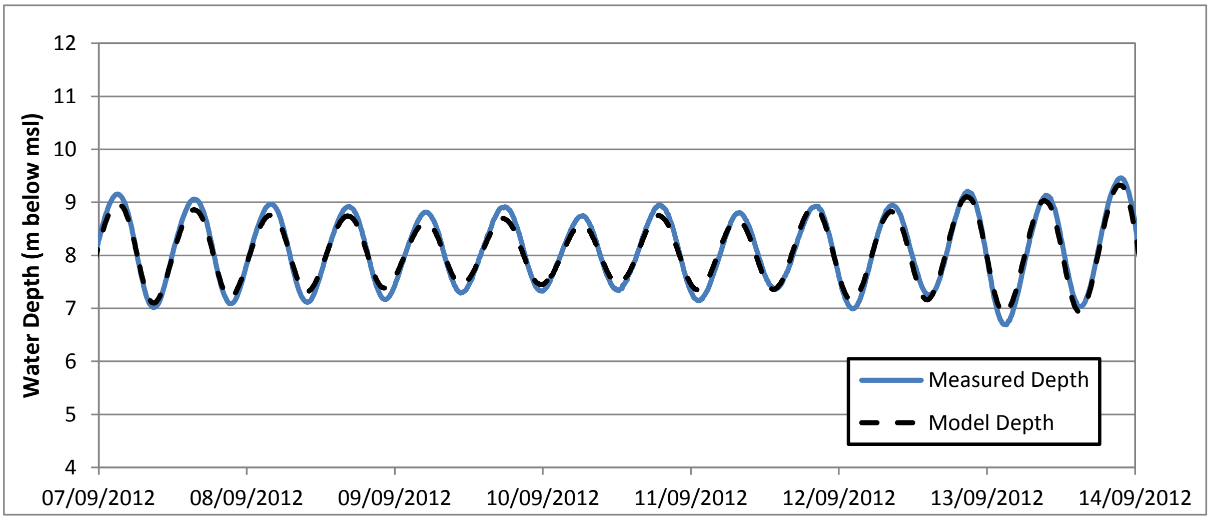
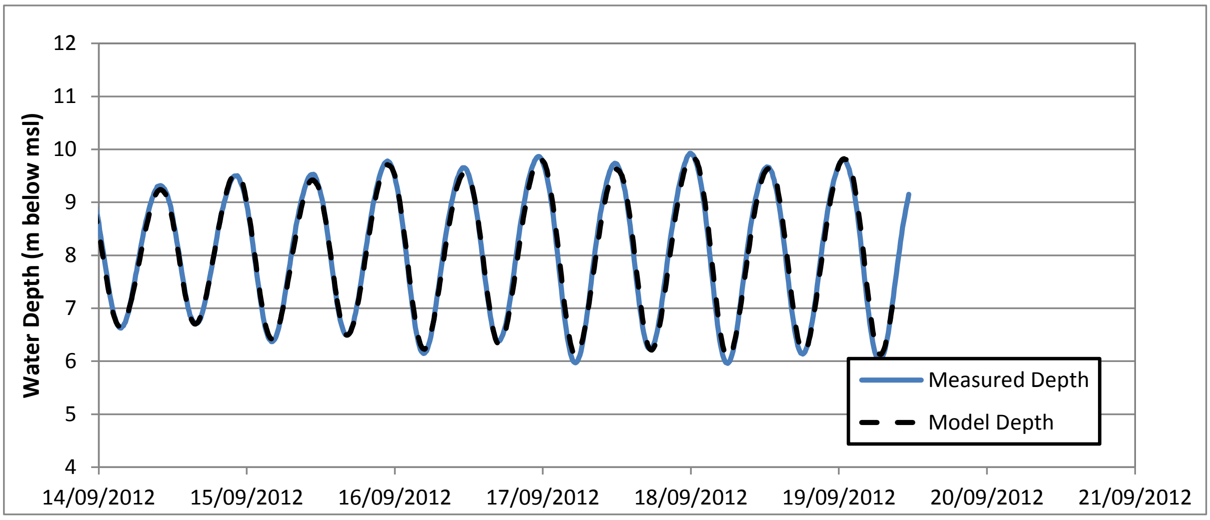


Figure 12.2 Model Calibration Results for South Kish ADCP (Tidal depths at 10minute intervals from 24 to 19th September 2012).





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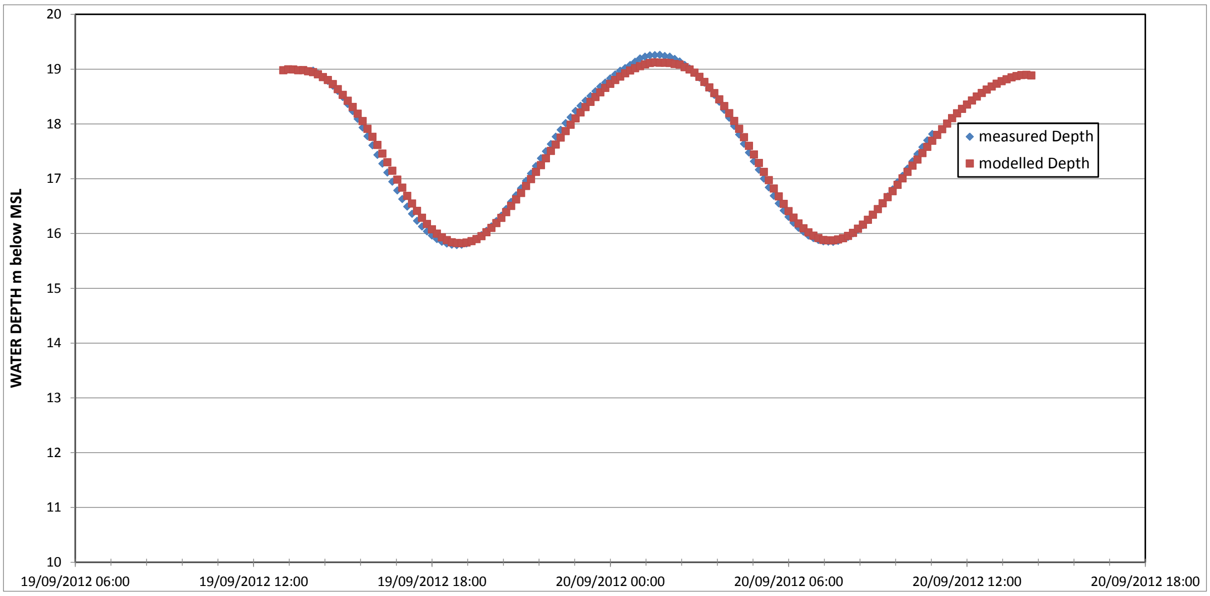


Figure 13.1 Measured and computed Water Depth at Site C1 (19th to 20th September 2012).

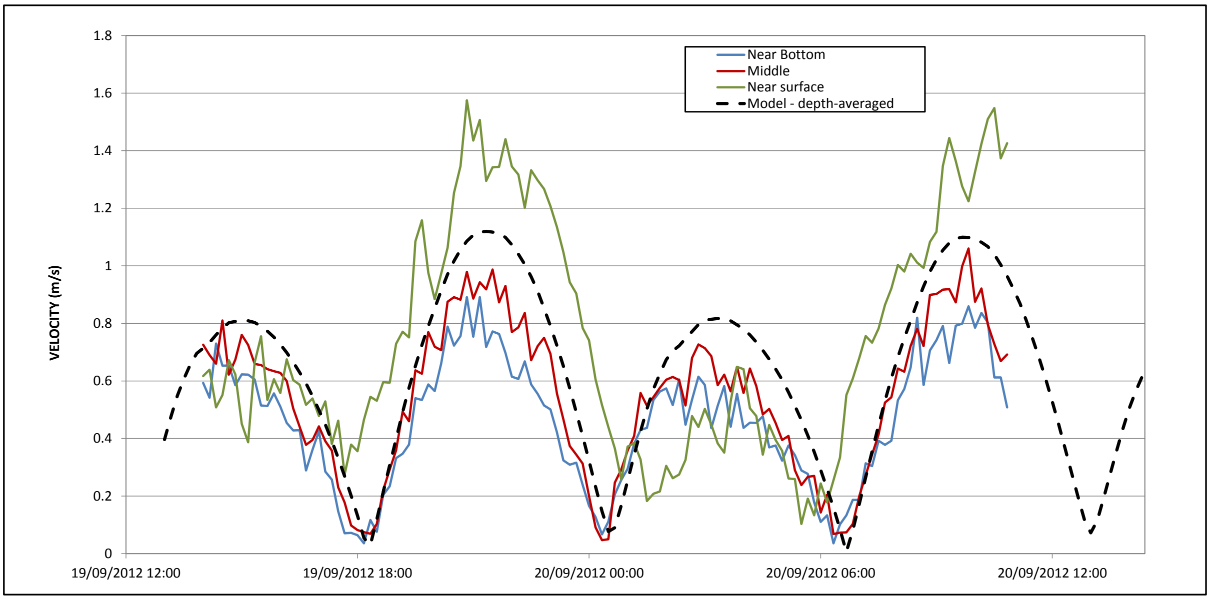


Figure 13.2 measured and computed current Speed Magnitude at Site C1 (19th to 20th September 2012)

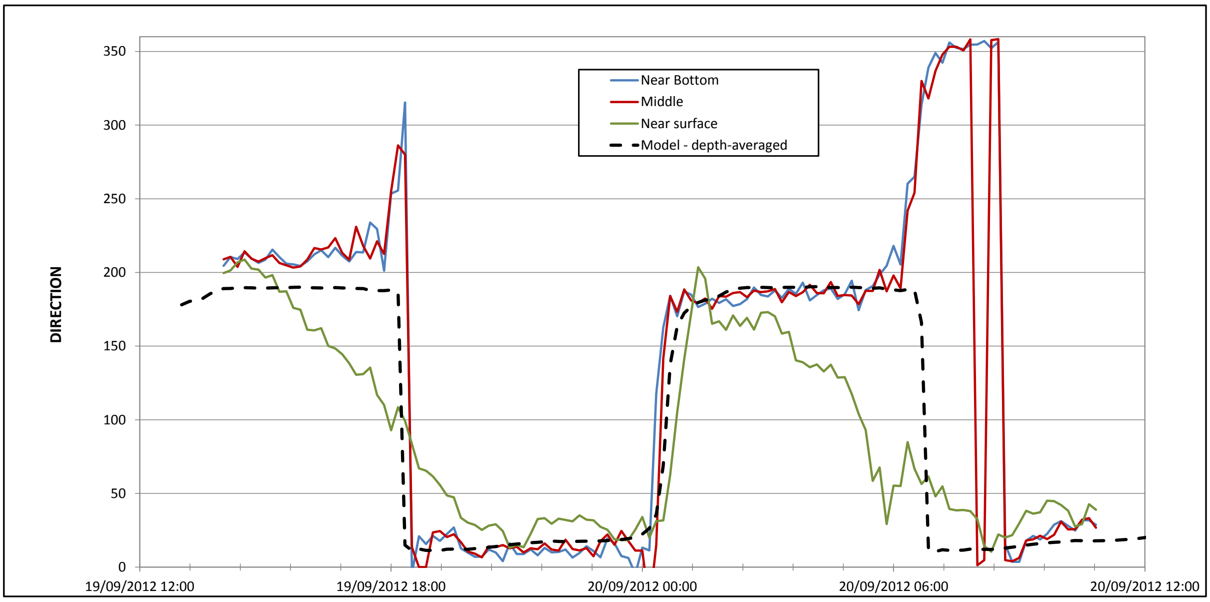


Figure 13.3 Measured and computed current Direction at Site C1 (19th to 20th September 2012)

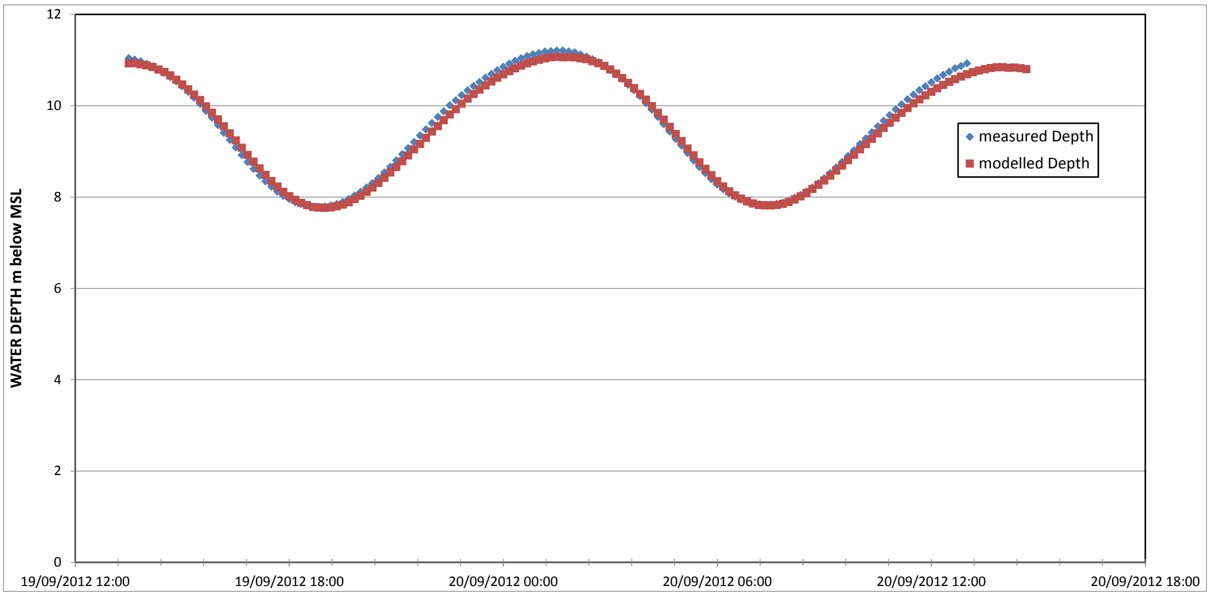


Figure 14.1 Measured and computed Water Depth at Site C2 (19th to 20th September 2012).

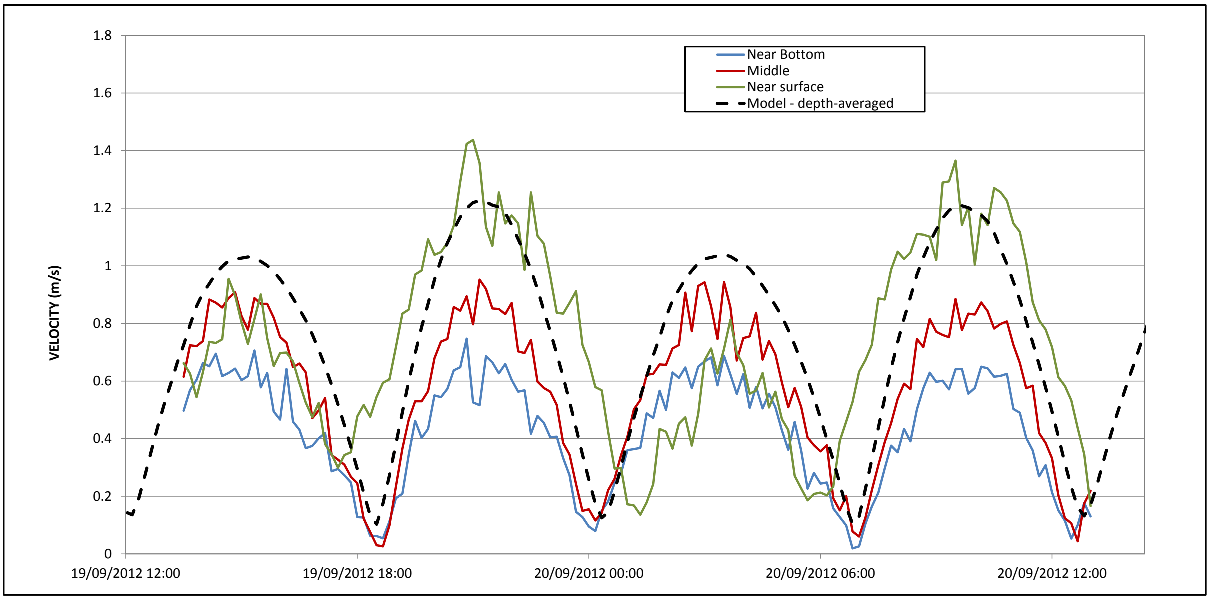


Figure 14.2 Measured and computed current Speed Magnitude at Site C2 (19th to 20th September 2012)

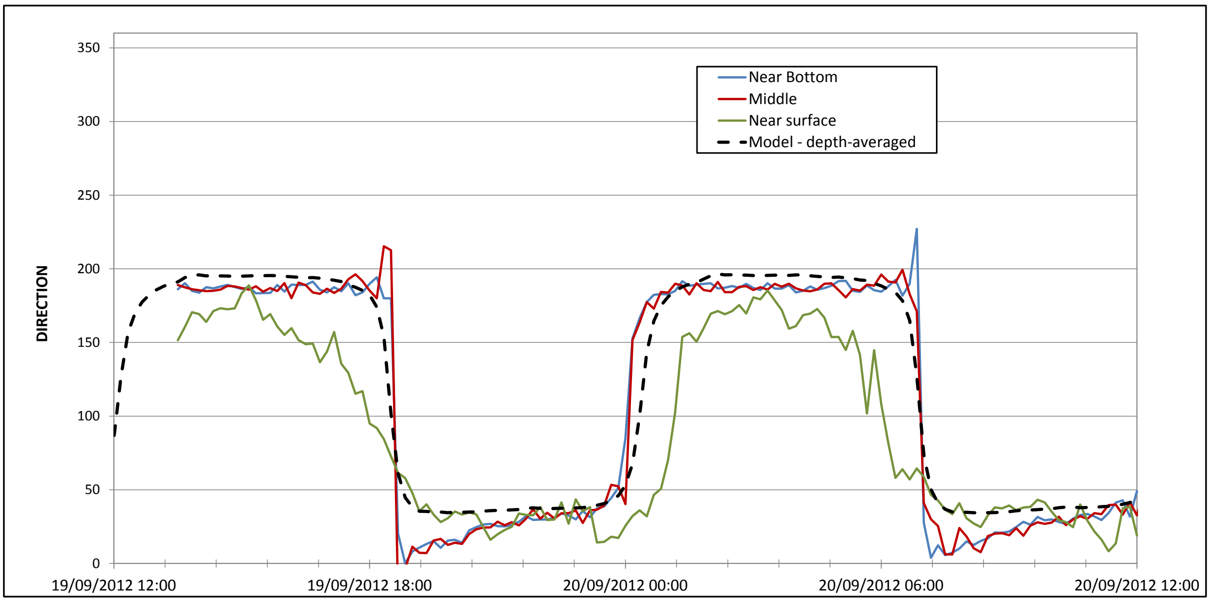


Figure 14.3 Measured and computed current Direction at Site C2 (19th to 20th September 2012)

3. HYDRODYNAMIC SIMULATIONS

3.1 Tidal Circulation

A 30-day simulation period set from the 23rd August to the 22nd September 2012 representing the tidal characteristics of a full lunar tidal cycle that includes spring, mean and neap tides was used to assess the baseline tidal flow regime within the area of interest and to assess the hydrodynamic impact of the proposed development.

Figures 16.1 to 16.6 present colour tonal vector plots of tidal velocities at two hourly intervals from the simulation period for the 2nd September 2012 representing a spring tide. For clarity the velocity vectors are shown on a less dense grid than the model mesh. These figures demonstrate the strong rectilinear type flow parallel to the Irish shoreline with cross bank flow direction in a SSW and NNE directions along the Kish and Bray Sand Banks. Similar characteristics are evident on neaps tides with velocity magnitudes typically 40% lower. Within the domain the velocity magnitudes generally increase southwards. A closer view of the tidal currents in the vicinity of the Dublin Array are presented in Figures 17.1 to 17.6 for the same date. Again for clarity the velocity vectors in these plots are shown on a less dense grid than the model mesh. The cross flow velocity direction and magnitude tends to follow the west to east curvature of the sand bank. The predicted tidal range about mean sea level for the north and south boundaries are presented in Figure 15.1. This Figure 15.1 illustrates the significant reduction in tidal range from north to south as one tends towards amphidromic point off Arklow with spring tidal range reducing from 4.6m to 2.2m and the neap tidal tide from 2.2m to 1.0m north to south. Conversely the tidal velocities strengthen from north to south, Refer to 18.1 and 18.2.

The residual current direction for Kish and Bray Sand Banks is presented in Figure 19 for the 30day simulation period. This figure demonstrates the transport characteristics in the vicinity of the banks with an overall clockwise circulatory movement around the banks with a northwards residual current on the inner west face and southwards residual (net) current along the east face. This long term circulatory movement retains sediment along the banks allowing relatively stable depositional conditions to prevail notwithstanding the strong erosive tidal velocities available during individual tidal cycle.

Table 2 presents a summary details of the tidal conditions at each of the Turbine sites which include water depth, average tidal velocity, maximum tide velocity, average bed shear stress and maximum shear stress.

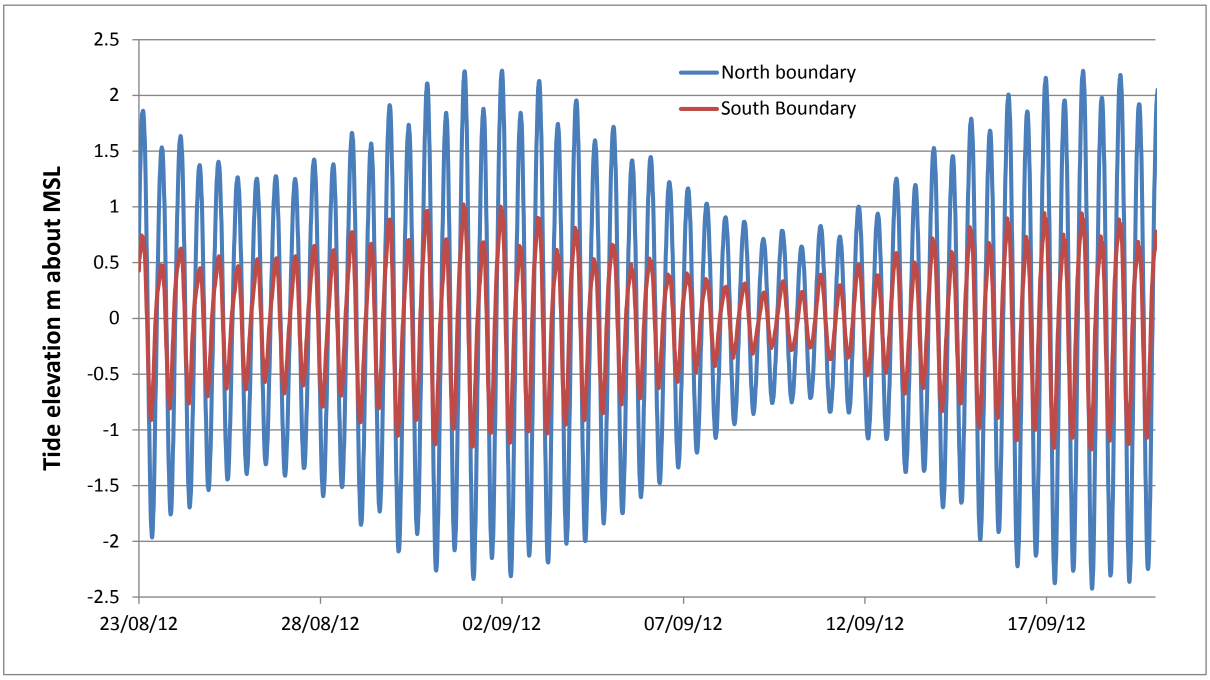
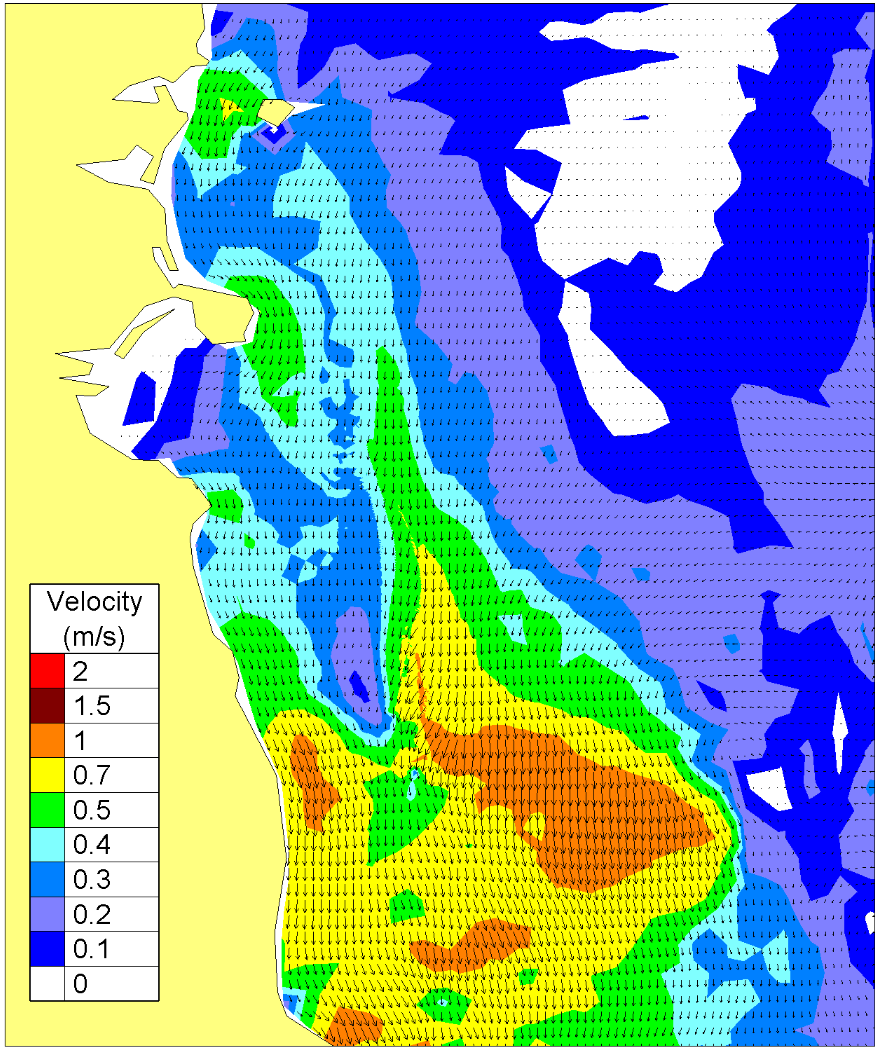


Figure 15.1 Computed Variation in tidal range between North and South model boundaries



