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EIAR Volume 4: Offshore Infrastructure Technical Appendices Appendix 4.3.1-2 Physical Process Modelling For Dublin Array Offshore Wind Farm

Kish Offshore Wind Ltd

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Dublin Array Offshore Wind Farm

Physical Process Modelling For Dublin Array Offshore Wind Farm

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SUMMARY

Background and Approach

Intertek Energy and Water Consultancy Services (Intertek) has been commissioned by Kish Offshore Wind Limited and Bray Offshore Wind Limited (hereafter referred to as the 'Applicant') to conduct physical process modelling to inform the Environmental Impact Assessment (EIA) for the Dublin Array Offshore Wind Farm (OWF) development. The shareholders in both companies are RWE (RWE Renewables Ireland Limited) and Saorgus Energy Limited.

To quantify the potential impacts of the OWF on the physical marine environment Intertek has built a suite of calibrated numerical models, which collectively form The Dublin Array Physical Process Modelling System (DAPPMS). This includes a Hydrodynamic (HD) model and a Spectral Wave (SW) model, which have been used to quantify changes to the physical environment from the proposed OWF development during its operational life span. In addition, proposed activities during the construction phase of the OWF development have been modelled by conducting dispersion modelling of both disturbed seabed sediments and direct disposals of sediments onto the seabed.

The Realistic Worst Case Scenario (RWCS), as developed from the Project Description, was modelled and outputs assessed. The RWCS was established by screening various construction and design options in the Project Description to conservatively and comparatively determine the largest source effects and therefore possible greatest effect on marine receptors.

Blockage Effects

To assess the impact of 'blockage effects'[1] on local hydrodynamics and wave climate from the proposed development, an indicative layout and foundation type, identified in the RWCS (see Appendix E), was modelled. The impact of the scheme was then assessed by looking at the difference between the baseline scenario and a scheme scenario which included a representation of the project design.

The impact of blockage on local hydrodynamics (water levels and current speeds) by the proposed wind farm array is predicted to be minor. The effects of the scheme are limited to within the array field, or in limited cases a few kilometres outside the array boundary. Changes to water levels are limited to localised differences of ± 2 mm, and only occur at certain stages of the tide. Changes to current speeds are limited to ± 0.04 m/s and are more pronounced at certain stages of the tide.

The impact of blockage effects on the local wave climate was assessed using the DAPPMS SW model. Model scenarios were assessed for waves approaching from northerly, easterly, southerly and westerly directions (the last of these representing offshore wind-generated waves). For each direction, four wave heights were modelled to cover the range of present day conditions from average waves up to 1-in-100 year return period waves. The modelling predicted that the blockage effects reduced the significant wave height[2] across the development site. However, height differences were small across all modelled scenarios, and localised within the development site. The maximum predicted difference in significant wave height (0.04 m occurring on a southerly 1-in-100 year event) represents a relative difference of less than 2% of the wave height.

[1] The modification of the surrounding tidal currents and wave climate from introducing OWF structures.
[2] Average wave height of the highest 1/3 of waves in a timeseries.

Effects of Future Sea Level Rise

For both the tidal hydrodynamics and wave climate an assessment was conducted to account for 0.60 m of sea level rise, as predicted for the year 2100 (EPA, 2017). It was identified that there was no meaningful change to the effect of the scheme under the future sea level rise scenario.

Impacts on Sediment Regime

To assess the impacts of the various activities during the construction phase that will disturb or release fine fraction sediments into the water column, a collection of seabed disturbance scenarios, identified in the RWCS, were modelled using the DAPPMS Particle Tracking model. Proposed activities represented in the modelling include: the clearance of material to level the seabed in preparation of the construction of foundations or seabed cables; the drilling of foundation piles; and trenching activities for the burial of seabed cables. Sediments disturbed or released during these activities are predicted to have only a transient impact on suspended sediment concentrations as material is dispersed quickly and fall below mean background levels within hours of the completion of construction works. Dominant flood tide currents generally transport material northwards from the development array. Deposited thickness of sediments is also assessed, with localised footprints identified for spoil mounds from dredge disposal. The predicted settling thickness for fine fraction material dispersed across the domain is low. Calculations on the total area susceptible to scour are presented, alongside calculations on the total area of seabed covered by scour protection.

The impact of the scheme on the local sediment regime during the operational phase was assessed through analysis of changes to bed shear stress around the array site for both baseline (pre-scheme) and with-scheme scenarios. This analysis predicted very limited changes to the sediment regime when compared to the critical thresholds for entrainment for local bed sediments.

Decommissioning

As a general precept, impacts during the decommissioning phase are assumed to be no higher than those identified during the construction phase, but in reverse.

Conclusions

In summary, the anticipated blockage effects and construction effects of the OWF development are shown to be minor across hydrodynamic, wave and sediment processes with the anticipated impacts being localised to the development array site.

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GLOSSARY

ADCP
Acoustic Doppler Current Profiler

BODC
British Oceanographic Data Centre

CD
Chart Datum

DAPPMS
Dublin Array Physical Process Modelling System

DHI
Danish Hydraulic Institute

ECMWF
European Centre for Medium-Range Weather Forecasts

EIA
Environmental Impact Assessment

EMODnet
European Marine Observation and Data Network

EPA
Environmental Protection Agency

ERA
European Re-Analysis – Interim Winds

FM
Flexible Mesh

FWR
Foundation for Water Research

GW
Gigawatt

HD
Hydrodynamic

H_{m0}
Significant Wave Height

IBI_Reanalysis_Wav_005_006
Iberian Biscay Irish- Wave Multi-Year Model

INFOMAR
Integrated Mapping for the Sustainable Development of Ireland's Marine Resource

innogy
innogy Renewables Ireland

Intertek
Intertek Energy and Water Consultancy Services

MSL
Mean Sea Level

OSI
Ordnance Survey Ireland

OWF
Offshore Wind Farm

OSP
Offshore Substation Platform

PT
Particle Tracking

RWCS
Realistic Worst Case Scenario

SLR
Sea Level Rise

SSC
Suspended Sediment Concentration

STFATE
Short Term Fate

SW
Spectral Wave

Tp
Peak Wave Period

UKHO
United Kingdom Hydrographic Office

USACE
United States Army Corps of Engineers

UTM
Universal Transverse Mercator co-ordinate system

WGS84
World Geodetic System 1984

1. INTRODUCTION

1.1 Project Overview

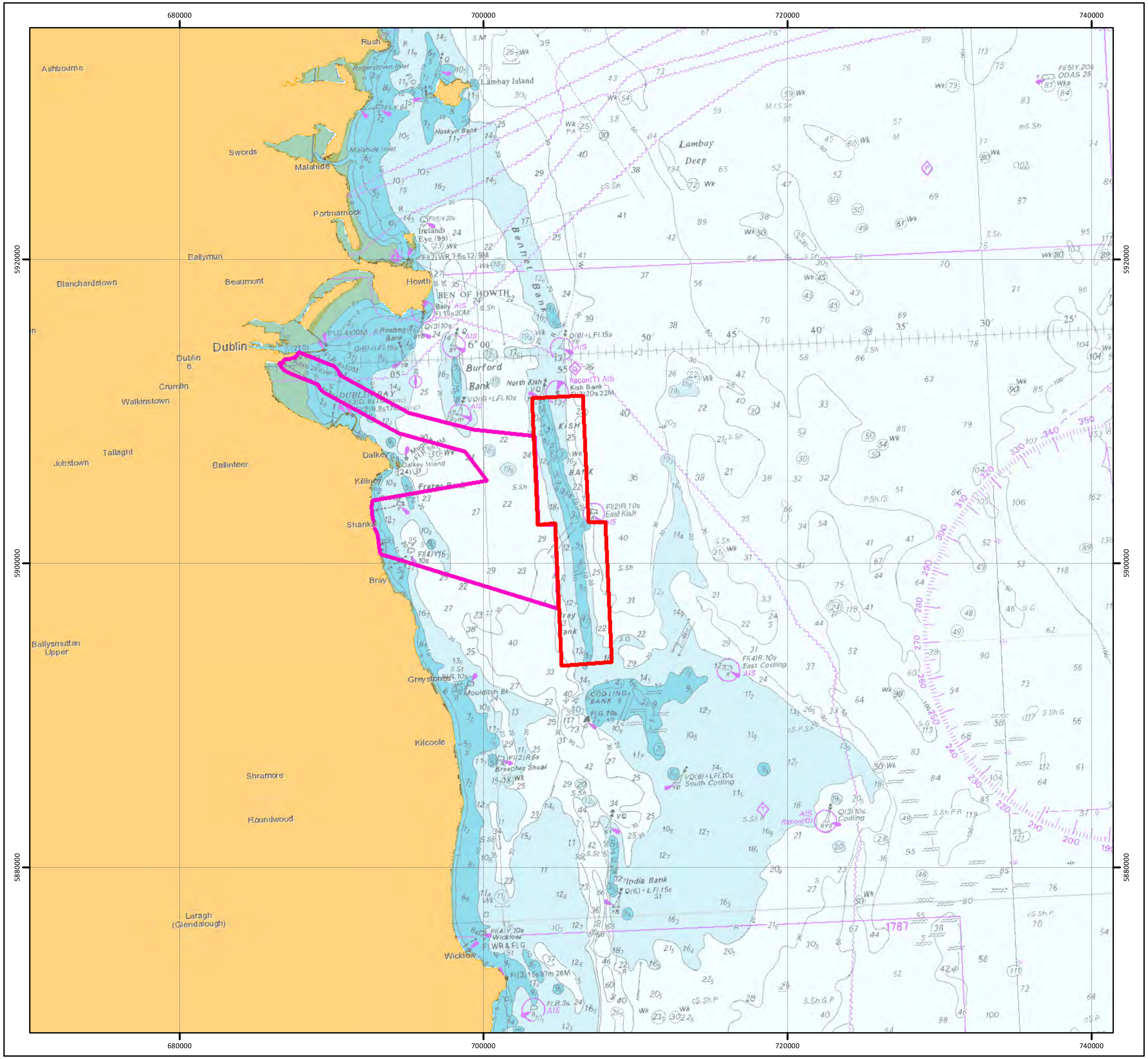
Intertek Energy and Water Consultancy Services (Intertek) has been commissioned by Kish Offshore Wind Limited and Bray Offshore Wind Limited (hereafter referred to as the 'Applicant') to conduct physical process modelling to inform the Environmental Impact Assessment (EIA) for the Dublin Array Offshore Wind Farm (OWF) development. The shareholders in both companies are RWE (RWE Renewables Ireland Limited) and Saorgus Energy Limited.

The physical process modelling includes an assessment of the potential impacts of the Dublin Array Offshore Wind Farm on the local tidal hydrodynamics and wave climate. In addition, modelling has been conducted to assesses likely sediment dispersion and deposition resulting from construction activities associated with the OWF construction. The suite of numerical models developed for the study are collectively termed the Dublin Array Physical Process Modelling System (DAPPMS), and this includes a Hydrodynamic (HD) model, a Spectral Wave (SW) model and a Particle Tracking (PT) model.

1.2 Study Site

The Dublin Array Offshore Wind Farm project is located on the Kish and Bray banks, approximately 10 km off the east coast of Ireland, southeast of Dublin. Dublin Array has a proposed electrical generating capacity of up to 1 GW. The offshore wind farm will be located within an area of 54 km^2, in water depths ranging from 2 to 30 m (Chart Datum). The variation in water depth causes a spatially varied range of metocean conditions over the site.

An overview of the study site is shown in Figure 1-1 (Drawing No. P2344-LOC-004).



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DUBLIN ARRAY OFFSHORE WIND FARM PHYSICAL PROCESSES ASSESSMENT

LOCATION OVERVIEW

Geographical Overview

Figure 1-1: P2344-LOC-004 | A

Legend

- Dublin Array OWF Site Boundary
- Cable Corridor Area

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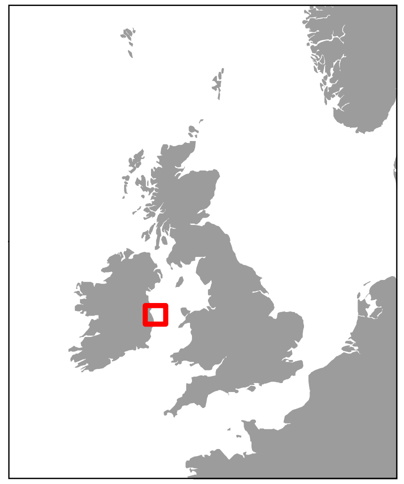
W E
S



NOTE: Not to be used for Navigation

Date	04 September 2020
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Projection	Transverse Mercator
Datum	WGS 1984
Data Source	OSI; MarineFind; ESRI; Innogy
File Reference	J:\P2344\Mxd\01_LOC\ P2344-LOC-004.mxd
Created By	Chris Goode
Reviewed By	Emma Langley
Approved By	Josh Gibson

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0 3.5 7 10.5 14

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1.2.1 Overview of Hydrodynamics

The hydrodynamics of the area are tidally-dominated, and the tidal regime is semi-diurnal with a mean spring and neap tidal range of 3.4 m and 1.9 m respectively at Dublin Port (UKHO, 2020). Across the Dublin Array development site, general tidal currents have peak speeds of 1.9 m/s during mean spring tides and 1.1 m/s during mean neap tides. The flood tide is slightly stronger than the ebb. The tidal streams run generally parallel to the Irish coast, ebbing southwards (Admiralty, 1974). Section 2.1 provides more detail on the hydrodynamic regime.

1.2.2 Overview of Wave Climate

The wave climate at the Dublin Array OWF site is dominated by waves approaching from a south to south easterly direction, both in terms of magnitude and frequency. Southerly waves in particular may approach the site from the Atlantic and are therefore relatively large and exhibit a stronger swell influence. Waves also approach the site from the north, north-east and easterly directions; however, these waves have shorter fetch lengths and therefore tend to exhibit lower heights and shorter periods than Atlantic waves; they also occur less frequently than waves from south and south easterly directions. Section 2.2 provides more detail on the wave climate.

1.2.3 Overview of Sediment Regime

A full collation and review of seabed sediment datasets covering the study area was conducted by Cooper Marine Advisors Ltd working as a sub-consultant to Intertek. The review combined the generalised mapping with sediment grab samples collected across the study site over a period between 1980 and 2020. The review identifies Kish Bank as a mainly sandy environment with a small amount of gravel in places, while the Bray Bank is noted to be similar, albeit with a slightly coarser sediment structure.

The export cable route is noted to comprise areas of courser and mixed sediments with high amounts of silts and muds around Dalkey Island, while Dublin bay is characterised by muddy sand and sandy mud. The very nearshore is characterised as rocky.

For further details see Appendix F.

1.3 Methodology

To assess the impact of the OWF on the physical processes in the study area project scale HD, SW and PT models of the DAPPMS have been constructed according to industry best practice. The data sources used for the study along with details of the DAPPMS calibration are reported in the Hydrodynamic Calibration and Validation Report (Intertek, 2020a) and the Spectral Wave Model Calibration and Validation Report (Intertek, 2020b).

The models, together with a data and literature review, have been used to characterise the environment and quantify the changes for the following:

- baseline conditions (i.e. pre-development);
- construction impacts from the wind farm;
- post-construction (in operation) impacts from the wind farm;
- scour potential around individual structures;
- short-term impacts on suspended sediment concentrations (SSC) during the construction phase;
- decommissioning impacts from the wind farm, which are assumed to be no worse than construction; and

- the possible implications of future climate change to the impacts predicted by the physical process assessment, specifically Sea Level Rise (SLR).

Using the calibrated HD and SW models a realistic characterisation of the typical tidal and wave climate conditions was developed at the site prior to construction. This forms the characterisation of the receiving environment for the purposes of the EIA.

To define the Realistic Worst Case Scenario (RWCS) information relating to the design of the OWF has been taken from latest Project Description (innogy, 2020). A separate note detailing the parameterisation of the RWCS has been produced that details the derivation of the design condition that presents that worst case and details the model scenarios necessary for assessing construction and operational impacts. This note has been produced by Cooper Marine Advisors Ltd working as a sub-consultant to Intertek and is included as an Appendix to this report (Appendix E).

To assess the construction impacts from the OWF the PT model was used, this was driven by the underlying hydrodynamics derived from the calibrated HD model (Intertek, 2020a). Construction impacts examine the short term effects to the local sediment regime of the disturbance and disposal of seabed sediments through a variety of construction processes. As processes such as dredging or cable trenching occur over timescales of days and weeks, the approach set out in the RWCS sets out unit scenarios, that can be multiplied up as required, to examine the full impact experienced over the construction phase. The assessment adopts an approach whereby once sediment settles to the bed, being similar in nature to the existing bed material, it effectively merges with existing bed material and becomes indistinguishable from it. In practise, sediment in a plume that has been deposited to a similar area of seabed will re-join the natural sedimentary environment and will be naturally eroded at the same time and rate as existing sediment at that location. For this reason, resuspension of settled material is not included in the construction impact assessment model.

During the operational phase, the main influence on marine and physical processes is from structures installed on the seabed that have the potential to interfere with passing waves and flows (and with consequential effects on sediment transport, including local scour); these effects are generally termed as ‘blockage’. To quantify the blockage effects of the OWF, both absolute and relative differences were determined by comparing the modelled baseline condition to model scenarios with the proposed development having been constructed.

To account for anticipated SLR over the life span of the development the HD and SW models were configured to model a future baseline environment. This is based on the latest advice / projections from the Environmental Protection Agency (EPA, 2017), which currently suggests a SLR of 0.55 to 0.60 m by 2100 (which encompasses the likely lifespan of the development). For the purpose of the physical process study the more conservative value of 0.60 m was adopted.

It is reported (Tiron *et al*, 2015) that there will be negligible moderation to the wave climate in this region due to future climate change; therefore, changes to the wave climate have not been explicitly modelled when assessing likely future scenarios associated with climate change.

2. PARAMETISATION OF THE SEDIMENTARY REGIME AND CALCULATION OF SEDIMENTARY PROCESSES

As noted in section 1.2.3, a full review of the local sediment regime was conducted for this study and formed the bases for the parameterisation of all sediment disturbance activities detailed in the RWCS report. To aid analysis of potential impacts and methodologies used to assess sediment disturbance activities, sediment data was graded into type based on grain size.

The fate of any sediment material placed in the water column is dictated by its settling velocity (a function of grain size). Coarse grained sediments (e.g. gravels and coarse sands) will typically fall out of suspension relatively quickly without opportunity to be advected away from the source of disturbance. Conversely, fine grained sediments (e.g. fine sands to silts / mud) will typically take a long time to fall out of suspension and will therefore have opportunity to be subjected to tidal advection and dispersion.

Accordingly, sediment sizes of very fine gravel to medium sands can be considered to fall out of suspension quickly and will not form part of any lasting sediment plume. The influence of these sediments to the marine environment are assessed through spoil mound analysis (see section 2.3), and their impact considered in relation to areas of deposition and associated sedimentation depths.

Sediment sizes of fine sand, very fine sand and silts all have settling velocities which allow for the influence of tidal flows to advect and disperse the material over a wider area. Accordingly, these sediment sizes are all relevant to the formation of sediment plumes and are represented in the particle tracking modelling detailed in section 4.3.1.

Table 2-1 provides a summary of representative sediment types expected to be present across the study area, the associated grain size, settling velocity and the methodology used to assess its impact on the marine environment (as defined in the RWCS, Appendix E).

Table 2-1 Representative sediment types, settling velocities and assessment methodology

Sediment type / aggregate name	Size range (mm)	Representative size (mm)	Settling velocity (m/s)	Seabed disturbance methodology
Very fine gravel	2.000 to 4.000	3.000	0.216	Spoil Mound Analysis
Very coarse sand	1.000 to 2.000	1.500	0.147	
Coarse sand	0.500 to 1.000	0.750	0.093	
Medium sand	0.250 to 0.500	0.375	0.049	
Fine sand	0.125 to 0.250	0.188	0.018	Particle Tracking modelling
Very fine sand	0.063 to 0.125	0.094	0.005	
Silt / Mud	0.004 to 0.063	0.033	0.001	

2.2 Scour

Scour around seabed structures occurs due to flow being blocked by the presence of the structure, causing a compensatory acceleration of flow around the structure. This can cause localised increases in bed shear stress, and potential further erosion. Scour develops, forming deeper and wider scour holes until an equilibrium condition is reached (equilibrium scour depth), where the hole is large enough to dissipate the faster flows and near-bed vortices.

The scale of local scouring is mainly related to the scale and shape of the structure (e.g. angle of repose) as well as sediment properties. The rate of scour development is fast if the sediment dynamics of the local seabed is highly mobile, and can be accelerated if wave induced sediment transport can occur (in shallow water). Conversely, the rate of scour development can be slowed if the local seabed has a thin (or absent) mobile layer of surface sediments and sub-soils are stiff or more resistant to erosion.

Assumptions on the width of scour development are that it is proportional to four times the diameter of the structure being examined.

Scour can be mitigated by placing protection around the structure to armour the seabed against the heightened erosional forces. This typically takes the form of a layer of rock armour. In addition to this, a filter layer can be installed prior to piling which would mitigate for scour holes developing between the period of installation and placement of rock armour scour protection. The impact of an unprotected foundation, leading to the creation of a scour hole, is the loss of sediment down drift of the structure, that this then lost to the wider sediment transport environment. This erosion process is likely to be short term, and small scale. In engineering terms, the absence of scour protection would be considered the realistic worst-case and typically require longer piles to compensate for increased over-turning moments.

2.3 Spoil Mound Analysis

Spoil mound analysis forms the assessment of the fate of coarse-grained sediment displaced during the seabed disturbance activities. The studies definition of coarse-grained sediment is anything greater in size than medium sand, as defined in Table 2-1 and the RWCS (Appendix E). The analysis of fate of coarse-grained sediment was undertaken by Cooper Marine Advisors Ltd working as a sub-consultant to Intertek. This section details an overview of the methodology undertaken, while the results of the analysis are presented in the relevant sections alongside the particle tracking modelling in section 4.3.1. The report, completed by Cooper Marine Advisors Ltd, that underpins these results is presented in full in Appendix G.

The formation of spoil mounds occurs when disposal from dredging activity falls to the seabed as a negatively buoyant density flow as part of the active phase of disposal; forming semi-permanent features on the seabed as coarser sediment may have limited capacity to be moved on by ambient flows. In some situations, multiple phases of spoil disposal across a defined area may overlap and gradually redefine the profile of the seabed over such an area unless onward sediment transport can move the material away.

The tool used to assess the formation of spoil mounds is the STFATE (Short-Term FATE) model, developed for split barge and hopper dredge disposal. The model is developed by the United States Army Corps of Engineers (USACE) and is applicable for dredged material disposal in open water.

The primary inputs to the model are the water depth and flow conditions at the location of the spoil sites along with the volume and type of sediment being disposed of. STFATE also allows for the spoil to be described with up to four different particle sizes with associated values for specific gravity, fall velocity and deposition voids ratio. Outputs from the STFATE model comprise dimensions of a spoil mound that is broadly conical in shape (often with an elongated footprint in the direction of tidal flow).

For the two indicative spoil sites selected within the Dublin Array lease area, details on water levels, current speeds and direction were extracted from the DAPPMS HD model. This was used to inform inputs to the STFATE model and undertake a preliminary assessment of sediment mobility at the spoil site locations. The STFATE model was run for two tidal states, slack water and peak flood flow on a spring tide to capture a maximum depth of deposition and a realistic worst-case for total area covered respectively.

Outputs from the model are the maximum depth of deposition and area covered by deposition for two key thresholds. These are defined as area covered by a threshold of 0.05 m and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels respectively.

Full details of the methodology, hydrodynamic and sediment conditions at the north and south indicative spoil sites and inputs derived to run the STFATE model are presented in Appendix G

3. BASELINE ASSESSMENT USING THE DUBLIN ARRAY PHYSICAL PROCESS MODELLING SYSTEM

The DAPPMS, having undergone a full calibration and validation process (Intertek, 2020a; 2020b), was used to determine the baseline metocean conditions (water levels, current velocities, bed shear stress and wave climate) against which any predicted changes due to the presence of the OWF development were compared.

3.1 Hydrodynamic Regime

The HD module of the DAPPMS was used to predict the typical tidal conditions across the Dublin Array site and the surrounding region.

The mean tidal conditions identified during the calibration phase of the study have been brought forward to this assessment stage, so that the present-day baseline, and future scheme configurations are assessed using mean spring and mean neap tides. These are taken to be representative of typical conditions for water level and current velocity.

The typical conditions across the region for water level, current speed and bed shear stress were extracted from the HD model and are presented in Appendix A. Where specific states of tide specified there are referenced to the centre of the OWF array. These plots provide an understanding of the general hydrodynamic regime, which is described below.