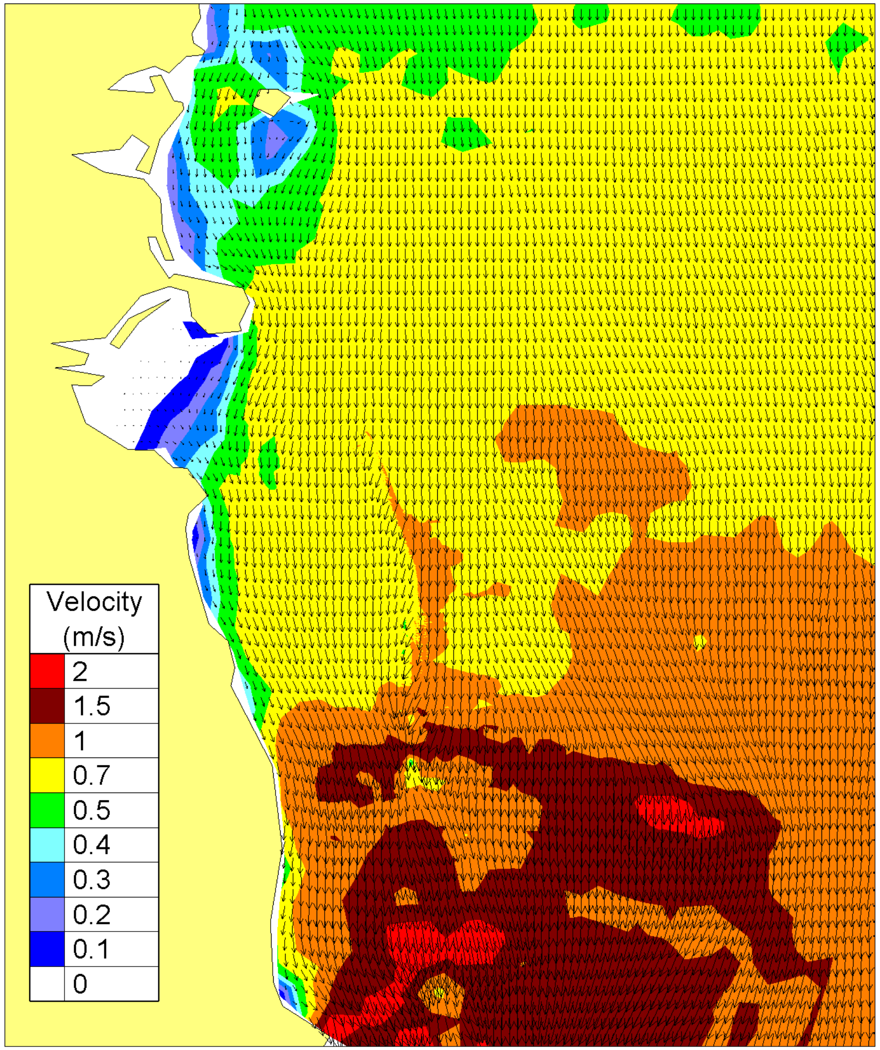


Figure 16.1 Tidal Currents – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin)	*Figure 16.2 Tidal Currents – Spring Tide HW (Dublin) Plus 2Hrs*

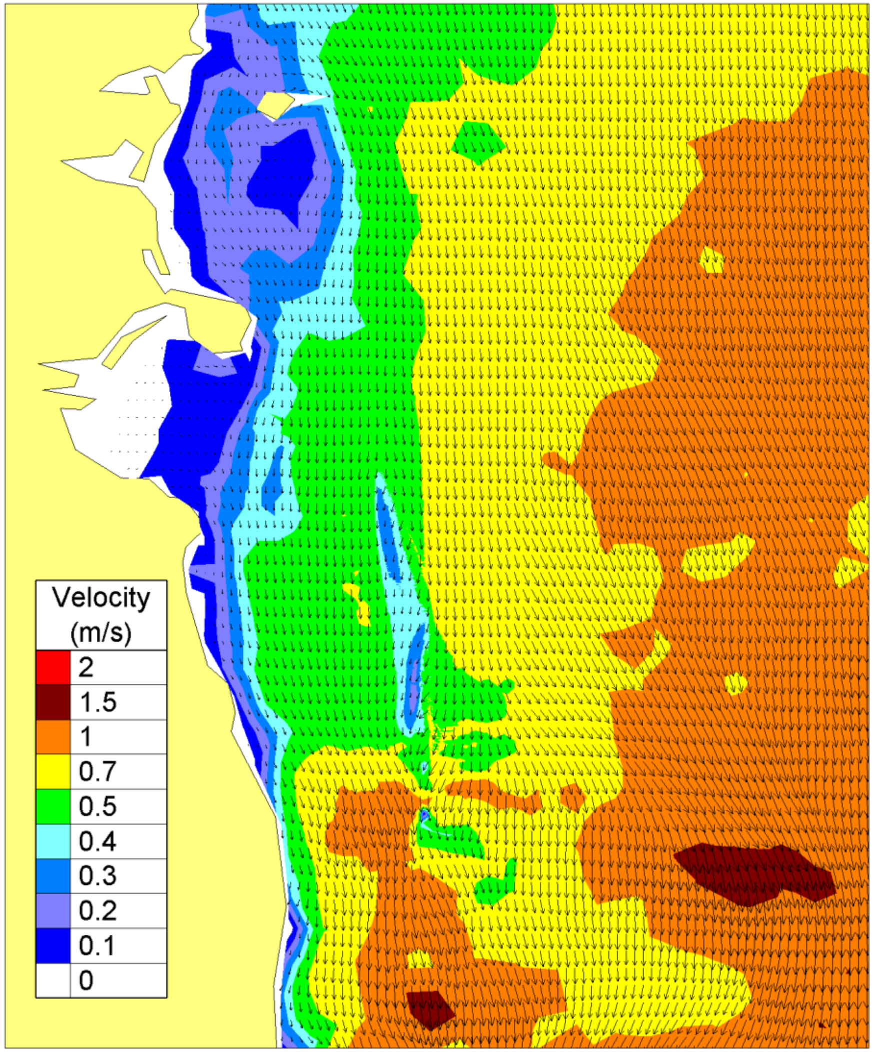


Figure 16.3 Tidal Currents – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin) Plus 4Hrs

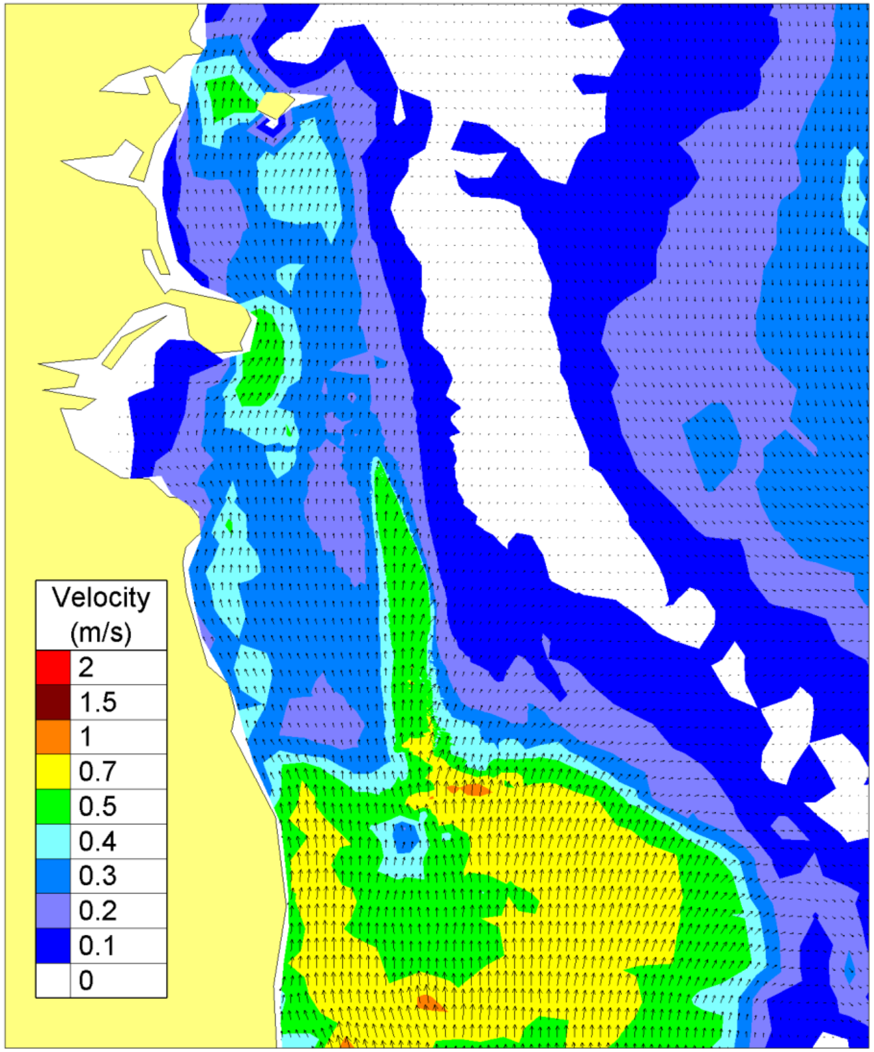


Figure 16.4 Tidal Currents – Spring Tide Low Water (Dublin)

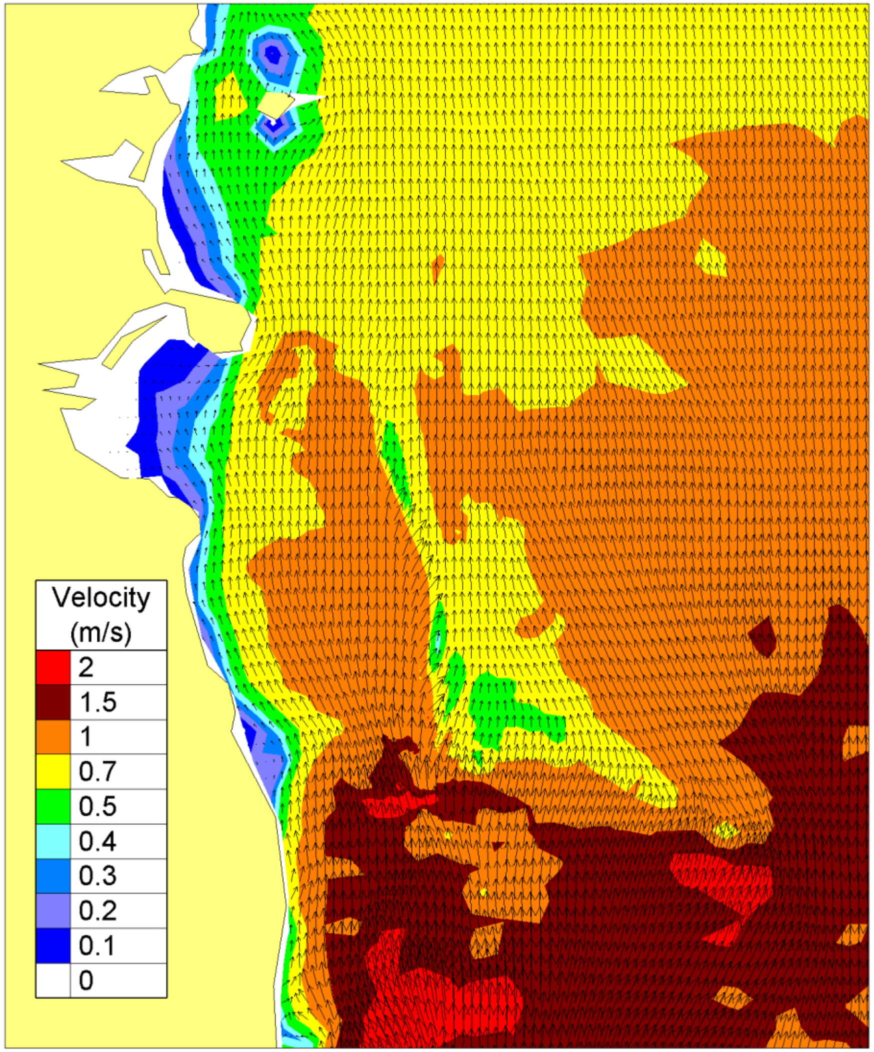


Figure 16.5 Tidal Currents – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin) minus 4Hrs

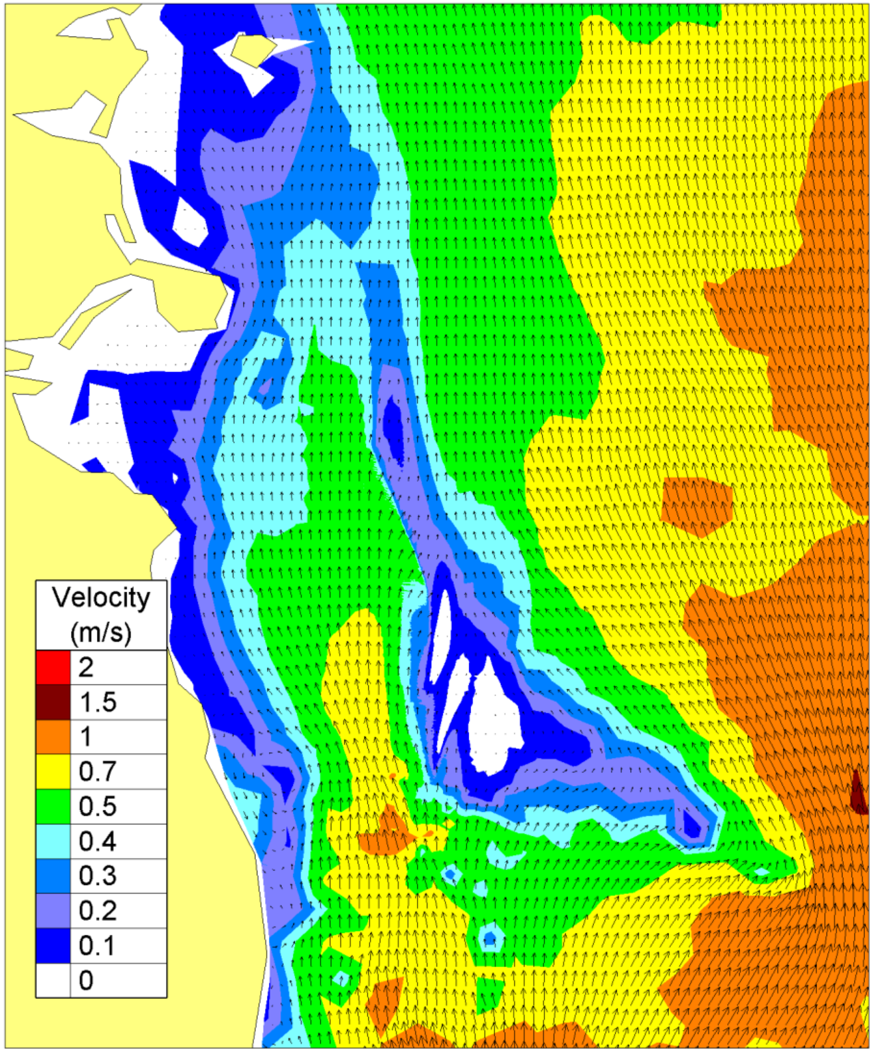


Figure 16.6 Tidal Currents – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin) minus 2Hrs

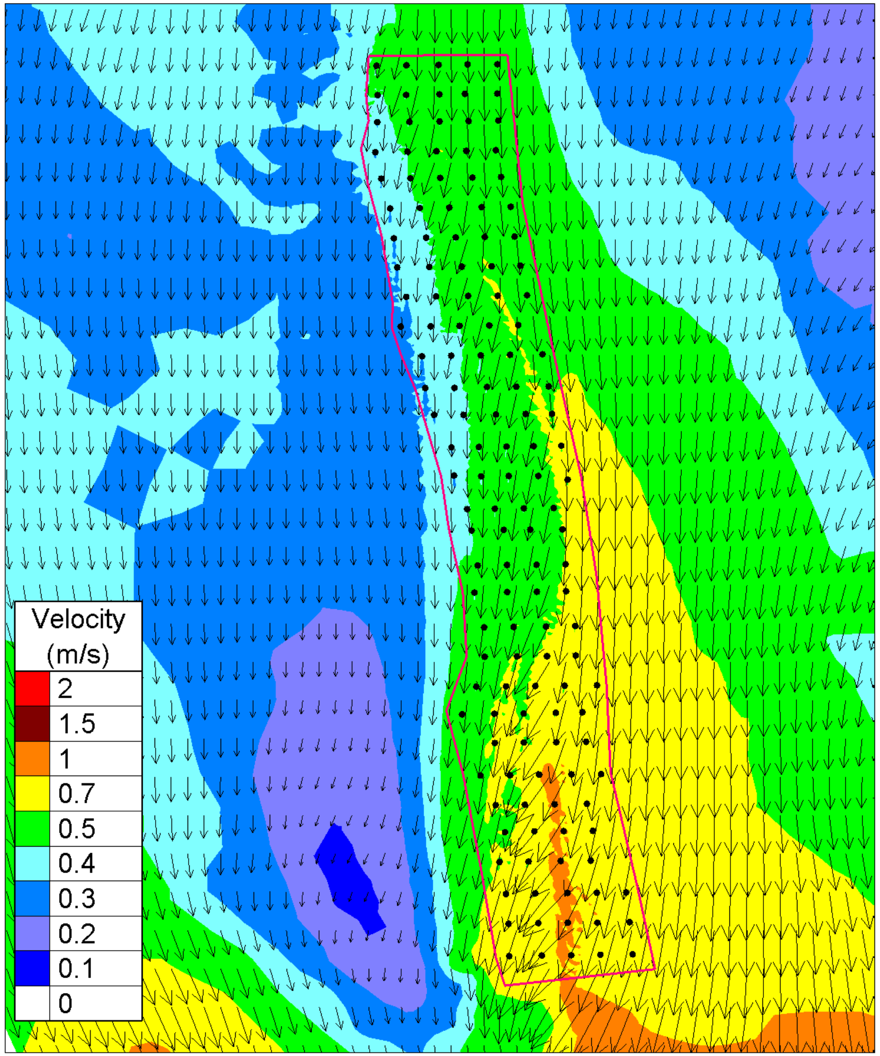


Figure 17.1 Tidal Currents in the vicinity of the Kish Bank – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin)

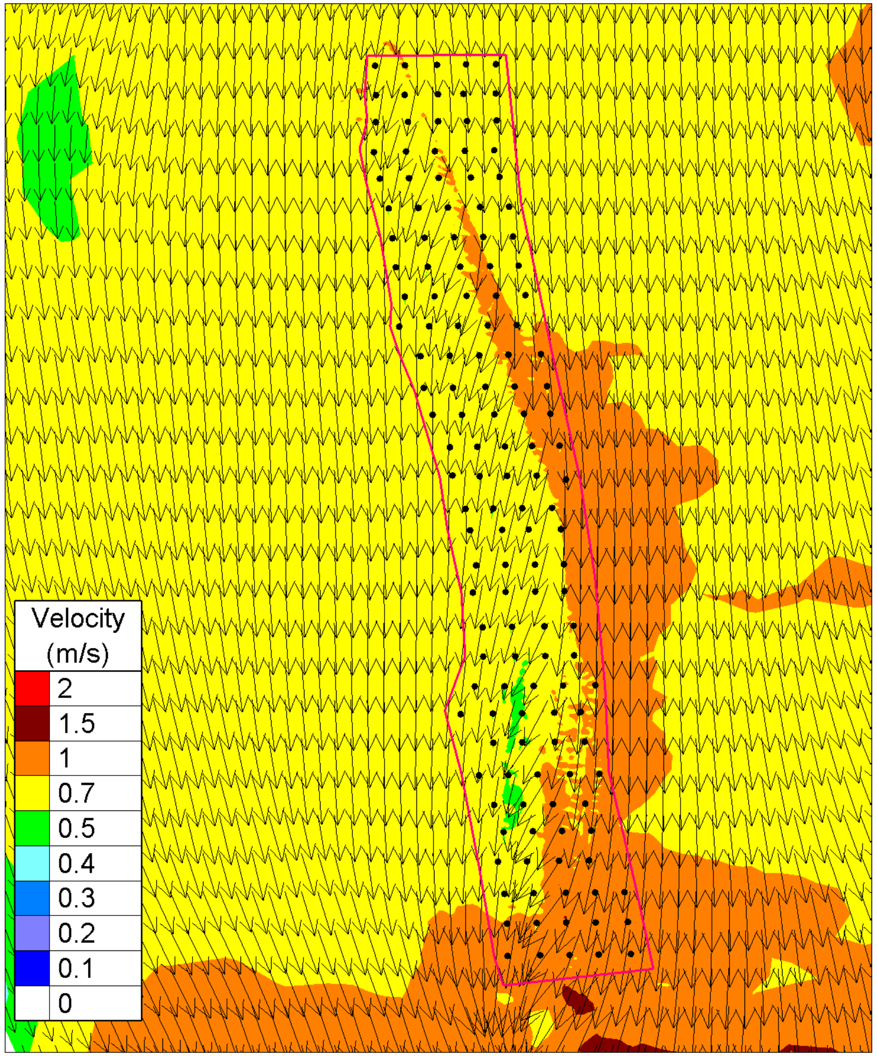


Figure 17.2 Tidal Currents in the vicinity of the Kish Bank – Spring Tide HW (Dublin) Plus 2Hrs

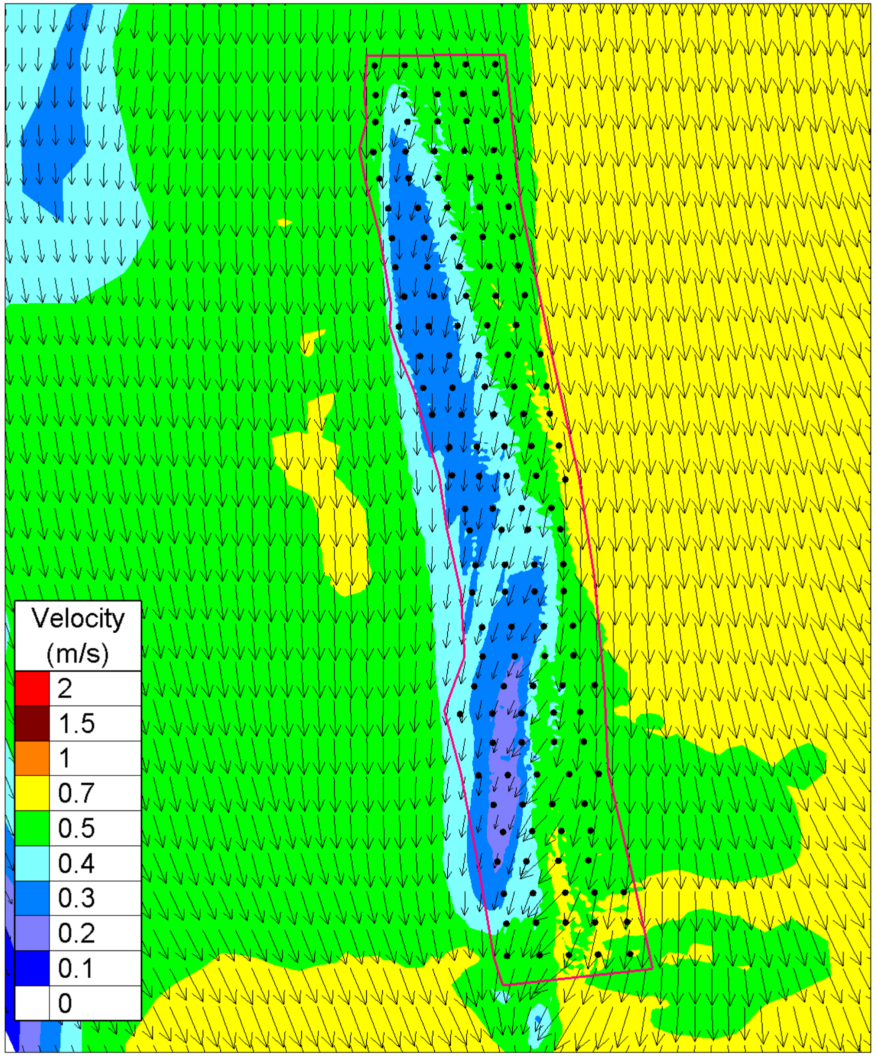


Figure 17.3 Tidal Currents in the vicinity of the Kish Bank – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin) Plus 4Hrs

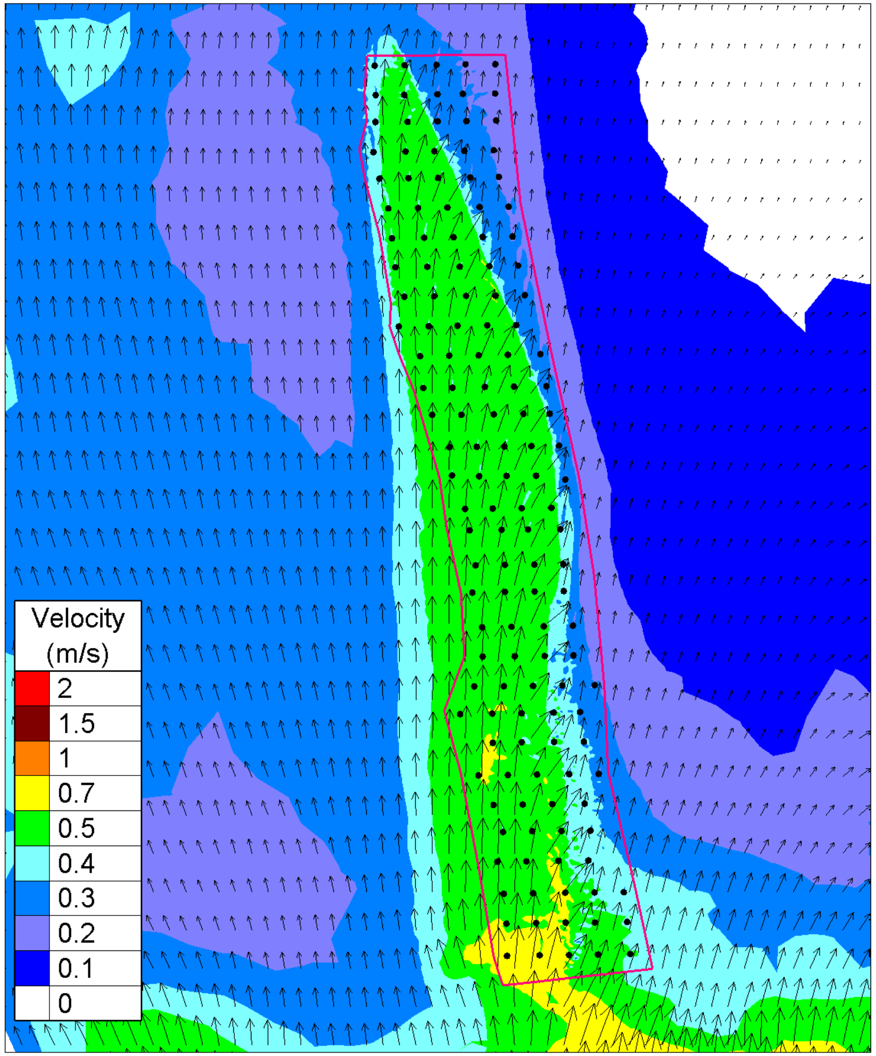


Figure 17.4 Tidal Currents in the vicinity of the Kish Bank – Spring Tide Low Water (Dublin)