Figure A-1 to Figure A-8 show the baseline tidal conditions across the study site. These show that tidal range does not vary much over the Dublin Array site and its surrounding locations, with little spatial variation in water level at each state of the tide. Modelled tidal levels for a location in the middle of the development array (705,829 E, 5,902,538 N UTM29 N) range from 1.6 m mean sea level (MSL) to -1.7 MSL during mean spring (Figure A-1 & Figure A-2), and from 0.9 m MSL to -1.0 m MSL on mean neap tides (Figure A-5 & Figure A-6). This gives mean spring and mean neap tidal ranges of 3.3 m and 1.9 m respectively at the array site. Across the development zone there is a slight gradient in water levels of 0.23 m along its north to south axis at high water on a mean spring tide, with the northern and southern ends of the site showing levels of approximately 1.61 m and 1.38 m MSL respectively. This high water gradient reduces for mean neap tides to 0.17 m (1.01 m and 0.84 m MSL at the northern and southern ends respectively).

The baseline condition for current speeds are shown in Figure A-9 to Figure A-16. The highest flows on Bray Bank, at the southern end of the array, occur during the peak flood and ebb phases of the mean spring tide (Figure A-11 & Figure A-12 respectively), with peak flood speeds of 1.4 m/s and peak ebb speeds of 1.2 m/s. During neap tides these reduce to speeds of 0.9 m/s during the peak flood (Figure A-15) and peak ebb stages (Figure A-16) of the tide. Speeds are generally higher in the southern part of the array.

Baseline bed shear stress conditions are presented in Figure A-17 to Figure A-24. These plots also show current speed vectors, with a reference vector of 1 m/s shown in the legend. Since bed shear stress varies as the square of current speed, the spatial and temporal distribution of highs and lows are analogous to the patterns observed in current speed (Figure A-9 to Figure A-16). As with current speeds, the highest instances of bed shear stress[3] on a mean spring tide occur during the peak flood and ebb phases (Figure A-19 & Figure A-20 respectively), recording highs of 6.0 N/m^2 and 4.8 N/m^2

[3] Units = Newtons per meter squared (N/m^2)

respectively. These reduce to 4.1 N/m² and 3.4 N/m² for flood (Figure A-23) and ebb (Figure A-24) respectively on a mean neap tide.

3.1.1 Tidal Excursion (Drogue Tracks)

The HD module of the DAPPMS was also used to predict distances for tidal excursion across the export cable route.

A series of six drogues were simulated in the HD model, with three on the northern edge of the export cable route and three along the southern edge. The model was run over a representative mean spring and neap tide for drogue releases at high and low water.

Results from these simulations are presented, for a spring tide, in Figure A-41 & Figure A-42 (for high water and low water respectively), and for a neap tide in Figure A-43 & Figure A-44 (for high water and low water respectively). These plots depict the track of each drogue over a two-day period from the time of release.

The plots demonstrate that, as expected, the tidal excursion is greater for spring tides, and that there is a general northward residual current, that is most pronounced offshore, in areas of highest flow speeds. The maximum length of excursion is approximately 16km, seen on the spring tide, low water release for the two offshore drogues (drogues C & F, green and red, respectively). This is approximately double the excursion distance seen for the near shore drogue, drogue D, (light blue) for the equivalent run. The maximum neap tide excursion is approximately 10km, observed in the two offshore drogues (drogues C & F, green and red, respectively).

3.2 Wave Climate

The SW model of the DAPPMS was used to simulate the typical wave climate across the Dublin Array site and the surrounding region. For further details of the DAPPMS SW model calibration refer to the Spectral Wave Model Calibration and Validation Report (Intertek, 2020b).

Due to the location of the Dublin Array OWF waves approach from a number of directions. The wave climate at the Dublin Array OWF site is dominated by waves approaching from a south to south easterly direction, both in terms of wave height and frequency. Southerly waves in particular may approach the site from the Atlantic and are therefore relatively large and exhibit a stronger swell influence. Waves also approach the site from the north, north-east and easterly directions; however, these waves have shorter fetch lengths and therefore tend to exhibit lower heights and shorter periods than Atlantic waves; they also occur less frequently than waves from south and south easterly directions.

To ensure that all possible directions of wave approach were considered, wave scenarios were established for waves approaching from the north, east, south and west. These directions were selected to represent a range of different fetch lengths and angles of incidence at the development site (for example, in relation to seabed bathymetry and shoaling effects); it is by chance that they reflect the four cardinal compass points. For the north, east and south directions, wave conditions were specified at the open boundaries of the SW model and allowed to propagate towards the development site and coast. Waves approaching from a westerly direction are purely wind generated, with wave growth limited to the fetch from the coastline to the array site.

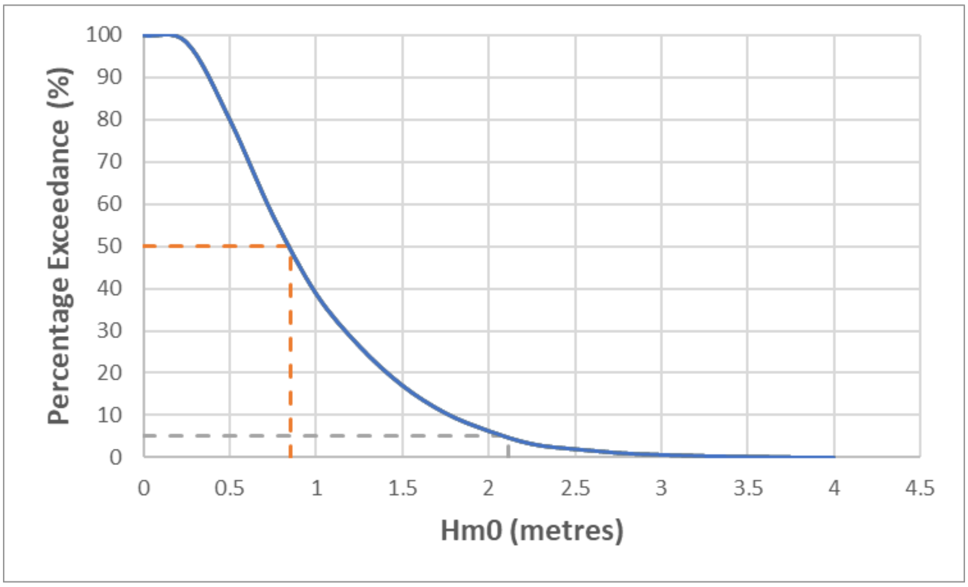
In order to simulate a full range of conditions covering typical to extreme wave heights, the following scenarios were selected for use in the SW modelling: 50%ile, 5%ile, 1-in-1 year and 1-in-100 year significant wave heights.

3.2.1 Parameterisation of Wave Scenarios

For the north, east and south directions, timeseries wave data were extracted from the Copernicus Iberian Biscay Irish (IBI) model (IBI_Reanalysis_Wav_005_006), which is the same hindcast model used to drive the model boundaries in the SW model calibration (Intertek, 2020b). For each direction of approach, the data were sectorised to 60 degree bins centred on the angle of wave approach. For example, waves from the east were represented by hindcast model waves taken from a 60 – 120 degree sector. Waves from the west are purely wind generated within the model owing to presence of the Irish coast land boundary, so therefore westerly wave model setups have no offshore boundary conditions.

A cumulative frequency analysis was conducted on the directional wave data based on the occurrence of significant wave heights[4] (H_{m0}) in bins of 0.25 m height. From this analysis, cumulative frequency tables were produced and the H_{m0} for the 50%ile[5] and 5%ile scenarios were derived, where the 50%ile and 5%ile describe the H_{mo} where 50% and 95% of wave events exceed the given value respectively. Figure 3-1 shows the cumulative frequency graph for waves approaching from a northerly direction, with the dashed lines showing the derivation of the 50%ile and 5%ile H_{m0}.

Figure 3-1 Cumulative frequency graph for northerly wave direction



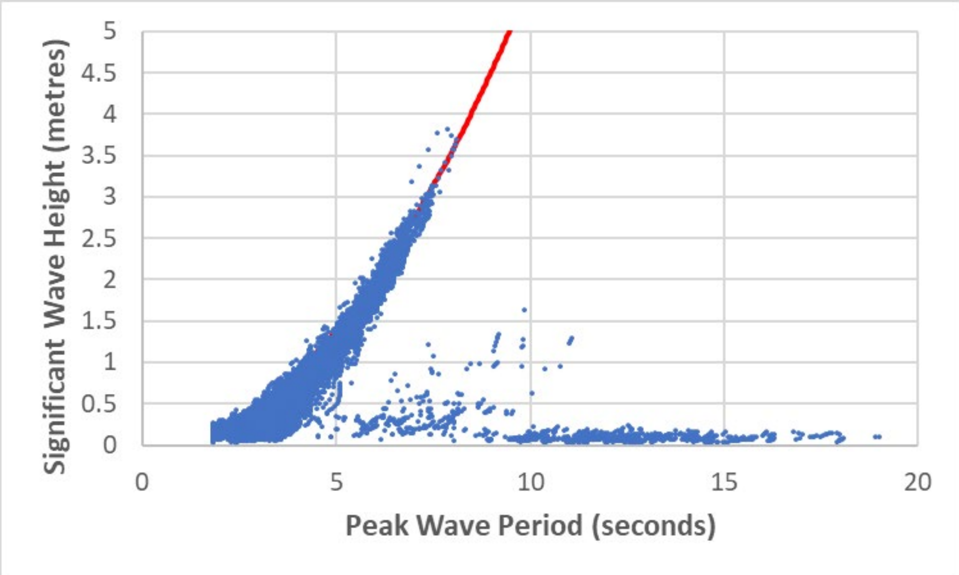
To derive H_{m0} for the 1-in-1 and 1-in-100 year scenarios[6] an extreme value analysis was conducted based on the cumulative frequency tables for the north, east and south directional wave data. See Appendix D for the plots relating to extreme value analysis.

To derive an appropriate peak wave period (Tp)[7] for each wave height scenario, H_{m0} was plotted against Tp for the directional wave data (north, east and south). A line of best fit was derived by applying a standard oceanographic equation that relates H_{m0} to Tp based on the observed wave steepness. This derived relationship was then used to calculate a suitable Tp for each of the H_{m0} wave scenarios (50%ile, 5%ile, 1-in-1 year and 1-in-100 year).

[4] Average wave height of the highest 1/3 of waves in a timeseries.
[5] Percentage of wave events that exceed the given percentile value within the given timeseries.
[6] 1-in-1 and 1-in-100 are equivalent to a chance of 100 % and 1% of a given H_{mo} occurring in a given year respectively.
[7] Peak Wave Period is the wave period associated with the most energetic waves in a wave spectrum.

An example of the derived best fit is presented in Figure 3-2 for northerly waves (that were input at the north boundary of the SW model).

Figure 3-2 Significant wave height (H_{m0}) versus peak wave period (Tp), north boundary



3.2.2 Wind Climate

Wind data are needed in the SW model in order to input energy to the propagating wave field. Without forcing winds, modelled wave heights would steadily decrease through energy losses resulting in an under-prediction of wave heights in the area of interest.

Wind data were sourced from the European Centre for Medium-Range Weather Forecasts (ECMWF) European Re-Analysis (ERA) Interim Winds data set. This wind field comprises 6-hourly data and has a spatial resolution of approximately 0.7° (approximately 78 km). These are the same winds that were applied to drive wave growth of the IBI_Reanalysis_Wav_005_006 wave model.

To derive suitable wind speeds to apply to the SW model scenarios, H_{m0} was plotted against wind speed for the directional wave data at each of the north, east and south model boundaries. A line of best fit was derived by applying a polynomial equation; this equation was then used to calculate a suitable wind speed for each of the H_{m0} scenarios.

Wind is applied within the SW model at the same angle of approach as the wave condition, ensuring maximum wave growth over the model domain.

For the westerly model scenarios, no wave inputs were required at the model boundary (since the boundary in this case is the Irish coast). The DAPPMS SW model was run with a uniform wind speed applied over the whole model domain. This is appropriate since only one node from the ERA Interim Winds is appropriate at the array site and wave growth to the east of the array is not a consideration of this study.

The same process was conducted to derive wind speed as per the wave heights. A cumulative frequency analysis was conducted on the directional wind data based on the occurrence of significant wave heights (H_{m0}) in bins of 0.25 m/s wind speed. A cumulative frequency table was produced and the wind speed for the 50%ile and 5%ile scenarios were derived.

To derive wind speed for the 1-in-1 and 1-in-100 year scenarios an extreme value analysis was conducted based on the cumulative frequency. See Appendix D for the plot relating to extreme value analysis.

3.2.3 Wave Modelling Scenarios

Based on the above parametrisation Table 3-1 details the scenarios run in the DAPPMS SW model. Each scenario was run within the DAPPMS SW model for both the baseline (pre-development) condition and for the RWCS. In addition, the 1-in-100 year scenarios for the north, east and south directions were run accounting for sea level rise for both the baseline scenario and the RWCS. This equates to a total of 38 runs.

Table 3-1 Spectral wave scenarios

Scenario	Wave Approach	Hm0 (m)	Tp (s)	Wave & Wind Direction (deg)	Wind Speed (m/s)
50%ile	Southerly	1.3	4.83	180	9.60
5%ile	Southerly	3.4	7.81	180	15.50
1yr	Southerly	6.33	10.65	180	21.10
100yr	Southerly	8.55	12.38	180	24.55
50%ile	Easterly	0.85	3.90	90	8.75
5%ile	Easterly	2.11	6.15	90	13.75
1yr	Easterly	3.53	7.96	90	17.80
100yr	Easterly	5.03	9.50	90	21.25
50%ile	Northerly	0.75	3.67	20*	7.40
5%ile	Northerly	1.89	5.82	20*	13.60
1yr	Northerly	3.21	7.59	20*	18.20
100yr	Northerly	4.48	8.96	20*	22.00
50%ile	Westerly	n/a	n/a	270	6.21
5%ile	Westerly	n/a	n/a	270	10.90
1yr	Westerly	n/a	n/a	270	15.76
100yr	Westerly	n/a	n/a	270	18.92

*20 degree angle of approach selected as this presents the largest uninterrupted fetch from a northerly direction and hence largest potential waves.

3.2.3.2 Baseline Wave Climate

Wave conditions across the region as predicted by the SW model are presented in Appendix A.2. These plots provide the baseline wave conditions against which the RWCS has been compared.

Figure A-25 to Figure A-40 show the predicted significant wave climate across the study site for each of the modelled baseline scenarios across the study site.

Waves from a northerly direction exhibit growth over the model run relative to the offshore boundary wave condition, reaching approximately 5 m H_{m0} just offshore the array site for the 1-in-100 year scenario. Waves diminish in height as they propagate over the array site due to interaction with the relatively shallow bed (in places approximately 5 m MSL).

Waves from an easterly direction exhibit growth over the model run relative to the offshore boundary wave condition, reaching approximately to 7 m H_{m0} just offshore the array site for the 1-in-100 year scenario. Waves diminish in height as they propagate over the array site due to interaction with the relatively shallow bed (in places approximately 5 m MSL).

Waves from a southerly direction diminish in height relative to the offshore boundary wave condition as they propagate through the model domain, with H_{m0} reducing from 8.55 m at the southern boundary to approximately 6 m just to the south of the array site for the 1-in-100 year scenario. Waves diminish in height as they propagate towards the array site due to interaction with the relatively shallower region to the south of the Dublin Array site (including Codling Bank).

Waves from a westerly direction are generated by wind forcing and grow progressively as they propagate from west to east. The maximum H_{m0} over the array field generated by the 1-in-100 year wind condition is approximately 2 m.

4. RESULTS OF IMPACT ASSESSMENT

This Section provides details of the assessment of the proposed development on physical processes. The discussion is divided into: changes to the hydrodynamic regime; changes to the wave climate; and changes to the sediment regime. A final section assesses changes to hydrodynamics and waves due to future climate change.

For the RWCS simulations the DAPPMS HD and SW models were configured to represent the OWF turbines and ancillary structures (such as the offshore substations and met masts), using the parameters defined in the RWCS.

The DAPPMS models have been used to define a present-day baseline scenario as presented in Section 2. These models were updated to create 'with development' configurations based on the RWCS, and the results were compared with the baseline to identify differences. The baseline results were subtracted from the 'as constructed' results, so that positive changes indicate an increase (say, in current speed) due to the development, and negative changes show a decrease.

In addition to the absolute difference plots, percentage difference plots have been produced. These indicate the relative difference, where the absolute difference is presented as a percentage of the total baseline value to provide context of the difference. Positive changes indicate an increase due to the development, and negative changes show a decrease. This approach seeks to offer further context to the magnitude of change and is to be considered in conjunction with the absolute differences.

All difference plots for hydrodynamics and waves are shown in Appendix B, while plots associated with the modelling assessment of sediments are shown in Appendix C.

4.1 Impacts on the Hydrodynamic Regime

4.1.1 Construction Phase

The construction phase will involve the presence of the engineering and construction equipment on site, such as jack-up rigs and cable-laying barges. Such equipment will be located at one location (i.e. a turbine foundation) at a time, and for relatively short durations. There is no source-receptor-pathway for the effects of these activities on the hydrodynamic regime, and thus these activities have not been modelled. Any effects on the hydrodynamic regime due to such equipment will be very small, localised and transient. It is considered that no cumulative impacts would result, even if several construction operations (i.e. cable burial and foundation preparation) were to occur simultaneously.

4.1.2 Operational Phase

The effects on the hydrodynamic regime due to the operational phase of the Dublin Array OWF have been modelled using the DAPPMS HD model. The results of the modelling are shown in Appendix B. These plots show the predicted change in water levels and current speeds, and indicate that effects on local hydrodynamics are small and are limited in range.

4.1.2.1 Changes to Water Levels

Predicted changes to water levels on both mean spring and mean neap tides are very small. Predicted changes for all states of the tide are less than 0.001 m (1 mm), with the exception of the peak flood and ebb stages of a mean spring tide, where changes of up to ± 0.002 m (2 mm) are predicted, which is immeasurable in reality. This occurs along the southern most edge of the development array, and at small isolated locations within the array. Changes are positive during the peak flood stage of the tide, and negative for peak ebb. The maximum extent of this small change beyond the development array is up to approximately 2 km from the southern edge of this site. The impacts on mean spring tides are shown for the peak ebb and flood stages of the tide in Figure B-4 & Figure B-3 respectively. Periods of high and low water do not record any differences greater than 0.001 m (1 mm), and are displayed in Figure B-1 & Figure B-2 respectively. No effects on the water level are predicted outside of the array field.

Predicted impacts are lower for mean neap tides (Figure B-5 to Figure B-8) than for mean spring, and water level changes >0.001 m (> 1 mm) are limited to the sites of individual turbine structures.

Very small differences in water level at the nearshore (as seen at Dublin harbour) are not considered to be effects related to the OWF development but are an artefact of the model numerical flooding and drying scheme. Therefore, these changes in current speed at the nearshore would not be anticipated to occur in reality following the construction of the proposed development.

Plots of relative difference (difference as a percentage of the total tidal range) are presented for all tidal states for the mean spring tide condition (Figure B-17 to Figure B-20), and the mean neap tide condition (Figure B-21 to Figure B-24).

4.1.2.2 Changes to Tidal Currents

The predicted changes to current speeds due to the presence of Dublin Array are very small. Changes of greater than ±0.01 m/s (0.019 knots) are shown to occur within the development array boundary, and its immediate surroundings. Changes to flow speeds are presented for mean spring tides in Figure B-9 to Figure B-12, and for mean neap tides in Figure B-13 to Figure B-16. Plots of relative flow speed difference (difference as a percentage of the baseline flow speed) are presented for all tidal states for the mean spring tide condition (Figure B-25 to Figure B-28) and the mean neap tide condition (Figure B-29 to Figure B-32).

As a general pattern, flow speed changes of greater than ±0.01 m/s (0.019 knots) are seen to occur in a north-south axis, aligning with the direction of the tidal stream. The maximum extent of flow speed change greater than ±0.01 m/s (0.019 knots) is seen to extend in a north-south axis of the array field during high water on a mean spring tide (Figure B-9). Here, the extent of change at - 0.01 m/s (0.019 knots) , or greater, is seen to extend approximately 6 km north of the northern array boundary. In the east-west axis, the greatest extent of flow speed change is approximately 2 km east of the array boundary during the peak flood stage of a mean spring tide (Figure B-11), with an increase in flow speeds at 0.001 m/s (0.0019 knots) or greater.

The maximum modelled changes to current speed magnitudes are limited to ±0.04 m/s (0.078 knots), with the greatest scales of change observed on mean spring tides. Mean neap tides generally follow the same pattern of change observed for mean spring tides, but with an overall reduction in magnitude.

During mean spring tides, the greatest changes to magnitude occur during the flooding and ebbing phase of the tide (Figure B-11 & Figure B-12 respectively). Changes can be seen to occur at the site of individual turbine structures, with a wider field of impacts seen around the boundary of the Dublin Array OWF development zone. The overall effect of the wind farm will reduce the momentum of the tidal wave. This impedes currents through the OWF site, with a resulting effect being the increase in current speeds around the array field to compensate. This is demonstrated in the figures for peak flood and ebb on a mean spring tide where, at the time of peak flood tide, with the tidal stream moving northward, there is a general reduction in current speeds of 0.03 m/s (0.058 knots) within the array field, while there is a compensatory increase in current speeds to the east of the development of up to 0.04 m/s (0.078 knots). This difference is equivalent to ± 4% of the total current speed at this stage of the tide (Figure B-27). The situation is mirrored on the ebb tide with a compensatory increase in current speeds to the west of the array field, with a marginally smaller magnitude at peak ebb of 0.03 m/s (0.058 knots) (Figure B-12). These differences in current speed are again equivalent to 4% of the total current speed at this stage of the tide (Figure B-28).

Changes during mean spring high water are generally associated with a decrease in current speeds of up to 0.03 m/s (0.058 knots) near the boundaries of the OWF development zone, but small areas of increase are observed within the array field (Figure B-9). This pattern is possibly associated with the preceding lee effects of the array field on the northward moving flood tide. The associated picture of percentage difference in current speeds (Figure B-25) displays broadly larger percentage values, but this is due to the low magnitude of current speeds during this time. At low water there are areas of increase and decrease in current speed (up to ±0.03 m/s (0.058 knots)), with the effects largely confined to within the development zone boundary (Figure B-10).

The overall changes to current speed magnitude are less on mean neap tides when compared to the mean spring period, with changes during peak flood and ebb limited to ±0.03 m/s (0.058 knots). The same pattern of flow reduction within the array field, and compensatory flow acceleration outside the field, are observed during peak flood and ebb (Figure B-15 & Figure B-16 respectively). The position of the areas of higher flows is consistent between spring and neap tides, with higher flows existing on the eastern side of the array during the flood tide, and the western side during the ebb.

At high and low water the absolute changes are again small (Figure B-13 & Figure B-14 respectively), ranging between 0.04 m/s (0.078 knots) to -0.03 m/s (0.058 knots). The associated percentage change to current speeds are higher, but again are more representative of the slack water state of the tidal stream (Figure B-29 for high water, and Figure B-30 for low water). Percentage differences in current speed at the nearshore (as seen within Dun Laoghaire harbour) are not considered to be effects related to the OWF development but are an artefact of the model numerical flooding and drying scheme. Therefore, these changes in current speed at the nearshore would not be anticipated to occur in reality following the construction of the proposed development.

4.1.3 Decommissioning Phase

It is not known what decommissioning processes will be employed after the end of the lifetime of the development. It is possible that all buried equipment (cables and foundations) would be left in situ, which would result in no further disturbances after construction. However, it is also possible that all equipment associated with the development would be removed, including the buried cables. In this case, the likely impacts on the hydrodynamic regime will be small, localised and temporary, and of a similar magnitude to those effects that might occur during the construction of the development.

4.2 Impacts on the Wave Climate

4.2.1 Construction Phase

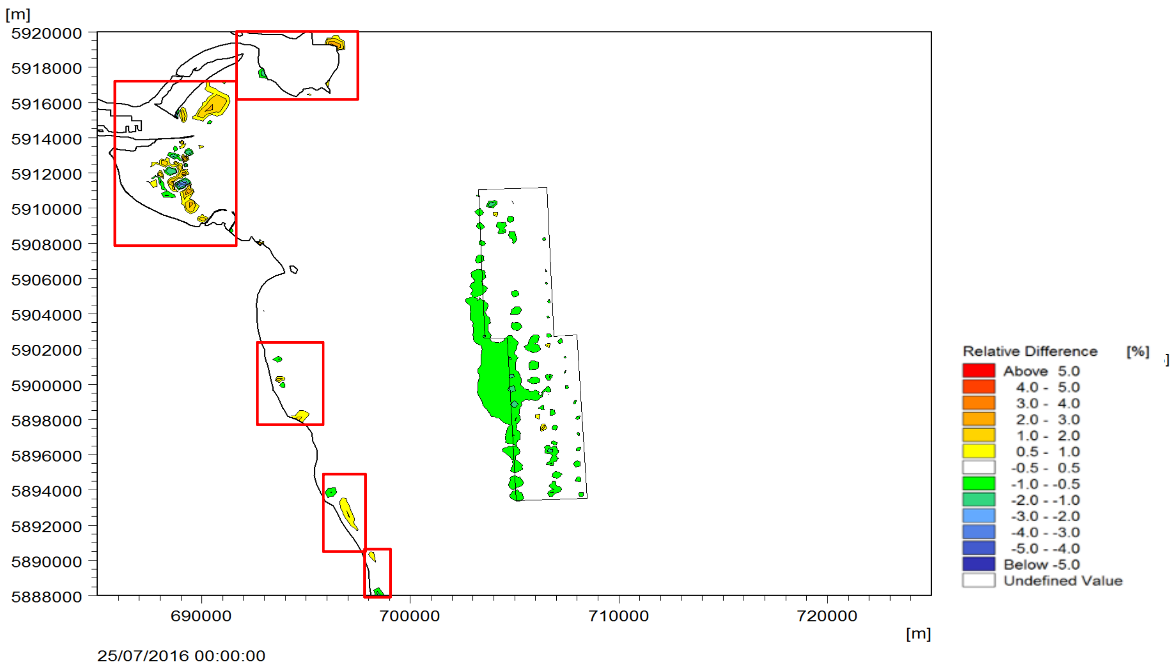
The impact of the construction phase on the wave climate will be due to the presence of the associated engineering and construction equipment, such as jack-up rigs and cable laying vessels, which will be deployed for short periods of time at one location at a time. Therefore, any impacts on the wave climate will be minimal, localised and transient.