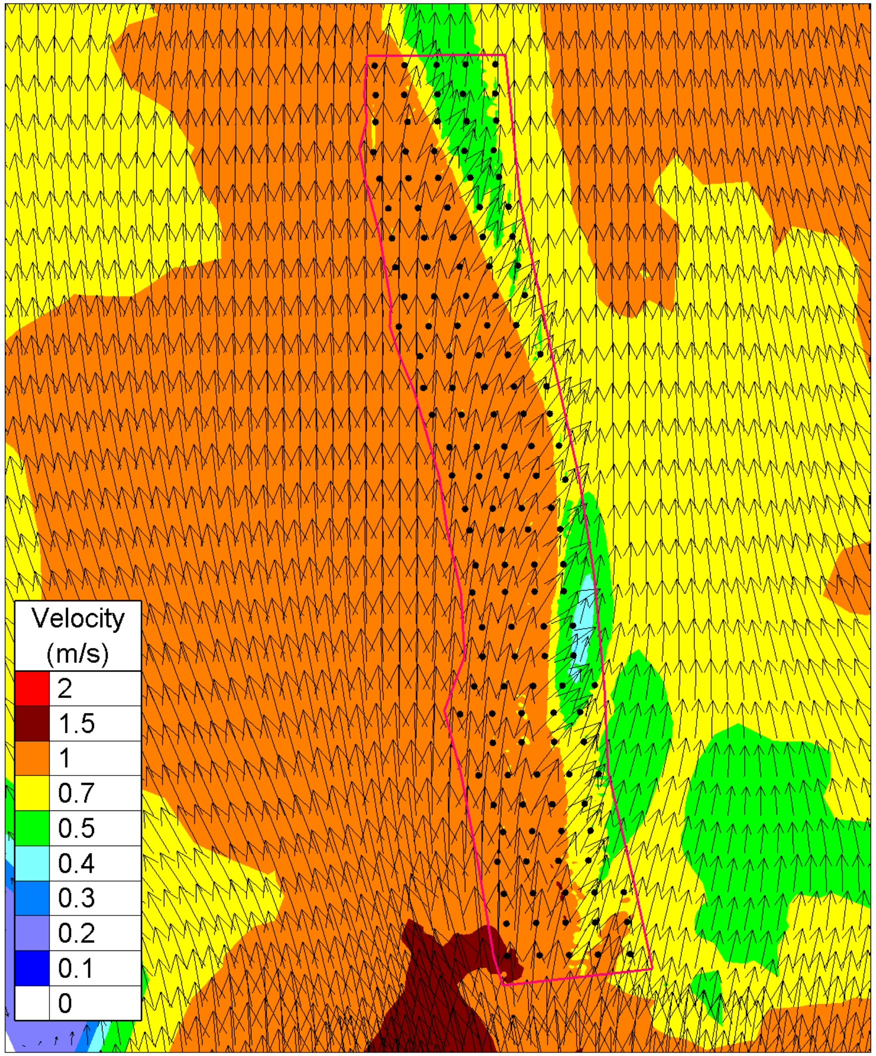


Figure 17.5 Tidal Currents in the vicinity of the Kish Bank – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin) minus 4Hrs

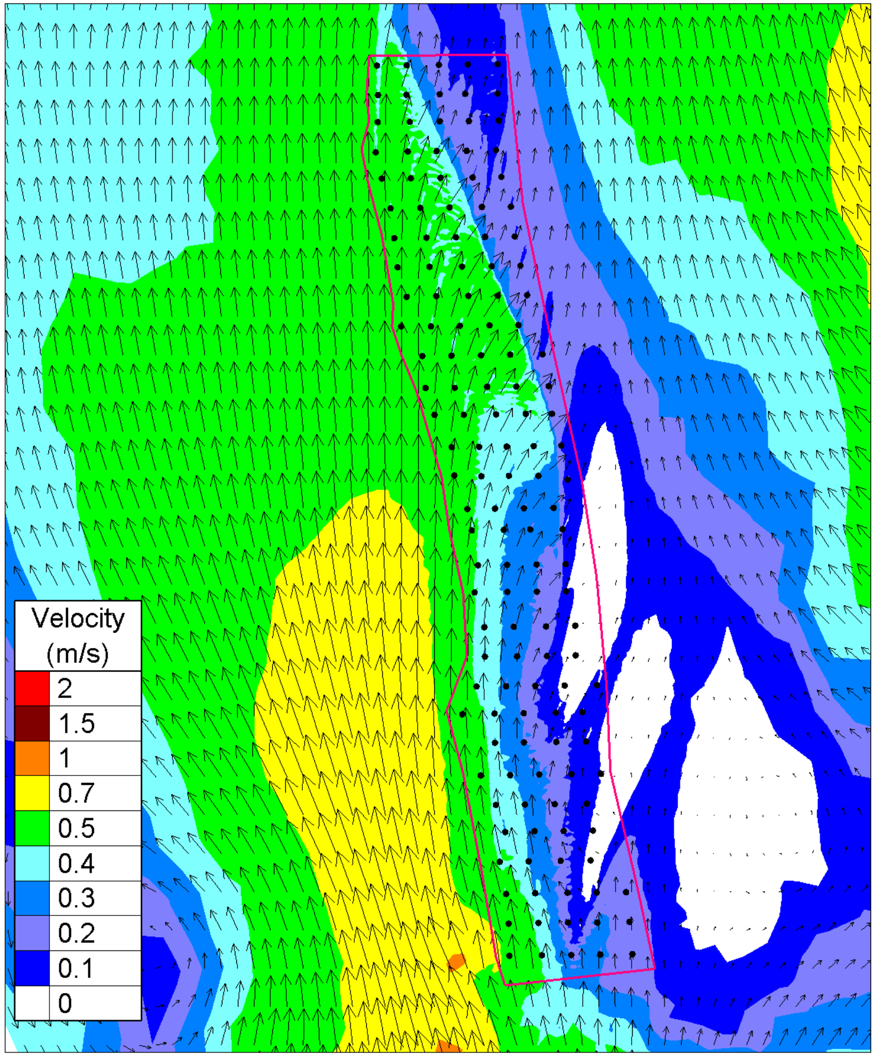


Figure 17.6 Tidal Currents in the vicinity of the Kish Bank – Spring Tide (2nd Sept 2012 00:00) Highwater (Dublin) minus 2Hrs

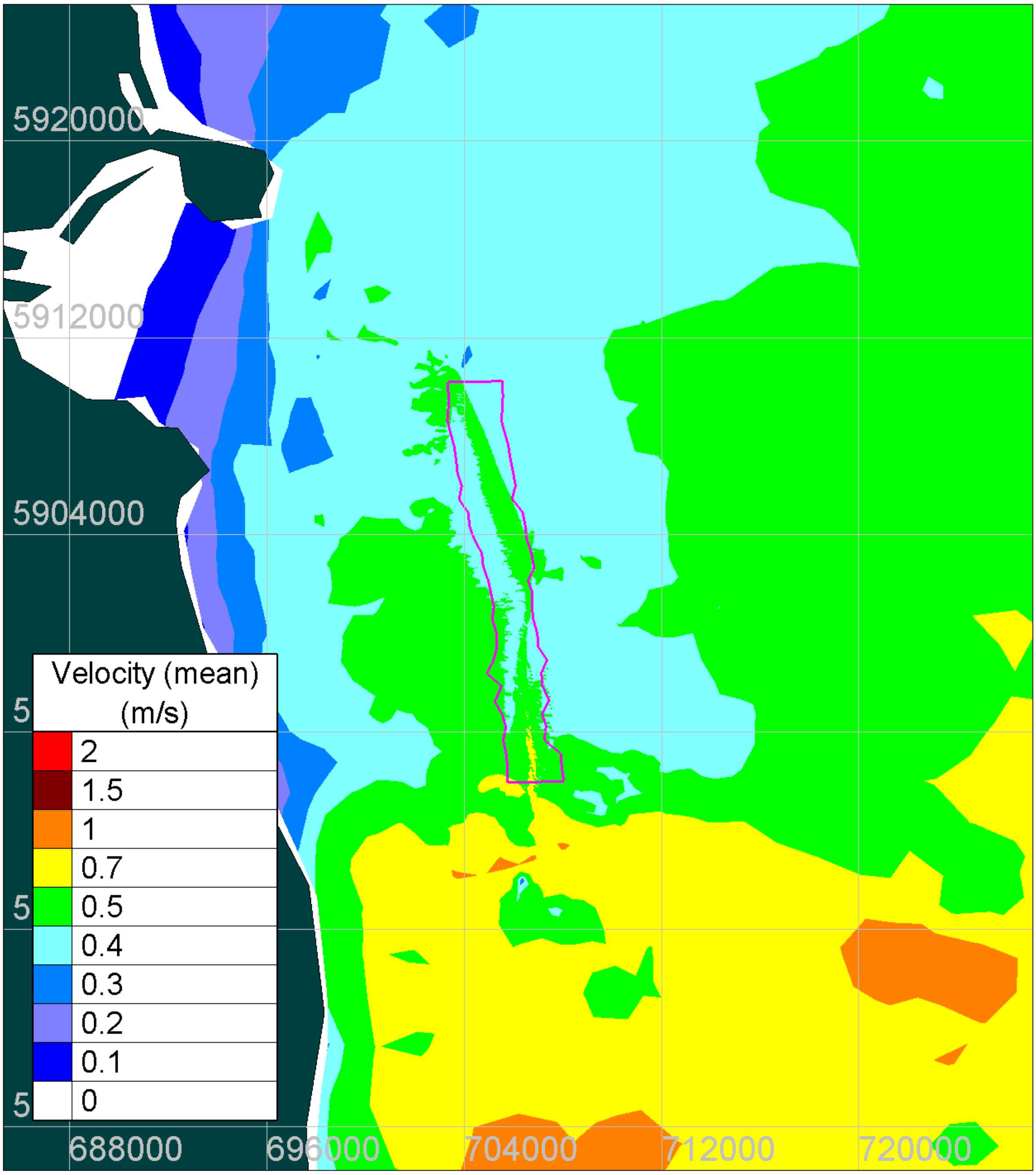


Figure 18.1 Computed Average Velocity Magnitude – Tidal period 23 Aug 2012 to 21 Sep 2012

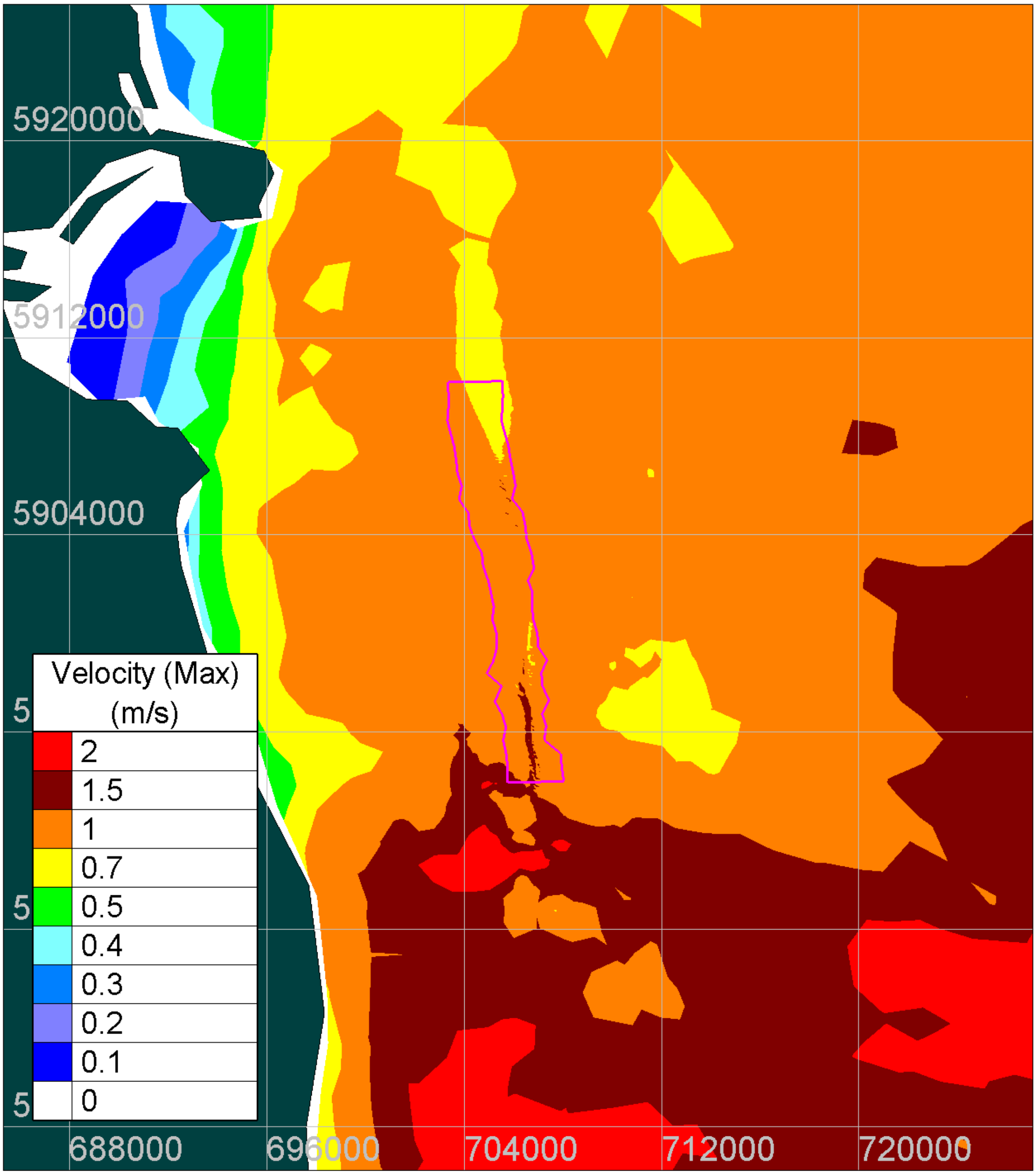


Figure 18.2 Computed Maximum Velocity Magnitude – Tidal period 23 Aug 2012 to 21 Sep 2012

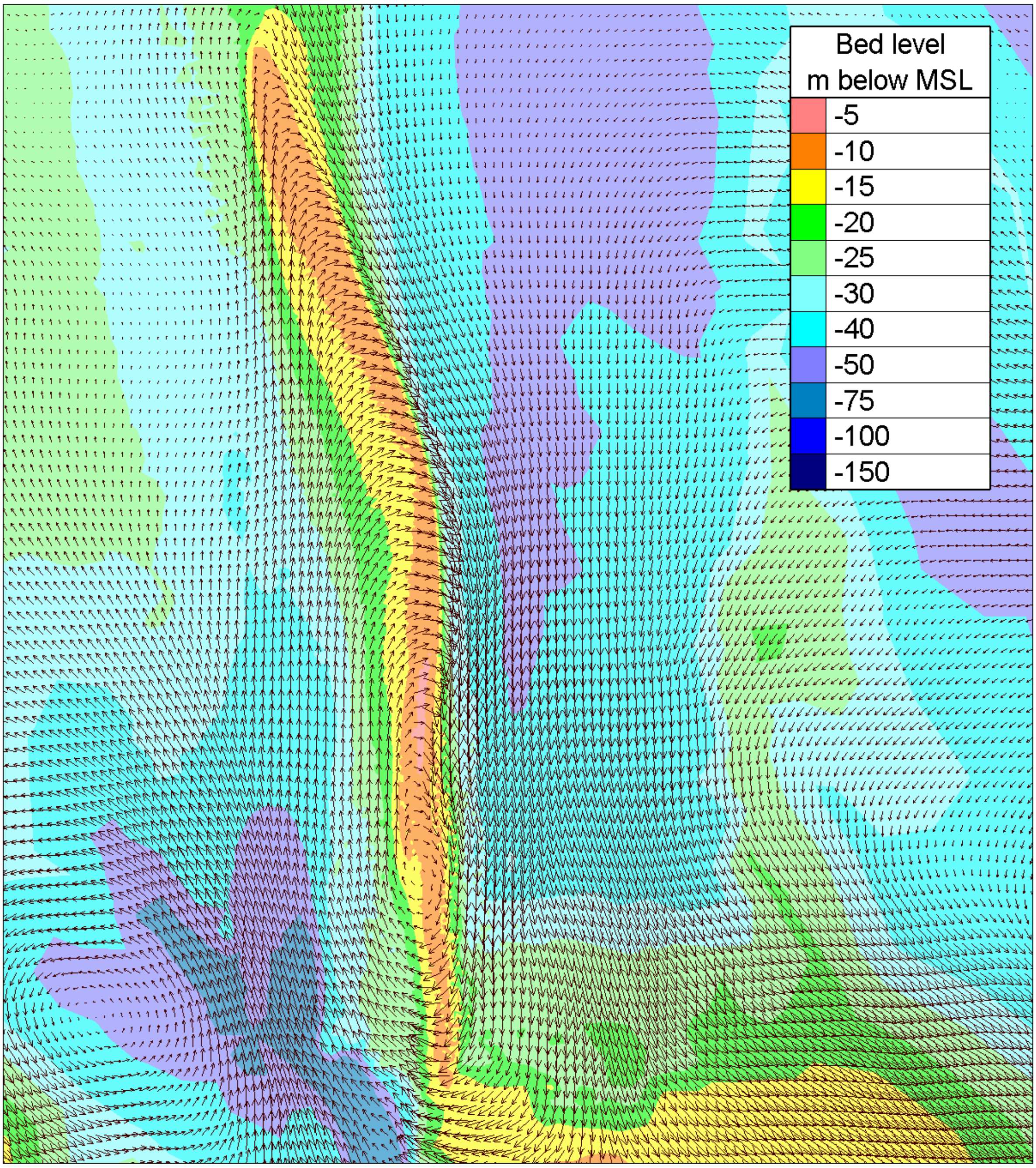


Figure 19 Computed Residual Current (net current) over full lunar cycle in the vicinity of the Kish and Bray Sand Banks

Table 2 Summary of Ambient Hydrodynamics at Turbine Sites

TURBINE	EASTING	NORTHING	Depth	Mean	Max	Mean	Max
	m	m	m below	m/s	m/s	Pa	Pa
T1	336839.3	229885.3	-5.6	0.52	1.21	0.42	1.79
T2	337375	229885.3	-14.2	0.55	1.75	0.70	2.59
T3	337964.3	229885.3	-19.6	0.43	1.03	0.31	1.14
T4	338500	229885.3	-29.1	0.42	0.92	0.28	1.00
T5	339035.7	229885.3	-19.8	0.44	0.94	0.26	0.94
T6	336839.3	229344.3	-7.0	0.52	1.21	0.42	1.80
T7	337375	229344.3	-13.5	0.49	1.38	0.53	2.13
T8	337964.3	229344.3	-18.5	0.42	1.12	0.30	1.09
T9	338446.4	229344.3	-27.6	0.42	0.92	0.28	1.04
T10	339035.7	229344.3	-20.9	0.45	0.97	0.28	1.01
T11	336839.3	228852.5	-7.3	0.50	1.19	0.39	1.69
T12	337428.6	228852.5	-11.6	0.50	1.33	0.56	2.40
T13	337964.3	228852.5	-18.9	0.42	1.18	0.32	1.15
T14	338500	228852.5	-27.8	0.42	0.96	0.28	1.03
T15	339035.7	228852.5	-22.6	0.44	0.96	0.27	0.98
T16	336785.7	228311.5	-8.6	0.78	1.95	1.64	8.07
T17	337375	228311.5	-6.9	0.50	1.20	0.51	2.35
T18	337910.8	228311.5	-16.5	0.53	1.72	0.62	2.35
T19	338446.4	228311.5	-27.7	0.42	1.12	0.29	1.08
T20	338982.2	228311.5	-22.5	0.44	0.96	0.26	0.98
T21	336892.9	227819.7	-9.5	0.49	1.19	0.36	1.65
T22	337428.6	227819.7	-7.3	0.49	1.20	0.49	2.25
T23	337964.3	227819.7	-16.7	0.53	1.62	0.59	2.36
T24	338553.6	227819.7	-27.9	0.43	1.13	0.30	1.12
T25	339089.3	227819.7	-22.4	0.44	0.99	0.27	1.03
T26	337053.6	227278.7	-10.2	0.47	1.18	0.34	1.64
T27	337589.3	227278.7	-8.2	0.48	1.17	0.45	2.09
T28	338125	227278.7	-17.9	0.51	1.48	0.53	2.17
T29	338714.3	227278.7	-28.3	0.44	1.09	0.30	1.17
T30	339250	227278.7	-22.7	0.46	1.02	0.28	1.09
T31	337107.2	226737.7	-11.8	0.48	1.20	0.35	1.67
T32	337696.4	226737.7	-8.4	0.46	1.12	0.40	1.84
T33	338232.2	226737.7	-15.2	0.53	1.46	0.59	2.51
T34	338767.9	226737.7	-27.9	0.45	1.32	0.34	1.29
T35	339303.6	226737.7	-23.6	0.45	1.02	0.28	1.10
T36	337160.7	226196.7	-13.3	0.48	1.20	0.35	1.65
T37	337750	226196.7	-8.8	0.46	1.15	0.39	1.84
T38	338339.3	226196.7	-12.0	0.55	1.41	0.62	2.66
T39	338875	226196.7	-28.2	0.51	1.24	0.46	1.60
T40	339410.7	226196.7	-23.2	0.45	1.03	0.28	1.13
T41	337321.4	225655.7	-14.0	0.47	1.18	0.33	1.60
T42	337857.1	225655.7	-9.7	0.48	1.17	0.40	1.89
T43	338446.4	225655.7	-7.9	0.54	1.28	0.59	2.57
T44	338982.1	225655.7	-28.2	0.65	1.79	0.88	3.57
T45	339517.9	225655.7	-26.4	0.46	1.04	0.29	1.15
T46	337214.3	225114.8	-18.3	0.48	1.19	0.33	1.55
T47	337750	225114.8	-12.6	0.46	1.14	0.34	1.62
T48	338285.7	225114.8	-10.1	0.50	1.21	0.45	2.07
T49	338821.4	225114.8	-16.1	0.55	1.29	0.59	2.55
T50	339357.1	225114.8	-23.2	0.50	1.22	0.40	1.53
T51	337589.3	224573.8	-16.5	0.46	1.16	0.33	1.55
T52	338125	224573.8	-12.1	0.47	1.17	0.38	1.79
T53	338660.7	224573.8	-9.4	0.51	1.23	0.48	2.20
T54	339196.4	224573.8	-29.8	0.58	1.37	0.66	2.77
T55	339785.7	224573.8	-23.7	0.47	1.08	0.30	1.20

Table 2 Cont'd Summary of Ambient Hydrodynamics at Turbine Sites

TURBINE	EASTING	NORTHING	Depth	Mean	Max	Mean	Max
	m	m	m below	m/s	m/s	Pa	Pa
T56	337642.9	223983.6	-18.6	0.47	1.17	0.33	1.58
T57	338178.6	223983.6	-12.4	0.47	1.17	0.36	1.71
T58	338767.9	223983.6	-9.5	0.53	1.28	0.51	2.37
T59	339303.6	223983.6	-26.0	0.61	1.45	0.74	3.31
T60	339892.9	223983.6	-23.1	0.50	1.13	0.36	1.39
T61	337803.6	223491.8	-18.4	0.48	1.20	0.35	1.67
T62	338339.3	223491.8	-13.0	0.48	1.19	0.37	1.77
T63	338928.6	223491.8	-10.4	0.50	1.23	0.46	2.14
T64	339464.3	223491.8	-26.0	0.57	1.36	0.62	2.83
T65	339946.4	223491.8	-22.6	0.50	1.13	0.35	1.39
T66	338107	222902	-17.6	0.49	1.22	0.36	1.74
T67	338607	222902	-13.1	0.49	1.21	0.39	1.85
T68	339107	222902	-10.8	0.52	1.27	0.48	2.28
T69	339607	222902	-26.5	0.56	1.32	0.59	2.63
T70	340107.1	222902.5	-23.6	0.50	1.15	0.35	1.42
T71	338143	222386	-18.9	0.49	1.24	0.37	1.75
T72	338642	222360	-15.8	0.47	1.18	0.36	1.73
T73	339142.9	222360.7	-10.2	0.49	1.20	0.41	1.91
T74	339678.6	222360.7	-27.0	0.53	1.25	0.54	2.41
T75	340214.3	222280.6	-23.0	0.50	1.15	0.35	1.42
T76	338375	221770	-18.5	0.49	1.22	0.36	1.73
T77	338875	221770.5	-13.6	0.48	1.19	0.37	1.76
T78	339410.7	221770.5	-7.2	0.48	1.14	0.41	1.82
T79	339946.4	221770.5	-23.3	0.53	1.85	0.61	2.70
T80	338446.4	221377.1	-17.7	0.50	1.25	0.37	1.79
T81	339035.7	221377.1	-10.0	0.49	1.17	0.39	1.76
T82	339517.9	221377.1	-12.8	0.51	1.19	0.50	2.23
T83	340107.1	221377.1	-23.5	0.49	1.16	0.43	1.67
T84	338553.6	220737.7	-16.0	0.50	1.24	0.38	1.77
T85	339089.3	220737.7	-8.8	0.50	1.20	0.43	1.89
T86	339625	220737.7	-18.8	0.50	1.18	0.50	2.29
T87	340160.7	220737.7	-25.1	0.48	1.08	0.35	1.40
T88	338500	220245.9	-15.5	0.51	1.26	0.38	1.78
T89	339089.3	220245.9	-9.0	0.50	1.20	0.43	1.92
T90	339625	220245.9	-18.5	0.49	1.19	0.49	2.31
T91	340160.7	220245.9	-23.3	0.45	1.07	0.32	1.38
T92	338660.7	219606.6	-14.0	0.50	1.21	0.38	1.68
T93	339196.4	219606.6	-4.3	0.50	1.20	0.44	1.99
T94	339785.7	219606.6	-25.7	0.53	2.00	0.74	4.03
T95	340321.4	219606.6	-23.4	0.45	1.08	0.30	1.28
T96	338660.7	219065.6	-14.9	0.50	1.19	0.38	1.62
T97	339250	219065.6	-4.6	0.49	1.16	0.41	1.83
T98	339785.7	219065.6	-24.9	0.56	2.00	0.78	3.91
T99	340321.4	219065.6	-26.2	0.43	1.04	0.28	1.20
T100	338500	218524.6	-18.6	0.51	1.20	0.37	1.59
T101	339035.7	218524.6	-5.4	0.50	1.17	0.39	1.71
T102	339571.4	218524.6	-15.8	0.51	1.37	0.59	2.82
T103	340107.1	218524.6	-30.1	0.44	1.05	0.33	1.42
T104	340696.4	218524.6	-29.6	0.49	1.08	0.32	1.21
T105	338232.1	218032.8	-23.1	0.53	1.29	0.39	1.77
T106	338821.4	218032.8	-11.0	0.51	1.18	0.38	1.62
T107	339357.1	218032.8	-11.2	0.47	1.13	0.42	1.92
T108	339946.4	218032.8	-26.0	0.46	0.99	0.38	1.38
T109	340428.6	218032.8	-24.7	0.49	1.08	0.33	1.27
T110	338821.4	217491.8	-9.4	0.51	1.19	0.38	1.59
T111	339357.1	217491.8	-11.3	0.50	1.23	0.49	2.39

Table 2 Cont'd Summary of Ambient Hydrodynamics at Turbine Sites

TURBINE	EASTING	NORTHING	Depth	Mean	Max	Mean	Max
	m	m	m below	m/s	m/s	Pa	Pa
T112	339946.4	217491.8	-26.0	0.52	1.08	0.51	1.70
T113	340482.1	217491.8	-26.2	0.51	1.14	0.39	1.47
T114	338553.6	216901.7	-21.3	0.53	1.24	0.41	1.72
T115	339089.3	216901.7	-7.4	0.49	1.17	0.37	1.63
T116	339625	216901.7	-15.8	0.63	1.55	0.86	4.23
T117	340214.3	216901.7	-31.3	0.52	1.11	0.45	1.55
T118	340750	216901.7	-26.9	0.52	1.19	0.39	1.56
T119	338821.4	216360.7	-14.4	0.51	1.21	0.37	1.61
T120	339357.1	216360.7	-8.3	0.50	1.19	0.44	1.94
T121	339892.9	216360.7	-25.5	0.66	1.59	0.94	4.39
T122	340482.1	216360.7	-26.0	0.51	1.16	0.37	1.48
T123	338982.1	215868.9	-14.4	0.51	1.25	0.40	1.84
T124	339517.9	215868.9	-10.6	0.58	1.28	0.56	2.25
T125	340053.6	215868.9	-28.5	0.68	1.51	0.95	3.79
T126	340589.3	215868.9	-25.3	0.49	1.12	0.33	1.32
T127	338875	215327.9	-20.6	0.52	1.26	0.39	1.79
T128	339410.7	215327.9	-7.8	0.54	1.17	0.43	1.66
T129	340000	215327.9	-26.2	0.71	1.56	1.05	4.20
T130	340535.7	215327.9	-23.7	0.52	1.19	0.39	1.53
T131	338982.1	214737.7	-19.7	0.56	1.33	0.46	2.02
T132	339517.9	214737.7	-9.9	0.55	1.20	0.46	1.75
T133	340107.1	214737.7	-23.3	0.68	1.41	0.87	3.17
T134	340642.9	214737.7	-23.0	0.50	1.22	0.38	1.66
T135	341178.6	214737.7	-22.6	0.56	1.23	0.45	1.71
T136	339035.7	214196.7	-19.7	0.64	1.49	0.61	2.58
T137	339571.4	214196.7	-5.7	0.61	1.34	0.56	2.21
T138	340107.1	214196.7	-21.3	0.82	1.80	1.42	5.86
T139	340642.9	214196.7	-20.8	0.57	1.33	0.49	2.04
T140	341232.1	214196.7	-21.5	0.57	1.26	0.49	1.81
T141	339035.7	213606.6	-20.3	0.75	1.71	0.83	3.47
T142	339625	213606.6	-11.0	0.68	1.50	0.70	2.72
T143	340160.7	213606.6	-20.1	0.64	1.41	0.80	2.81
T144	340696.4	213606.6	-20.6	0.62	1.35	0.58	2.13
T145	341285.7	213606.6	-20.6	0.58	1.26	0.51	1.87

3.2 Sedimentation

The sediment survey of the area showed that bed sediment to the north were generally classified as a fine to medium sand with sand content varying from 90% to 95%. Other surveys from grab sampling indicate a coarser bed to the south of the Bray Bank associated with higher tidal flow activity.