4.2.2 Operational Phase

The blockage effects on the wave climate due to the operational phase of the Dublin Array OWF have been modelled using the DAPPMS SW model. The results of the modelling are shown in Appendix B (Section B.2.3). These plots show that the predicted changes in H_{m0} are small and are generally limited in range to within or in the immediate vicinity (up to a maximum of 0.04 m H_{mO}, 200 m outside the array site (1 in 100 year condition from east)) of the Dublin Array OWF development zone (near field). There are no significant impacts in the areas away from the array site (far-field).

It is noted, however, that a number of the plots appear to show scattered, localised impacts in places near the Irish coast and within Dublin Bay. Based on expert judgement these are considered to be SW model artefacts. In modifying the SW model from the baseline scenario to the RWCS, minor set-up changes are introduced that can affect the numerical solution of the model in shallow water. These effects should be ignored. The small changes to the iteration scheme needed to solve an SW model are robust and necessary to solve changes to the wave dynamics local to the scheme. However, in shallow water these small changes will become exaggerated due to small numerical changes in local flooding and drying amplifying absolute and relative changes. Where the SW model scenarios predict valid changes in the near-coast areas, these will show up as smoother differences covering a larger area which are visually quite distinct from the small-scale model artefacts. An example of this is presented in Figure 4-1, with regions boxed in red illustrating where such artefacts occur in the model. These highlighter changes occur when calculating relative differences of very small magnitude in shallow water.

Figure 4-1 Example relative Hmo difference plot showing model artefact away from array



Absolute and relative plots are shown for every model scenario (four different wave heights from four different directional sectors, plus the selected future SLR scenarios). Where H_{m0} is small there are instances where the absolute difference shows very small impacts but the relative plot appears to indicate larger impacts; in such cases, it needs to be recognised that a relatively large change to an initially small value will not necessarily indicate a noteworthy impact. Figure B-82 presents a good example of this, where the OWF development causes quite widespread relative impacts to what is a very small wind-generated wave from the west ($H_{m0} < 0.2$ m). The plot legends cover a scale of ±0.1 m for the absolute difference plots and ±5% for the relative difference plots, these ranges being greater than the predicted maximum differences across all modelled wave scenarios.

For wave scenarios approaching from the north, east and south there is a predicted reduction in H_{m0} when the array field is introduced to the model in the RWCS simulations. For the 50%ile scenarios from all directions the absolute difference is below 0.02 m (20 mm). However, the 50%ile wave scenarios also display the largest predicted relative difference of all scenarios, for all direction sectors. As explained previously, this indicates *relatively* larger changes to waves that are small in absolute height. For the larger wave conditions (1-in-1 and 1-in-100 year) wave height differences of up to a 0.04 m reduction are predicted, with the greatest changes localised around the turbine structures. Likewise, the greatest relative differences are localised to the turbine structures and in the order of less than a 2% reduction in significant wave height.

Within the array field there are very localised areas where an increase in wave height is predicted for the north, east and west scenarios. This generally occurs over a couple of SW model cells equating to approximately 100 m distance from the turbines. The effect is most frequently predicted in the shallower areas of the array field, and may be due to waves slowing and steepening locally due to the blocking effects of the OWF infrastructure.

For wave scenarios approaching from the west, which simulates purely wind-generated wave growth, predicted wave height reduction under the RWCS is below 0.02 m (20 mm) for the 50%ile and 5%ile scenarios and below 0.04 m (40 mm) for the 1-in-1 and 1-in-100 year scenarios. Generally, this equates to less than a 3% relative reduction in significant wave height. For the 50%ile condition the relative difference plot (Figure B-82) shows widespread differences; however, since the baseline scenario predicts an H_{m0} of approximately 0.1 m (100 mm) in the array field these relative differences are unlikely to be considered significant.

It can be summarised that the introduction of the turbine array will lead to a predicted reduction in H_{m0} during the operational phase of the OWF. The impact is generally small in both absolute and relative terms, and localised to the vicinity of the array field.

4.2.3 Decommissioning Phase

As with the effect of the construction phase on the wave climate, it is anticipated that any equipment required on site for the decommissioning of the development would have only a very limited, localised and transient impact on the wave climate. Equipment on site would be located at one place at a time, so cumulative impacts would not result.

4.3 Impacts on the Sediment Regime

4.3.1 Construction Phase

The impact of the construction phase on the sediment regime will primarily be due to the release of disturbed seabed sediments into the water column and direct disposals onto the seabed through the various construction processes. The RWCS review (Appendix E) identifies the activities that will create seabed disturbance events. A total of five specific proposed activities which have been modelled are detailed below:

- Seabed preparation for foundations for structures within the array.
- Drilling of foundation piles.
- Pre-construction sweeping of cable route:
    - Inter-array cables.
    - Export cable route.
- Cable trenching:
    - Inter-array cables.
    - Export cable route.
- Horizontal directional drilling (HDD) punch-out.

The range of seabed material found within the study site, and release methods detailed in the RWCS review require different methodologies to assess the fate of disturbed sediments. Finer fractions of sediment are likely to advect and disperse away from the release location as a sediment plume while coarser fractions fall quickly to the seabed. The coarse fractions are not likely to be subject to further erosive transport. Finer fractions take longer to fall out of the water column, but are expected to fall to the seabed within a few hours. Re-erosion of sediments does not take place in the model simulations as once sediment reaches the seabed it is considered to be part of the background sedimentary environment and subject to the same erosive processes as existing sediments in that location. By not including erosion within the model, the thickness and coverage of bed depositions resulting directly from the seabed disturbance activities can be assessed directly, and will tend to be conservative as no subsequent re-suspension occurs.

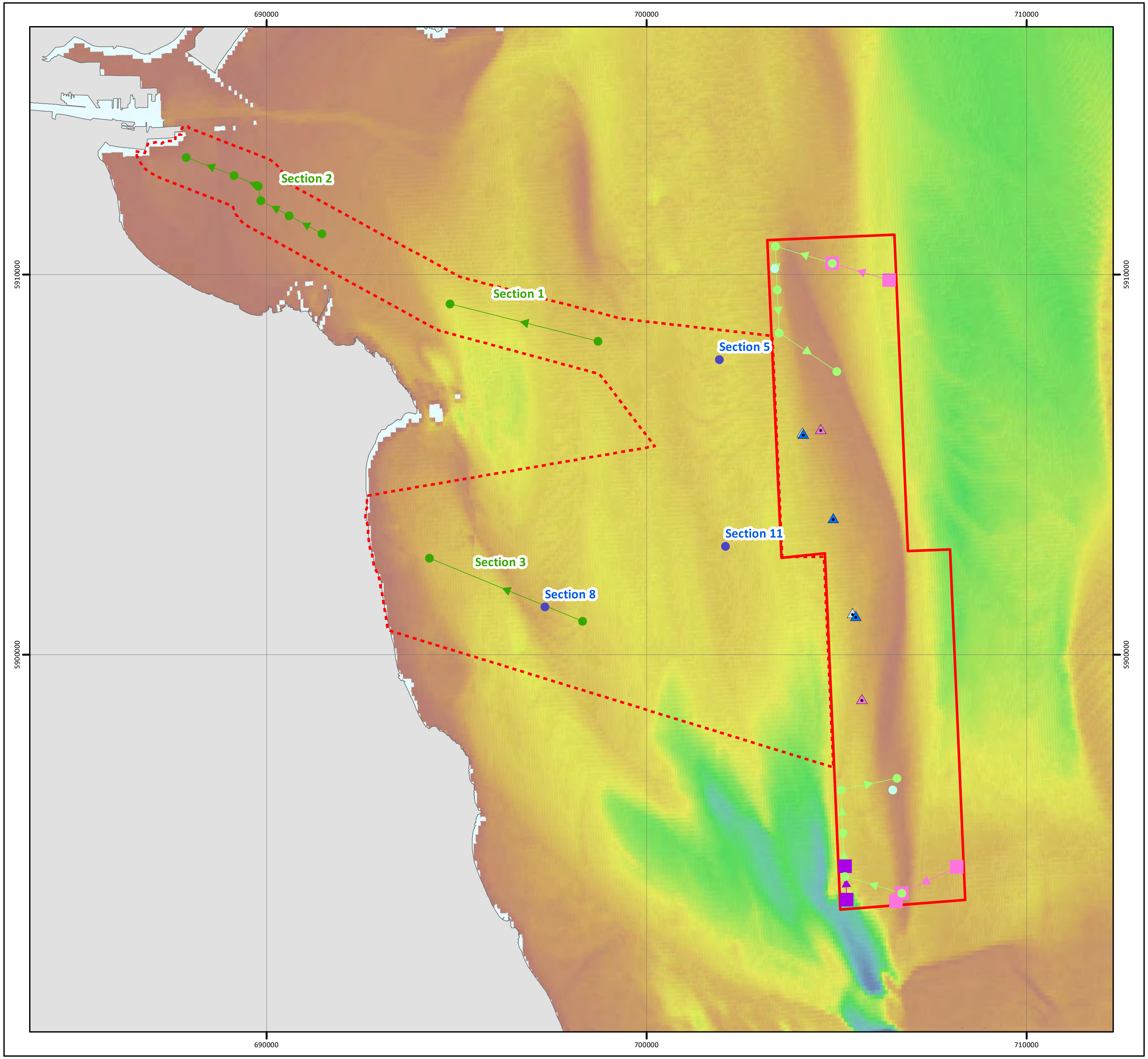
The fate of finer fractions (defined as fine sand, very fine sand and silts/clays) have been predicted within the DAPPMS using the Particle Tracking module. Coarser sediment fractions (defined as very fine gravel, very coarse sand, coarse sand, and medium sand), are assessed empirically to quantify the dimensions of near-field spoil mounds created during the disposal phase of dredging activity (see Section 2.3).

Together, these provide a complete overview of the total impact of deposition and temporary sediment plumes associated with the seabed disturbance events.

It must be noted that modelled scenarios relate to the activity of a vessel of defined characteristics, such as a dredger of defined size, or drilling rig of defined drill rate. As each scenario simulates a unit impact, such as one full hopper load or equivalent unit time for cable trenching, the full impact of deposition must be calculated by multiplying up the modelled unit impact by the required number of events to complete the specific task. Conversely, as plumes of SSC arising from instillation and preparation activities are seen to disperse within hours of the completion of the task, this process is transient, and not an additive effect.

The locations of all the seabed disturbance scenarios are displayed in Figure 4-2. This plot splits different scenarios by colour, with points depicting a release location and a track connecting two (or multiple) points representing a moving release source. It must be noted that all disposal locations, foundation locations and cable routes are indicative at the time of writing.

Appendix C provides figures from the modelling of the seabed disturbance scenarios, while a description of each scenario is provided in the following sections.



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DUBLIN ARRAY OFFSHORE WINDFARM PHYSICAL PROCESSES ASSESSMENT

PARTICLE TRACKING MODELLING

Modelling Sceanrio Locations

P2344-PART-001	A

Legend

N W E S

Modelling Location
- Seabed Preparation
- Drilling of Foundation Piles
- Pre Installation Sweeping: Inter Array Cables
- Pre Installation Sweeping: Export Cable
- Cable Trenching: Inter Array Cables
- Cable Trenching: Export Cable

Modelling Disposal Location
- Seabed Preparation
- Pre Installation Sweeping: Inter Array Cables
- Pre Installation Sweeping: Export Cable

Modelling Trackline
- Cable Trenching: Export Cable
- Cable Trenching: Inter Array Cables
- Drilling of Foundation Piles
- Seabed Preparation
- Proposed Wind Turbine Array Area
- Export Cable Area of Search

Bathymetry

Value

High : 0

Low : -75

Date	07 September 2020
Coordinate System	WGS 1984 UTM Zone 29N
Projection	Transverse Mercator
Datum	WGS 1984
Data Source	EMODNET; EPA; OSI; ESRI; INNOGY
File Reference	J:\P2344\Mxd\05_PART\ P2344-PART-001.mxd
Created By	Chris Dawe
Reviewed By	Chris Carroll
Approved By	Josh Gibson

0 1 2 3 4 km

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4.3.1.2 Seabed Preparations Around Foundations

The seabed preparation scenario examines the pre-construction activities to flatten the seabed for suction bucket foundations. This scenario follows a dredger undertaking seabed clearance until the hopper is full of cleared material. During this phase, a constant release of sediments would occur as overspill at the sea surface. Once complete, the dredger would make its way to a nominated disposal site and release the spoil to the bed. This is represented as an instantaneous bed release.

Details of Modelled Scenarios

A total of four scenarios were modelled, to examine the activity of one dredger load over both the Kish and Bray banks on spring and neap tides. The scenarios simulate over spill released during dredger activity and the resulting disposal at the indicative north and south disposal grounds. Locations of the overspill and dredge disposal locations are displayed in Figure 4-2.

Spoil site disposal was timed to coincide with low water, thus minimising the dispersion of the disposal mass and presenting a worst case for deposition thicknesses on the bed and highest instantaneous suspended sediment concentrations.

For the southern scenario, overspill was modelled for two turbine foundation sites and the met mast foundation, with no overspill occurring during the transition between sites. This schedule occurred over a period of 5.5 hours. In the northern scenario, only two turbine foundation sites and associated transit times were simulated, releasing overspill intermittently over 4.5 hours. The difference in the number of foundations modelled between the two scenarios the inclusion of a met mast only in an indicative location within the southern part of the array field, and the capacity of the dredge hopper assumed in the simulation (see Appendix E for details).

Details of the modelled transit schedules are represented in Table 4-1 and Table 4-2.

Table 4-1 Modelled schedule – south site scenario

Task	Duration (minutes)	Dredge phase
Foundation 1	104	Overspill
Transfer	30	
Foundation 2	104	Overspill
Transfer	15	
Met Mast	45	Overspill
Transfer	30	
Disposal Release	Disposal timed to occur at low water	Disposal

Table 4-2 Modelled schedule – north site scenario

Task	Duration (minutes)	Dredge phase
Foundation 1	104	Overspill
Transfer	30	
Foundation 2	104	Overspill
Transfer	30	
Disposal Release	Disposal timed to occur at low water	Disposal

Table 4-3 details the quantities of fine fraction sediment modelled for each scenario. Full details of the values behind the modelled scenario are presented in the RWC document (Appendix E).

Table 4-3 Seabed preparation: modelled sediment quantities

	North Site scenario		South Site Scenario	
Sediment Fraction	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**
Fine Sand	44.78	368	44.88	445
Very Fine Sand	4.23		3.43	
Silt / Clay	0.16		0.87	

Sediment Fraction	**Disposal Mass (Tonnes)**	**Disposal Mass (Tonnes)**
Fine Sand	875.2	338.5
Very Fine Sand	82.6	25.9
Silt / Clay	3.2	6.5

Results of Modelled Scenarios

In both the spring and neap scenarios, overspill concentrations are small with typical SSC of 20 mg/l, and a maximum of 50 mg/l seen on the spring scenarios, and 140 mg/l seen on the neap scenarios. Plumes form in the direction of the tidal stream to a maximum of 900 m from the point of release. The presence of all plumes has gone within 60 minutes of the end of a release, with the majority falling to background levels within 30 minutes.

The largest concentrations are associated with the disposal plume, with concentrations of up to 300 mg/l seen before settling immediately to the bed. As this activity occurs within one model cell (released 1 meter above the bed) this process can be considered to occur at a sub-grid scale, with no meaningful interpretation for the size of the disposal plume.

Plots of SSC at the time of the disposal release are shown for the north release in Figure C-1 and Figure C-2 for spring and neap tides respectively, and for the south release in Figure C-3 & Figure C-4 (for spring and neap tides respectively).

Bed deposition thicknesses occurring on spring and neap tides is shown in Figure C-5 & Figure C-6 for the north scenario and Figure C-7 & Figure C-8 for the south scenario. Settled sediments arising from overspill releases are seen to form discrete patches located close to the release locations. The proximity of the second foundation with the met mast in the southern scenario mean that these deposition footprints combine. Deposition depths of up to 5 mm in the northern scenarios and 10 mm in the southern scenarios are observed, with the footprint of deposition for all thicknesses typically being 600 m by 200 m. The footprint of the disposal plume is distinct, typically being 250 m by 250 m with a maximum depth of up to 45 mm.

The deposition of coarse-grained sediment not modelled in the particle tracking models is assessed using the STFATE model (see section 2.3). The resulting dimensions of spoil mounds, from the coarse-grained sediment, from one dredger load of material at the north and south spoil sites is presented in Table 4-4.

Table 4-4 Summary of spoil mound dimensions for the northern & south disposal areas from the seabed preparation scenario for a single disposal

Disposal Site	Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
North Site Disposal	Slack tide, low water	1.77	1,045	581
	Peak flood	0.84	2,032	639
South Site Disposal	Slack tide, low water	0.70	20,148	4,355
	Peak flood	0.52	23,690	3,252

The maximum depth of coarse-sized material deposition across both sites is seen at the north site, with a maximum depth of a cone shaped spoil mound being 1.77 m, for a slack low water release. The total area covered for both the light and heavy thresholds is highest at the south site. The difference in total proportion of coarse grained material deposited at each site accounts for this, with a total of 938 m^3 material deposited at the north spoil site, as opposed to 5,057 m^3 at the south site. This is due to differences in the composition in material size and composition in each scenario.

4.3.1.3 Drilling of Foundation Piles

The drilling of foundation piles scenario examines drill cuttings released from the surface of a drilling rig while a drill bit is driven into the seabed. A continuous release of sediment occurs during the drilling process while the RWCS is represented by a site that produces the largest volume of fine sediments released into the water column over the shortest interval relative to alternative foundation installation techniques. This then has the potential to lead to the highest suspended sediment concentration within a plume that advects away from the point of discharge.

Details of Modelled Scenario

The model scenario simulated drilling at two indicative foundation sites, with a transition time during which there was no release while the drilling rig repositioned to the neighbouring site. The locations and sequence undertaken in the modelling is shown in Figure 4-2.

The model was run for a mean spring and a mean neap scenario, with the release of sediments occurring intermittently over a period of 5.5 days. Full details of the values behind the modelled scenario are presented in the RWC document (Appendix E).

Table 4-5 details the schedule that was modelled for both spring and neap scenarios, while Table 4-6 details the release rates used in the model.

Table 4-5 Modelled schedule: seabed drilling

Task	Duration (days)	Dredge phase
Drilling at Foundation 1	2.2	Drill Cuttings
Transfer	0.8	
Drilling at Foundation 2	2.2	Drill Cuttings

Table 4-6 Modelled sediment rates for drill cuttings

Sediment Fraction	Overspill Rate (kg/s)
Fine Sand	18
Very Fine Sand	18
Silt / Clay	25

Results of Modelled Scenario

Plumes of SSC are continuously observable during drilling activity and advect in the direction of the tidal stream. Concentrations are very low, typically 8 mg/l but can be up to 12 mg/l. Maximum concentrations in the simulation are associated with slack tide, with values of up 200 mg/l and 600 mg/l observable on spring and neap tides respectively albeit within 150 m of the release location.

Due to the continuous release of sediments over the tide, plumes are able to extend over a large area (10 km from source), albeit at concentrations close to background levels. An example is shown in Figure C-9, depicting the plume 11 hours after the start of sediment release on a spring tide and the maximum extent of its tidal excursion.

Figure C-10 & Figure C-11 show the plume at the time of completion of sediment release. Concentrations are high at the location of sediment release but are seen to fall to background levels within 1.5 km of the source. All sediments are seen to have settled to the bed within 3 hours of the end of release.

Bed deposition is depicted in Figure C-12 and Figure C-13 for the spring and neap tide scenarios respectively. Both scenarios show a wide footprint for bed thicknesses less than 2 mm, with areas of thicker deposition up to a maximum of 20 mm seen within 2 km of the drilling locations.

The composition of coarse-sized sediment arising from drill cuttings is a function of the material encountered and the drill rate employed at the site. The total volume of coarse-fraction drill cuttings assumed in the RWCS for one drill site is 4380 m³. Therefore, drill cuttings are likely to form a mound on the seabed that is comparable to those defined in the spoil analysis for a scenario of equal volume, which is best matched by the north site scenario for the pre-construction sweeping of inter array cables (section 4.3.1.6), which describes the deposition of 4194 m³ of coarse sized material.

4.3.1.4 Pre-construction sweeping of cable routes – inter-array cables

The pre-construction sweeping scenario is concerned with the removal of steep sandwave bedforms required to be removed before the use of cable laying equipment. This scenario simulates the use of a dredger at a fixed location releasing an overspill discharge of sediments while clearance is undertaken. On completion, the hopper load is released as an instantaneous discharge at a nominated spoil disposal ground. This scenario examines locations within the development array site, with disposal grounds also located within the development array site.

Details of Modelled Scenarios

A total of four scenarios were modelled, to examine activity over the Kish and Bray banks (and the resulting north and south disposal grounds), with both modelled over a mean spring and mean neap tide. Locations of the overspill and dredge disposal locations are displayed in Figure 4-2.

Spoil site disposal was timed to coincide with high and low water for the north and south disposal sites respectively. This is intended to minimise the dispersion of the disposal mass and present a worst case for deposition thicknesses on the bed and instantaneous suspended sediment concentrations.

In all scenarios, dredge overspill is modelled as a continuous release for a 4-hour period. No transit time between the seabed clearance site and dredge disposal site is included, and the dredge release occurs simultaneously with the end of the overspill phase.

Table 4-7 details the quantities of fine fraction sediment modelled for each scenario. Full details of the values behind the modelled scenario are presented in the RWC document (Appendix E).

Table 4-7 Sandwave sweeping for inter-array cables: modelled sediment quantities

	North Site scenario		South Site Scenario	
Sediment Fraction	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**
Fine Sand	45.41	482	47.73	482
Very Fine Sand	2.37		0.19	
Silt / Clay	0.13		0.00	

Sediment Fraction	**Disposal Mass (Tonnes)**	**Disposal Mass (Tonnes)**
Fine Sand	672.9	997.9
Very Fine Sand	35.1	3.9
Silt / Clay	2.0	0.0

<u>Results of Modelled Scenarios</u>

In both the north and south scenarios, concentrations arising from the overspill are small, with SSC typically 15 mg/l on spring tides and 25 mg/l on neap tides, with plumes from the discharge location observed for a distance of around 1 km. Peak overspill plume concentrations are observed at slack water, timed for the end of the release, with 30 mg/l and 150 mg/l observed for the spring and neap scenario respectively. All sediments are seen to settle out of the water column within one hour of the end of the release.

The highest concentrations are associated with the disposal plume which is timed to occur at slack water. Concentrations are high (up to 600 mg/l), before settling immediately to the bed. As this activity occurs within one model cell (released 1 meter above the bed) this process can be considered to occur at a sub-grid scale, with no meaningful interpretation for the size of the disposal plume.

Plots of SSC at the time of the sediment release are depicted for the north scenario in Figure C-14 & Figure C-15 (for spring and neap respectively), and for the south scenario in Figure C-16 & Figure C-17 (for spring and neap respectively). In the plots for the north scenario the disposal plume has already fallen out of suspension at the end of the operation, and the overspill plume is still visible, while in the southern scenario plots, the disposal plume is observed alongside the overspill plume in both the spring and neap plots, and is dispersed fully within 30 minutes.

Bed deposition thicknesses occurring on spring and neap tides for the north scenario are shown in Figure C-18 & Figure C-19 respectively, while the spring and neap tides for the south scenario are shown in Figure C-20 & Figure C-21 respectively. All plots show two distinct patches, one associated with overspill and a second associated with the disposal. Overspill footprints are larger and elongated in the direction of the tidal stream. Typically, they cover an area of 900 m by 200 m, with settled depths of 2 mm to 6 mm. The footprint of dredge disposal covers a smaller area, typically 250 m by 250 m, with a maximum depth of 40 mm to 60 mm.

The deposition of coarse-grained sediment not modelled in the particle tracking models is assessed using the STFATE model (see section 2.3). The resulting dimensions of spoil mounds, from coarse-grained sediment, from one dredger load of material at the north and south spoil sites is presented in Table 4-8.