The movement of the sediment on the seabed is dependent on the tidal currents and the sediment type (grain size). The tidal flow gives rise to generating shear stress along the seabed. When the shear stress increases to a critical value, the sediment will move, refer to Table 4 below for critical shear stress values for different non-cohesive sediment sizes. Shear stresses above 0.1 N/m^2 (Pa) will erode the silt fraction with the fine to medium sand requiring shear stresses of 0.18 N/m^2 to 0.23 N/m^2.

The hydrodynamic simulation provided velocity and depth information used to determine the resulting bed shear stresses within the study area. Figures 21.1 and 21.2 present the average and maximum shear stress magnitudes in the vicinity of the Kish and Bray Sand Banks. The simulation average shear stress exceeds 0.37N/m^2 (Pa) which exceeds the critical shear stress to erode / mobilise coarse sand and the southern section along the crest of the bar exceed 0.83N/m^2 which exceeds the critical shear stress for a very coarse sand. The simulation maximum shear stresses within the proposed Dublin Array exceed 0.83N/m^2 (critical shear for very coarse sand) and along the crest of the Kish and Bray Sand Banks it exceeds 2.16 N/m^2 which would erode a fine gravel.

It can be concluded that sufficient ambient tidal shear force is available for the surface sand layers on the Kish and Bray Sand Banks to be active, being constantly mobilised and deposited during tidal cycles. The residual tidal circulation is important for retaining sediment along the sand bank.

Table 3 Standard Sediment grain size distributions (grain size in mm)

Desired Graduation	Class	D average	Porosity	D10	D35	D50	D60	D90
Fine sand	FS	0.08	0.4	0.07	0.09	0.1	0.11	0.15
Medium Sand	MS	0.3	0.4	0.27	0.34	0.38	0.41	0.56
Coarse Sand	CS	0.9	0.4	0.8	1.01	1.15	1.24	1.68
Fine Gravel	FG	3	0.4	2.67	3.38	3.83	4.12	5.6
Medium Gravel	MG	9	0.4	8	10.1	11.5	12.4	16.8
Coarse Gravel	CG	30	0.4	26.7	33.8	38.3	41.2	56

D10 is 10% passing through sieve and D90 is diameter at 90%.passing through Sieve

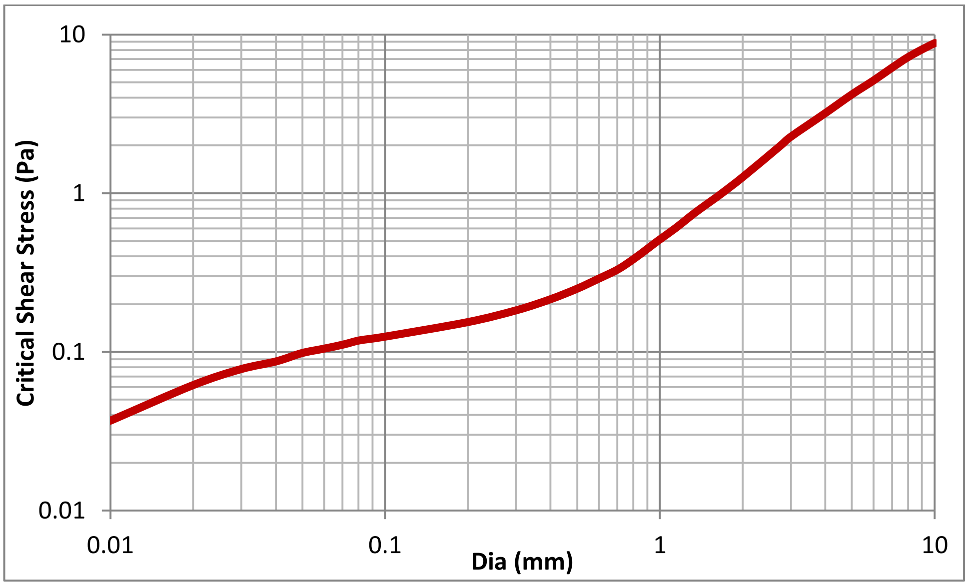


Figure 20 Critical shear Stress versus Particle diameter

Table 4 Sediment size classification and critical shear stress for erosion.

Material Type	Sediment Size (mm)	Critical shear stress (N/m^2)
Fine gravel	6	5.24
Very fine gravel	3	2.16
Very coarse sand	1.5	0.83
Coarse sand	0.75	0.37
Medium sand	0.38	0.23
Fine sand	0.19	0.18
Very fine sand	0.09	0.14
Coarse silt	0.047	0.11

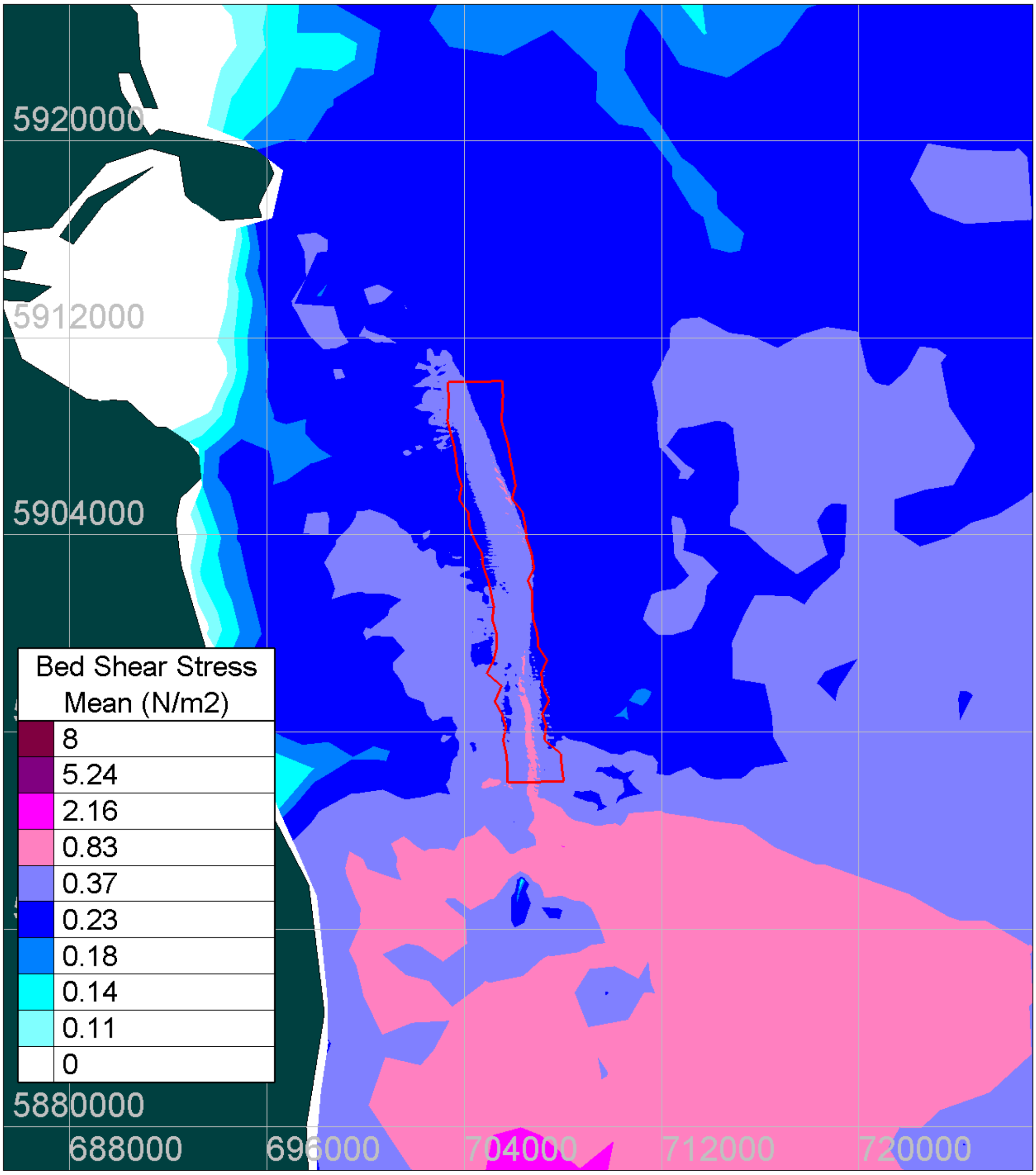


Figure 21.1 Computed Tidal Average Bed Shear Stress (for 30day lunar simulation)

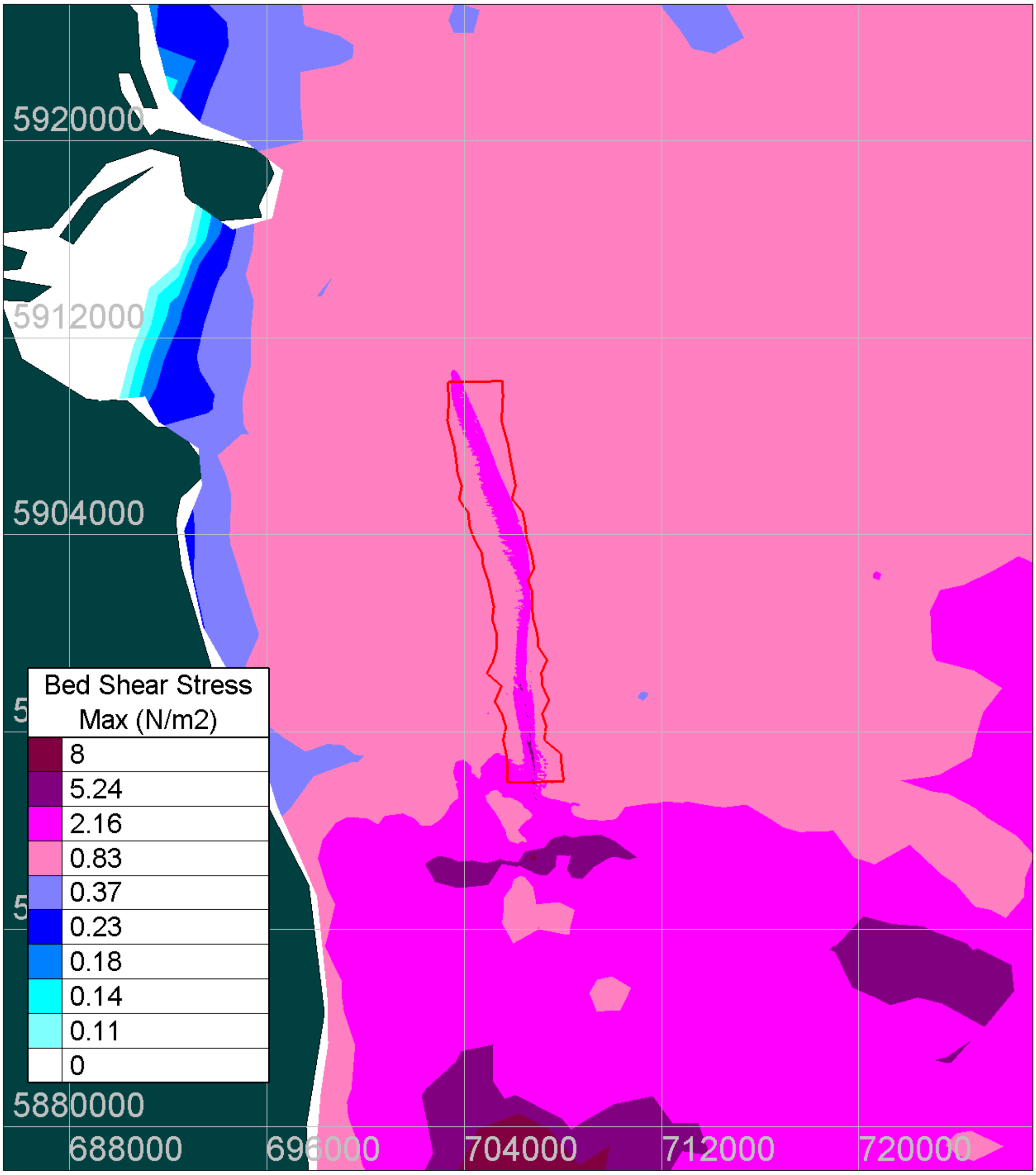


Figure 21.2 Computed Maximum Bed Shear Stress (for 30day lunar simulation)

3.3 Hydrodynamic Impact of Dublin Array

30 day Lunar Cycle simulations were carried out with and without the proposed development. In order to determine the change in velocities by the proposed 145 Turbine monopiles, similar finite element grids (in terms of node locations and elements) were used so as to eliminate any potential numerical meshing effects on results. Velocity difference contours were produced by subtracting the existing case from the proposed case at each output time. Overall the impact on velocities was relatively minor and very localised with increases in velocities confined to the immediate area of the monopile. The reduction in velocities due to the wake produced by the structure during strong tidal flows was less localised than the zone of increased velocity but changes were not significant particularly given the overall natural range in velocities over spring and neap tidal cycles for a given location. Figures 22.1 and 22.2 present the maximum (greater than 0.05m/s) increase and decrease in velocities over the full 30day simulation period. Given the localised scale of the changes it is difficult to present scale of impact for the entire Array as a graphical output (as is evident fro Figures 22.1 and 22.2. A typical Array area, that includes T131, T132, T133, T136, T137, is used to demonstrate the level of impact within the Array. Figures 23.1 to 23.6 present the change in velocity over a typical spring tide and Figures 24.1, 24.2 and 24.3 present the average and maximum increase and decrease in velocity magnitude over the 30day simulation period.

The maximum predicted increases in velocity over the 30day simulation period are immediately local to the pile (i.e. within 5 to 10m) and typical maximum values throughout the array vary between0.2 to 0.4m/s with the majority of monopiles less than 0.3m/s increase.

The hydrodynamic simulations show that the main effect from these structures is to reduce velocities at the upstream stagnation point and in the downstream wake from the monopile. The maximum wake effect from the piles is generally 100 to 150m at a 0.05m/s reduction (the simulation average effect is typically 50m from the pile at 0.05m/s and greater).

The overall conclusions from the modelling study is that very localised changes in velocity will arise but on the scale of the normal ambient tidal currents such changes are not significant and will not alter the hydrodynamic regime of the Kish/Bray Sand Banks. The modelling exercise clearly shows that impact from the 145 individual monopiles spaced at approximately 500m are independent of each other and will not give rise to any cumulative impact. In terms of the residual tidal circulation pattern for the Kish and Bray Sand Banks which dictates overall sediment movement the proposed Array has no discernible effect on the residual current.

In terms of sediment transport balance the local impact on velocities will not have any perceptible impact on the sediment regime within the Kish and Bray Sand Banks system. Local erosion is likely in the immediate vicinity of the Monopile but within 5 to 10m this effect will be minimal. The reduction in velocities as a result of the wake effect of the monopile is not likely give rise to any noticeable deposition as the returning flow will remove any additional deposition.

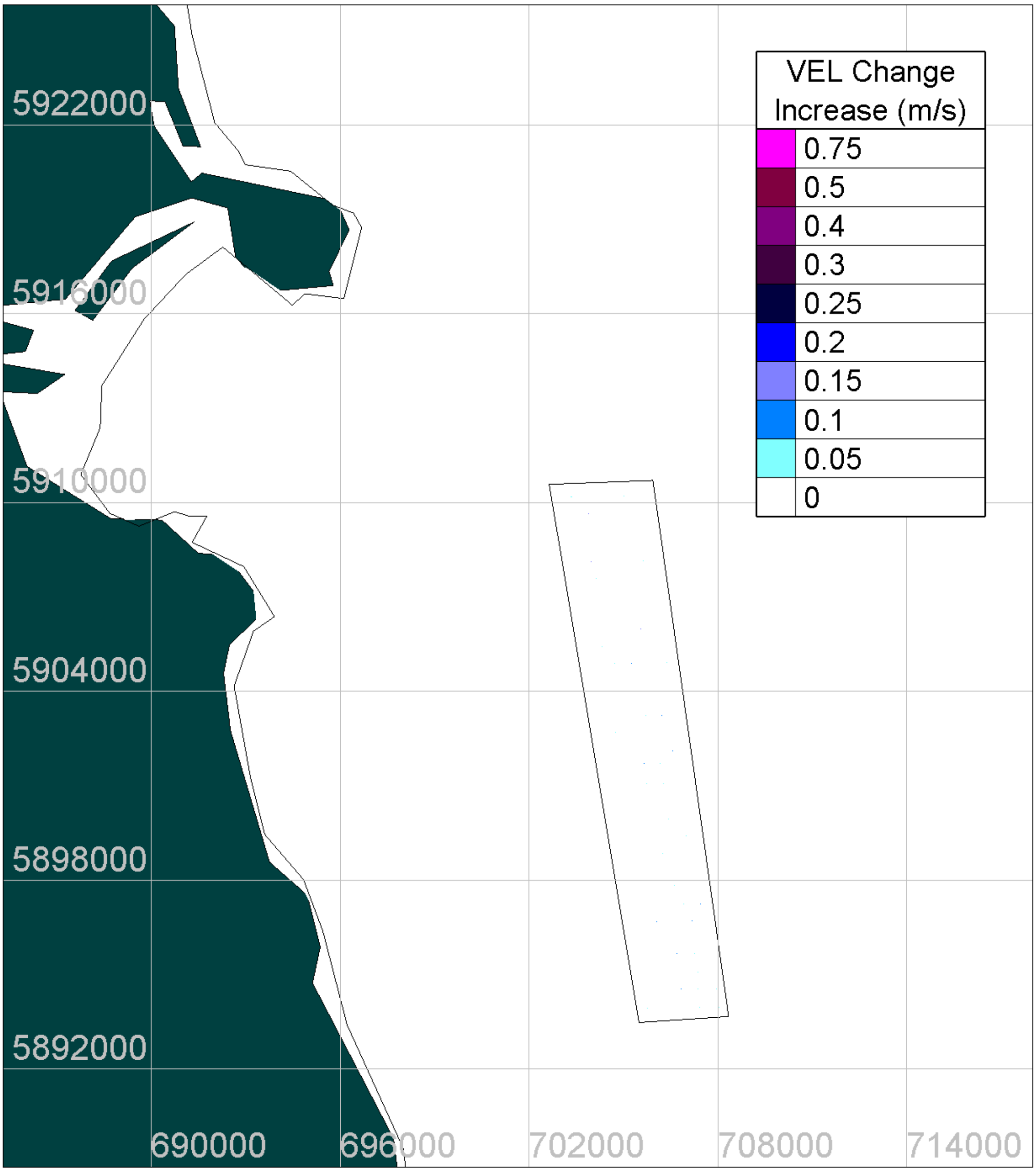


Figure 22.1 Maximum predicted Increase in Velocities around Monopiles

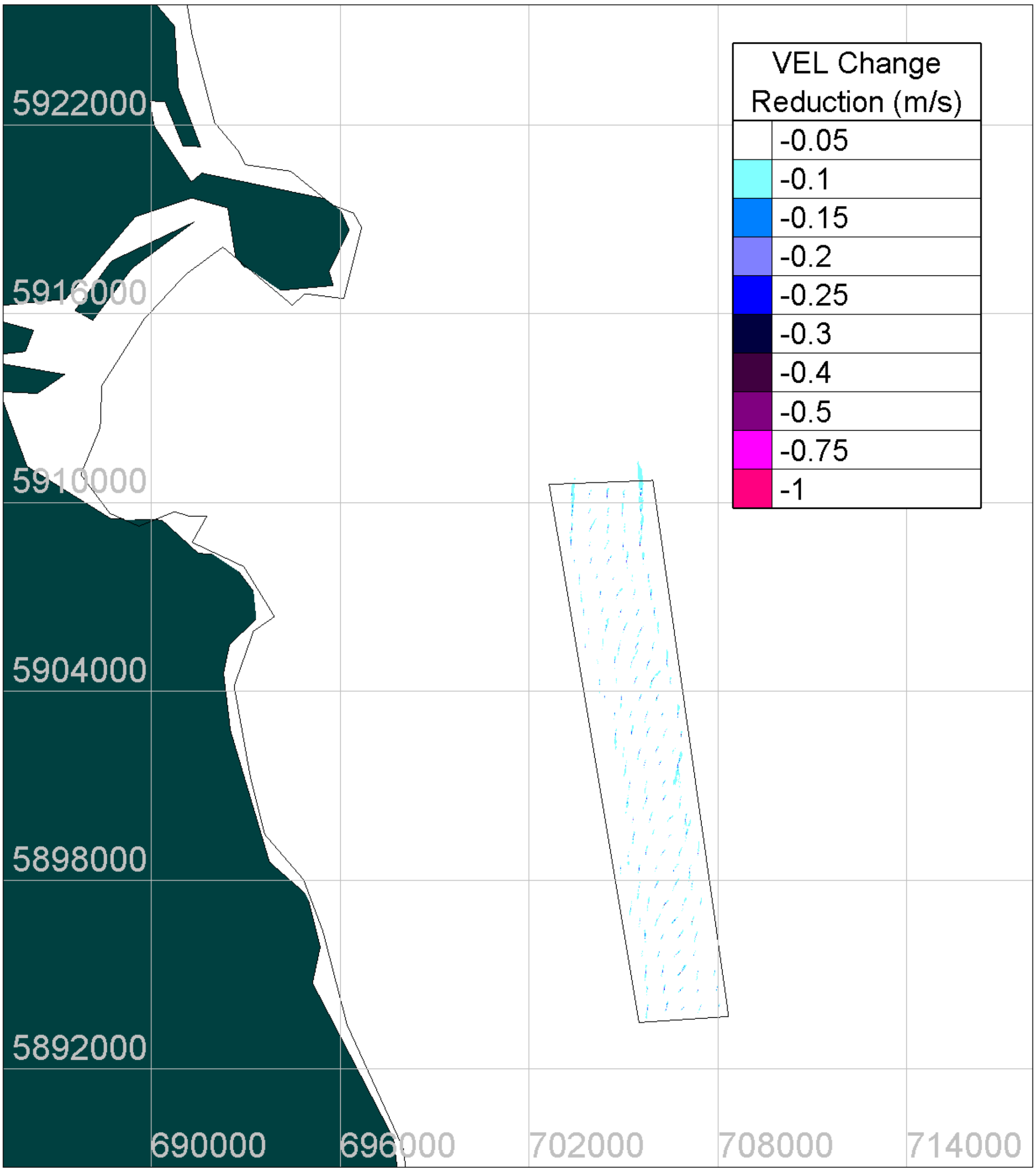


Figure 22.2 Maximum predicted Reduction in Velocities due to wake effect of Monopiles

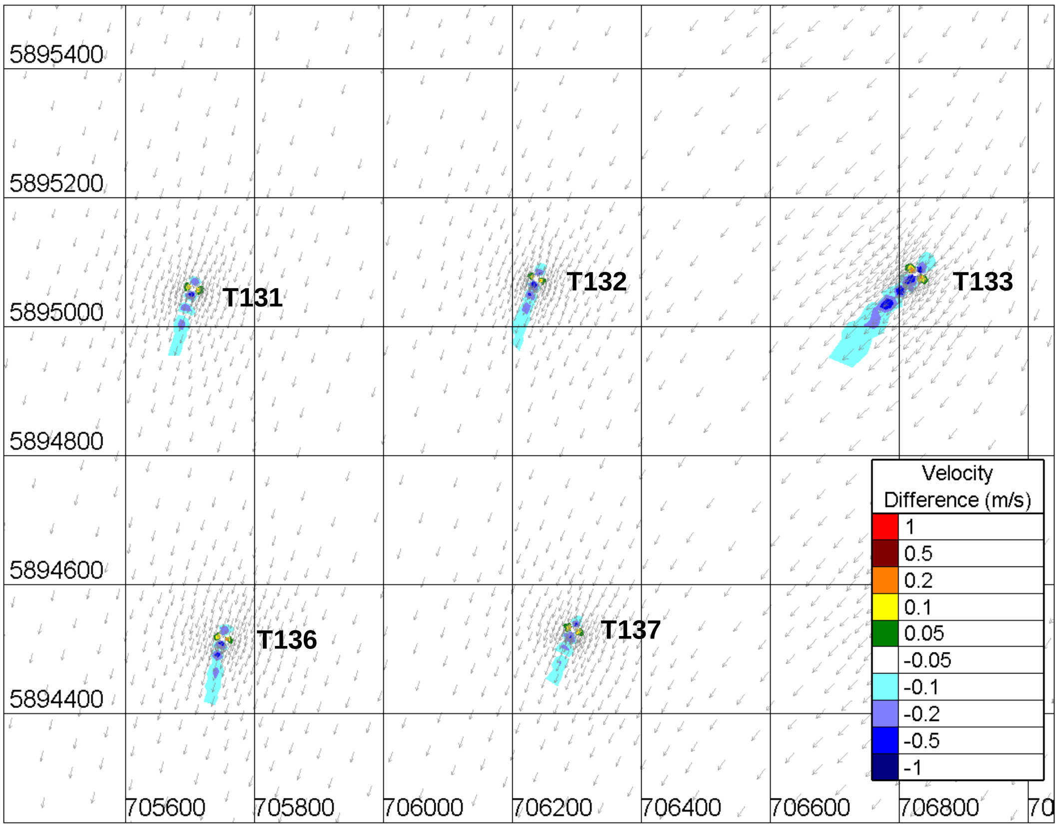


Figure 23.1 Computed change in velocities - Spring tide HW (Dublin)