Table 4-8 Summary of spoil mound dimensions for the northern & south disposal areas from the pre-construction sweeping of inter array cables scenario for a single disposal

Disposal Site	Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
North Site Disposal	Slack tide, low water	0.98	14,864	7,084
	Peak flood	0.91	15,039	6,445
South Site Disposal	Slack tide, low water	0.77	9,232	4,123
	Peak flood	0.75	9,232	4,123

The maximum depth of coarse-sized material deposition across both sites is seen at the north site, with a maximum depth of a cone shaped spoil mound being 0.98 m, for a slack low water release. The overall areas for deposition are higher at the north site, due to the proportion of coarse-grained being higher for than the south site scenario. The total volume of material within the spoil disposal is 4,194 m^3 and 2,157 m^3 for the north and south site, respectively. This is due to differences in the composition in material size and composition in each scenario.

4.3.1.5 Pre-construction sweeping of cable routes – export cable route

The pre-construction sweeping scenario is concerned with the removal of steep sandwave bedforms required to be removed before the use of cable laying equipment. This scenario simulates the use of a dredger at a fixed location releasing an overspill discharge of sediments while clearance is undertaken. On completion, the hopper load is released as an instantaneous discharge at a nominated spoil disposal ground. This scenario examines clearances occurring along the various export cable routes. In each scenario, spoil is then taken back to disposal sites within the development array.

Details of Modelled Scenarios

A total of three sandwave clearance locations within the cable corridor were modelled in this scenario. These were modelled for spring and neap tidal conditions, creating a total of six modelled scenarios. Locations of the overspill and dredge disposal locations are displayed in Figure 4-2.

The scheduling of the runs are identical to the pre-construction sweeping scenario for the inter-array cables, with a spoil disposal timed for high and low water for the north and south disposal sites respectively, preceded by 4 hours of continuous overspill release. As with the inter-array cables scenario, no transit time is simulated between the overspill and dredge release phases of the scenario.

Table 4-9 details the quantities of fine fraction sediment modelled for each scenario. Full details of the rationale behind the locations selected for modelling and the values used in the modelled scenarios are presented in the RWC document (Appendix E).

Table 4-9 Sandwave sweeping for export cable route: modelled sediment quantities

	Section 5 North Spoil Site		Section 11 North Spoil Site		Section 8 South Spoil Site	
Sediment Fraction	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**	**Overspill Rate (kg/s)**	**Total Overspill Volume (m³)**
Fine Sand	44.66	482	47.18	482	41.23	482
Very Fine Sand	2.44		0.59		6.13	
Silt / Clay	0.81		0.15		0.56	

Sediment Fraction	**Disposal Mass (Tonnes)**	**Disposal Mass (Tonnes)**	**Disposal Mass (Tonnes)**
Fine Sand	11.6	376.4	42.7
Very Fine Sand	0.6	4.7	6.4
Silt / Clay	0.2	1.2	0.6

Results of Modelled Scenarios

The behaviour of suspended sediments is broadly the same for each of the different export cable clearance locations, taking into account differences in the total sediment quantities between scenarios.

The volumes of released sediments in the overspill phase across the three locations are the same, with different proportions of sand and silt sediments. In all cases the plumes arising from the overspill are small, with SSC typically 15 mg/l on spring tides and 25 mg/l on neap tides, with plumes from the discharge location observed up to around 1 km from the discharge location. The maximum concentrations occur at slack water when concentrations increase to between 110 mg/l and 160 mg/l at the end of the release, with the highest concentrations seen on the Section 8 scenario. All sediments are seen to settle out of the water column within one hour of the end of the release in all scenarios.

Plots of the overspill plumes, one hour after the start of sediment release, are shown for Section 5 in Figure C-22 & Figure C-23 (for spring and neap tides respectively) and for Section 11 in Figure C-26 & Figure C-27 (for spring and neap tides respectively).

Release of the disposal plume is timed to occur at slack water. As this activity occurs within one model cell (released 1 meter above the bed) this process can be considered to occur at a sub-grid scale, with no meaningful interpretation for the size of the disposal plume. Plots of SSC at the time of the disposal for the Section 8 scenario are show in Figure C-24 & Figure C-25 for spring and neap tides respectively. The concentration of the disposal plume is small (12 mg/l and 24 mg/l for spring and neap tides respectively) due to the comparatively smaller quantities to other scenarios. All sediment associated with the disposal plume in all scenarios hit the bed immediately after release.

Bed deposition thickness plots are presented for spring and neap tides for Section 5 in Figure C-28 & Figure C-29, for Section 8 in Figure C-30 & Figure C-31, and for Section 11 in Figure C-32 & Figure C-33. The pattern of bed deposition is similar for all three scenarios with an elongated footprint of sediment associated with the overspill and a smaller patch associated with the disposal. The footprints for the overspill plume are generally 2 km long for a spring tide release, and 1.5 km for a neap tide release, with depths of typically 1 mm to 2 mm, with a maximum depth less than 10 mm. The footprint of the disposal sediments take a footprint of around 200 m by 200 m with a thickness of 0.5 mm to 1 mm (maximum) for the Section 5 and Section 8 scenarios. The footprint and depths for Section 11 are slightly larger, due to the larger volumes disposed, and shows a footprint of around 250 m by 200 m at depths of between 3 mm and 12 mm (maximum).

The deposition of coarse-grained sediment not modelled in the particle tracking models is assessed using the STFATE model (see section 2.3). The resulting dimensions of spoil mounds, for coarse-grained material, from one dredger load of material at the north and south spoil sites is presented in Table 4-10.

Table 4-10 Summary of spoil mound dimensions for the northern & south disposal areas from the pre-construction sweeping of export cable route scenario for a single disposal

Disposal Site	Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
North Site Disposal (from Section 5 scenario)	Slack tide, low water	1.20	20,381	9,232
	Peak flood	0.75	23,226	9,058
South Site Disposal (from Section 8 scenario)	Slack tide, low water	1.19	19,277	9,290
	Peak flood	1.13	20,206	9,523

The maximum depth of coarse-sized material deposition across both sites is seen at the north site, with a maximum depth of a cone shaped spoil mound being 1.20 m, for a slack low water release. The total area covered for both the light and heavy thresholds are broadly the same between scenarios. The difference in total proportion of coarse-grained material deposited at each site is similar with a total of 9,089 m^3 material deposited at the north spoil site, as opposed to 8,819 m^3 at the south site.

4.3.1.6 Cable Trenching – Inter-array Cables

The cable trenching scenario simulates the movement of a vessel-towed mass flow excavator along a series of transects between turbine sites. Sediments are released at the bed and released continuously while trenching is underway. During periods of repositioning, no sediments are released. Where the composition of seabed sediments changes through the transect, the total mass or proportion of sediment fractions released is changed. Coarse-grained sediments are not assessed in this scenario as any sediment larger than fine sand is expected to rapidly fall out of suspension to bury the cable in the trench as the mass flow excavator progresses.

<u>Details of Modelled Scenarios</u>

A total of four model scenarios were undertaken, following two routes over mean spring and mean neap tides. The two routes follow trenching between indicative individual wind turbine locations with time for repositioning. The tracks used in this trenching scenario are displayed in Figure 4-2.

Line 1 follows a route in the northern part of the array between four turbine locations, then finishing at the offshore platform (OSP). Line 2 follows a route in the southern part of the array, visiting four indicative turbine locations. Each leg of trenching has its own sediment release quantities, based on the nearest available data on seabed sediments. All sediment releases are modelled 2 m above the bed. Calculations are based on an assumed trench dimension of 5.71 m width, and 7 m depth. Full details of the values behind the modelled scenario are presented in the RWC document (Appendix E).

The schedules for Line 1 and Line 2 are shown in Table 4-11 and Table 4-12 respectively.

Table 4-11 Cable trenching – inter-array cables Line 1: modelled sediment quantities

Leg	Task	Duration (minutes)	Sediment Fraction	Trench Spoil Release Rate (kg/s)
1	WTG1 - to - WTG2	522	Fine Sand	3172
			Very Fine Sand	408
			Silt / Clay	4
	Repositioning	90		
2	WTG2 - to - WTG6	378	Fine Sand	2180
			Very Fine Sand	216
			Silt / Clay	9
	Repositioning	90		
3	WTG6 - to - WTG7	378	Fine Sand	1793
			Very Fine Sand	8
			Silt / Clay	0
	Repositioning	90		
4	WTG7 - to - OSP North	612	Fine Sand	1683
			Very Fine Sand	40
			Silt / Clay	11
Total Distance: 5.7 km; Total Time: 36 hours				

Table 4-12 Cable trenching – inter-array cables Line 2: modelled sediment quantities

Leg	Task	Duration (minutes)	Sediment Fraction	Trench Spoil Release Rate (kg/s)
1	WTG44 - to – WTG40	522	Fine Sand	1469
			Very Fine Sand	4
			Silt / Clay	0
	Repositioning	90		
2	WTG40 - to – WTG39	378	Fine Sand	1469
			Very Fine Sand	4
			Silt / Clay	0
	Repositioning	90		
3	WTG39 - to – WTG37	378	Fine Sand	1469
			Very Fine Sand	4

Leg	Task	Duration (minutes)	Sediment Fraction	Trench Spoil Release Rate (kg/s)
			Silt / Clay	0
	Repositioning	90		
4	WTG37 - to - OSP South	492	Fine Sand	1469
			Very Fine Sand	4
			Silt / Clay	0
Total Distance: 5.3 km; Total Time: 34.1 hours				

<u>Results of Modelled Scenarios</u>

In all cable trenching scenarios, sediment is released 2 m above the bed, and creates small plumes of high suspended sediment concentration, that fall out of the water column quickly (within 30 minutes), and thus remain close to the trenching track as the chance for tidal advection is limited. While trenching is underway, plumes typically have high concentrations (up to 5000 mg/l) within a single model cell, before decreasing rapidly to between 5 mg/l and 20 mg/l within 200 m. A typical depiction of the trenching plume is shown in Figure C-34 which shows the Line 1 neap tide scenario, two hours after the start of trenching. This figure shows a small plume extending northward approximately 700 m from the point of release, in the direction of the tidal stream.

Plots of SSC at the time of the end of sediment release are shown in Figure C-35 (for the Line 1 spring scenario), Figure C-36 (for the Line 2 spring scenario) & Figure C-37 (for the Line 2 neap scenario). All show that the high concentrations at the point of release have reduced to between 500 mg/l and 1500 mg/l, with concentrations falling to background levels (5 mg/l) within a few hundred meters. All sediments are seen to have settled to the bed within 30 minutes of the end of release, with the exception of the Line 1 neap tide release, which have returned to background levels 60 minutes.

Bed deposition thicknesses occurring on spring and neap tides for the Line 1 scenario are shown in Figure C-38 & Figure C-39 respectively, while the spring and neap tides for the Line 2 scenario are shown in Figure C-40 & Figure C-41 respectively. All figures show that sediments deposit in a linier feature following the modelled cable trenching track. Maximum depositions for the Line 1 scenario along the track are between 100 mm and 750 mm, and slightly less for the Line 2 scenario at between 100 mm and 500 mm. This and the wider overall footprint observed in the Line 1 plots are reflective of the reduced quantities released in this scenario.

Results from the modelling are likely to represent thinner deposition over a wider footprint as the model does not resolve the trench itself, which is smaller than the model mesh (100 m triangles). The use of a mass flow excavator, as detailed in the RWC document (Appendix E), often involves laying the cable at the same time as trenching, with coarse and fine sediment fluidised from the seabed expected to rapidly fall out of suspension to bury the cable in the trench. As such, the settled material is expected to fall close to or into the excavated trench. Despite this, results from the modelling do indicate that sedimentation beyond the trench is minimal and is limited to 600 m from the trench.

4.3.1.7 Cable Trenching – Export Cable Route

The process for the cable trenching or the export cable route is the same as for the inter-array cables described in Section 4.3.1.6. The scenarios detailed in this section represent a transect, simulating a 24 hour period at a trenching rate of 180 m/hr. Section 1 & 3 scenarios describe transects along a straight line, while the Section 2 scenario is composed of four transects, over a directionally changing path. Where the composition of seabed sediments changes through the transect, the proportion of sediments released is changed. Coarse-grained sediments are not assessed in this scenario as any sediment larger than fine sand is expected to rapidly fall out of suspension to bury the cable in the trench as the mass flow excavator progresses.

Details of Modelled Scenarios

A total of six model scenarios were undertaken, following three routes over mean spring and mean neap tides. The three routes follow trenching along a defined route and are referred to as Sections 1, 2 and 3. The tracks used in this trenching scenario are displayed in Figure 4-2.

Sections 1 and 3 follow a straight line, moving at a speed of 180 m/hour, with a constant release of sediments. Section 2 follows a line made up of four changing legs, moving at a speed of 180 m/hour. Each individual leg has its own sediment release quantities, based on the nearest available data on seabed sediments. All sediment releases are made 2 m above the bed. As in the scenario for inter -array cables above, calculations are based on an assumed trench dimension of 5.71 m width, and 10 m depth. Full details of the values behind the modelled scenario are presented in the RWC document (Appendix E).

The quantities of released sediments and the travel time of individual legs are presented in Table 4-13.

Table 4-13 Cable trenching – export cable route: Sections 1, 2 & 3: modelled sediment quantities

Section	Leg	Sediment Fraction	Trench Spoil Release Rate (kg/s)	Distance Travelled & Time Taken
Section 1		Fine Sand	223	4 km in 24 hours
		Very Fine Sand	12	
		Silt / Clay	4	
Section 2	1	Fine Sand	2460	992 m in 5.5 hours
		Very Fine Sand	1173	
		Silt / Clay	284	
	2	Fine Sand	3142	839 m in 4.7 hours
		Very Fine Sand	543	
		Silt / Clay	189	
	3	Fine Sand	2293	1080 m in 6 hours
		Very Fine Sand	1405	
		Silt / Clay	145	
	4	Fine Sand	2438	1361 m in 7.6 hours
		Very Fine Sand	1477	
		Silt / Clay	103	
Section 3		Fine Sand	1491	4.3 km in 24 hours
		Very Fine Sand	138	
		Silt / Clay	32	

Results of Modelled Scenarios

In all cable trenching scenarios, sediment is released 2 m above the bed, which generally creates small plumes of high suspended sediment concentration, that fall out of the water column quickly. In general, this means that sediments don't have an opportunity to be advected far by the tide. Tidal current speeds do vary across the cable corridor route, which affect the time in which material does settle out of the water column, creating some variance across the scenarios.

While trenching is underway, plumes typically have high concentrations (up to 5700 mg/l) within a single model cell, before decreasing rapidly. The comparatively smaller quantities of sediment released in the Section 1 scenario give peak concentrations at 300 mg/l. Figure C-42 & Figure C-43 show SSC for Section 1 on a spring and neap tide respectively, 1 hour after the start of trenching and sediment release. Both show peak concentration at 300 mg/l, falling away rapidly to background concentration within 400 m.

Section 2 has the largest quantities of sediment in its release, and also encounter comparatively lower current speeds along it's transect. Figure C-44 shows SSC 2 hours after the start of sediment release on a spring tide, and Figure C-45 the same but for a neap tide. Both show high SSC at the point of release (5700 mg/l), with concentrations of up to 100 mg/l extending 600 m beyond this. Concentrations are above background levels (5 mg/l) for approximately 2 km on a spring tide, and 1.5 km on a neap tide. In both cases sediment has fully dispersed within 60 minutes of the completion of sediment release. Plots of SSC at the time of the end of sediment release are shown for Scenario 3 in Figure C-46 for a spring tide and Figure C-47 for a neap tide. These plots show that SSC has fallen from a typical concentration of 500 mg/l at the point of release to 50 mg/l. The plume itself occupies an area of approximately 250 m², and all sediment has dispersed to background levels within 30 minutes.

Plots of bed deposition thicknesses for Scenario 1 are shown in Figure C-48 & Figure C-49 (for spring and neap tides respectively), while Scenario 2 is shown in Figure C-50 & Figure C-51, and scenario 3 shown in Figure C-52 and Figure C-53 (both for spring and neap tides respectively). All figures show that sediments deposit in a linier feature following the modelled cable trenching track. With sediments released over a 24-hour period in all scenarios, a wider footprint of sediment maps the flood and ebb directions of the tide clearly in Scenario 1 and 3, with these being straight line transects. For Scenario 1, the maximum deposition depth is 80 mm along the trenching transect in both the spring and neap scenarios, with the tide advecting smaller quantities of sediment up to 500 m from the cable trenching track. A similar pattern is seen for Scenario 3, with maximum depositions along the transect length of between 100 mm and 500 mm. The deposition is thicker, and footprint of deposition is larger (up to 2 km on both spring and neap tides) due to the comparatively larger quantities of sediment released in Scenario 3 as opposed to Scenario 1.

Scenario 2 sees the largest depositions and footprint of all the export cable route scenarios due to it having the highest quantities of sediment released and occurring in the lowest energy environment of the three scenarios. Deposition along the cable trenching track is typically between 250 mm and 750 mm with maximum values of 980 mm on a neap tide. Deposition beyond model cells that define the trench track deposition is small, with thicknesses of between 0.2 mm and 30 mm. Deposition is almost exclusively within the cable corridor area, extending a maximum of 1.8 km from the cable trenching transect.

Across all three scenarios, results from the modelling are likely to represent thinner deposition over a wider footprint as the model does not resolve the trench itself, which is smaller than the model mesh (100 m triangles). The use of a mass flow excavator, as detailed in the RWC document (Appendix E), often involves laying the cable at the same time as trenching, with coarse and fine sediment fluidised from the seabed expected to rapidly fall out of suspension to bury the cable in the trench. As such, the settled material is expected to fall close to or into the excavated trench. Despite this, results from the modelling do indicate that sedimentation beyond the trench is minimal.

4.3.2 Operational Phase

The impact of the Dublin Array OWF on the local sediment regime and sediment dynamics will be primarily associated with changes to bed shear stress as a result of the proposed scheme. The potential for the entrainment or deposition of sediments will change with increases or decreases in bed shear stress, induced on the seabed through the movement of the tides. Increases in bed shear stress due to higher flow speeds mean there is a potential for greater quantities of sediment to become entrained, as the critical threshold for erosion is met for different sediment types and grain sizes. Conversely, a reduction in bed shear stress may potentially cause greater deposition of sediments, or a reduction of sediment transport rates as flow speeds reduce.

Spatial changes in current-induced bed shear stress due to the presence of the Dublin Array OWF are shown in Figure B-33 to Figure B-40. As bed shear stress varies as the square of current speed, the spatial and temporal distribution of positive and negative shear stress changes are broadly analogous to the patterns observed in the current speed difference plots, shown in Figure B-25 to Figure B-32.

On both spring and neap tides, the array scale effects of flow acceleration around the array field and reductions within the array field are shown for peak flood and ebb states of the tide. For mean spring tides, maximum bed shear stress differences are predicted to be ±0.12 N/m² during peak flood (Figure B-35) and ±0.11 N/m² during peak ebb (Figure B-36). This changes to between 0.08 and -0.13 N/m² during the neap peak flood (Figure B-39), and between 0.08 and -0.10 N/m² on the neap peek ebb tide (Figure B-40).

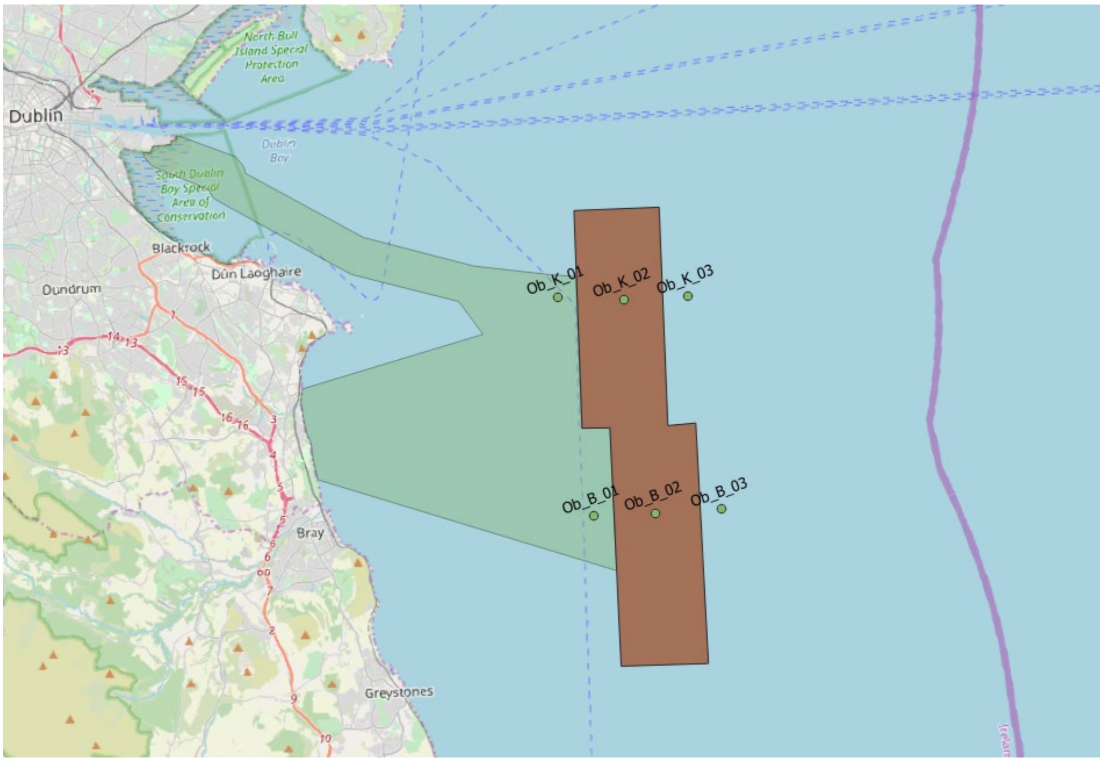
These changes are small, relative to absolute values of bed shear stress shown in Figure A-17 to Figure A-24, and as was predicted with the differences in current speeds, the changes are limited in spatial extent to within and a few km around the development zone boundary.

4.3.2.1 Analysis of Critical Thresholds

The application of changes to bed shear stress requires an understanding on how these differences compare to the critical threshold of sediment entrainment. To capture the distribution of increases and decreases of bed shear stress observed in the difference plots, a series of six locations was analysed for the northern (Kish) and southern (Bray) banks in a west to east transect, three locations on each bank. This enables examination of conditions within the development zone, and in the areas to the east and west which experience positive changes in flow speed / bed shear stress at the peak flood and ebb period of the tide.

These locations are shown in Figure 4-3.

Figure 4-3 Locations across the Kish and Bray Banks used in bed shear stress threshold analysis



Time series of bed shear stress for spring and neap tides across the Kish Bank are shown in Figure 4-4 to Figure 4-9. Three stations named Ob_K_01, Ob_K_02 and Ob_K_03 align in a west to east transect across the northern part of the development zone. These sites are in 27 m, 15 m and 41 m of water relative to MSL respectively.

Figure 4-4 to Figure 4-6 show time series of predicted bed shear stress and water level on a spring tide, for both the baseline (pre-scheme) and scheme (RWCS) scenarios. Bed shear stress follows the standard form of a standing tidal wave, with peaks occurring at mid tide when current speeds are highest. Peak flow speeds vary across the three sites as does the asymmetry of flood and ebb peaks. The highest bed shear stresses occur on the western side of the bank at site Ob_K_01, with the flood tide peak reaching 2.1 N/m^2 and the ebb peak reaching 1.8 N/m^2 on a mean spring tide. Peak values for both states of the tide are higher than the critical threshold for very fine gravel. The lowest predicted bed shear stresses occur within the development zone, at site Ob_K_02, with a near balance in flood and ebb peak values. Site Ob_K_03 has the most marked asymmetry in peak bed shear stress, with the flood tide generating 2.1 N/m^2 of bed shear stress and the ebb tide generating 1.5 N/m^2.

At all three locations the difference between the scheme and baseline time series is very small, with the largest differences at sites Ob_K_01 and Ob_K_03 occurring at peak flows, at which time the predicted bed shear stress is above the entrainment threshold for fine gravel. The absolute differences are very small (c.0.02 N/m^2) and indicate no meaningful change to the sediment regime will occur at these locations. At the location within the OWF array, a very minor shift to the phasing of bed shear stress is observed, with the RWCS scheme condition lagging behind the baseline by approximately 10 minutes. This does not change the overall peak magnitudes or asymmetry in the bed shear stress time series, and as such will likely have a negligible impact to the sediment regime.

During neap tides, bed shear stress is reduced due to the reduction of flow speeds. Overall differences between scheme and baseline are lower than those on spring tides, with a minor phase shift on the ebbing tide observed at Ob_K_01 and Ob_K_02. The scheme condition is again shown to lag marginally behind the baseline.

Figure 4-4 Comparison of baseline & scheme bed shear stress and critical erosion thresholds for a mean spring tide at Ob_K_01

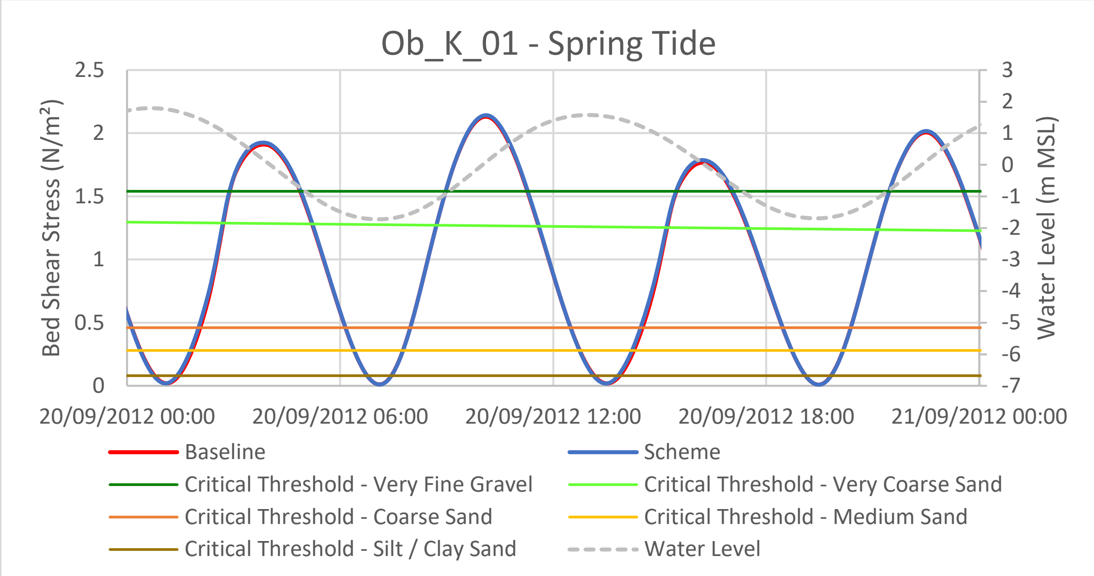


Figure 4-5 Comparison of baseline & scheme bed shear stress and critical erosion thresholds for a mean spring tide at Ob_K_02

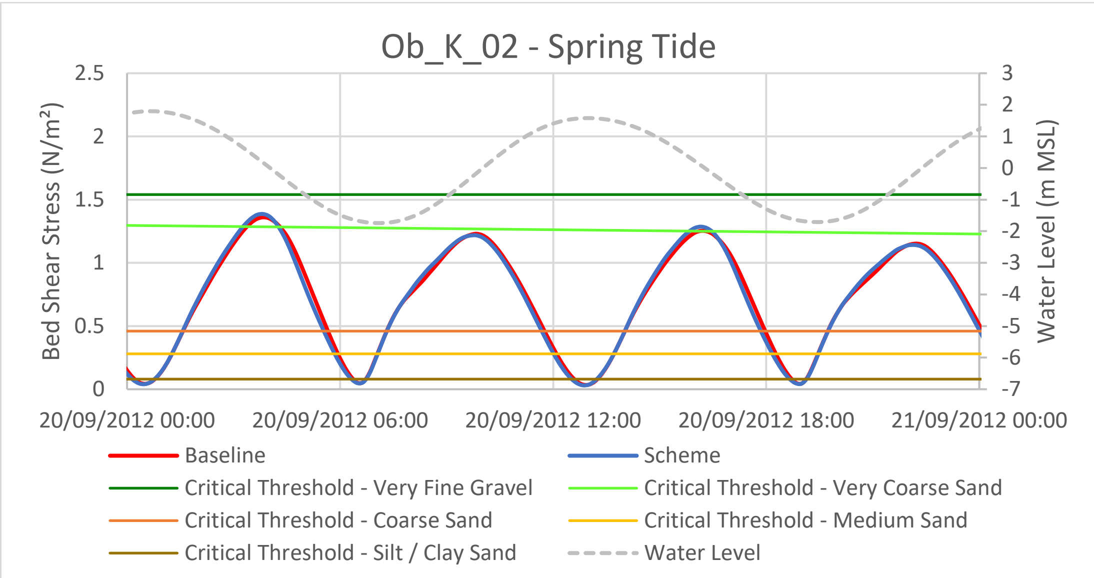


Figure 4-6 Comparison of baseline & scheme bed shear stress and critical erosion thresholds for a mean spring tide at Ob_K_03

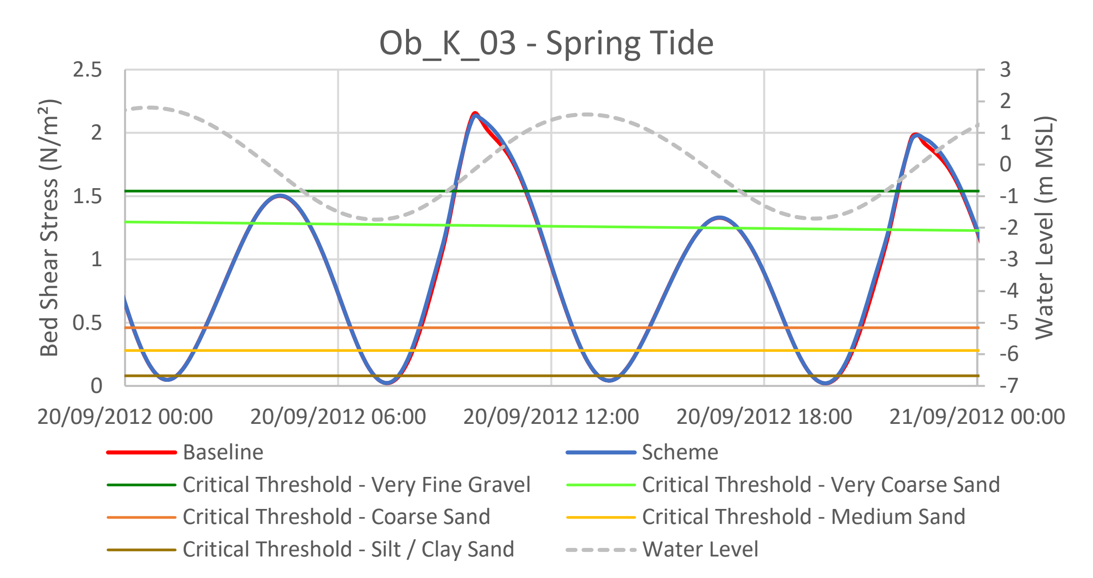


Figure 4-7 Comparison of baseline & scheme bed shear stress and critical erosion thresholds for a mean neap tide at Ob_K_01

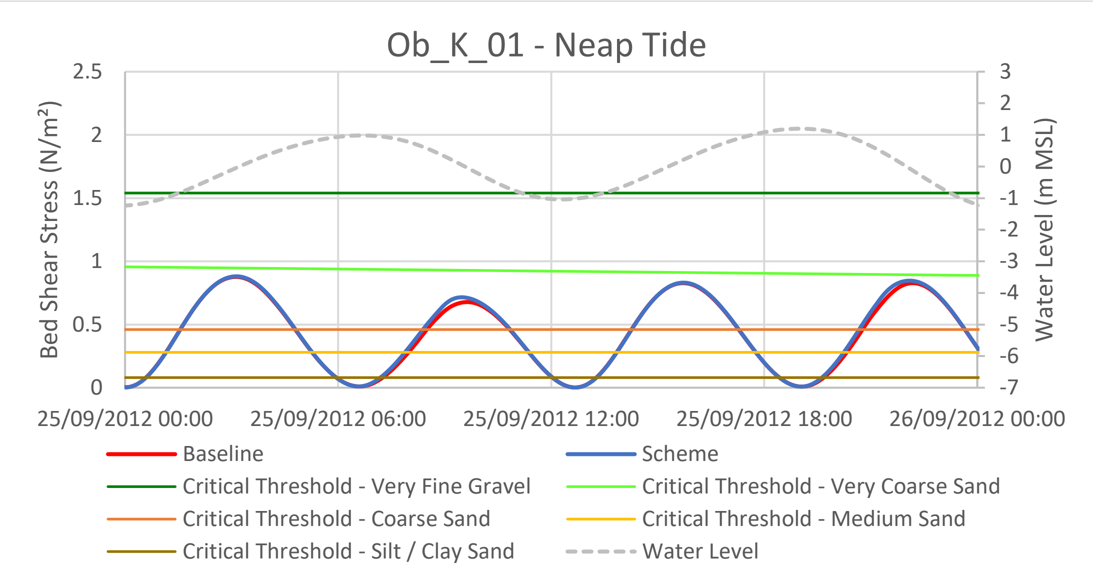


Figure 4-8 Comparison of baseline & scheme bed shear stress and critical erosion thresholds for a mean neap tide at Ob_K_02

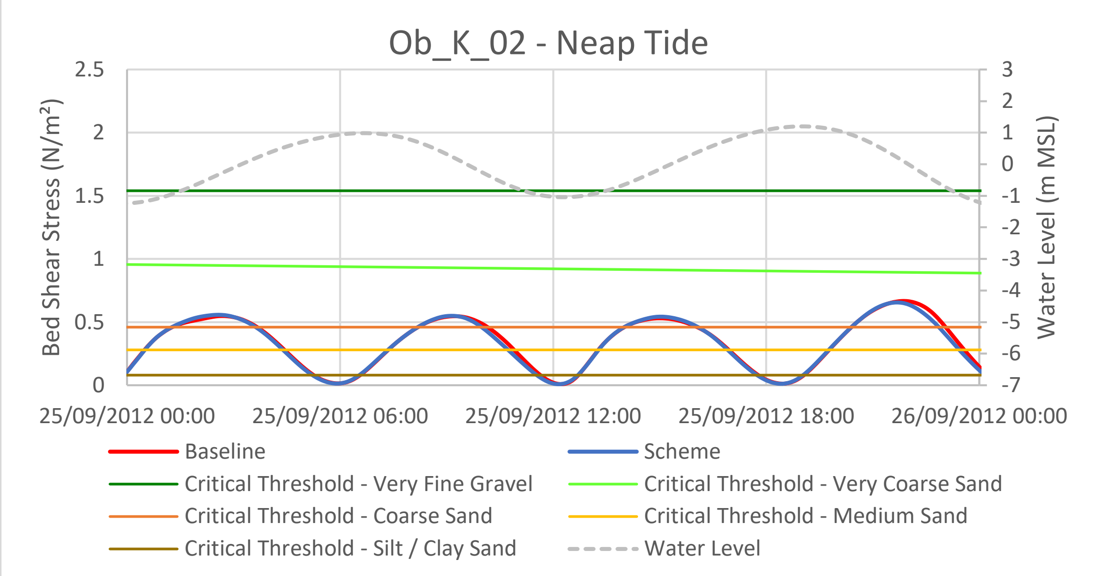
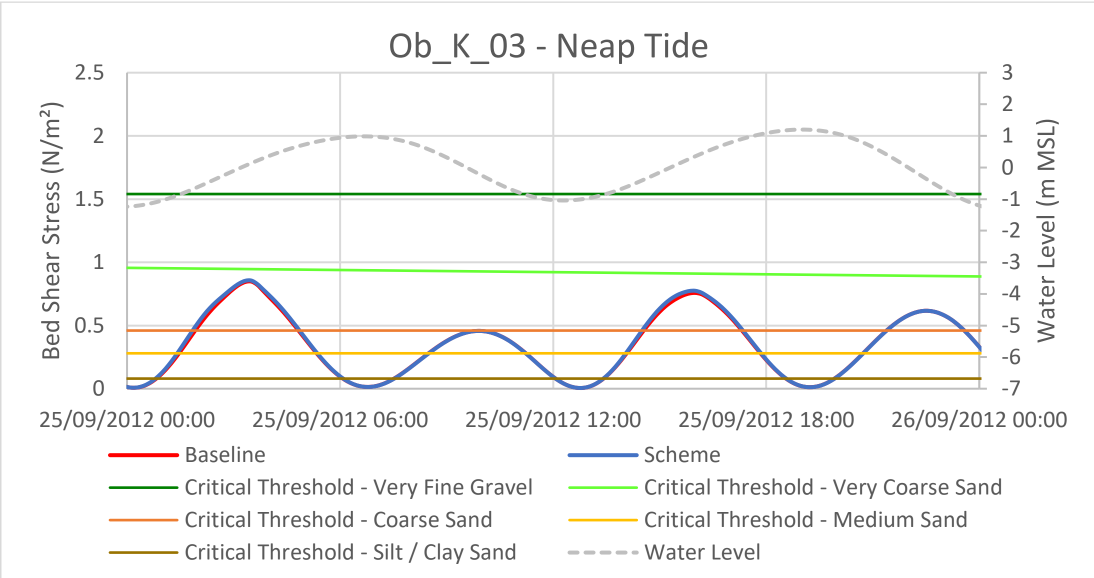


Figure 4-9 Comparison of baseline & scheme bed shear stress and critical erosion thresholds for a mean neap tide at Ob_K_03



For the Bray Bank, time series of predicted bed shear stress and water level for mean spring and mean neap tides are shown in Figure 4-10 to Figure 4-15. Three stations named Ob_B_01, Ob_B_02 and Ob_B_03 align in a west to east transect across the northern part of the development zone. These sites are in 37 m, 5 m and 37 m of water relative to MSL respectively.

Overall, flows and resulting bed shear stresses are higher than observed in the Kish Bank transect, with shear stresses on spring tide peak flows above 4 N/m² for Ob_B_02 (within the OWF development zone). Differing degrees of asymmetry in the time series of bed shear stress are predicted between the three sites, with Ob_B_01 displaying the greatest difference between peak flood (4 N/m²) and peak ebb (3 N/m²) phases of the tide. Across all three sites, the very small differences between the scheme and baseline scenarios are predicted to occur mostly when the bed shear stress is above the critical entrainment threshold for very fine gravels. A very marginal lag in the bed shear stress time series under the RWCS scheme scenario is predicted at Ob_B_01 and Ob_B_03, occurring on the ebb and flood tide respectively.

The predicted time series for neap tides at all three sites show very little change in bed shear stress between the scheme and baseline scenarios.

Figure 4-10 Comparison of Baseline & Scheme Bed Shear Stress and Critical Erosion Thresholds for a Mean Spring Tide at Ob_B_01

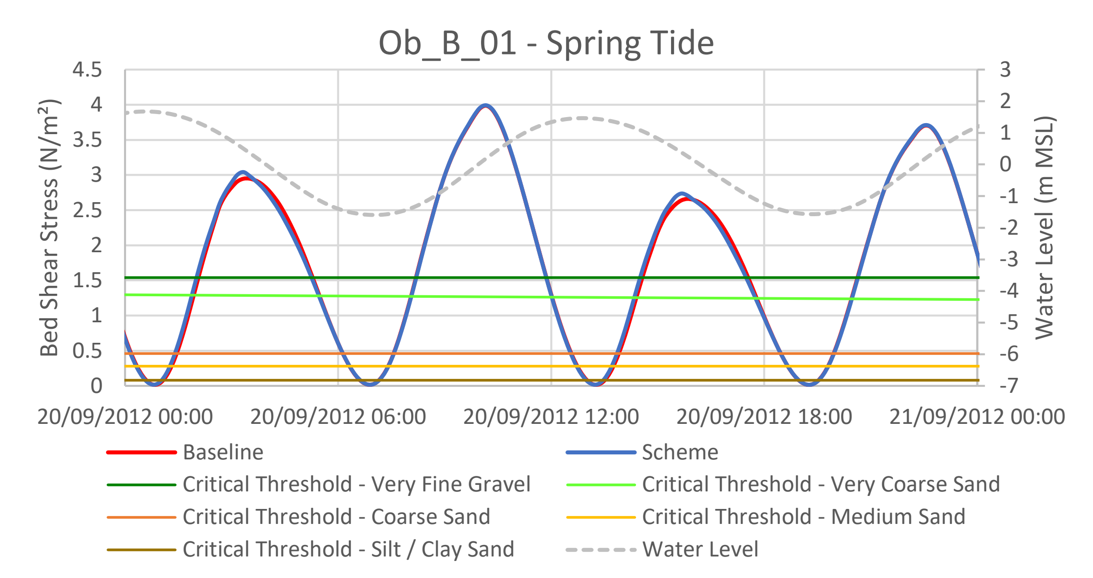


Figure 4-11 Comparison of Baseline & Scheme Bed Shear Stress and Critical Erosion Thresholds for a Mean Spring Tide at Ob_B_02

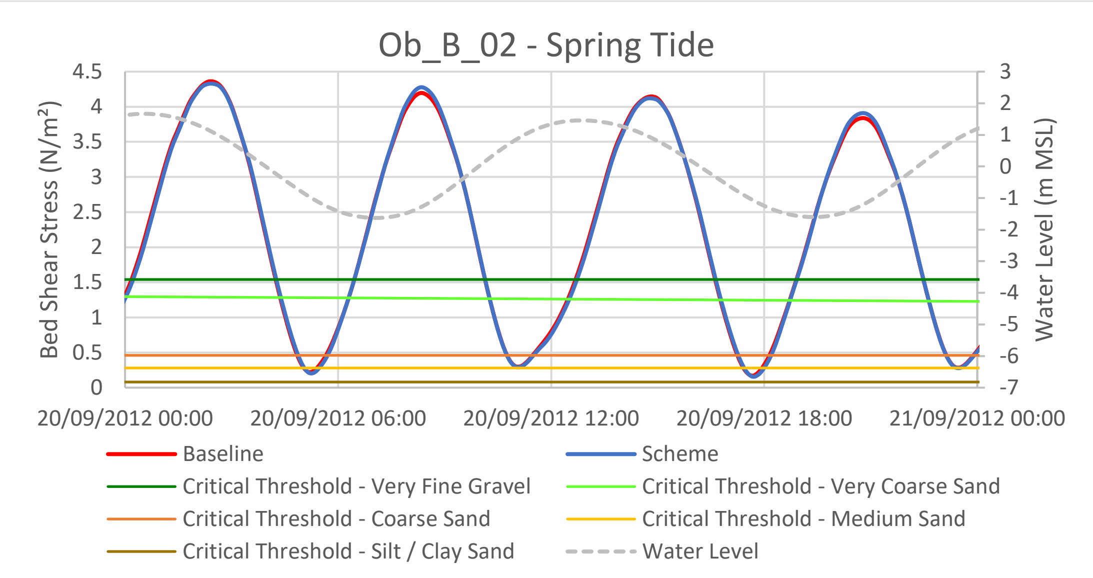


Figure 4-12 Comparison of Baseline & Scheme Bed Shear Stress and Critical Erosion Thresholds for a Mean Spring Tide at Ob_B_03

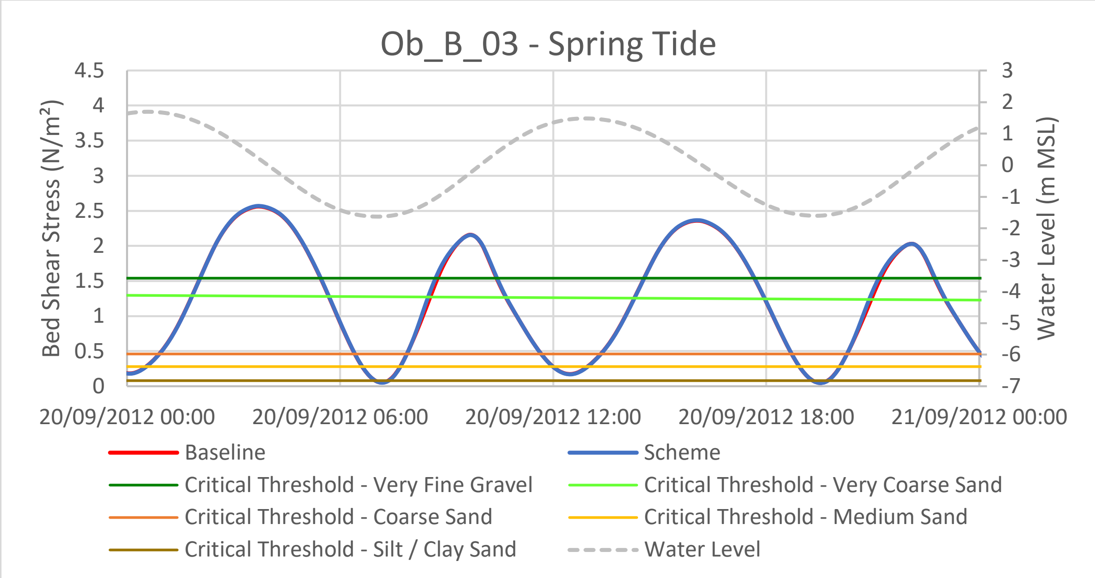


Figure 4-13 Comparison of Baseline & Scheme Bed Shear Stress and Critical Erosion Thresholds for a Mean Neap Tide at Ob_B_01

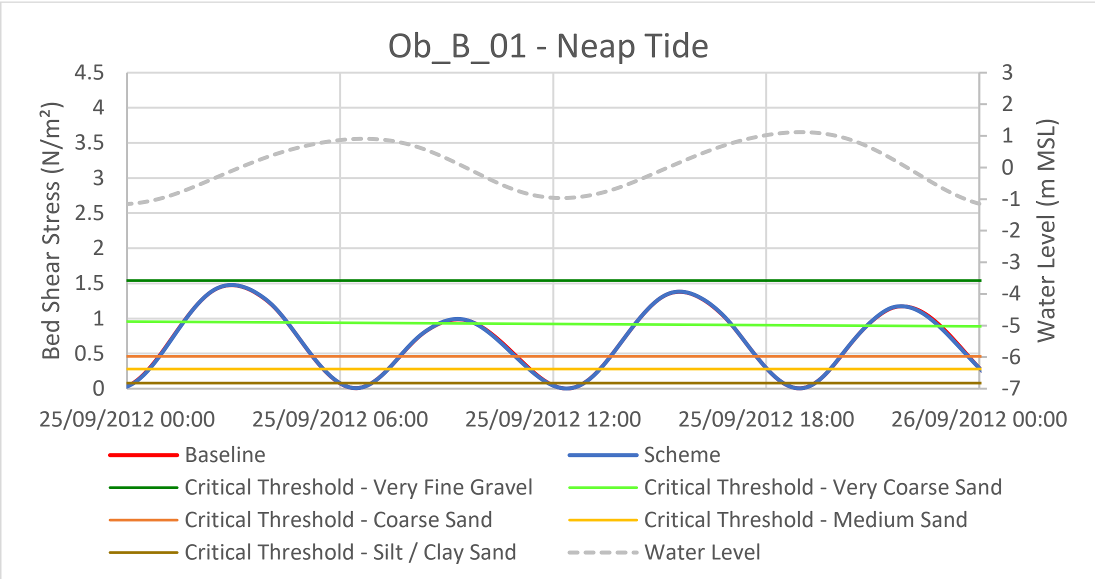


Figure 4-14 Comparison of Baseline & Scheme Bed Shear Stress and Critical Erosion Thresholds for a Mean Neap Tide at Ob_B_02

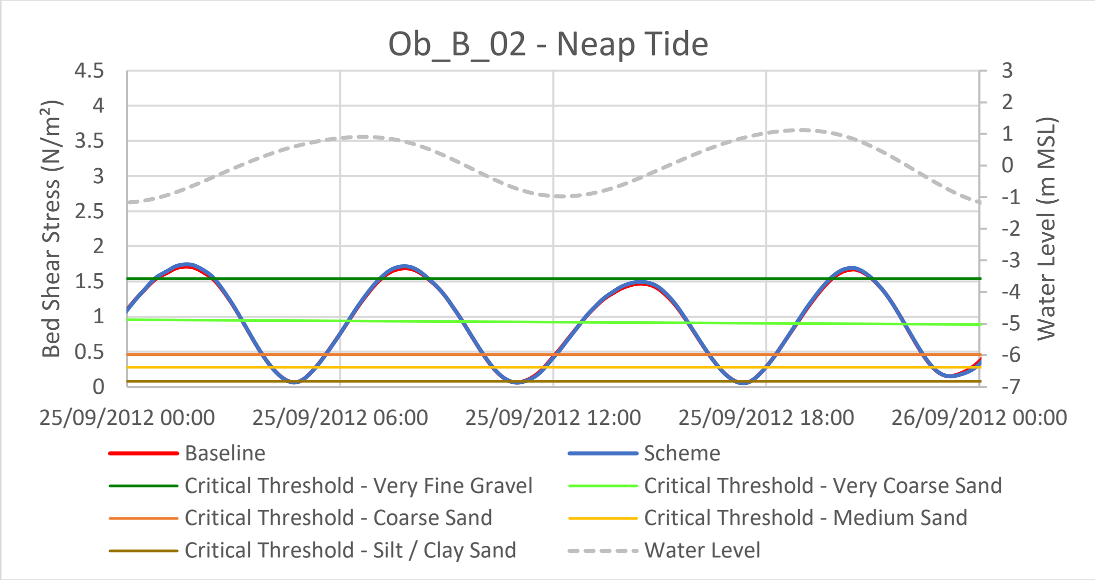
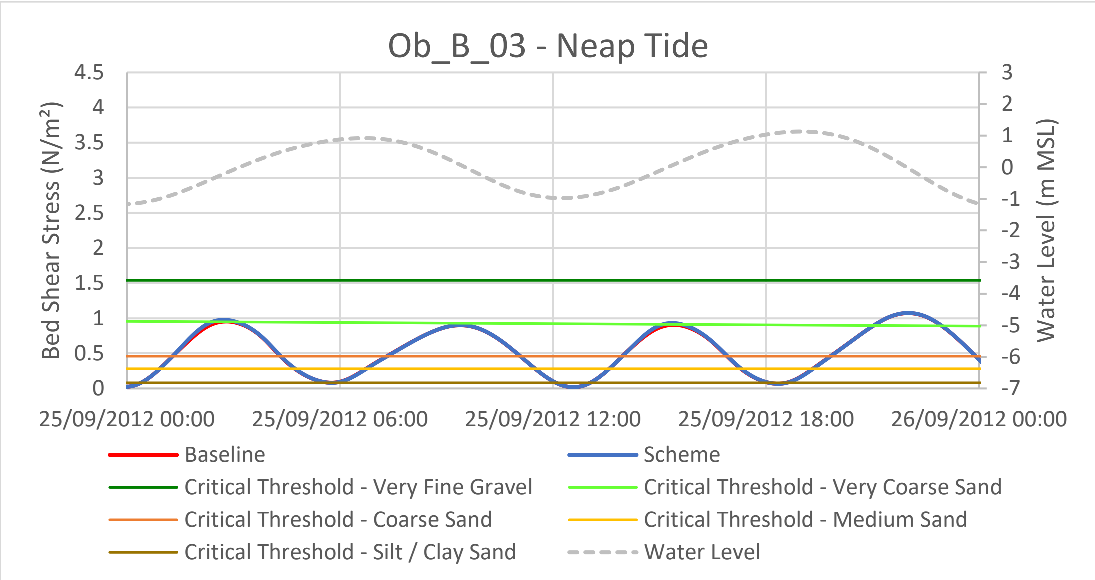


Figure 4-15 Comparison of Baseline & Scheme Bed Shear Stress and Critical Erosion Thresholds for a Mean Neap Tide at Ob_B_03



4.3.2.2 Scour Development and Protection

The process scour around structures and typical mitigation measures is introduced in Section 2.2.