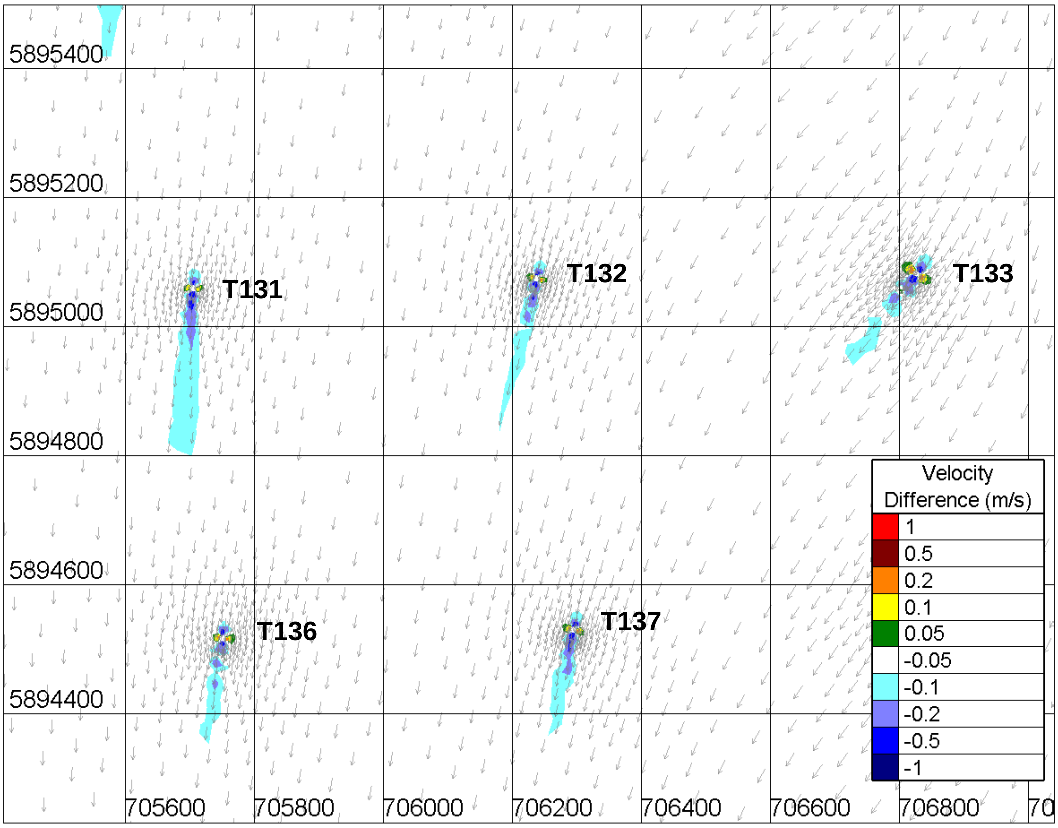


Figure 23.2 Computed change in velocities - Spring tide HW+2 hrs(Dublin)

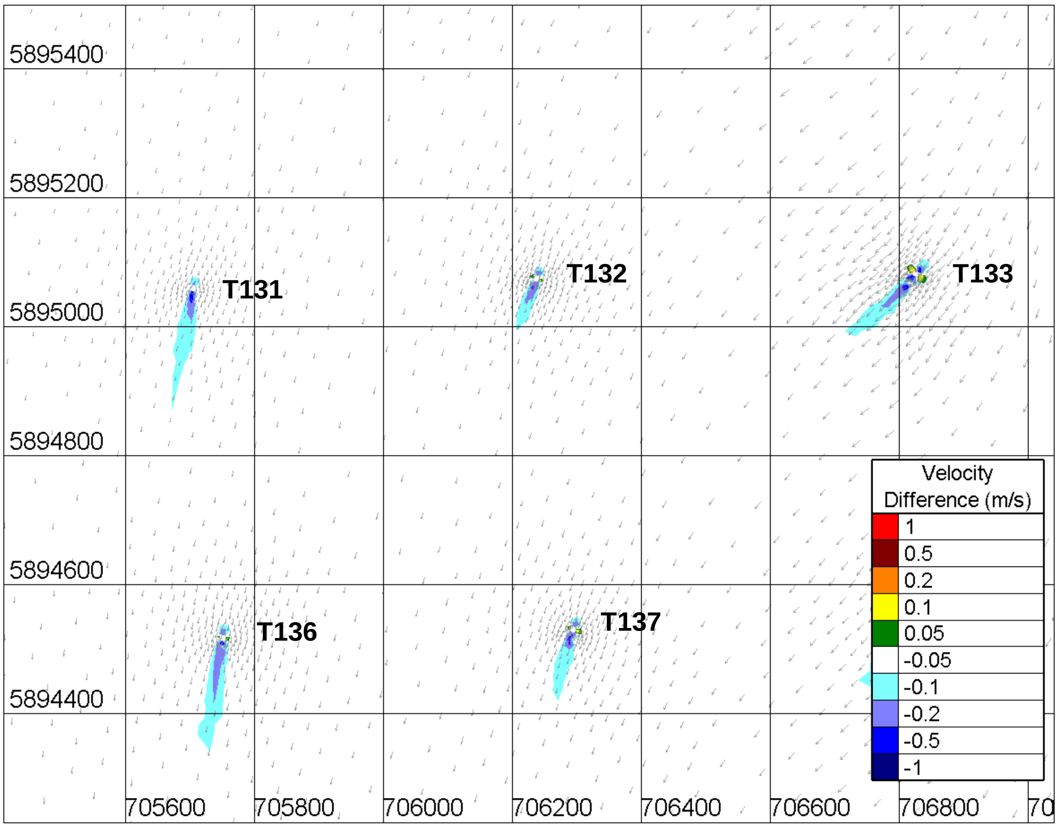


Figure 23.3 Computed change in velocities - Spring tide HW+4 hrs(Dublin)

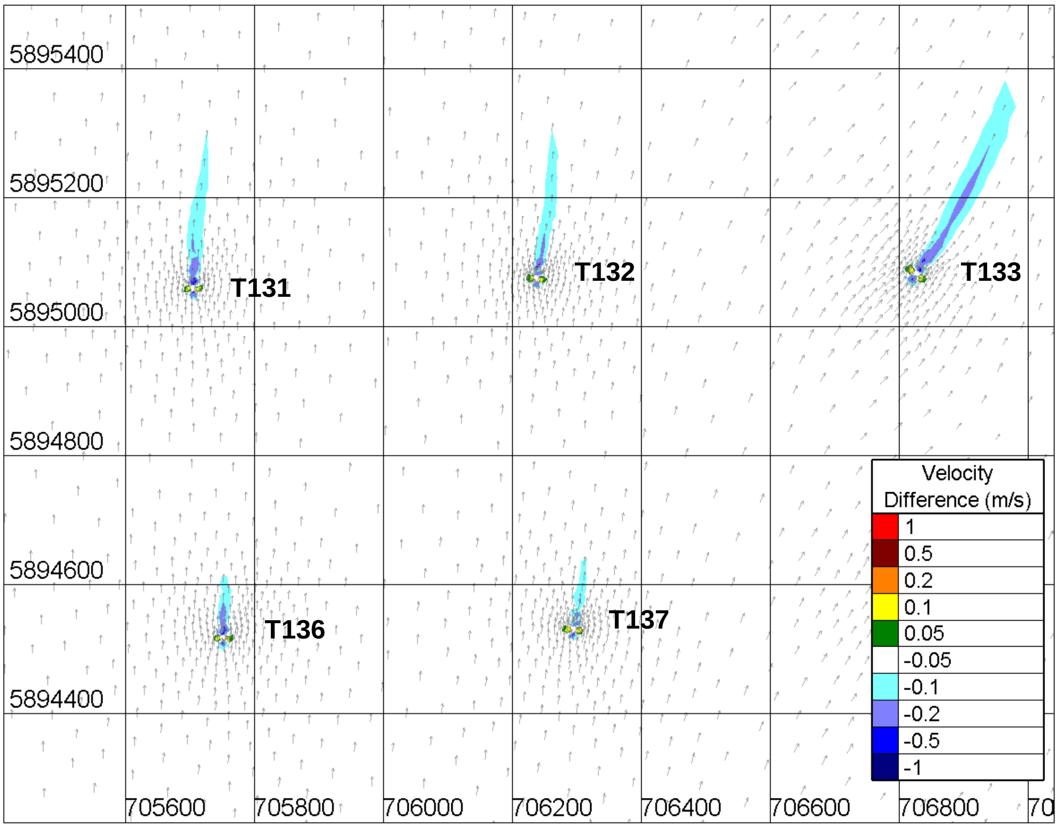


Figure 23.4 Computed change in velocities - Spring tide Low Water (Dublin)

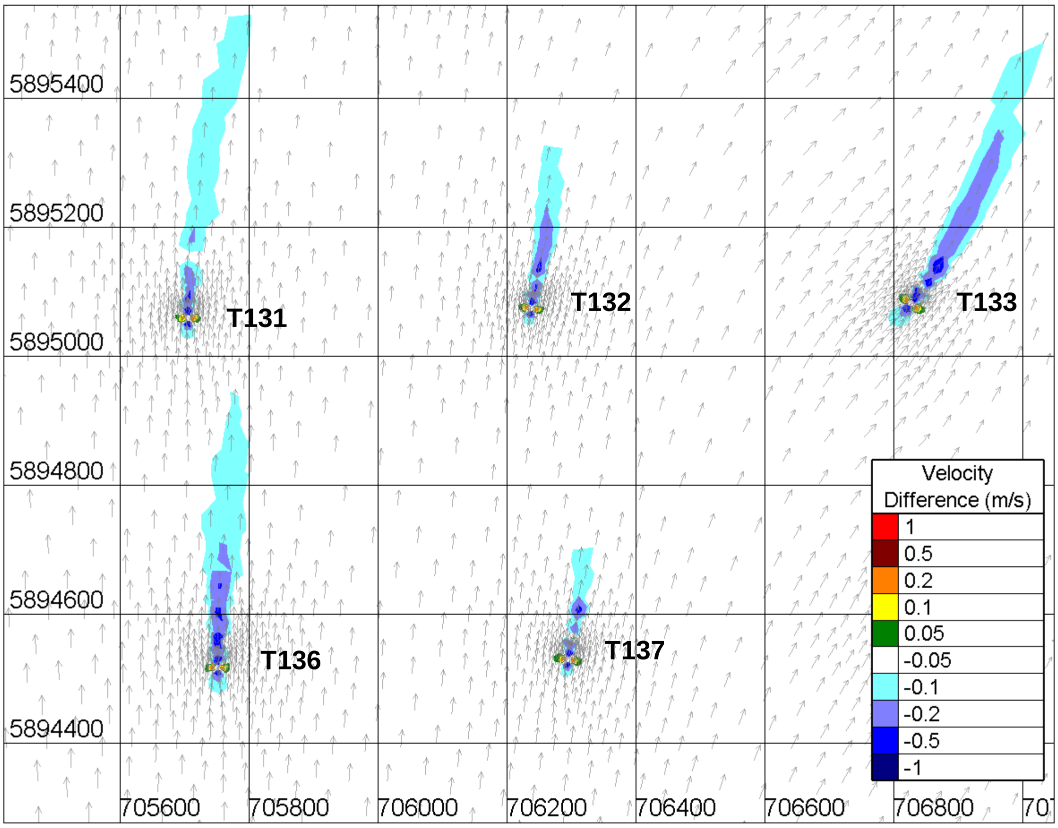


Figure 23.5 Computed change in velocities - Spring tide HW – 4hrs (Dublin)

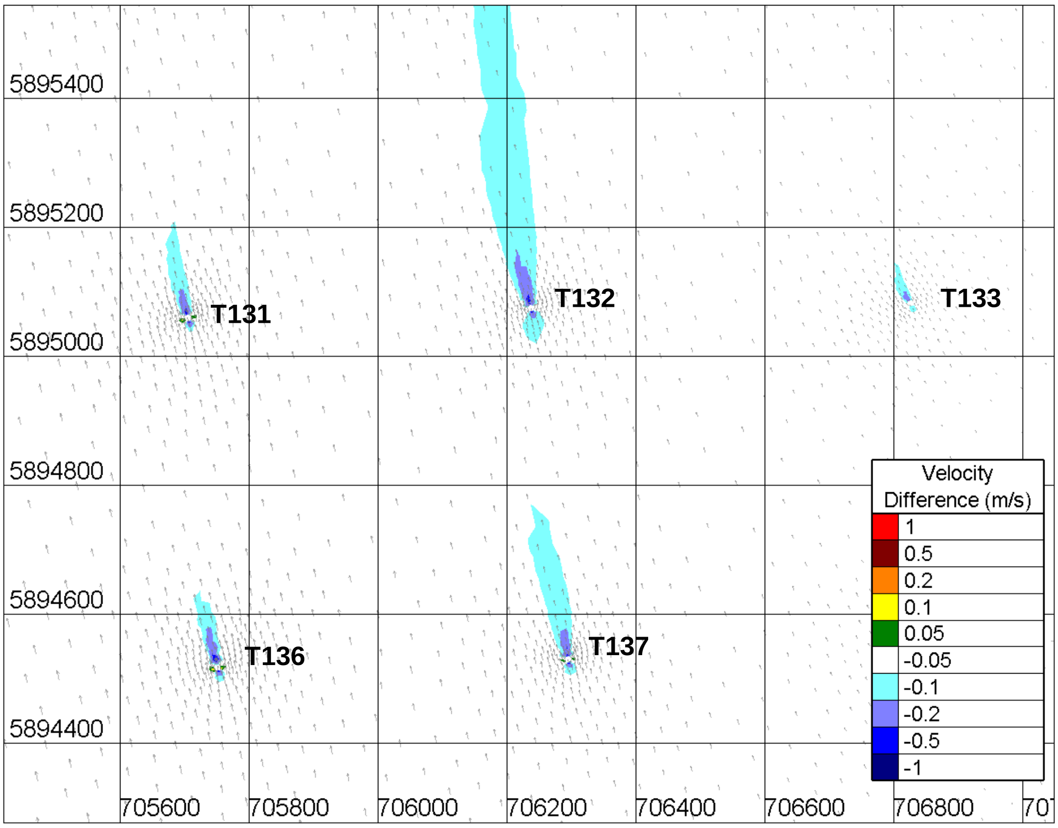


Figure 23.6 Computed change in velocities - Spring tide HW – 2hrs (Dublin)

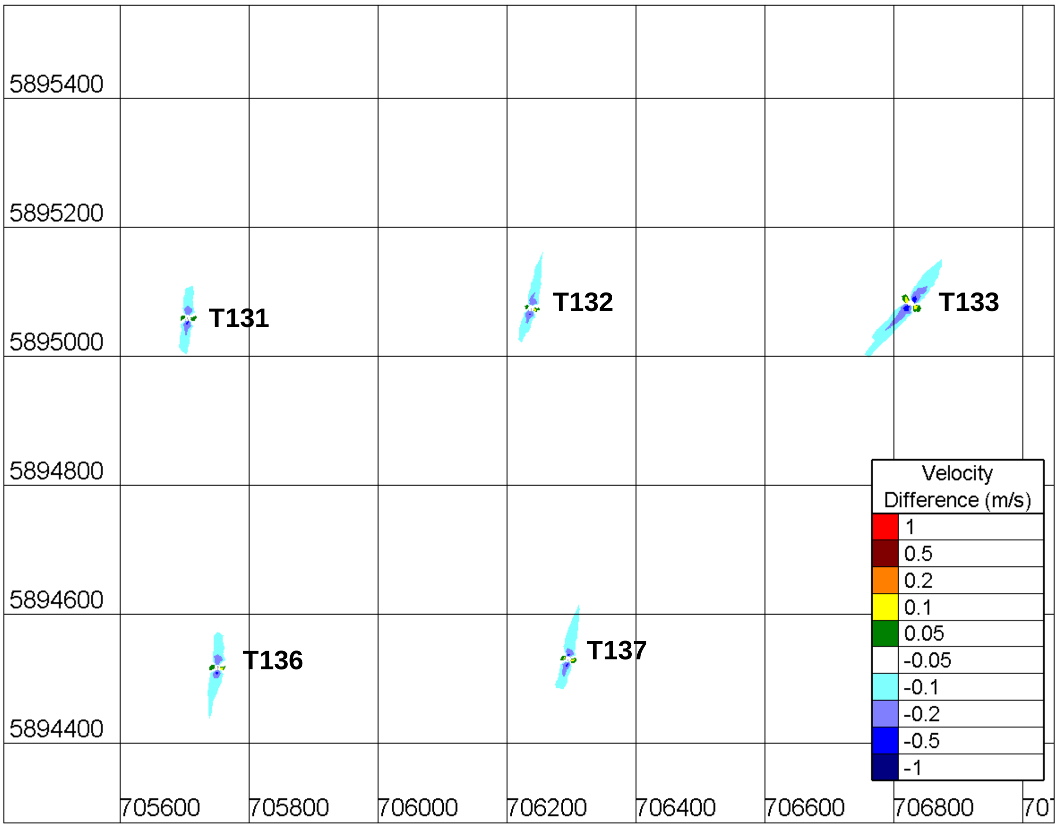


Figure 24.1 Average change in Velocity for 30 day Simulation period

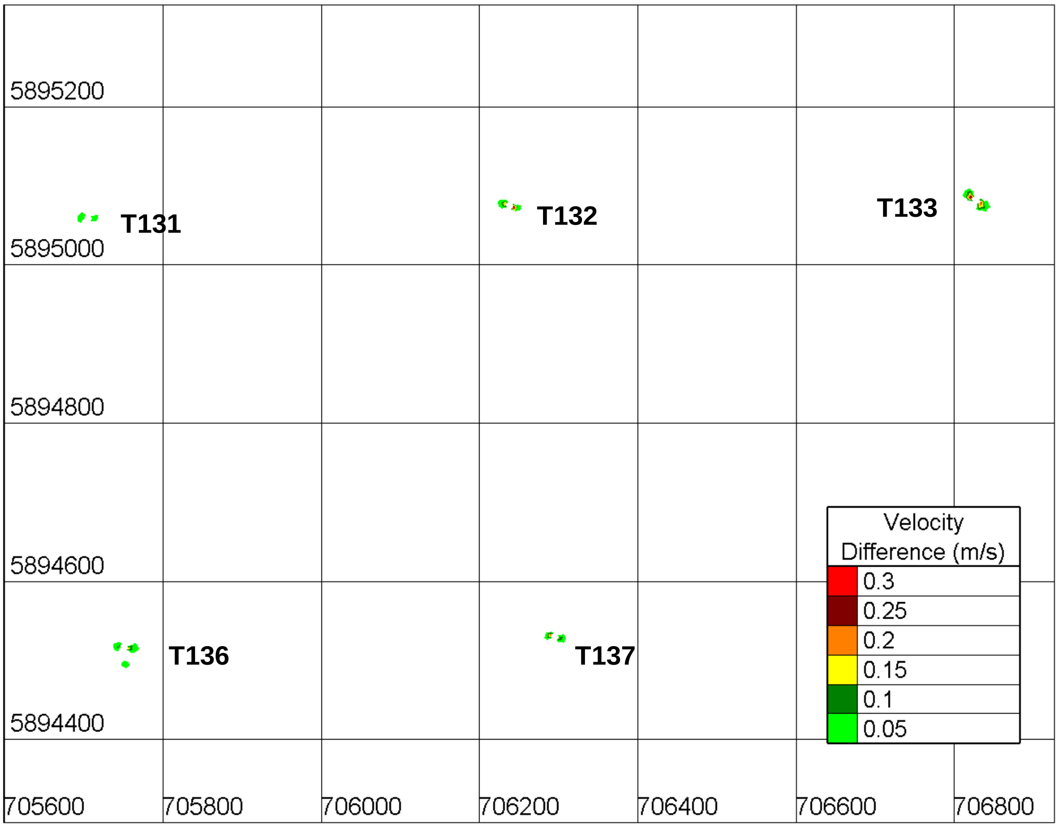


Figure 24.2 Predicted maximum increase in velocity magnitude adjacent to Turbine Monopiles

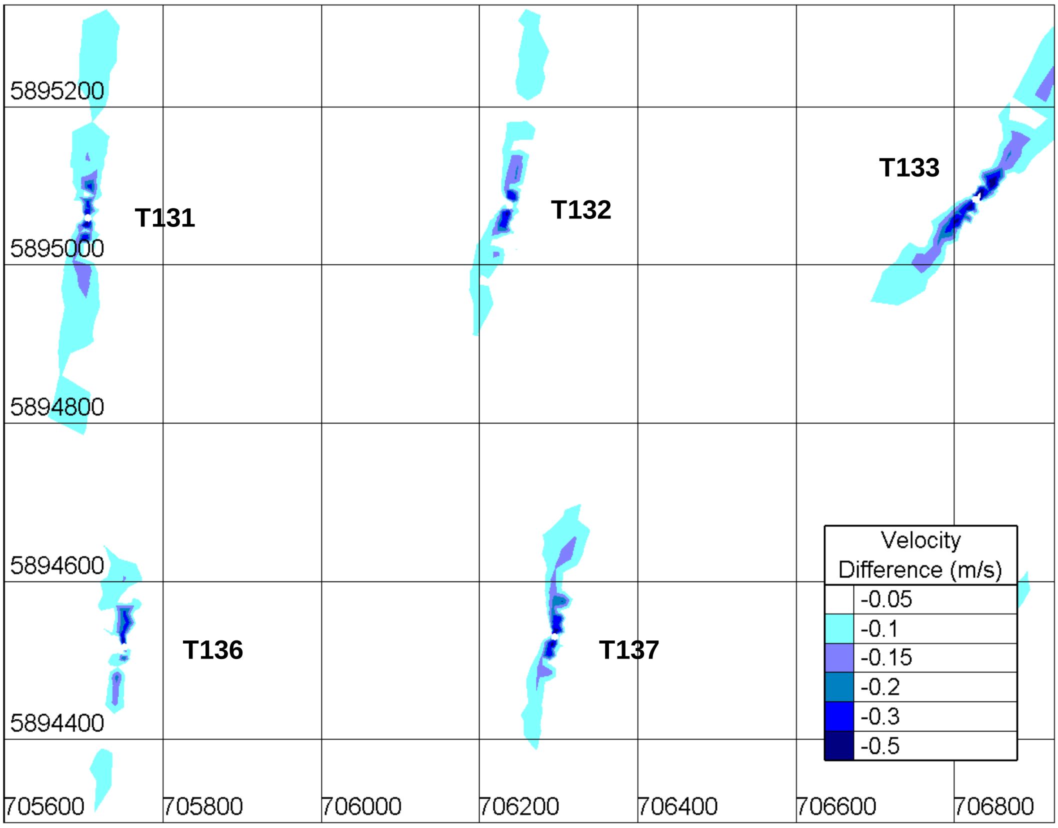


Figure 24.3 Predicted maximum decrease in velocity magnitude as a result of the Turbine

4. CONCLUSIONS

A hydrodynamic mathematical model capable of accurately simulating tidal dynamics in the vicinity of the proposed Dublin Array and Kish and Bray Sand banks study area was developed. This model was calibrated and validated against extensive field survey data conducted by Aquafact International Services Ltd.

The hydrodynamic study confirmed that tidal flow velocities and their corresponding bed shear stresses were high throughout the study area. The modelling showed that the tidal range increased northwards away from the amphidromic point off Arklow, whereas the tidal velocities increase southwards. The computed average bed shear stress over simulation period was found to be of sufficient magnitude to be capable of mobilising (eroding) a coarse to very coarse sand and that maximum computed shear velocities along the crest of the sand bar and to the south were sufficient to mobilise a fine gravel. These high ambient shear stresses indicate a mobile surface bed layer given that bed survey shows the majority of the bank area to consist of fine to medium sands. It is concluded that the upper sand layer within the banks is mobile and capable of successive erosion and deposition taking place over spring and neap tidal cycles. Computation of the residual currents which indicate the overall net transport characteristics reveal a clockwise circulation along the bar having a northwards trending residual flow on the west side and southwards trending residual flow on the east side. Such residual flow pattern maintains the sand bar integrity by retaining sediment within the circulation.

The hydrodynamic impact assessment between the existing and proposed cases shows only a local minor impact on current velocities and revealed no discernible cumulative/combined impact from the 145 monopiles within the 54km^2 area and no impact on the residual circulation of the banks and wider area. The modelling revealed only very localised increases in velocity at the structure itself resulting in increases of 0.2 to 0.4m/s and only within 5 to 10m of the structure. These localised increases in velocity will increase the local scour effects which can easily be mitigated by providing a scour blanket armouring around the structure sea bed base.

The simulations show that the main effect from these structures is to reduce velocities at the upstream stagnation point and in the downstream wake from the Monopile. The maximum wake effect from the piles is generally 100 to 150m at a 0.05m/s reduction (the simulation average effect is typically 50m from the pile at a reduction of 0.05m/s and greater).

In terms of sediment transport the local impact on velocities will have no discernible impact on the sediment regime within the Kish and Bray sand bar system. Local erosion is likely in the immediate vicinity of the Monopile but limited to within 5 to 10m of the pile. The reduction in velocities as a result of the wake effect from the monopile will not give rise to any noticeable deposition effects as the returning tidal flow will remove any such additional deposition.

The overall conclusions from the modelling study is that very localised changes in velocity will arise, but on the scale of the normal ambient tidal currents such changes will not be significant and will not alter the hydrodynamic regime of the Kish/Bray Sand bank system. Given the localised minor scale of impact it is concluded that there will be no perceptible hydrodynamic impact to the adjacent Irish shoreline or neighbouring sand bank areas such as the Coddling bank to the South.

APPENDIX 1 HYDROGRAPHIC SURVEY OF THE KISH AND BRAY BANK AUG-SEP 2012 AQUAFACT INTERNATIONAL

MARINE HYDROGRAPHIC SURVEY,
KISH BANK, CO. WICKLOW

AUGUST SEPTEMBER 2012

Report to
Saorgus Energy Ltd.

Produced by

AQUAFACT International Services Ltd

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1. Introduction

This document reports on the deployment of two recording current profilers for the measurement of water currents, tidal elevations and wave characteristics at the Kish Bank located east of Bray, Co. Wicklow over a one month period. Additional recordings were made over a single tide to supplement the profilers. These measurements were required for model calibration as part of a wind farm development being proposed by Saorgus Energy Ltd. as outlined in Figure 1.1.

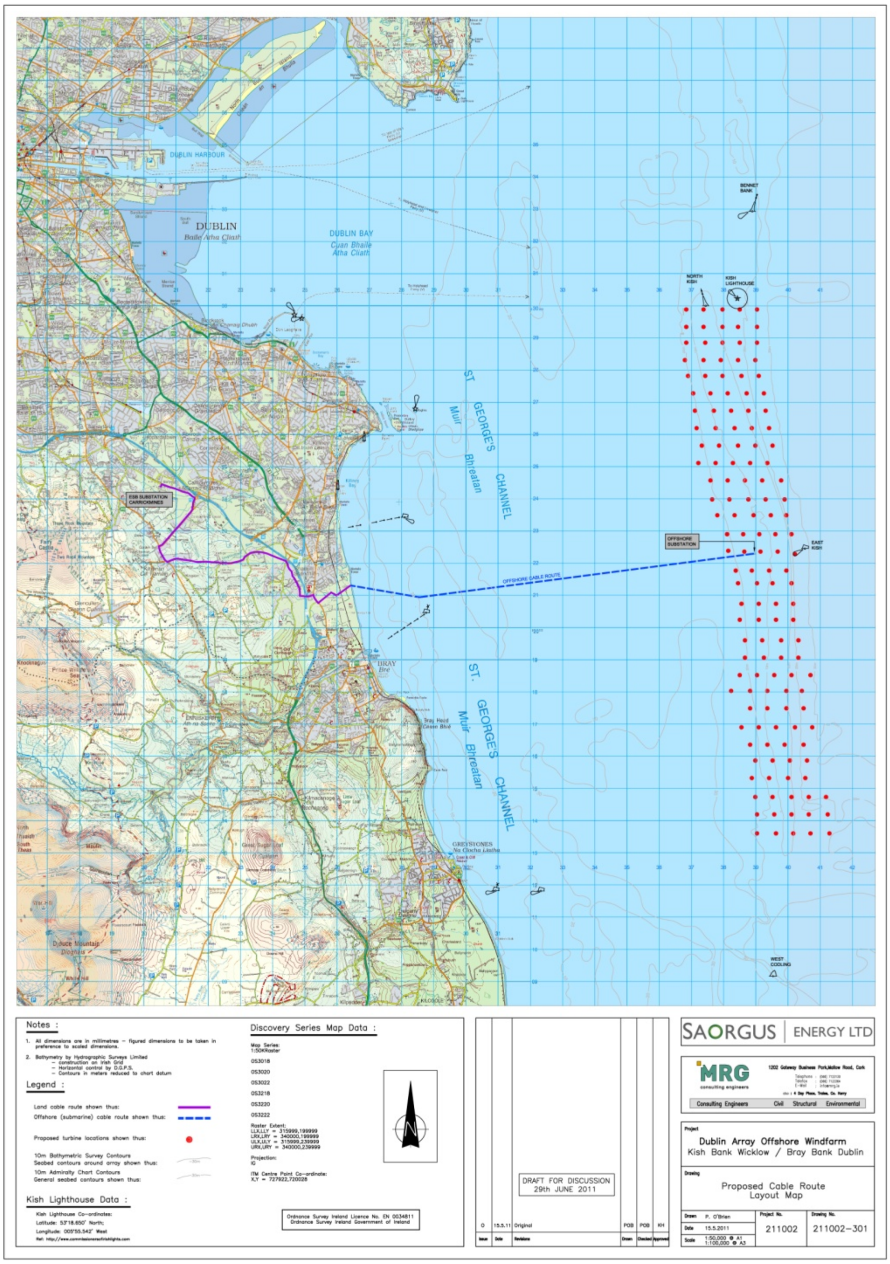


Figure 1-1 Location of the Marine Study Area Off North County Wicklow.