Calculations undertaken in the RWCS review considered a total of six options, comprising 3 foundation types and two types of WTG design.

The total area of seabed susceptible to scour is calculated by aggregating the estimated width of scour development (to the equilibrium scour depth) as being proportional to 4 times the diameter of the structure being examined. The range of area lost to scour across all six options considered is between 42,942 m² to 119,282 m², with the worst case relating to the monopile structure for the > 15 MW WTG option. This quantifies the potential maximum area that could develop during the period prior to scour protection being installed. However, the present option allows for a filter layer to be pre-installed to help mitigate scouring in this period.

When full scour protection is installed the height of rock armour above the seabed is estimated as being up to 2 m with a 1:2 slope. Across all scenarios assessed, the seabed area lost due to the instillation of scour protection ranges from 92,704 m² to 160,076 m², with the worst case relating to the 3-legged multi-leg for the 12 to 15 MW WTG option.

4.3.3 Decommissioning Phase

As it is not yet known what decommissioning plan will be put in place, no modelling of the impacts due to the decommissioning phase has been undertaken. However, it is possible that all equipment, including cables and foundations, may need to be removed, in which case a similar level of impact as predicted by the construction phase modelling would result, although it is noted that impacts are likely to be less due to the fact that no bed-levelling through dredging would be required.

4.4 Impacts due to the Future Climate Change

4.4.1 Impacts on the Hydrodynamic Regime

The effect on the hydrodynamic regime due to potential climate change has been modelled using the DAPPMS HD model. The results of the modelling are shown in Appendix B.2. For hydrodynamics, climate change effects have been simulated by modelling an increase in water depth of 0.60 m. This predicted rise is based on the latest advice / projections from the Environmental Protection Agency (EPA), which currently suggests a SLR of 0.55 to 0.60 m by 2100.

4.4.1.1 Changes to Water Levels

Difference plots based on the RWCS and baseline scenarios with sea level rise included are presented for water levels in Figure B-41 to Figure B-48, and cover spring and neap conditions. The increase in water levels is shown to have a very small change in the impact of the scheme compared to the present day condition (shown in Figure B-1 to Figure B-8).

The projected rise in sea level under climate change is far greater in magnitude than the predicted change in water levels resulting from the proposed OWF development.

4.4.1.2 Changes to Tidal Currents

Difference plots based on the RWCS and baseline scenarios with sea level rise included are presented for current speeds in Figure B-49 to Figure B-56.

As with water levels, there is no meaningful change to the impact of the scheme under sea level rise compared to present day conditions (shown in Figure B-9 to Figure B-16).

4.4.2 Impacts on the Wave Climate

4.4.2.1 Changes to Significant Wave Height

Difference plots for the RWCS and baseline simulations that include sea level rise are presented for significant wave height in Figure B-89 to Figure B-94. These plots represent the 1-in-100 year scenarios for waves approaching from the north, east and south.

In general, predicted differences under the sea level rise scenarios are comparable to the model scenarios without sea level rise. The north, east and south 1-in-100 year wave scenarios without SLR predicted a maximum reduction in H_{mo} of 0.04 m from the baseline to the RWCS. For the SLR scenario this predicted reduction was slightly larger at 0.06 m. For both with and without SLR this change equates to less than a 2% of significant wave height.

5. DISCUSSION AND CONCLUSIONS

5.1 Overview of Assessment and Model Predictions

The DAPPMS has been used to predict the potential impacts of the Realistic Worst Case Scenario arising from the Project Design of the Dublin Array Offshore Wind Farm. The RWCS was derived from the Project Description and details of its derivation are reported in the Dublin Array Marine Processes Determination of Realistic Worst Case memo (Appendix E). The DAPPMS is calibrated to an appropriate standard for conducting impact assessment as reported in the Hydrodynamic and Spectral Wave Calibration and Validation Reports (Intertek 2020a, 2020b).

The work undertaken in this physical process assessment is based on applied assumptions that form a 'realistic worst case'. The final design of the scheme will be within the design envelope considered and subsequently modelled. Therefore, the changes to the physical marine environment are not anticipated to be greater than those predicted and may be less than presented in line with the Rochdale Envelope approach.

To assess the operational blockage effects of the RWCS on local hydrodynamics within the array site and surrounding coastal waters Intertek used the calibrated DAPPMS HD model. The impact of the scheme was assessed for mean spring and neap tide conditions. The model predictions indicate that impacts on water levels and current speeds will be very small. Effects of the scheme are largely limited to within the array, or in limited cases a few kilometres outside of the array boundary. The magnitude of impacts are limited to a localised ± 2 mm change in water level (less than ± 0.03 % change in tidal range), and a ± 0.04 m/s change to current speeds. As the changes to the hydrodynamics are localised to the vicinity of the array, no material changes to the nearshore coastal processes have been predicted.

Blockage effects were also assessed for a precautionary future scenario incorporating the projected sea level rise for the year 2100. Hydrodynamics were again assessed for a mean spring and neap tide. The model predictions show that potential impacts under the RWCS for the sea level rise scenario will not be materially different to potential impacts for the present day simulations with no sea level rise.

To assess the in-operation blockage effects of the RWCS on the wave climate within the array site and surrounding coastal waters Intertek used the calibrated DAPPMS SW model. In total 38 scenarios were investigated including waves approaching from the north, east, south and west (the last of these being purely wind-driven). The results show that the operational impacts of the Dublin Array Offshore Wind Farm on the local wave climate are very small, with significant wave heights reducing by a maximum of 0.04 m (less than 3%) for even the most extreme return-period model scenarios. As the changes to the wave climate are localised to the vicinity of the array, no material changes to the littoral processes have been predicted.

Three additional scenarios were modelled to investigate the potential impact of the OWF on the wave climate under conditions of future sea level rise. The model predictions showed that the development would cause a marginally larger change from baseline conditions under future sea level rise than under present day conditions, with a maximum difference of 0.06 m in H_{m0} for the biggest storm waves (equating to a relative reduction in height of 2%). Sea level rise may therefore be considered an immaterial factor with respect to the changes in the wave climate from the presence of the proposed development.

To assess the impacts of the construction phase on the local sediment regime, a number of seabed disturbance scenarios were modelled for different construction activities using the DAPPMS Particle Tracking model. These scenarios assessed the impacts of finer sediment fractions released into the water column or disposed of on the bed. For the majority of seabed disturbance scenarios modelled, impacts are shown to be transitory, with suspended sediments returning to mean background levels within hours (up to 3 hours)of the completion of construction works.

The deposited thickness of sediments was also assessed, with localised footprints identified for spoil mounds from indicative dredge disposal. The settling thickness for fine fraction material dispersed across the domain is predicted to be low. The deposition of coarse-grained material is presented in the dimensions of spoil mounds, assessed through a separate methodology.

An assessment of local changes to bed shear stress during the operational phase of the development showed very little change to the magnitude or duration from baseline conditions. As such, potential changes to the local sediment regime resulting from changes to bed shear stresses are likely to be *de minimis*.

5.2 Limitations

The assessment of baseline conditions is taken from calibrated and validated HD and SW models. The calibration and validation process has demonstrated that these models are consistent with field data and other relevant sources of information, such as previous studies, but models are only representations of reality and can never be 100% accurate. However, the numerical models used in this physical process assessment are very good at identifying relative differences between scenarios. The results and conclusions presented here are therefore valid and fit for the requirements of the EIA and specifically for assessing the potential effects on physical processes.

5.3 Conclusions

The following key conclusions are drawn from the Dublin Array OWF physical process assessment:

- The predicted impact of the scheme on water levels is very small, with a maximum absolute impact of ± 2 mm, equating to less than 0.1% of the tidal range.
- The predicted impact of the scheme on current speeds is also very small, with a maximum absolute impact of ± 0.04 m/s.
- Hydrodynamic impacts are localised to within and occasionally around the array site, and therefore it can be inferred that there will be a very small impact from the OWF on nearshore coastal processes.
- There is very little difference between predicted scheme impacts assessed under present day conditions and those assessed for a future scenario accounting for sea level rise to 2100.
- The predicted impact of the OWF on the wave climate during the operational phase is very small, with a maximum predicted impact under the highest wave scenarios of less than 0.04 m, equating to a relative difference of less than 3%.
- Predicted impacts on the wave climate are generally confined to the vicinity of the array site. As such, no measurable changes on the littoral processes or receptors away from the array site are anticipated.
- The predicted impact of the development on the wave climate under conditions of future sea level rise is not materially different to those impacts predicted for the present-day situation.
- An assessment of changes to bed shear stress and resultant changes to the local sediment regime during the operational phase indicates that the sediment regime will not be substantially affected by the development.
- Sediment disturbance from construction processes occurring during the construction phase result in transient impacts in terms of elevated suspended sediment concentrations, and only very small impacts to the deposition of fine fraction sediments for the majority of scenarios modelled.

- Concentrations of suspended sediment are shown to persist for up to 3 hours after completion of sediment release, with most scenarios returning to background values within 30 minutes. The size and thickness of spoil mounds within the nominated disposal sites are considered, with an estimation of maximum thickness depth and area of coverage. The maximum covering depth for one hopper load of dredged material is 1.77 m if deposited at low water.

REFERENCES

1 Admiralty (1974). NP256: Irish Sea and Bristol Channel, *Admiralty Tidal Stream Atlas Tables,* 3rd ed.

2 Environmental Protection Agency (2017). *'A summary of the State of Knowledge on Climate Change Impacts for Ireland.* EPA Research Report No. 223.

3 innogy (2020). *'Consents Project Description Spreadsheet.* Document Reference : 002758829-01

4 Intertek (2020a). *'Dublin Array Offshore Windfarm: Hydrodynamic Calibration and Validation Report.* R2344_R4968_Rev1.

5 Intertek (2020b). *'Dublin Array Offshore Windfarm: Spectral Wave Model Calibration and Validation Report.* R2344_R2894_Rev0.

6 Tiron, Gallagher, Gleeson, Dias & McGrath (2015). '*The future wave climate of Ireland: from averages to extremes'*. IUTAM Symposium on the Dynamics of Extreme Events Influenced by Climate Change.

7 United Kingdom Hydrographic Office, 2019. NP201A 2020: United Kingdom, English Channel to River Humber, *Admiralty Tide Tables,* **Vol. 1A**, 2020 ed.

Appendix A

Baseline Modelled Outputs

A.1 BASELINE HYDRODYNAMIC REGIME

A.1.1 Water Levels

Figure A-1 Mean spring tide water level at high water

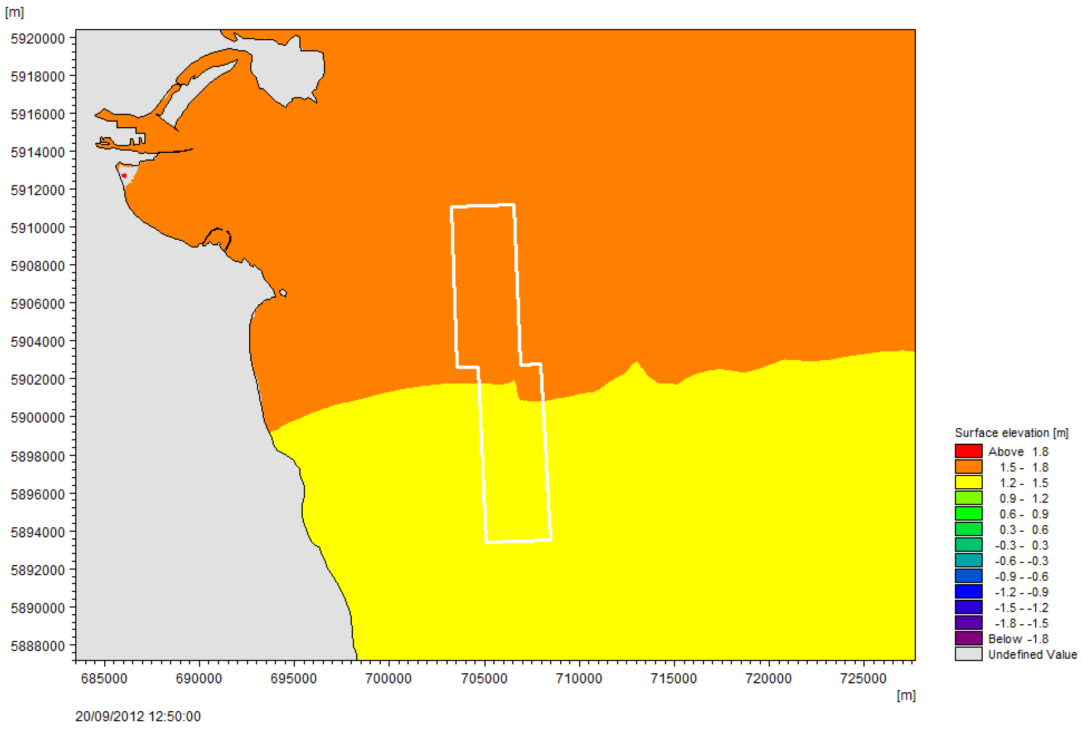


Figure A-2 Mean spring tide water level at low water

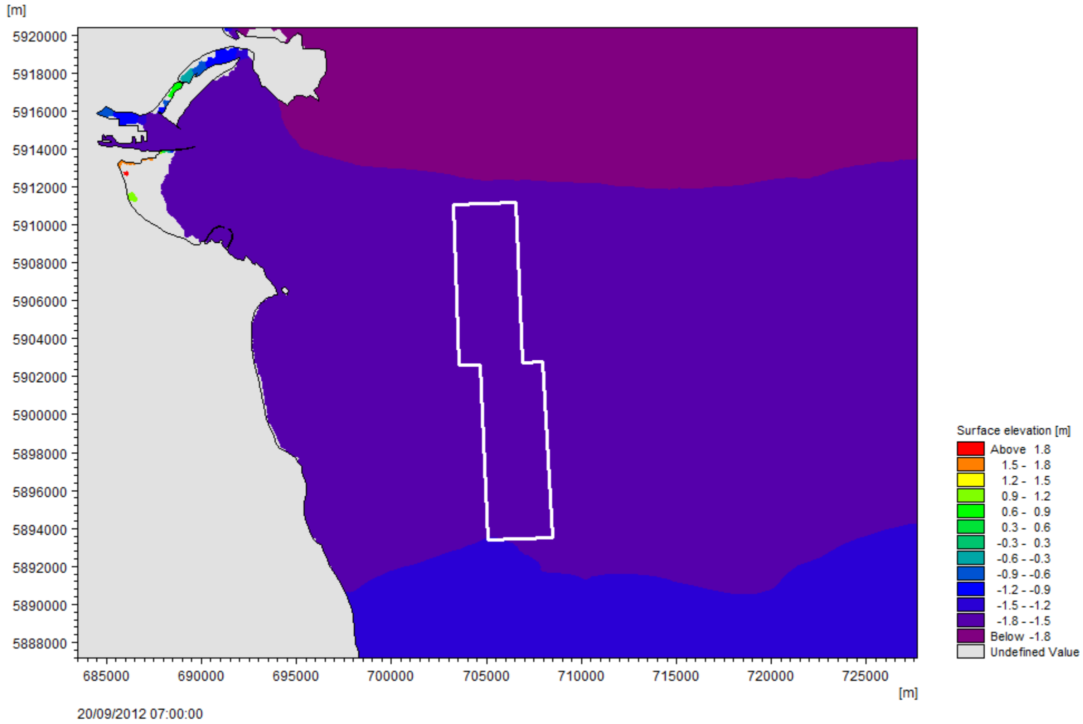


Figure A-3 Mean spring tide water level at peak flood

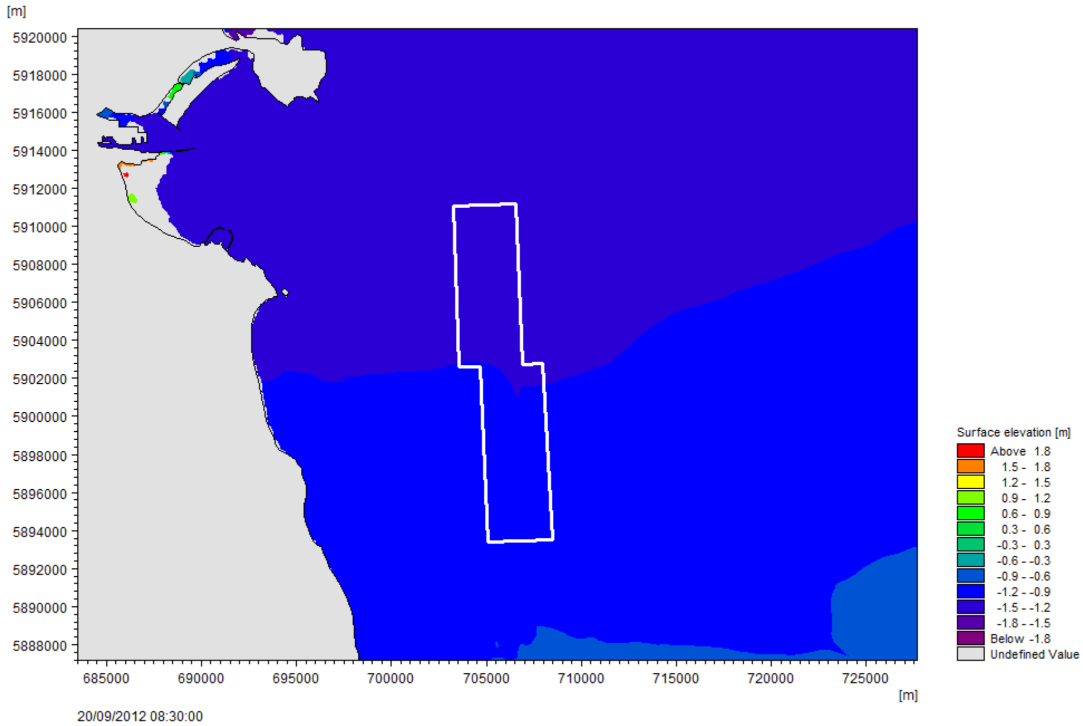


Figure A-4 Mean spring tide water level at peak ebb

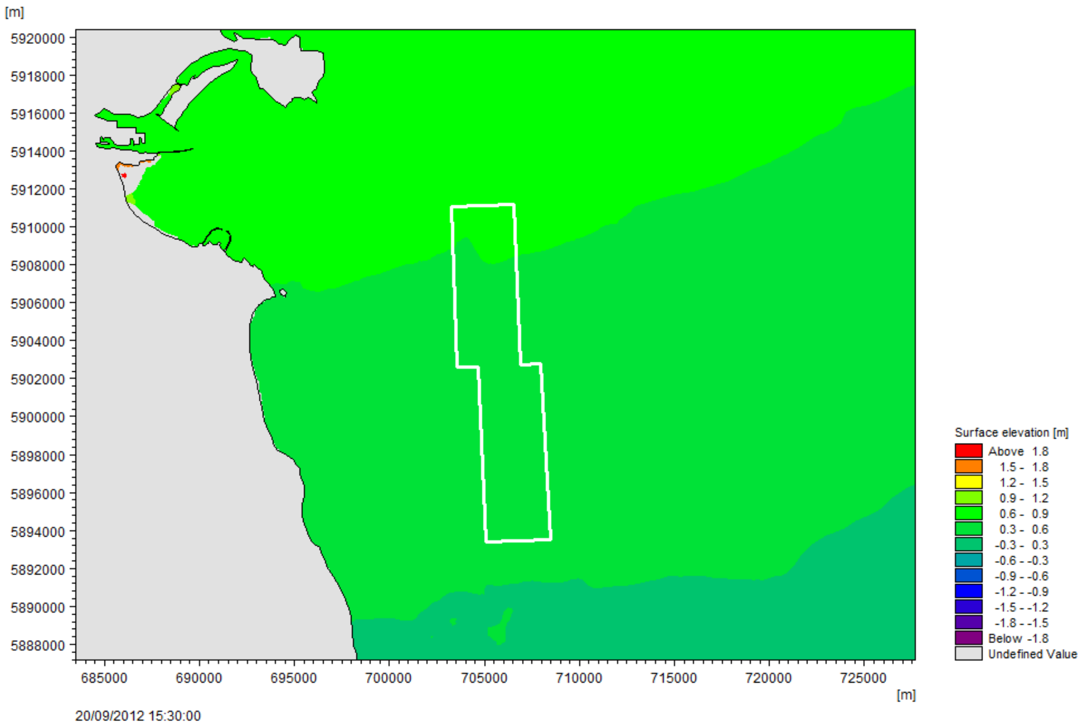


Figure A-5 Mean neap tide water level at high water

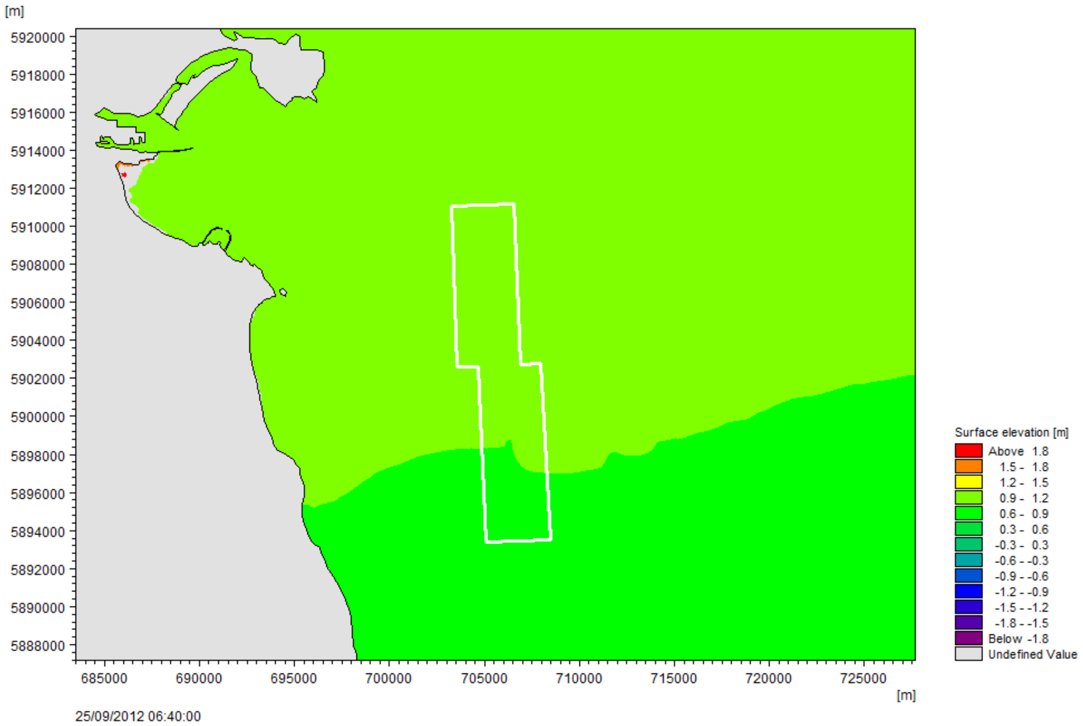


Figure A-6 Mean neap tide water level at low water

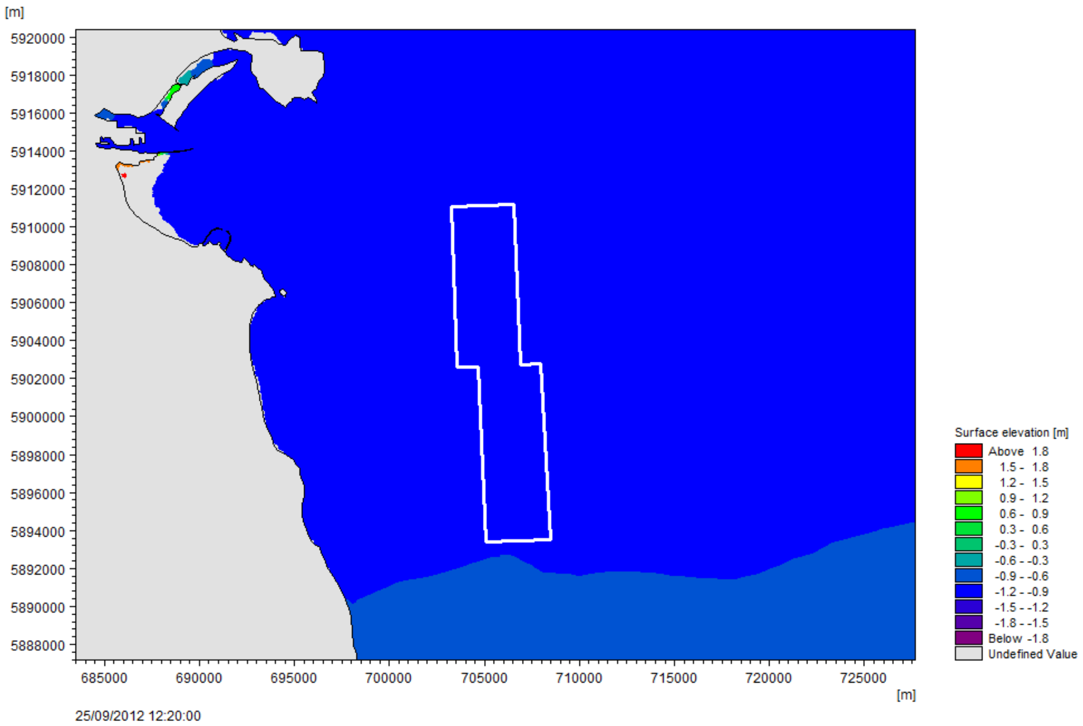


Figure A-7 Mean neap tide water level at peak flood

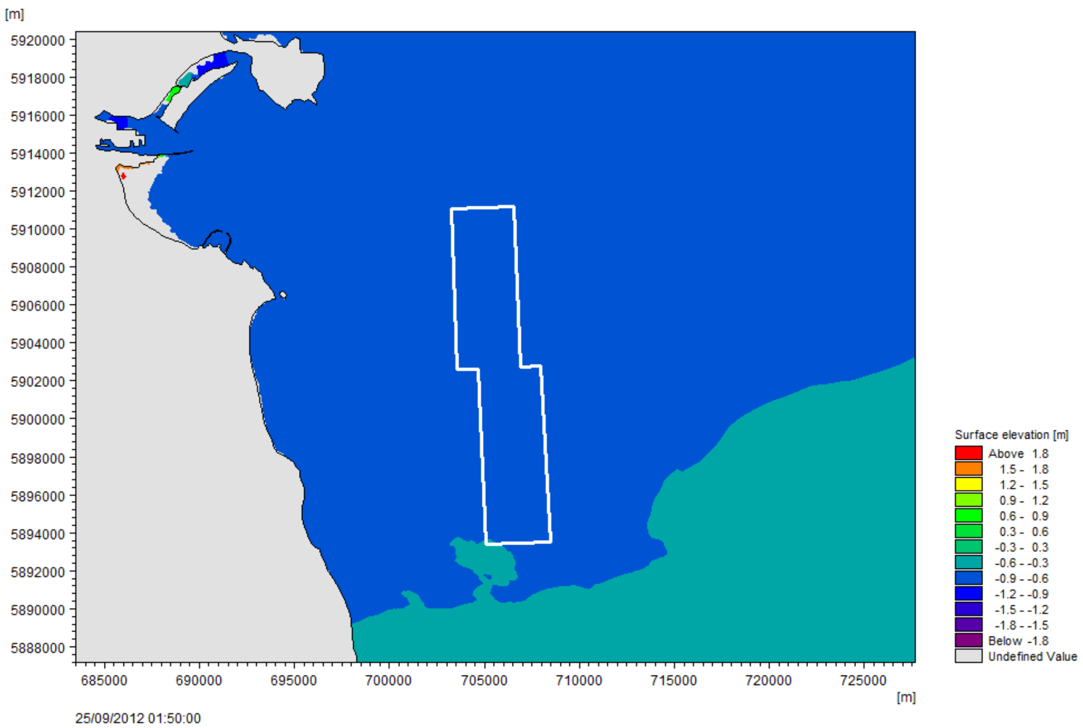
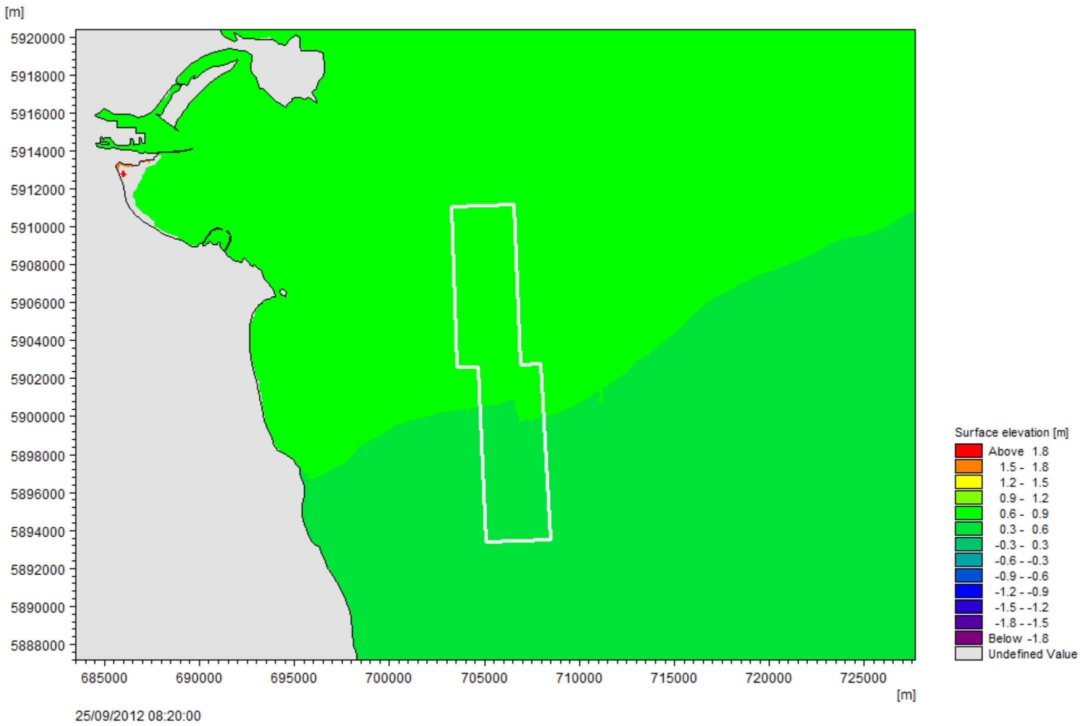


Figure A-8 Mean neap tide water level at peak ebb



A.1.2 Current Speeds

Figure A-9 Mean spring tide current speeds at high water

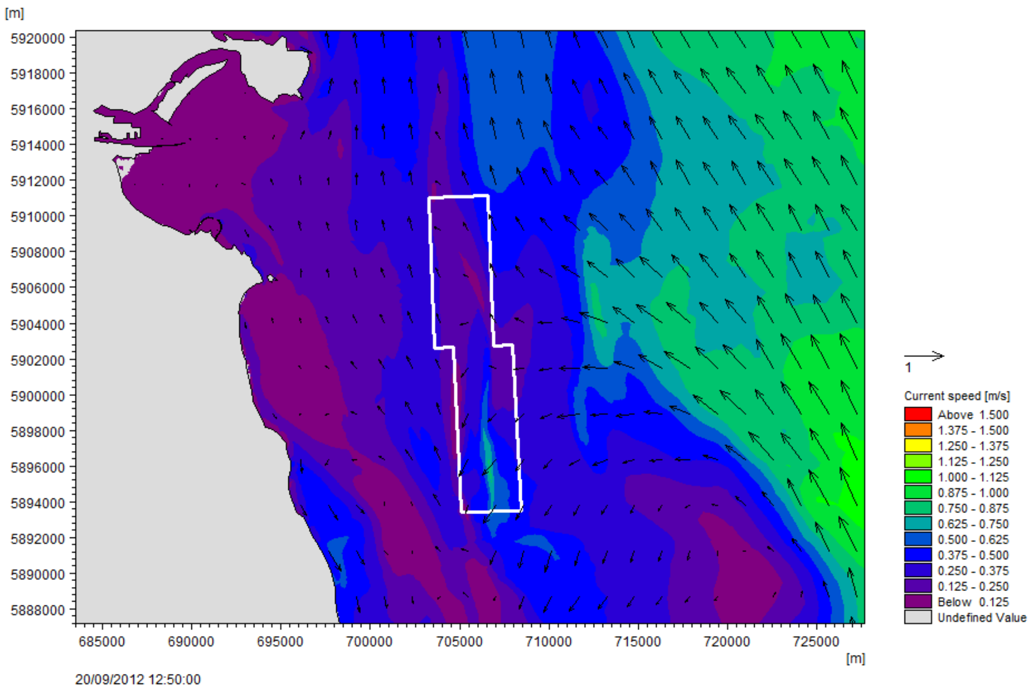


Figure A-10 Mean spring tide current speeds at low water

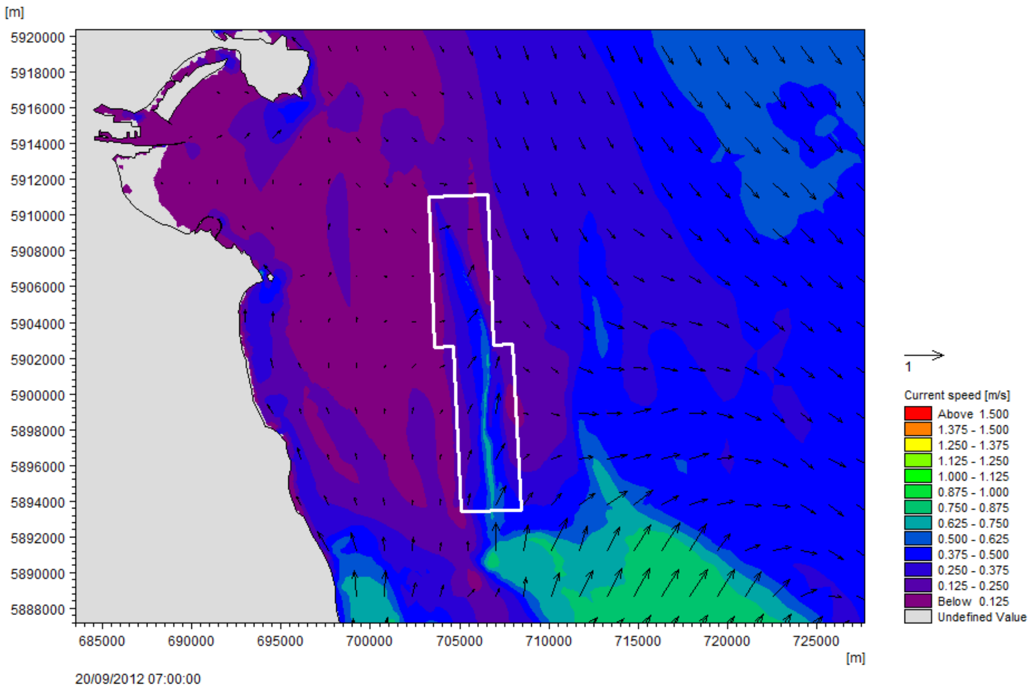


Figure A-11 Mean spring tide current speeds at peak flood

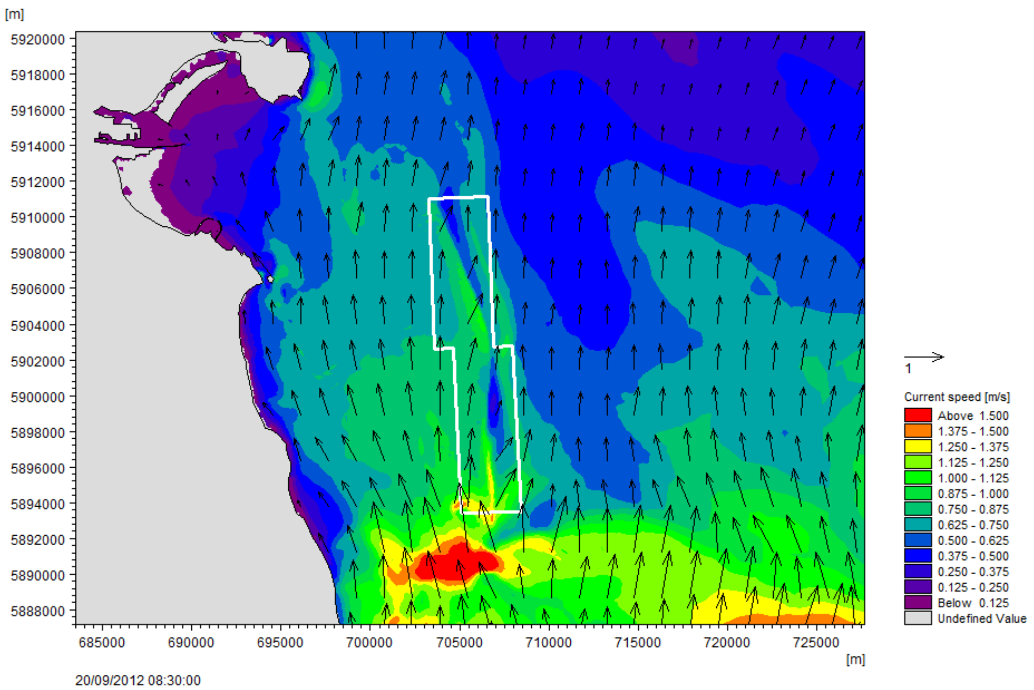


Figure A-12 Mean spring tide current speeds at peak ebb

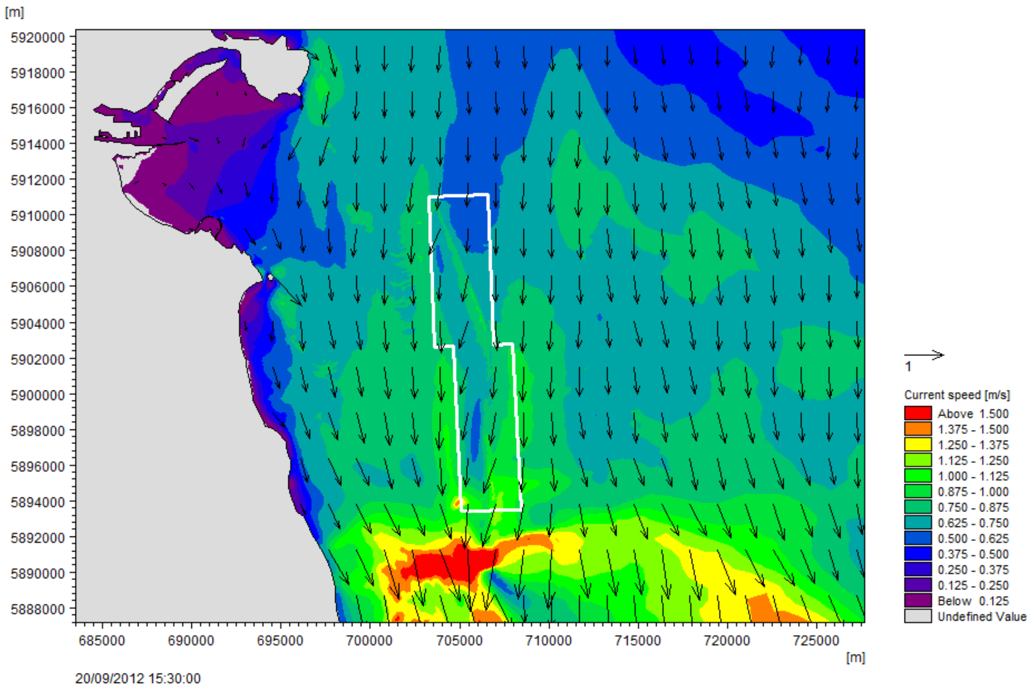


Figure A-13 Mean neap tide current speeds at high water

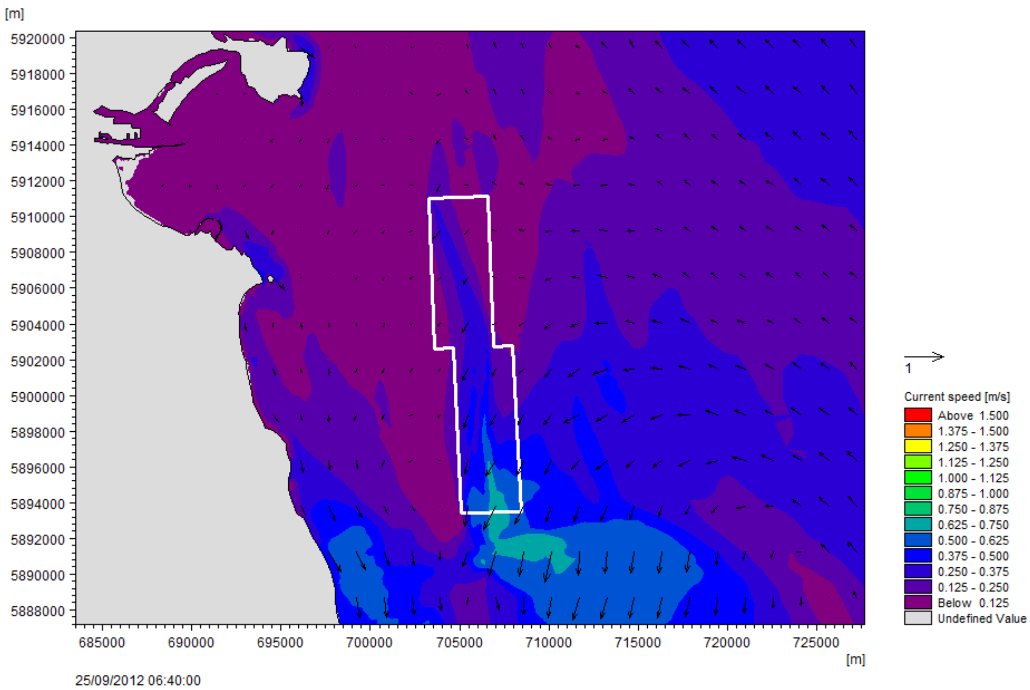


Figure A-14 Mean neap tide current speeds at low water

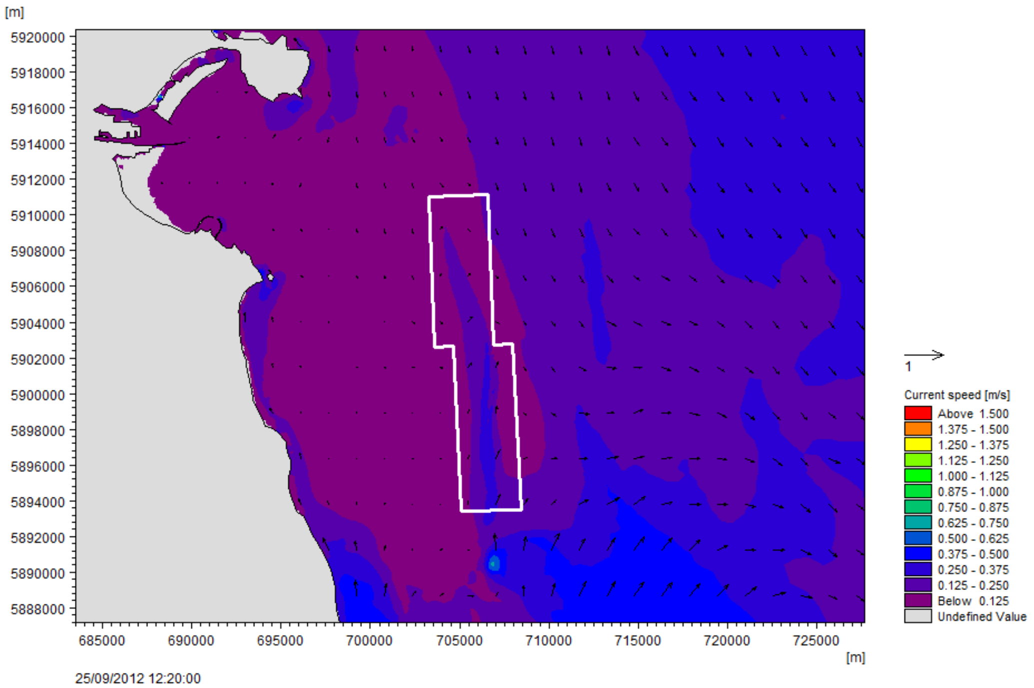


Figure A-15 Mean neap tide current speeds at peak flood

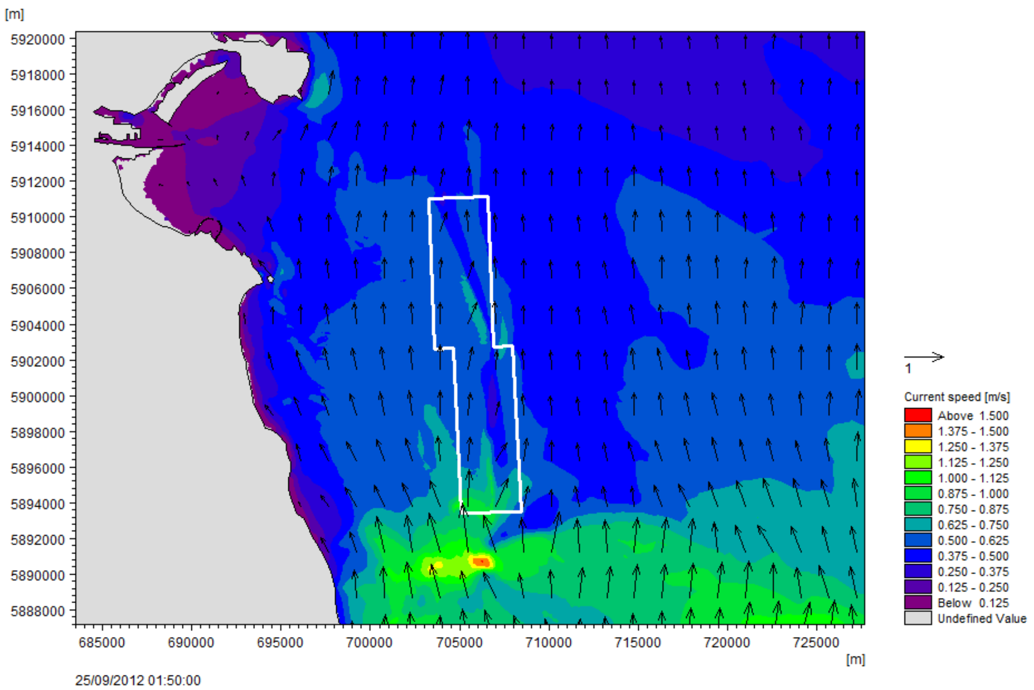
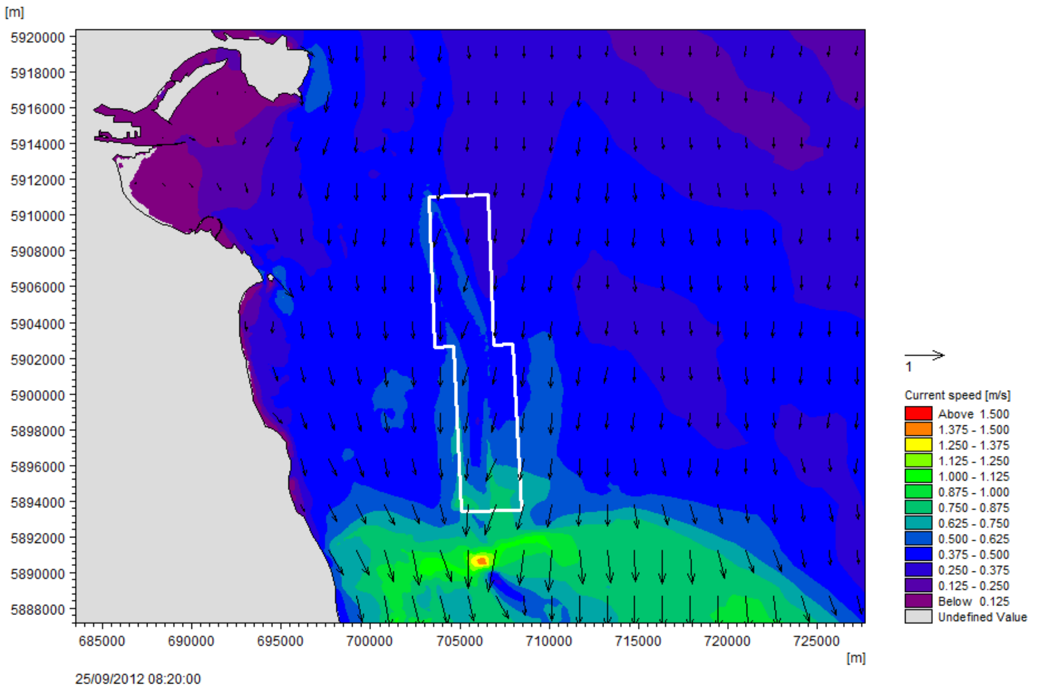