2. Methodology

2.1. *Introduction*

Acoustic Doppler Current Profilers (ADCP's) were deployed north and south of the Kish Bank on 23rd August 2012. The locations and coordinates of the deployment sites as recommended by the modeller are presented in Figure 2-1 and Table 2-1, respectively.

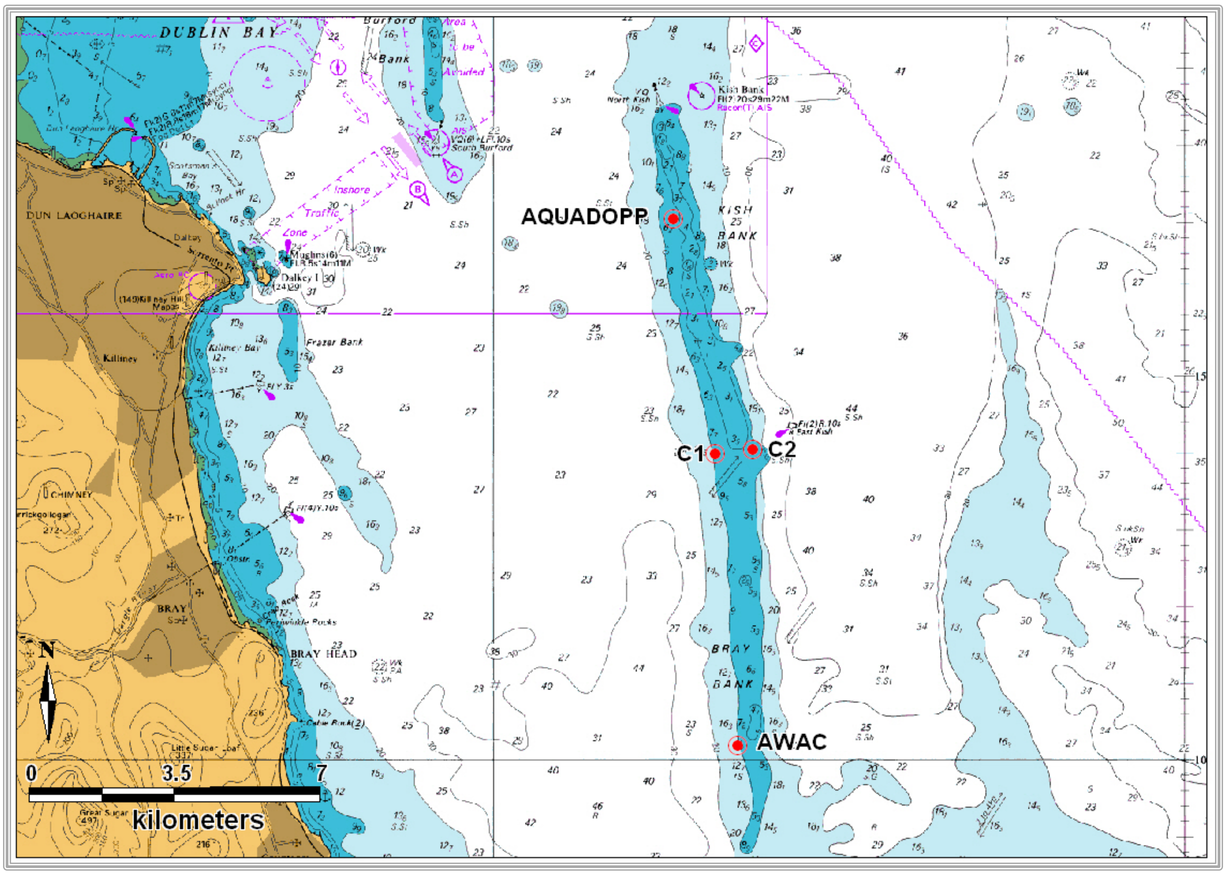


Figure 2-1 Location of the recording stations on Kish Bank

	Irish National Grid		WGS 84	
	North	East	North	West
AWAC	227947.7	337703.9	53° 10.187	5° 54.766
Aquadopp	215271.7	339625.4	53° 17.053	5° 56.165
Current 1	222327.0	338792.0	53° 13.992	5° 55.270
Current 2	222472.0	339697.0	53° 14.056	5° 54.453

Table 2-1 Location coordinates for the recording stations on Kish Bank

A 1 MHz Nortek Acoustic Wave and Current Profiler (AWAC) and a 1 MHz Nortek Aquadopp current profiler with Z cell were deployed on the southern and northern ends of the Kish bank, respectively. These profilers sit on their own mooring on the seafloor looking up into the water column and record current speed and direction at set distances above the transducer head. Prior to deployment the profilers were calibrated and set up to record currents in one meter bins above the transducer heads every ten minutes. The AWAC was also set to record wave characteristics every hour. The upright stable condition of both profilers was checked by diver following deployment and prior to retrieval.

On retrieval of the meters one month later (19th September) additional measurements were taken at positions C1 and C2 over a single tide. These measurements were taken with Aquadopp profilers at both locations.

In order to confirm that the meters were reading accurately, a Braystroke direct reading current meter was used to measure currents through the water column at each of the recording locations.

Water depth and tidal variations were recorded at each location with the internal pressure sensor that is inbuilt in the profilers.

3. Results

3.1. Introduction

All data recorded by the meters during the hydrographic survey at the Kish Bank are included as Excel files and accompany this report.

3.2. South Kish Bank (AWAC)

The visual inspection of the AWAC prior to retrieval found that it had sunk, along with its mooring, into the loose sand that makes up the seafloor at this location. A light cover of sand was observed over the transducer head. Quality checks of the data and sensors aboard the AWAC revealed that the meter was slowly enveloped by sand over the deployment period. However, apart from some individual records towards the end of the recording period, the data set was generally of good quality as the transducer head remained above the seafloor. All data that was found to be of poor quality was removed from the data set.

3.2.1. Tidal Variation

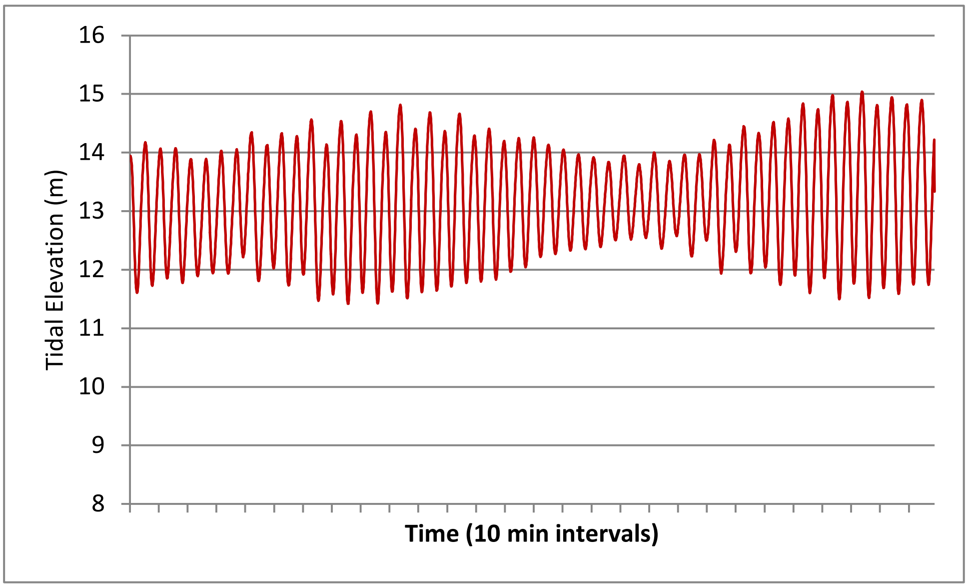


Figure 3-1 Tidal variation recorded by the AWAC, North Kish Bank

The AWAC was located in approximately 13 m water depth and the tidal range recorded over the deployment period is presented in Figure 3-1. Maximum range during a spring tide was just over 3 m while the range during neaps was just over 1 m.

3.2.2. Water Currents

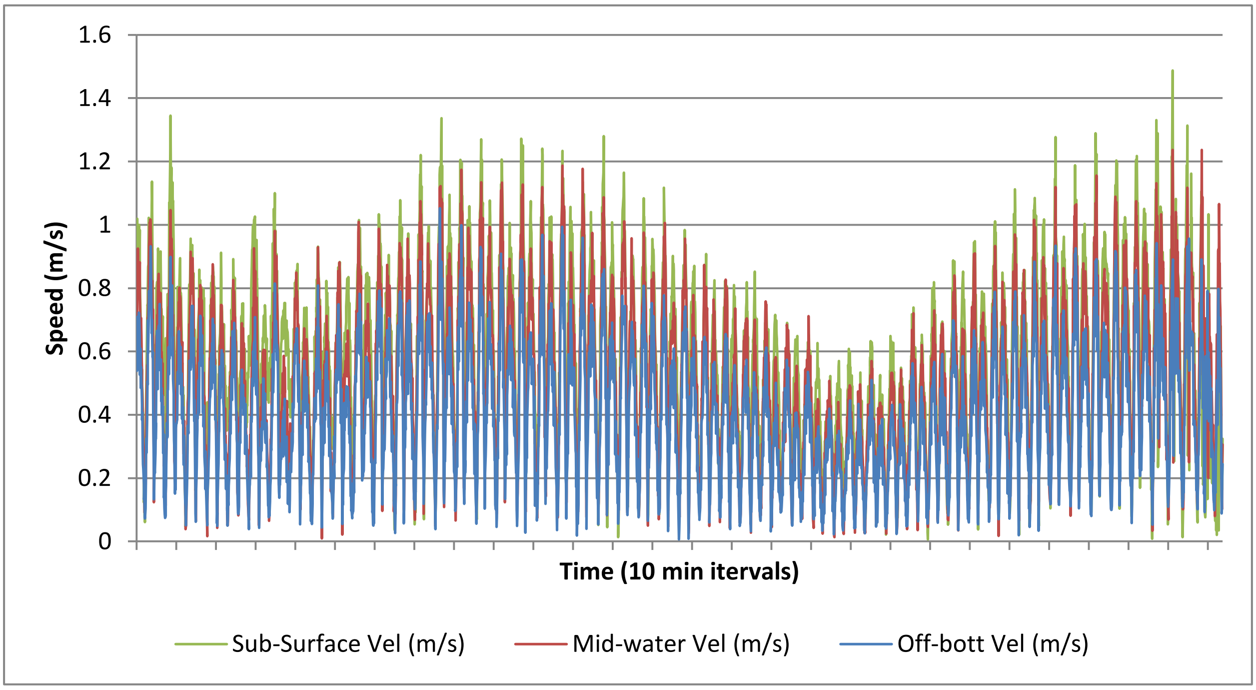


Figure 3-2 Current speed recorded at three depths, South Kish Bank

Current speeds recorded at three depths in the south of the Kish from 23rd August to 20th September 2012 are presented in Figure 3-2. Maximum current speed recorded sub-surface, mid-water and off bottom were 1.49 ms^{-1}, 1.24 ms^{-1}, 1.05 ms^{-1}, respectively. The sub-surface current was calculated across the range of bins close to the surface boundary layer and not a single bin that doesn't move with tidal variation.

Horizontal current vector scatter plots from 1.4 m, 6.4 m and 10.4 m above the meter (Figures 3-3 to 3-5) show a south-southwest to north-northeast directional trend at all depths. This is also clear from the cumulative frequency roses (Figures 3-6 to 3-8).

Cumulative vector plots at these depths (Figures 3-9 to 3-11) indicate a slight residual flow to the north west at all depths.

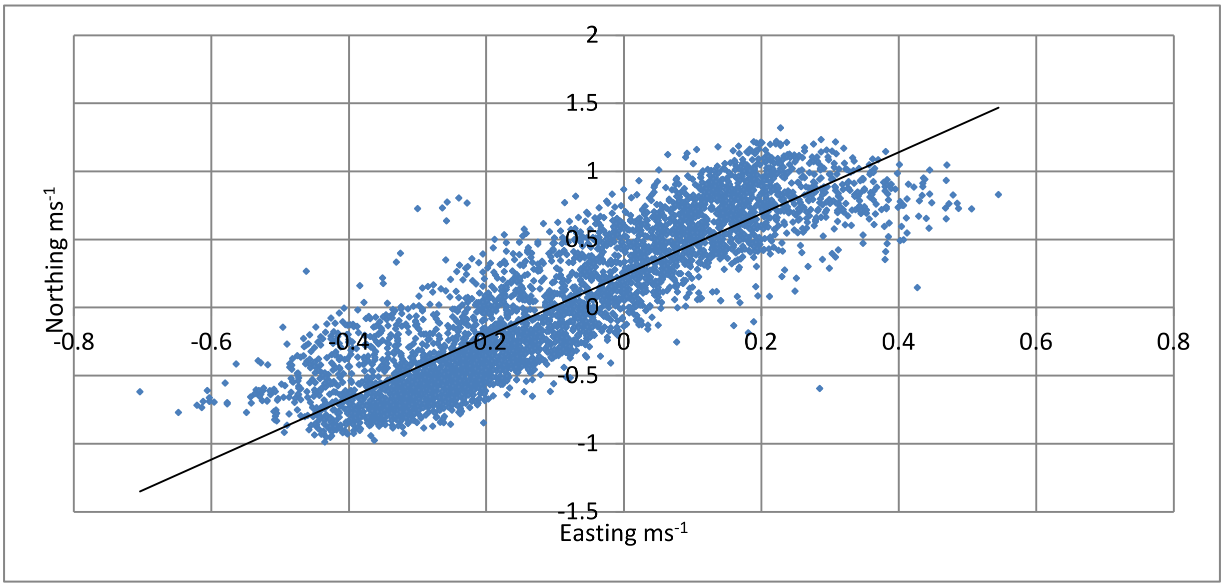


Figure 3-3 Subsurface current scatter plot, South Kish Bank,

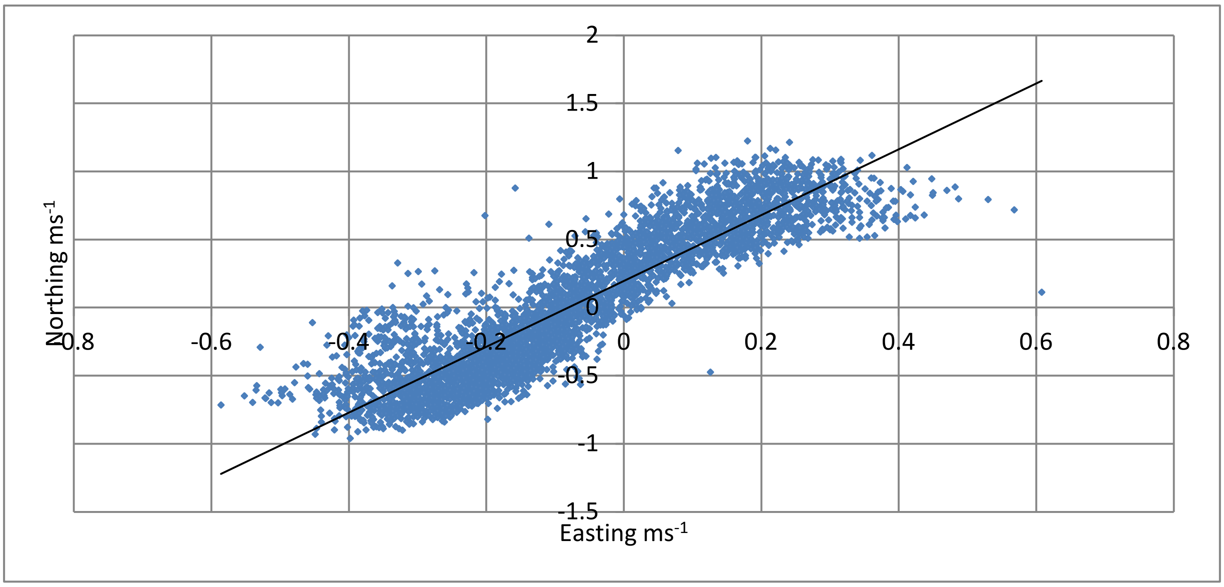


Figure 3-4 Mid-water current scatter plot, South Kish Bank

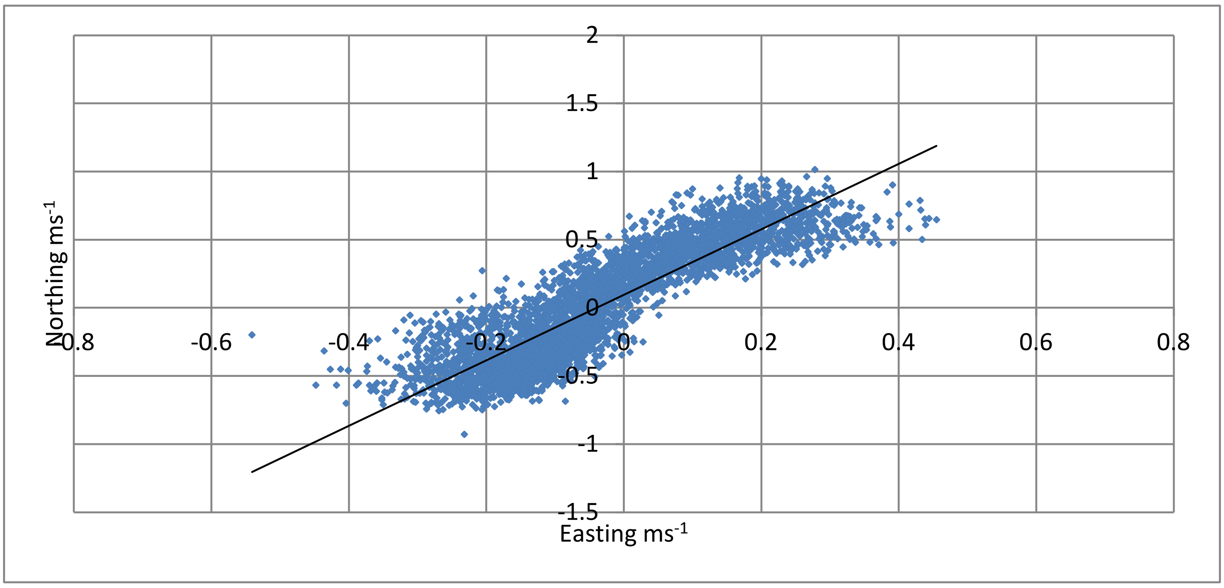
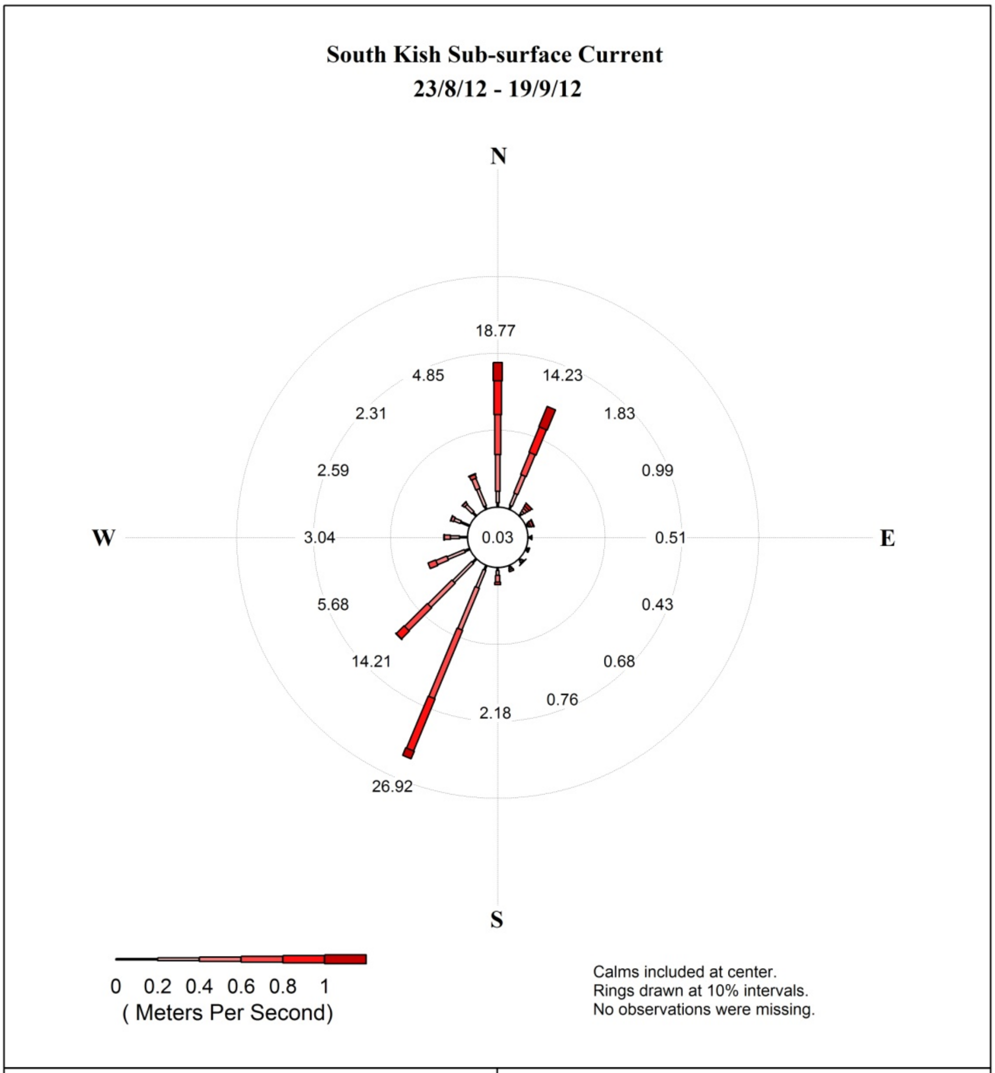


Figure 3-5 Off-bottom current scatter plot, South Kish Bank



Calms included at center.
Rings drawn at 10% intervals.
No observations were missing.

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
N	0.56	1.47	4.77	5.20	4.41	2.36
NNE	0.53	1.67	2.56	3.07	3.55	2.84
NE	0.38	0.33	0.41	0.33	0.36	0.03
ENE	0.18	0.15	0.23	0.33	0.10	0.00
E	0.30	0.13	0.08	0.00	0.00	0.00
ESE	0.10	0.20	0.13	0.00	0.00	0.00
SE	0.30	0.23	0.13	0.00	0.00	0.03
SSE	0.28	0.23	0.25	0.00	0.00	0.00

TOTAL OBS = 3942 MISSING OBS = 0

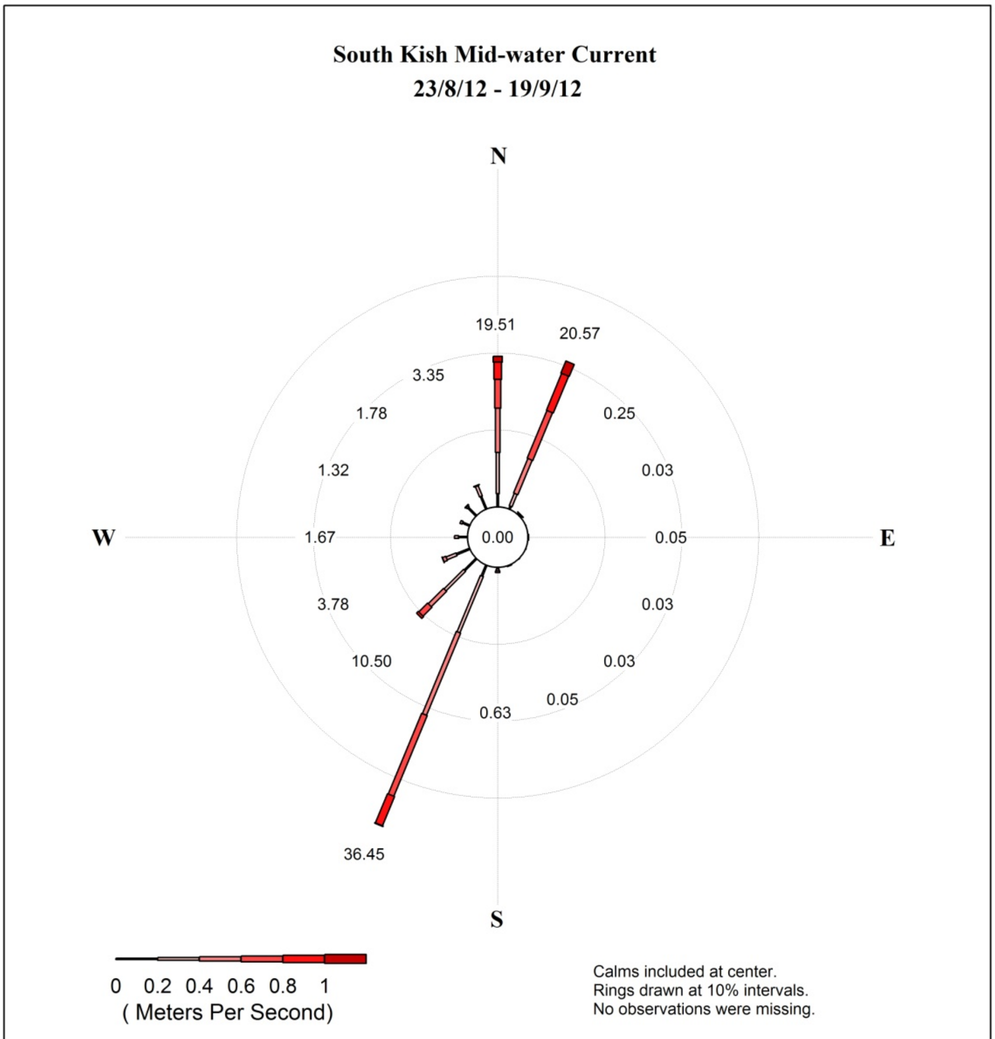
PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
S	0.36	0.61	0.89	0.33	0.00	0.00
SSW	0.61	2.46	5.89	9.59	7.33	1.04
SW	0.68	3.50	4.39	4.16	1.45	0.03
WSW	0.71	2.38	1.55	1.04	0.00	0.00
W	1.01	1.17	0.79	0.08	0.00	0.00
WNW	1.27	0.89	0.41	0.03	0.00	0.00
NW	0.63	1.27	0.33	0.08	0.00	0.00
NNW	0.46	2.41	1.40	0.48	0.10	0.00

CALM OBS = 1 PERCENT CALM = 0.03

Figure 3-6 Sub-surface current cumulative frequency rose, South Kish Bank

(note: current direction is to direction shown)



Calms included at center.
Rings drawn at 10% intervals.
No observations were missing.

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
N	1.70	5.35	5.73	3.73	2.23	0.76
NNE	0.43	1.73	4.85	6.70	5.20	1.67
NE	0.13	0.00	0.00	0.08	0.05	0.00
ENE	0.03	0.00	0.00	0.00	0.00	0.00
E	0.03	0.00	0.00	0.03	0.00	0.00
ESE	0.03	0.00	0.00	0.00	0.00	0.00
SE	0.03	0.00	0.00	0.00	0.00	0.00
SSE	0.03	0.00	0.03	0.00	0.00	0.00

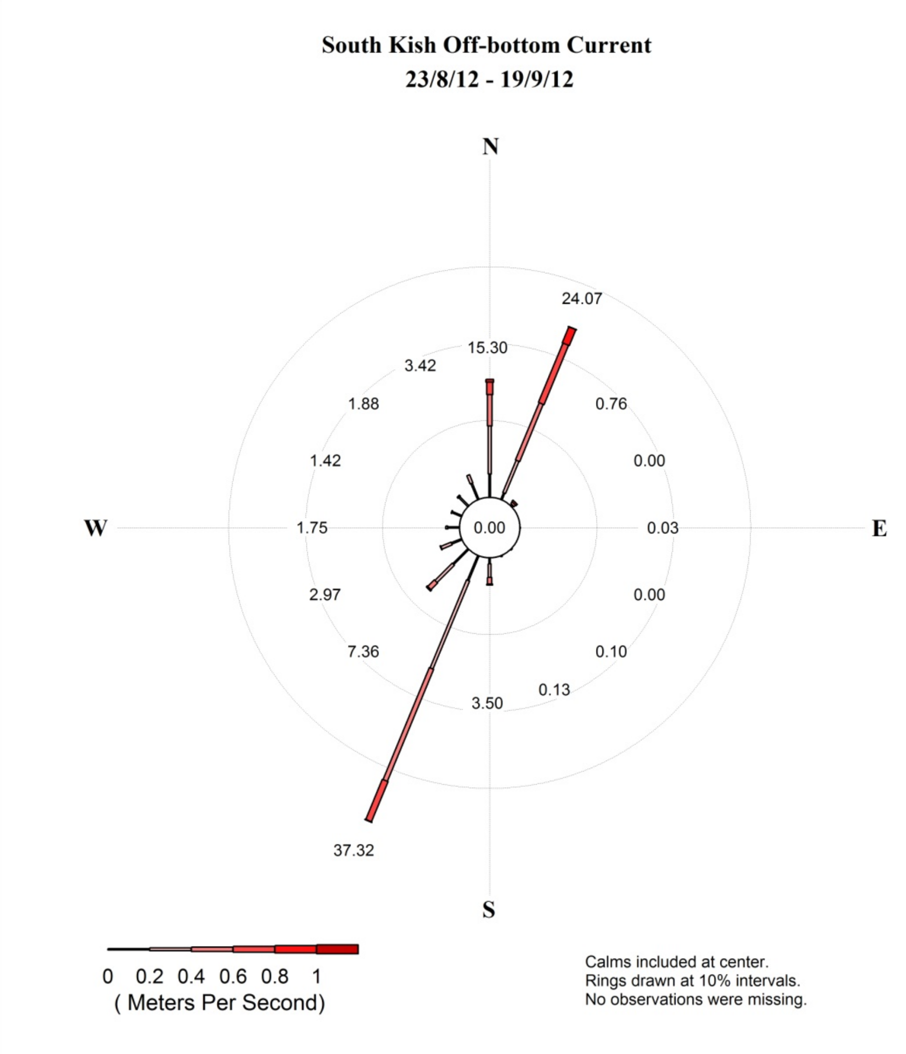
TOTAL OBS = 3942 MISSING OBS = 0

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
S	0.15	0.25	0.23	0.00	0.00	0.00
SSW	1.50	7.91	11.57	11.31	4.11	0.05
SW	2.16	3.58	2.82	1.62	0.33	0.00
WSW	1.88	1.42	0.46	0.03	0.00	0.00
W	1.14	0.53	0.00	0.00	0.00	0.00
WNW	1.01	0.30	0.00	0.00	0.00	0.00
NW	1.50	0.23	0.05	0.00	0.00	0.00
NNW	1.80	1.45	0.08	0.03	0.00	0.00

CALM OBS = 0 PERCENT CALM = 0.00

Figure 3-7 Mid-water current cumulative frequency rose, South Kish Bank



Calms included at center.
Rings drawn at 10% intervals.
No observations were missing.

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
N	3.02	6.24	4.08	1.60	0.36	0.00
NNE	0.94	4.52	8.04	8.32	2.23	0.03
NE	0.13	0.10	0.30	0.23	0.00	0.00
ENE	0.00	0.00	0.00	0.00	0.00	0.00
E	0.03	0.00	0.00	0.00	0.00	0.00
ESE	0.00	0.00	0.00	0.00	0.00	0.00
SE	0.10	0.00	0.00	0.00	0.00	0.00
SSE	0.13	0.00	0.00	0.00	0.00	0.00

TOTAL OBS = 3942 MISSING OBS = 0

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
S	0.76	1.78	0.84	0.13	0.00	0.00
SSW	3.48	12.38	15.73	5.66	0.08	0.00
SW	2.77	3.20	1.22	0.18	0.00	0.00
WSW	1.45	1.45	0.08	0.00	0.00	0.00
W	1.50	0.25	0.00	0.00	0.00	0.00
WNW	1.37	0.05	0.00	0.00	0.00	0.00
NW	1.67	0.20	0.00	0.00	0.00	0.00
NNW	2.28	1.14	0.00	0.00	0.00	0.00

CALM OBS = 0 PERCENT CALM = 0.00

Figure 3-8 Mid-water current cumulative frequency rose, South Kish Bank

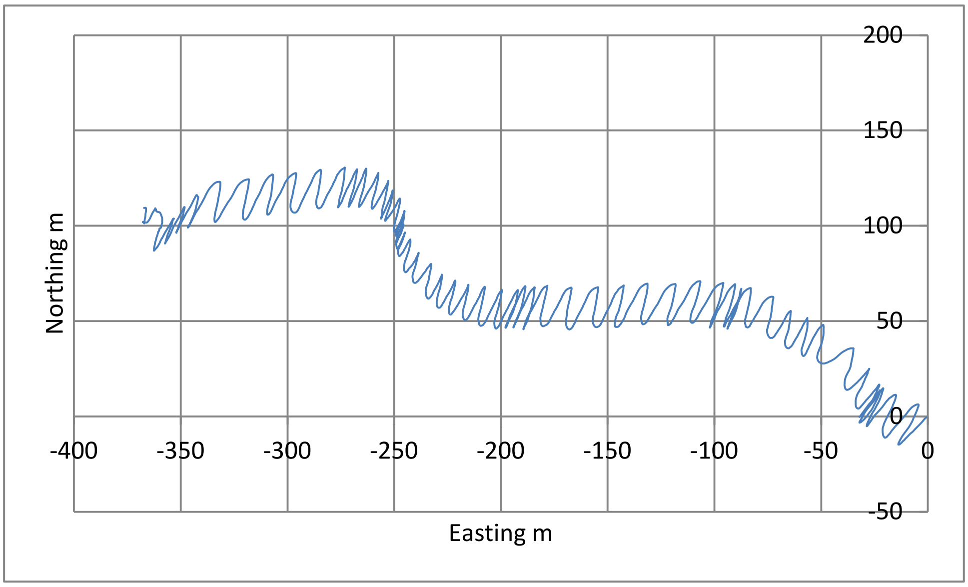


Figure 3-9 Sub-surface current cumulative vector plot, South Kish Bank

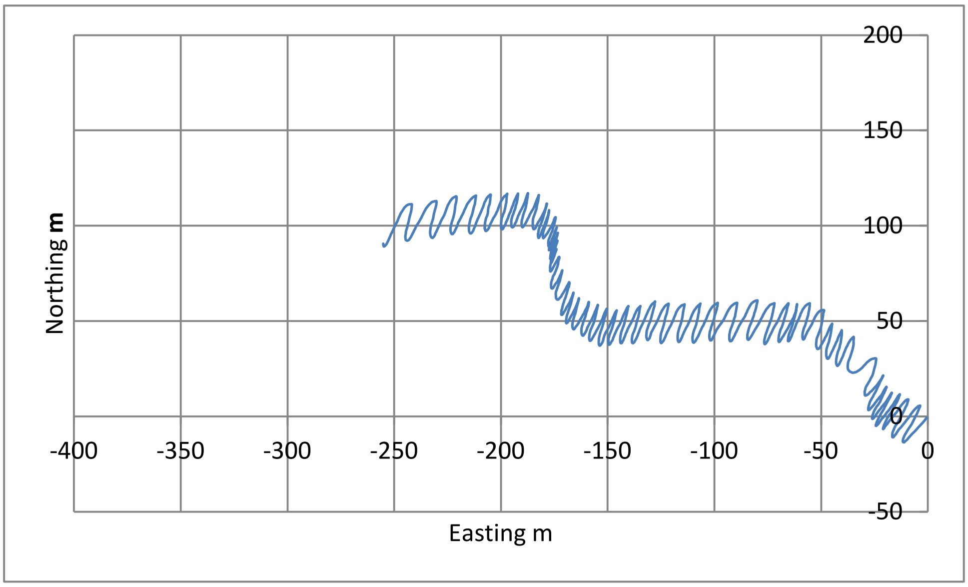


Figure 3-10 Mid-water current cumulative vector plot, South Kish Bank

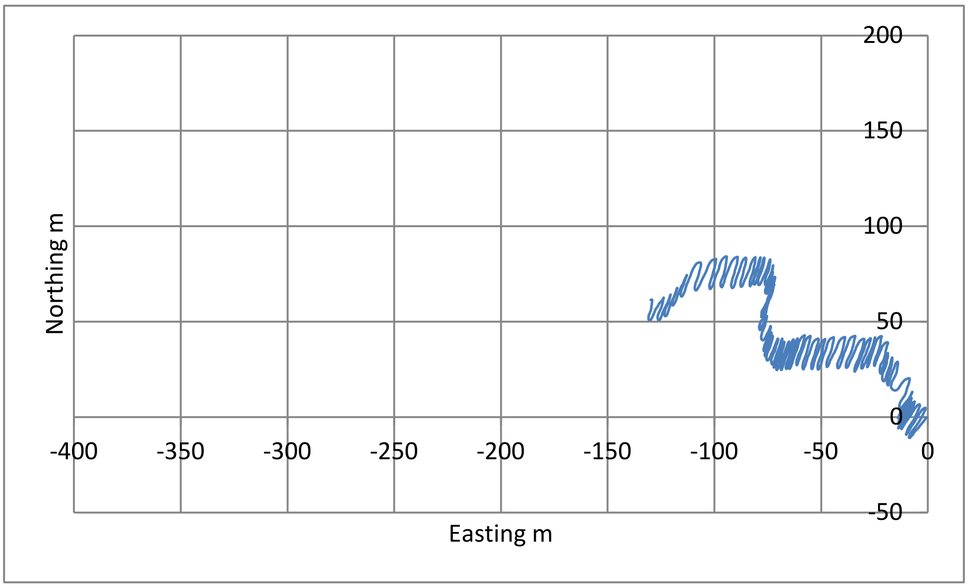


Figure 3-11 Off-bottom current cumulative vector plot, South Kish Bank

3.2.3. Waves

The AWAC measures three independent quantities that can be used to estimate wave parameters. These quantities are pressure, orbital velocities and Acoustic Surface Tracking (AST). However, due to the movement of the AWAC on the mobile sand seafloor, the wave data collected is of medium to low quality. All wave parameters recorded are included in the relevant excel file that accompanies this report while Figure 3-12 outlines significant wave height recorded by the AWAC.

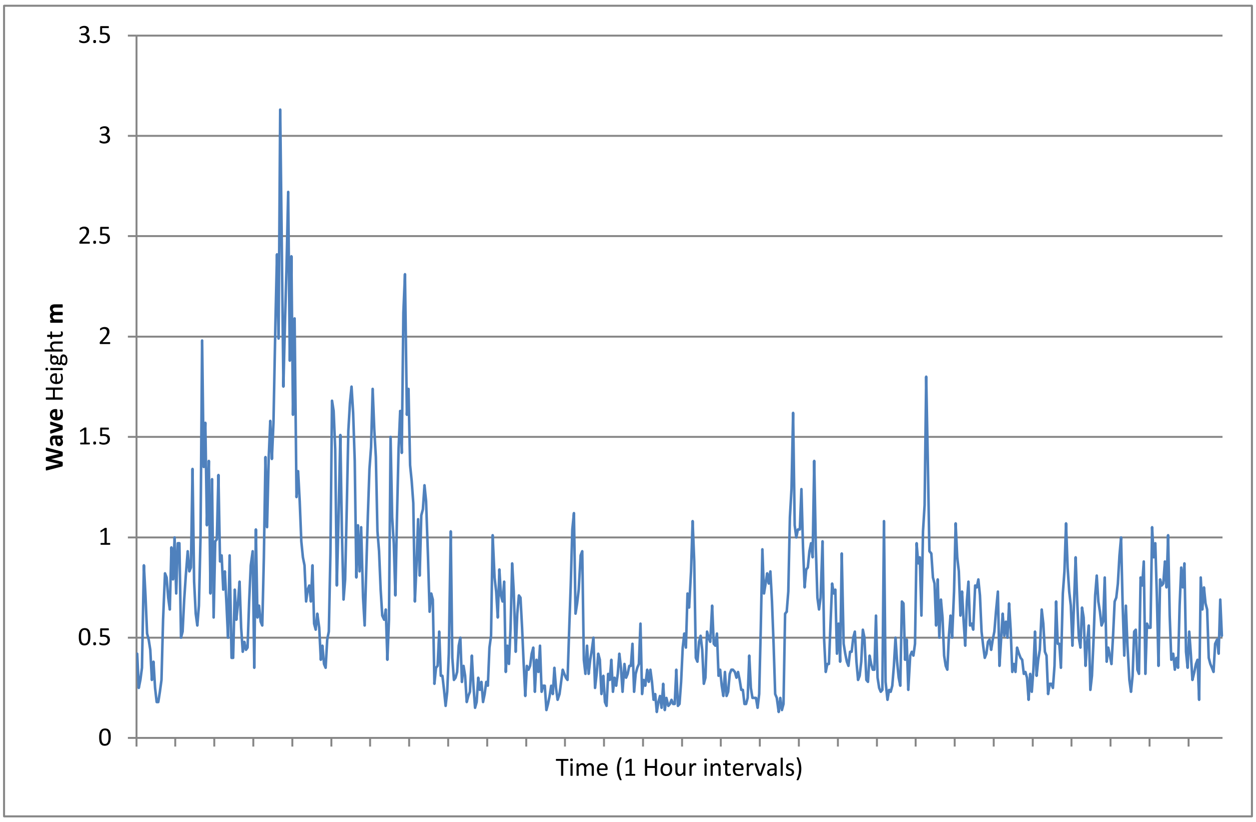


Figure 3-12 Significant wave height recorded on the south side of Kish Bank, 23/8/2012 to 20/9/2012.

The highest significant wave recorded on the bank was just over 3 m. Although wind data wasn't recorded in conjunction with these measurements, data is available from other sources and a mean wind speed of 26 knots was recorded in the Irish Sea at this time. In general, significant recorded waves were less than 1 m in height.

3.3. North Kish Bank

Visual inspection of the Aquadopp profiler prior to retrieval found that the meter was still in an upright state and in a similar condition as it was when inspected after deployment. All data records were of good quality.

3.3.1. Tidal Variation

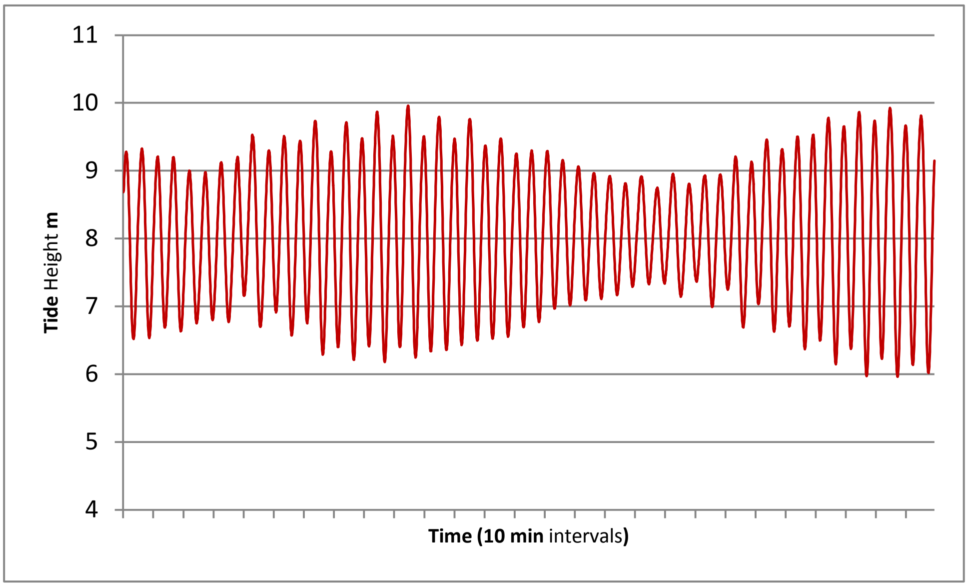


Figure 3-13 Tidal variation recorded by the Nortek Aquadopp, South Kish Bank

The Aquadopp was located in approximately 8 m water depth and the tidal range recorded over the deployment period is presented in Figure 3-13. Maximum range during a spring tide was just over 3.5 m while the range during neaps was just under 2 m.

3.3.2. Currents

Current speed recorded at three depths in the north of the Kish from 23rd August to 19th September 2012 are presented in Figure 3-14. Maximum current speeds recorded sub-surface, mid-water and off bottom were 1.34 ms^{-1}, 0.92 ms^{-1}, 0.81 ms^{-1}, respectively. The sub-surface current was calculated across the range of bins close to the surface boundary layer and not a single bin that doesn't move with tidal variation.

Horizontal current vector scatter plots from 0 m, 3 m and 6 m above the meter (Figures 3-15 to 3-17) show a south-southwest to north-northeast directional trend at all depths (Z cell technology allows measurements at the transducer head) although the sub-surface does show a broader range of directional currents. This is also clear from the cumulative frequency roses (Figures 3-18 to 3-20).

Cumulative vector plots at these depths (Figures 3-21 to 3-23) indicate a slight residual flow to the east-northeast at all depths.

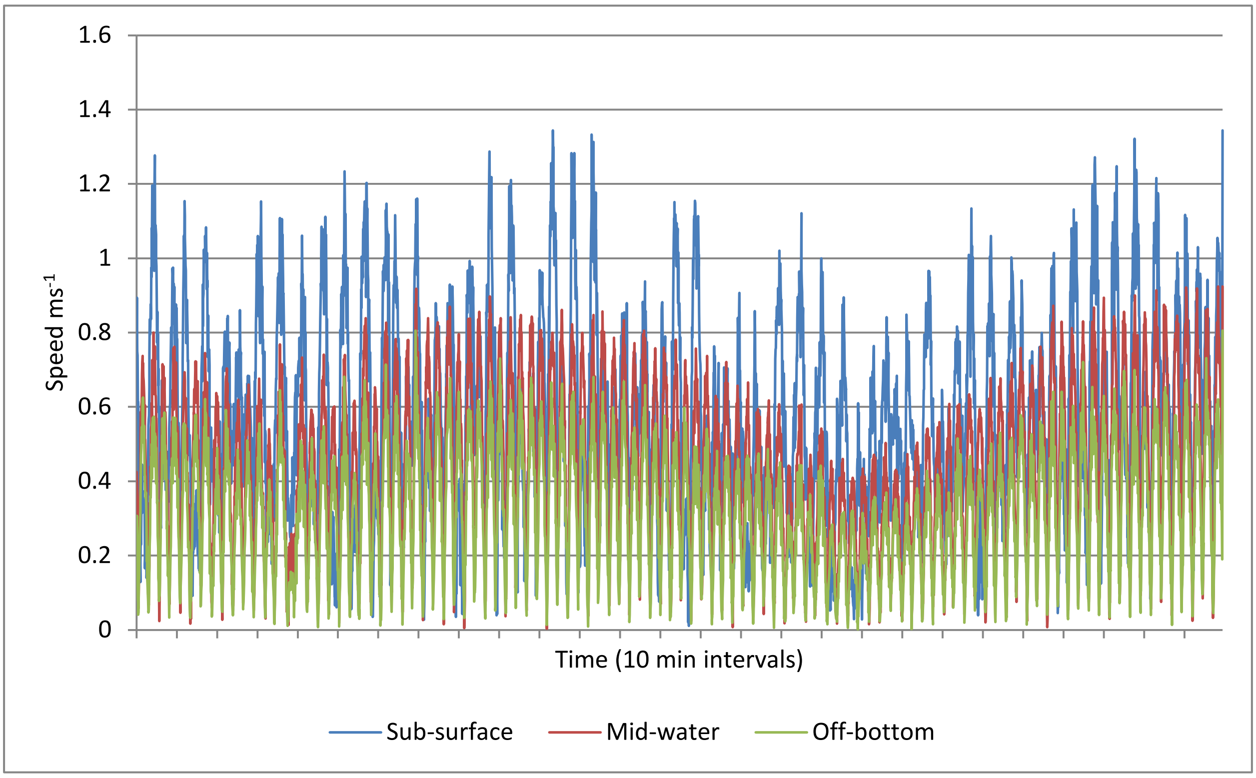


Figure 3-14 Current speed recorded at three depths, North Kish Bank

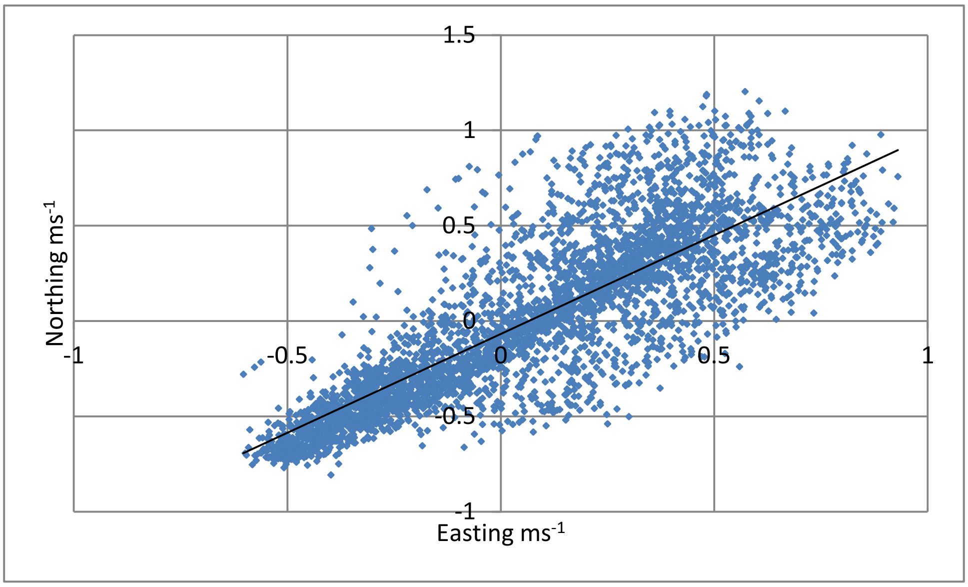


Figure 3-15 Sub-surface current scatter plot, North Kish Bank

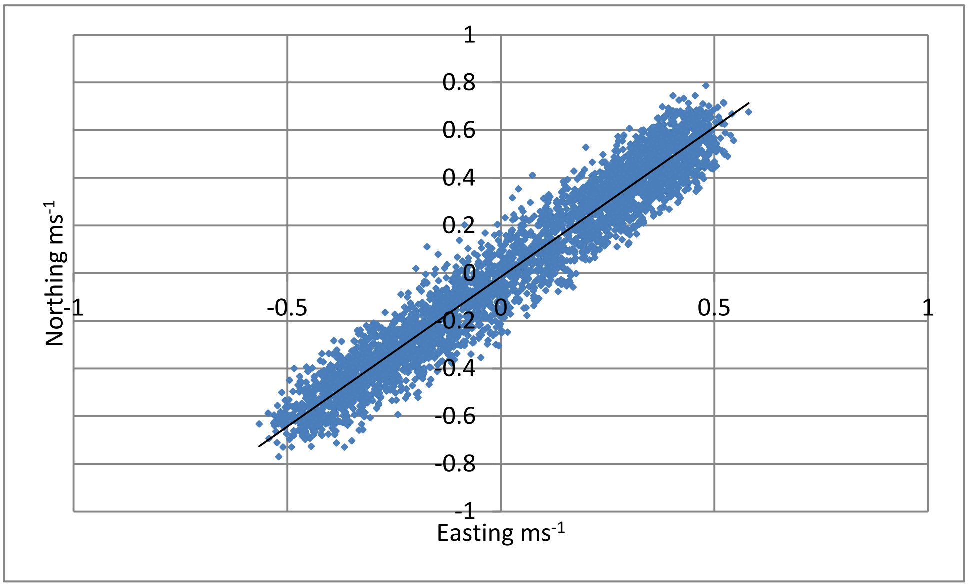


Figure 3-16 Mid-water current scatter plot, North Kish Bank

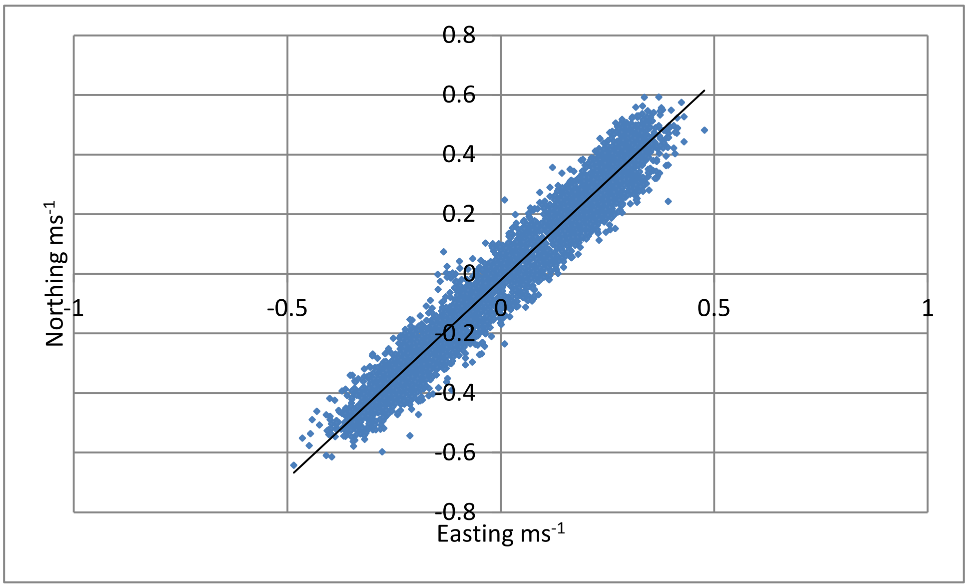
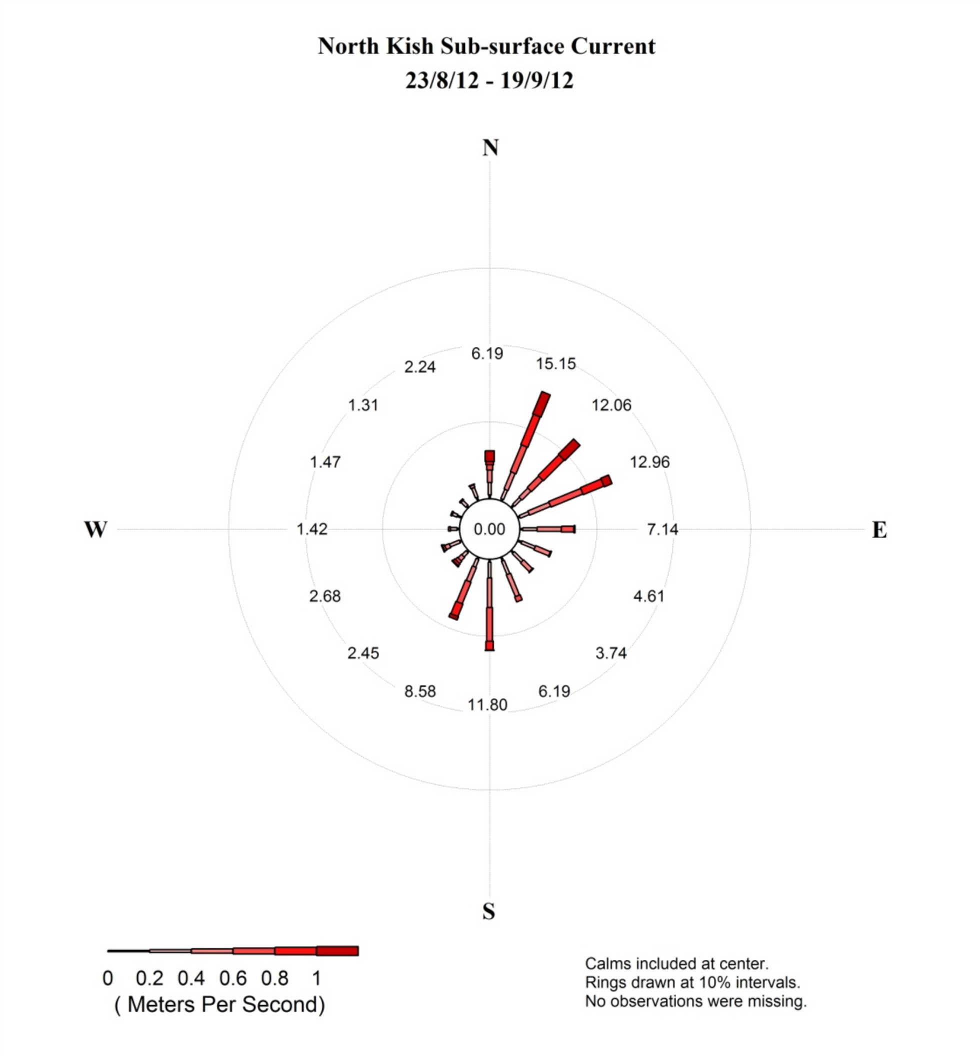


Figure 3-17 Off-bottom current scatter plot, Nouth Kish Bank



Calms included at center.
Rings drawn at 10% intervals.
No observations were missing.

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
N	0.49	1.62	1.60	0.70	0.41	1.37
NNE	0.31	1.31	2.40	3.74	4.25	3.14
NE	0.46	1.26	1.65	2.09	3.81	2.78
ENE	0.31	1.24	2.94	4.48	2.89	1.11
E	0.34	1.86	3.14	1.62	0.18	0.00
ESE	0.54	1.88	2.06	0.13	0.00	0.00
SE	0.39	1.62	1.62	0.10	0.00	0.00
SSE	0.54	1.88	3.07	0.70	0.00	0.00

TOTAL OBS = 3880 MISSING OBS = 0

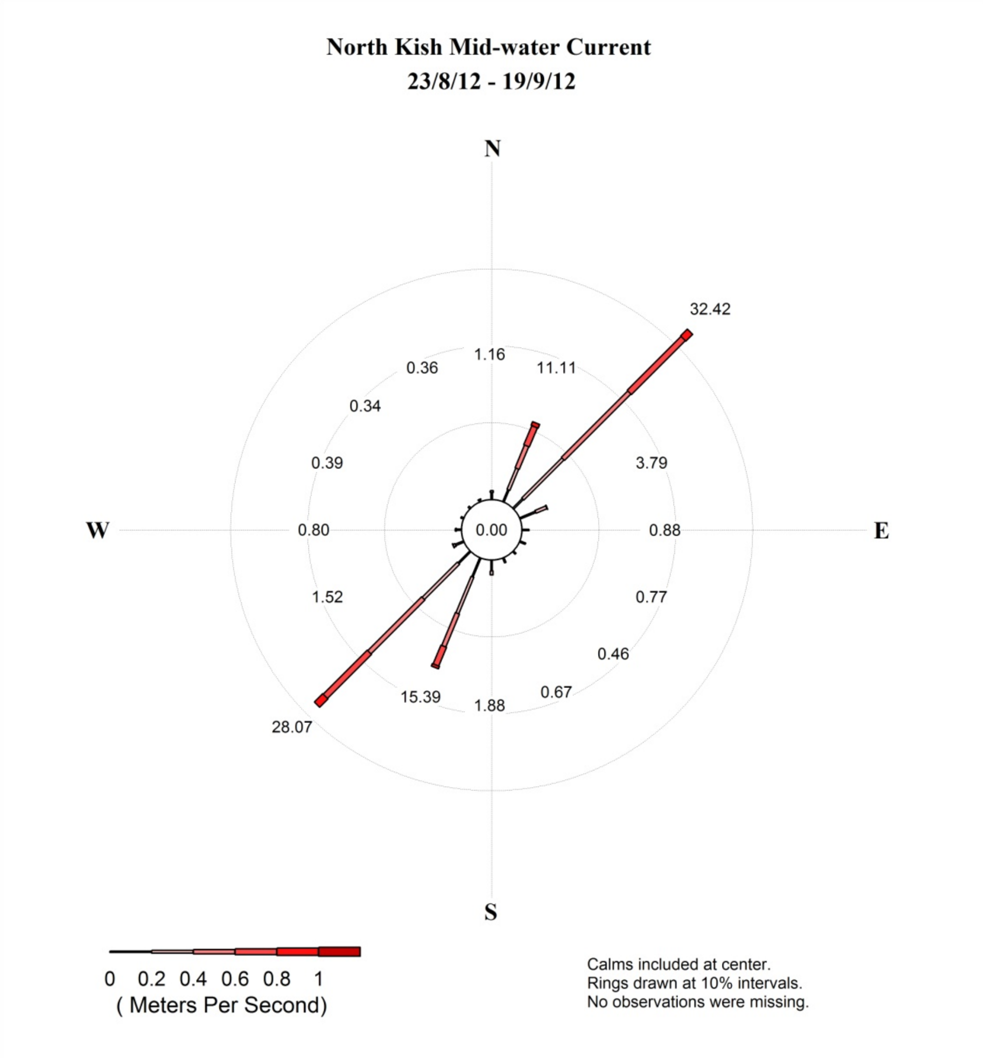
PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
S	0.36	2.04	3.84	4.38	1.13	0.05
SSW	0.26	1.08	2.04	3.02	1.73	0.46
SW	0.23	0.75	0.62	0.39	0.34	0.13
WSW	0.31	1.37	0.62	0.26	0.13	0.00
W	0.31	0.85	0.26	0.00	0.00	0.00
WNW	0.62	0.64	0.21	0.00	0.00	0.00
NW	0.28	0.88	0.15	0.00	0.00	0.00
NNW	0.52	1.31	0.36	0.05	0.00	0.00

CALM OBS = 0 PERCENT CALM = 0.00

Figure 3-18 Sub-surface current cumulative frequency rose, North Kish Bank

(note: current direction is to direction shown)



PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
N	0.93	0.23	0.00	0.00	0.00	0.00
NNE	1.70	2.99	3.20	2.71	0.52	0.00
NE	1.78	7.35	12.16	9.90	1.24	0.00
ENE	2.19	1.55	0.05	0.00	0.00	0.00
E	0.88	0.00	0.00	0.00	0.00	0.00
ESE	0.77	0.00	0.00	0.00	0.00	0.00
SE	0.46	0.00	0.00	0.00	0.00	0.00
SSE	0.67	0.00	0.00	0.00	0.00	0.00

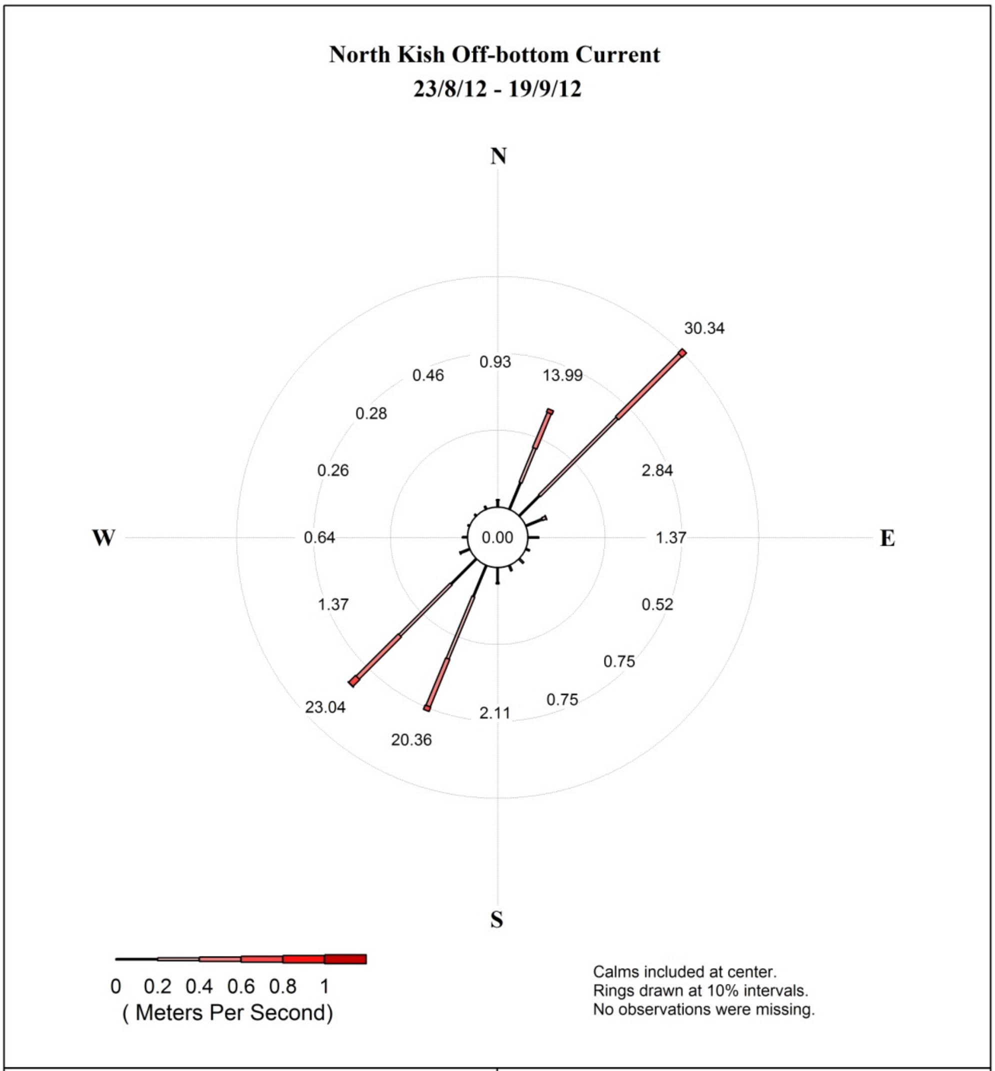
TOTAL OBS = 3880 MISSING OBS = 0

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
S	1.37	0.52	0.00	0.00	0.00	0.00
SSW	2.65	5.13	4.61	2.63	0.36	0.00
SW	2.19	6.42	9.87	8.09	1.49	0.00
WSW	1.19	0.31	0.03	0.00	0.00	0.00
W	0.67	0.13	0.00	0.00	0.00	0.00
WNW	0.39	0.00	0.00	0.00	0.00	0.00
NW	0.34	0.00	0.00	0.00	0.00	0.00
NNW	0.31	0.05	0.00	0.00	0.00	0.00

CALM OBS = 0 PERCENT CALM = 0.00

Figure 3-19 Mid-water current cumulative frequency rose, North Kish Bank



Calms included at center.
Rings drawn at 10% intervals.
No observations were missing.

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
N	0.88	0.05	0.00	0.00	0.00	0.00
NNE	3.76	4.82	4.92	0.49	0.00	0.00
NE	3.74	14.20	11.60	0.80	0.00	0.00
ENE	2.29	0.52	0.03	0.00	0.00	0.00
E	1.37	0.00	0.00	0.00	0.00	0.00
ESE	0.52	0.00	0.00	0.00	0.00	0.00
SE	0.75	0.00	0.00	0.00	0.00	0.00
SSE	0.75	0.00	0.00	0.00	0.00	0.00

TOTAL OBS = 3880 MISSING OBS = 0

PERCENT OCCURRENCE: (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	0	0.2	0.4	0.6	0.8	1
S	1.91	0.21	0.00	0.00	0.00	0.00
SSW	4.38	8.74	6.65	0.59	0.00	0.00
SW	4.61	9.41	7.71	1.29	0.03	0.00
WSW	1.34	0.03	0.00	0.00	0.00	0.00
W	0.64	0.00	0.00	0.00	0.00	0.00
WNW	0.26	0.00	0.00	0.00	0.00	0.00
NW	0.28	0.00	0.00	0.00	0.00	0.00
NNW	0.46	0.00	0.00	0.00	0.00	0.00

CALM OBS = 0 PERCENT CALM = 0.00

Figure 3-20 Off-bottom current cumulative frequency rose, North Kish Bank

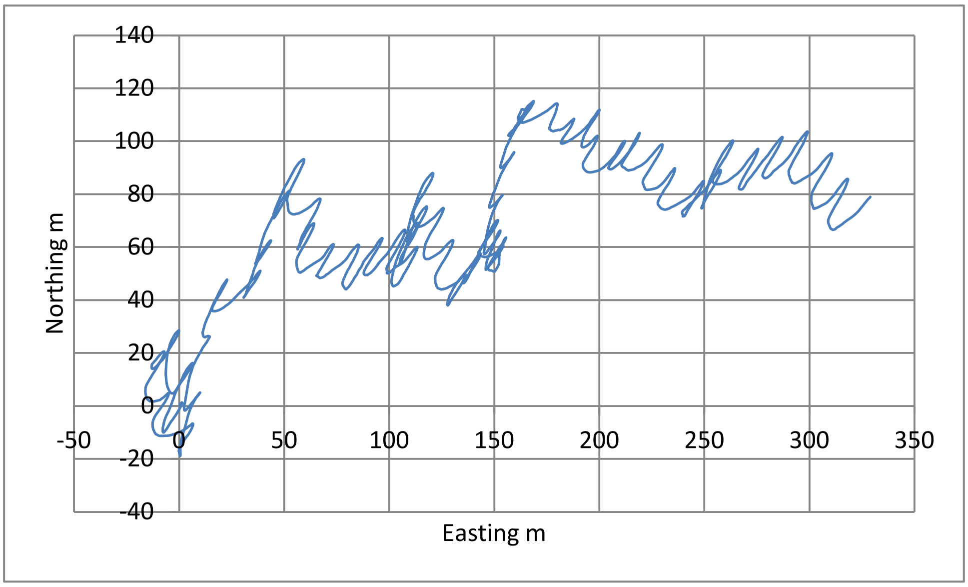


Figure 3-21 Sub-surface current cumulative vector plot, North Kish Bank

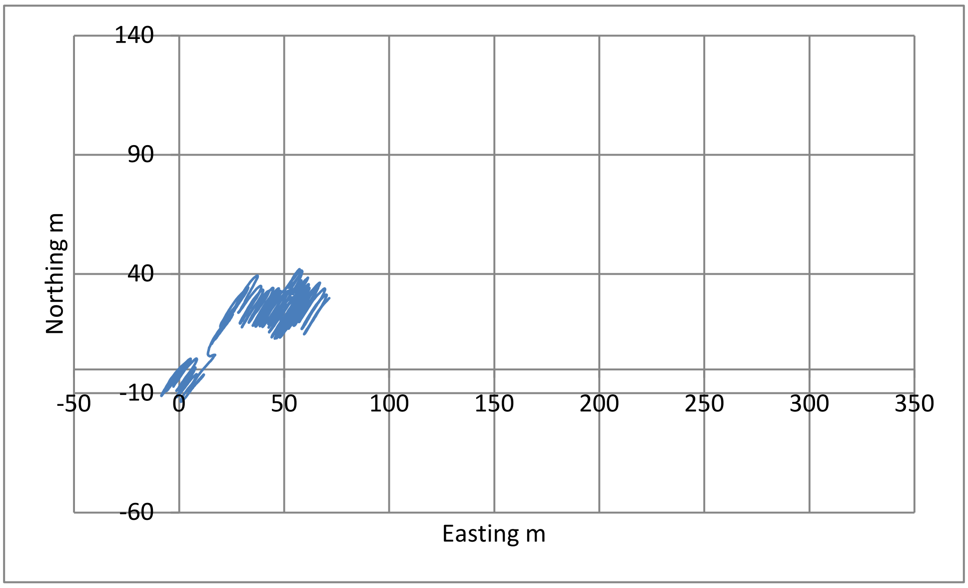


Figure 3-22 Mid-water current cumulative vector plot, North Kish Bank

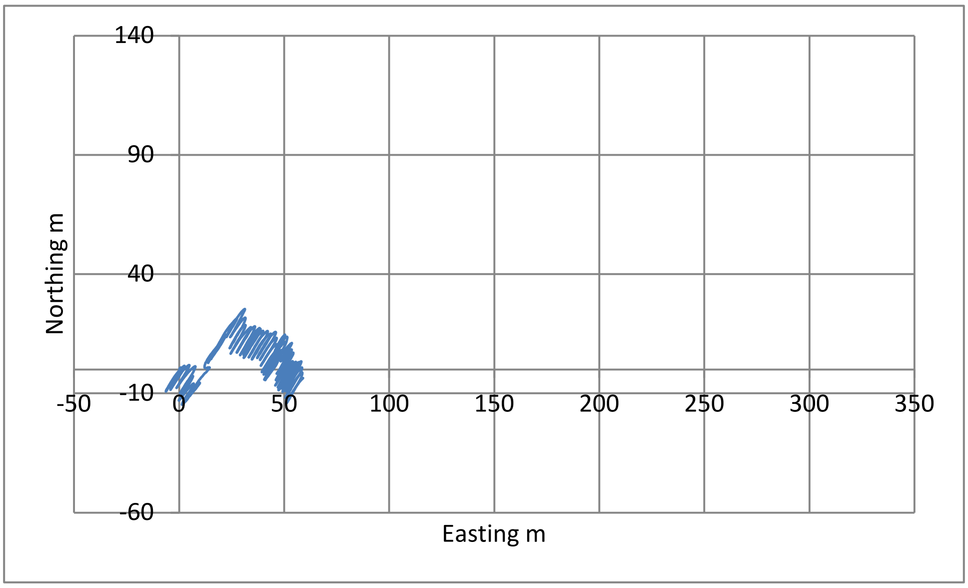


Figure 3-23 Mid-water current cumulative vector plot, North Kish Bank

3.4. Additional Current Measurements

Tide heights and current speeds recorded at the two additional sites at the Kish Bank (C1 & C2, Figure 2.1) over a single tide are included as Figures 3-24 and 3-25.

The profiler was deployed at 14:30 just after high water at C1 on the 19th September in 11 m water depth and left recording until 14:00 the following day. Tidal range was just over 3 m and the maximum sub-surface current was 1.4 ms^{-1} recorded during the flooding tide.

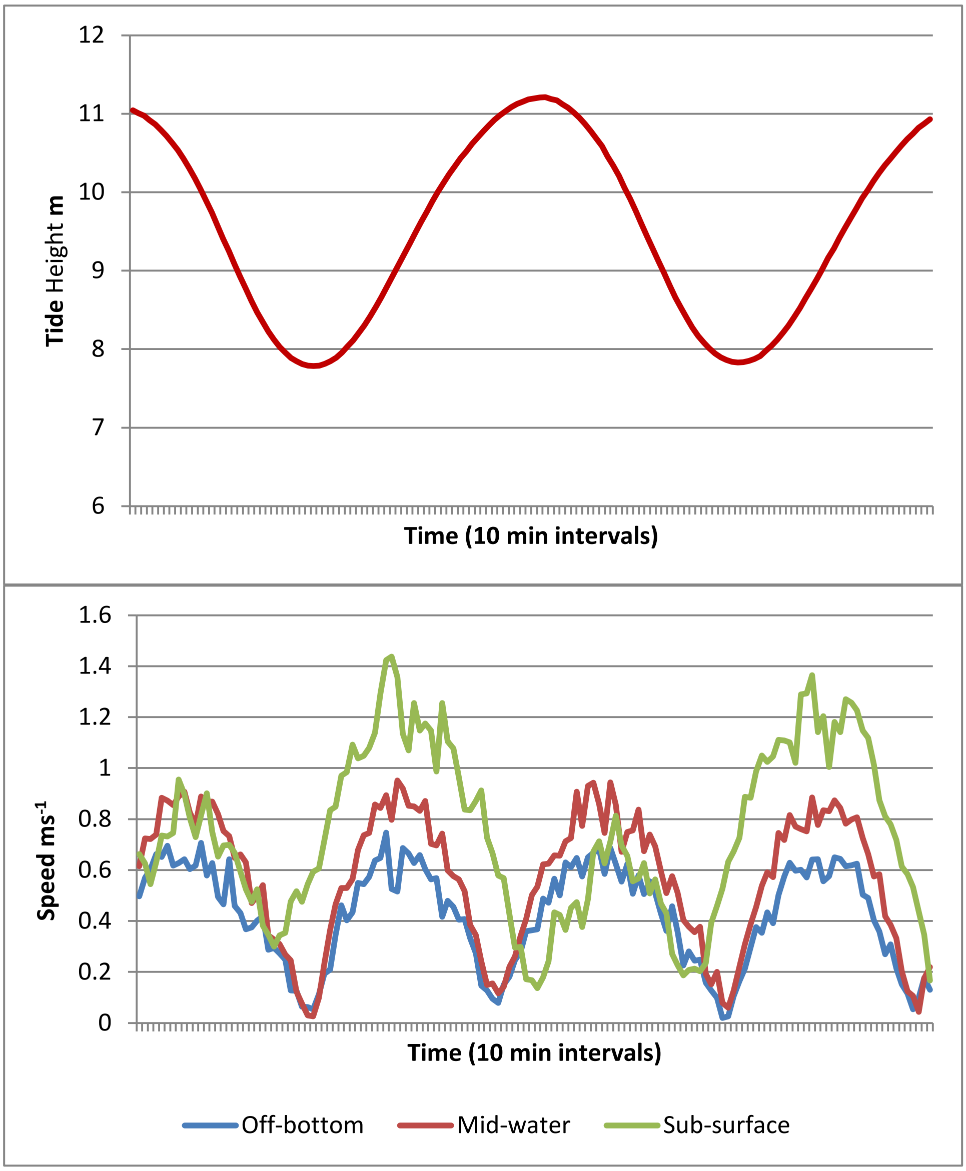


Figure 3-24 Tide and current records, C1, Kish Bank , 14:30 19/9/2012 to 14:00 20/9/2912

A second profiler was deployed at 15:00 just after high water at C2 on the 19th September in 19 m water depth and left recording until 11:50 the following day. Tidal range was just over 3 m and the maximum sub-surface current was 1.57 ms^{-1} recorded during the flooding tide.

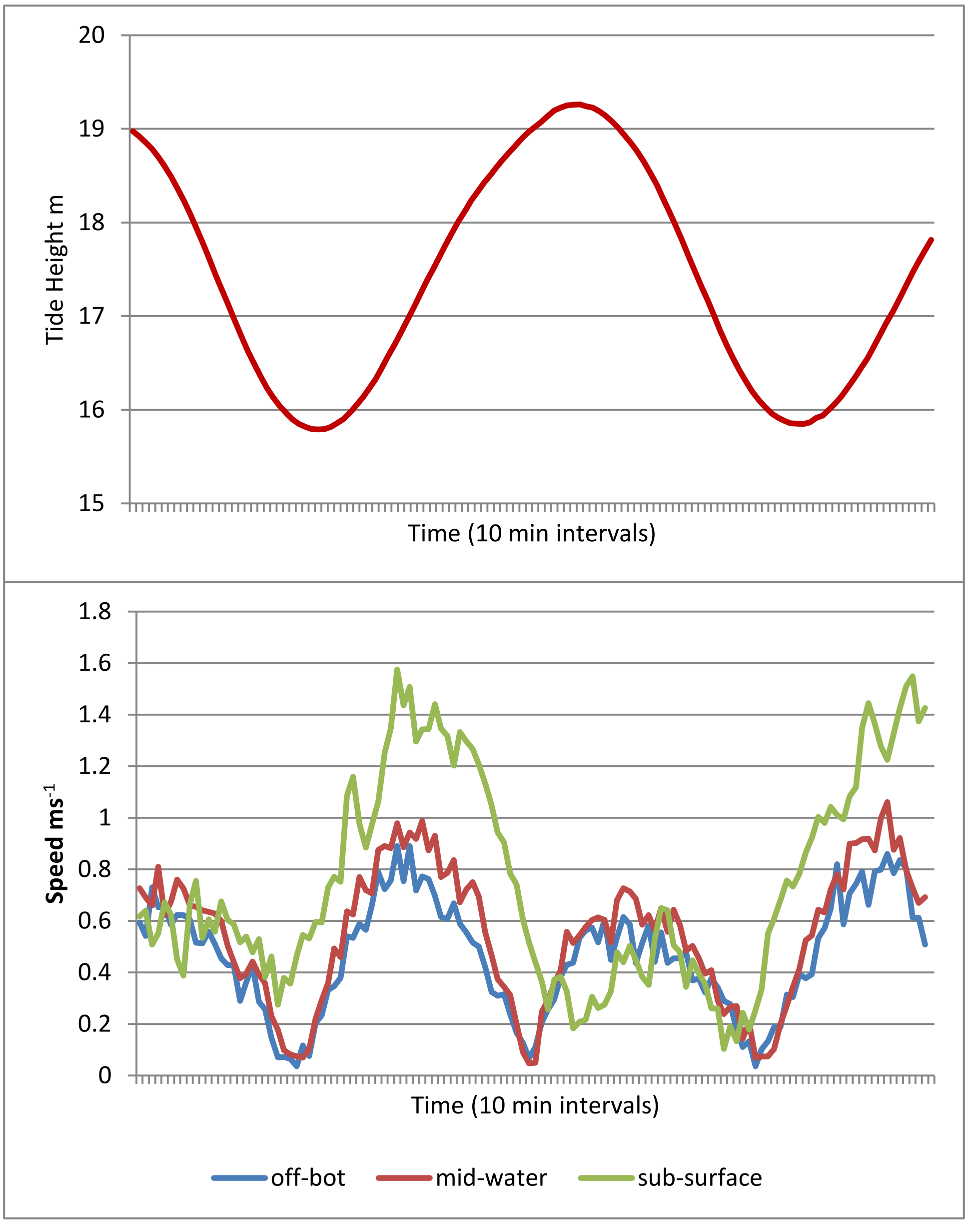


Figure 3-25 Tide and current records, C2, Kish Bank, 15:00 19/9/2012 to 11:50 20/9/2912