Figure A-16 Mean neap tide current speeds at peak ebb



A.1.3 Bed Shear Stress

Figure A-17 Mean spring tide bed shear stress at high water

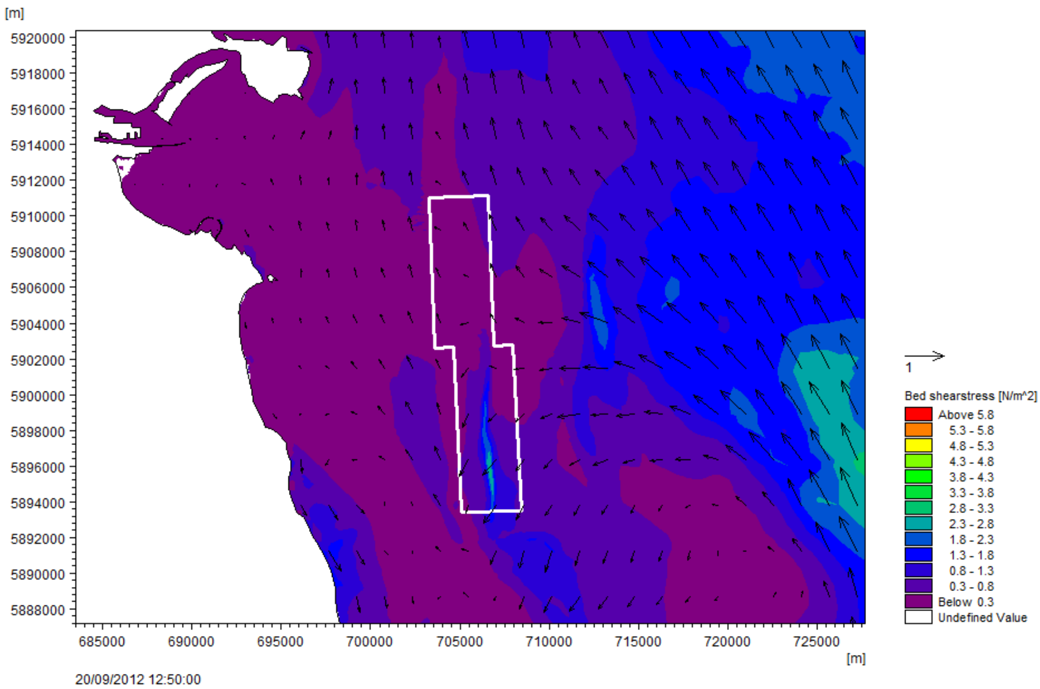


Figure A-18 Mean spring tide bed shear stress at low water

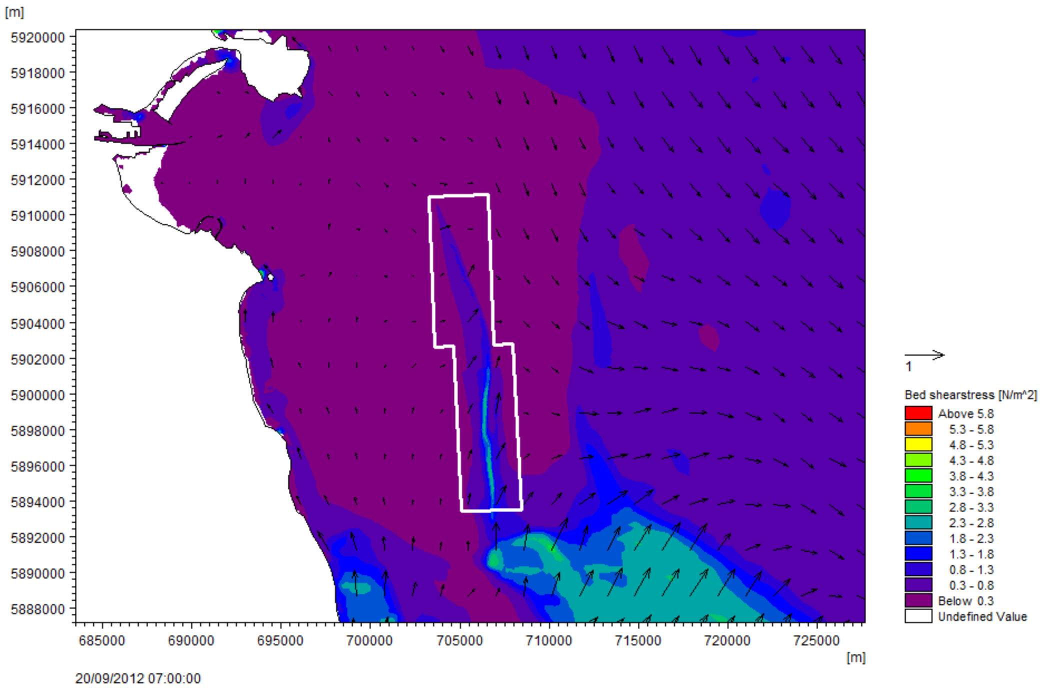


Figure A-19 Mean spring tide bed shear stress at peak flood

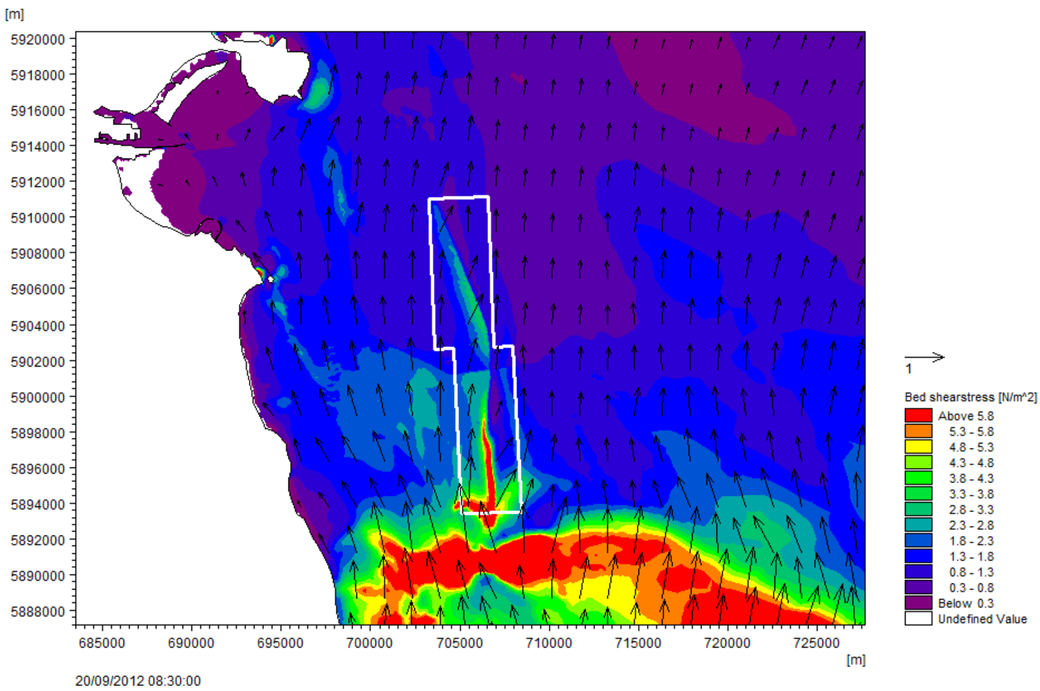


Figure A-20 Mean spring tide bed shear stress at peak ebb

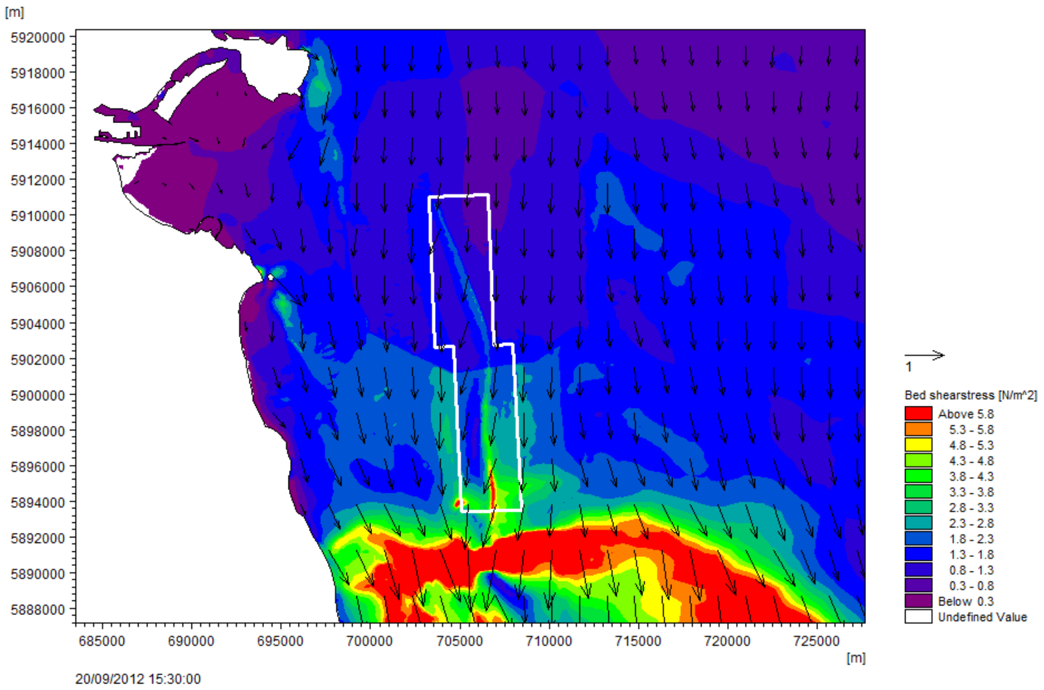


Figure A-21 Mean neap tide bed shear stress at high water

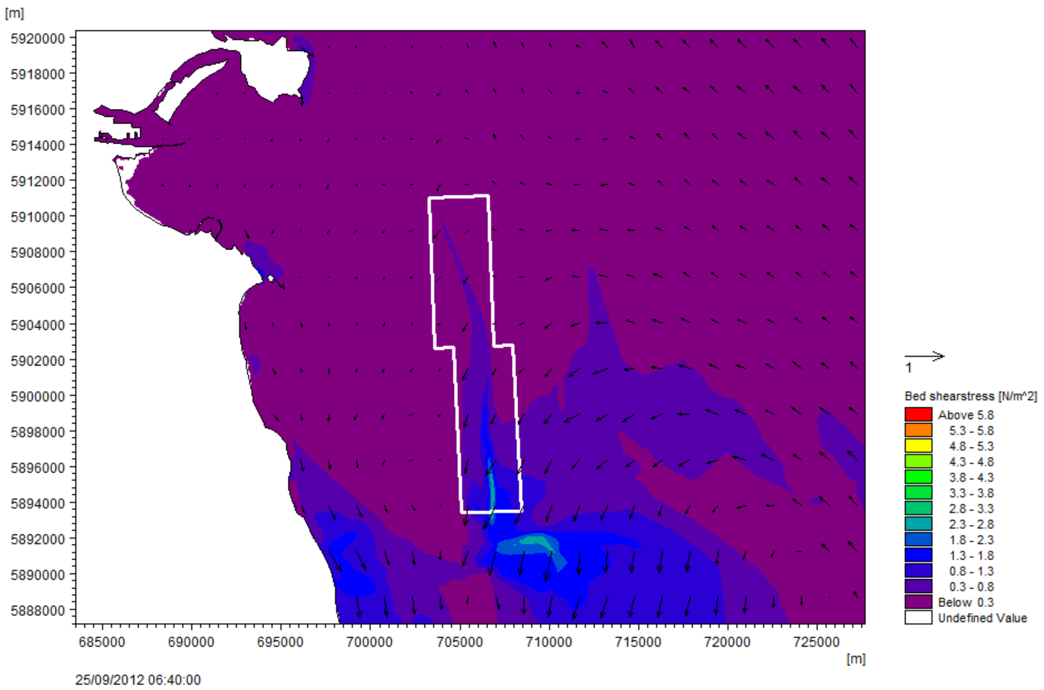


Figure A-22 Mean neap tide bed shear stress at low water

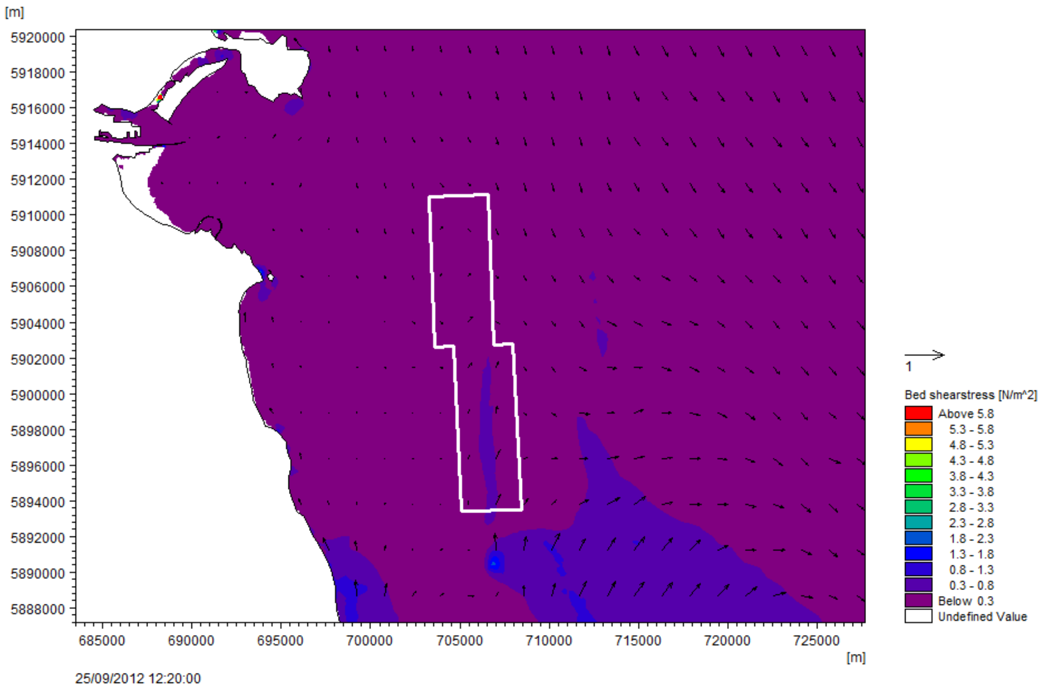


Figure A-23 Mean neap tide bed shear stress at peak flood

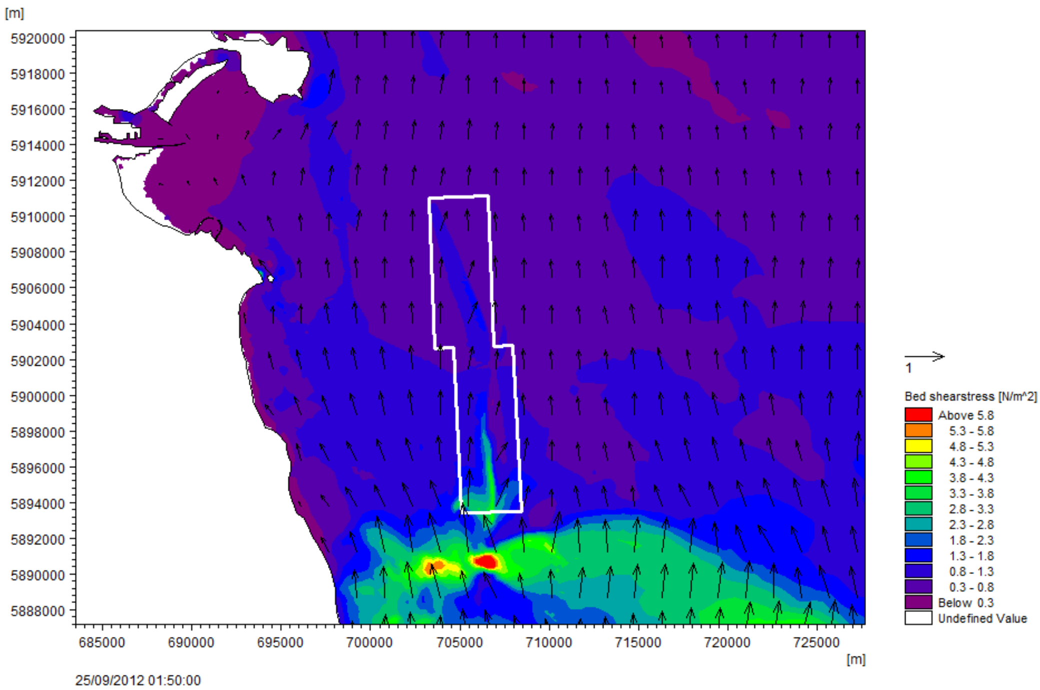
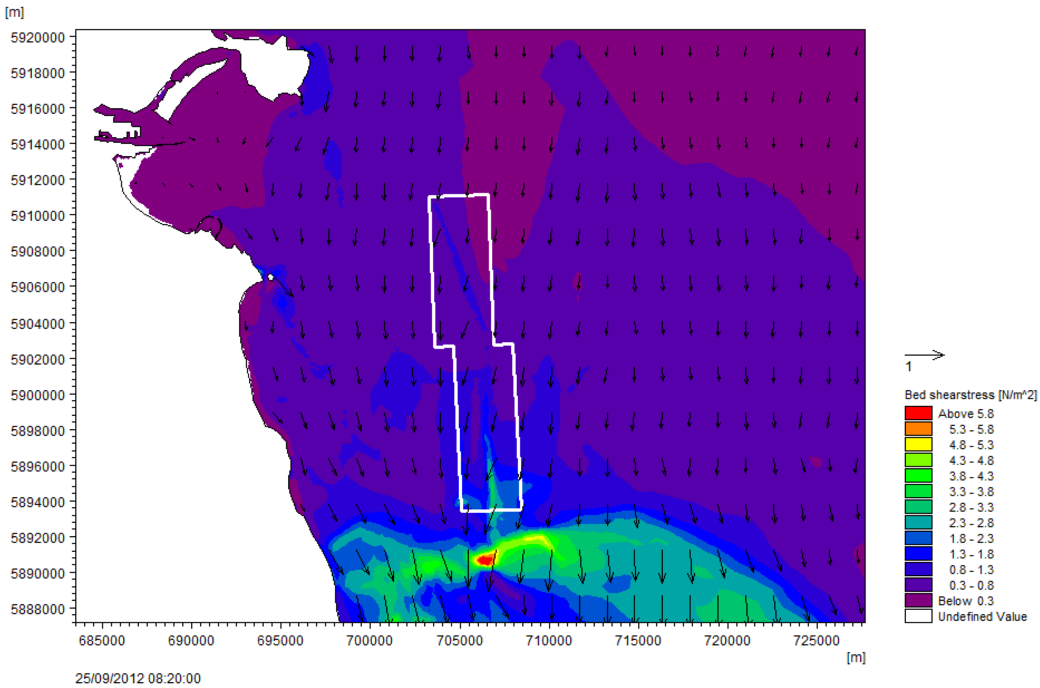


Figure A-24 Mean neap tide bed shear stress at peak ebb



A.2 WAVE CLIMATE

Figure A-25 H_{m0} (m), wave direction from north, 50%ile scenario

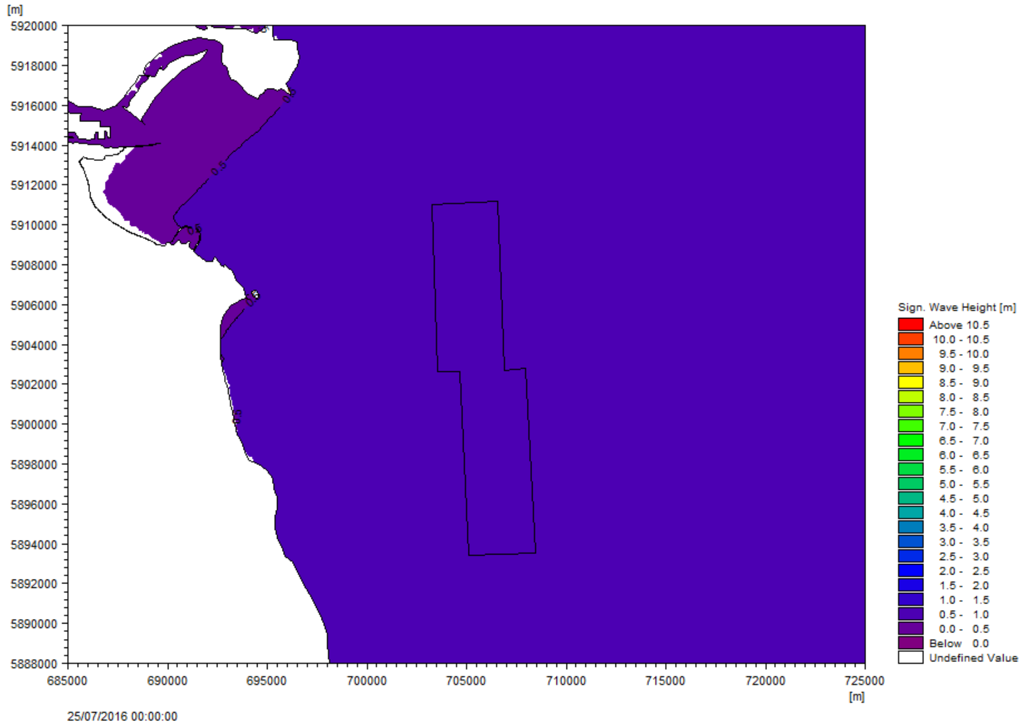


Figure A-26 H_{m0} (m), wave direction from north, 5%ile scenario

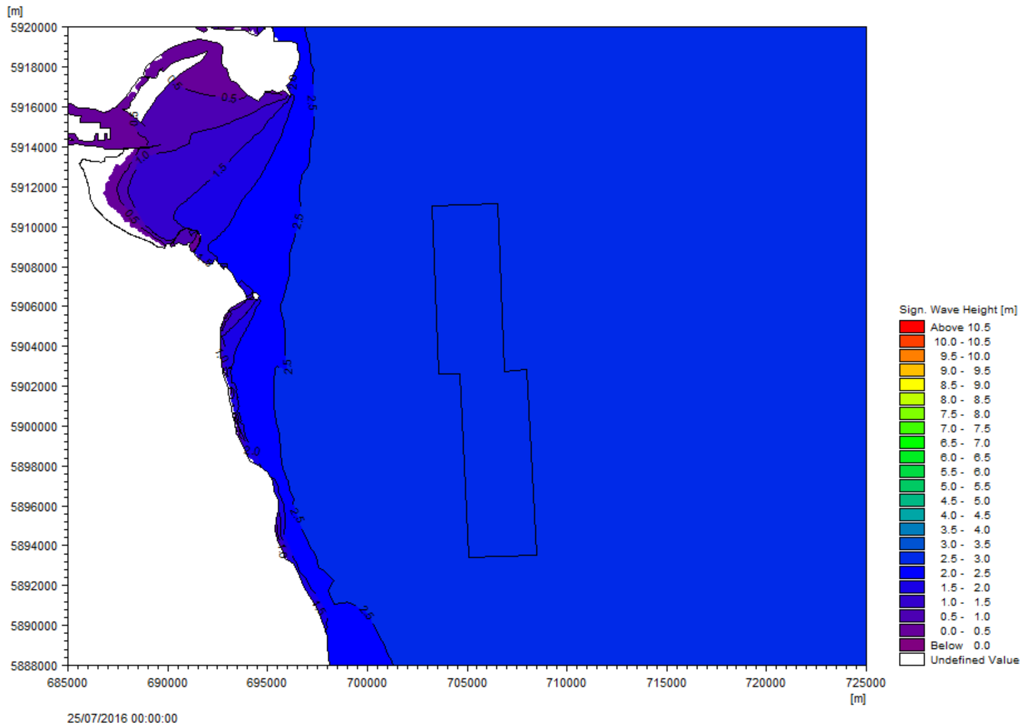


Figure A-27 H_{m0} (m), wave direction from north, 1 in 1 year scenario

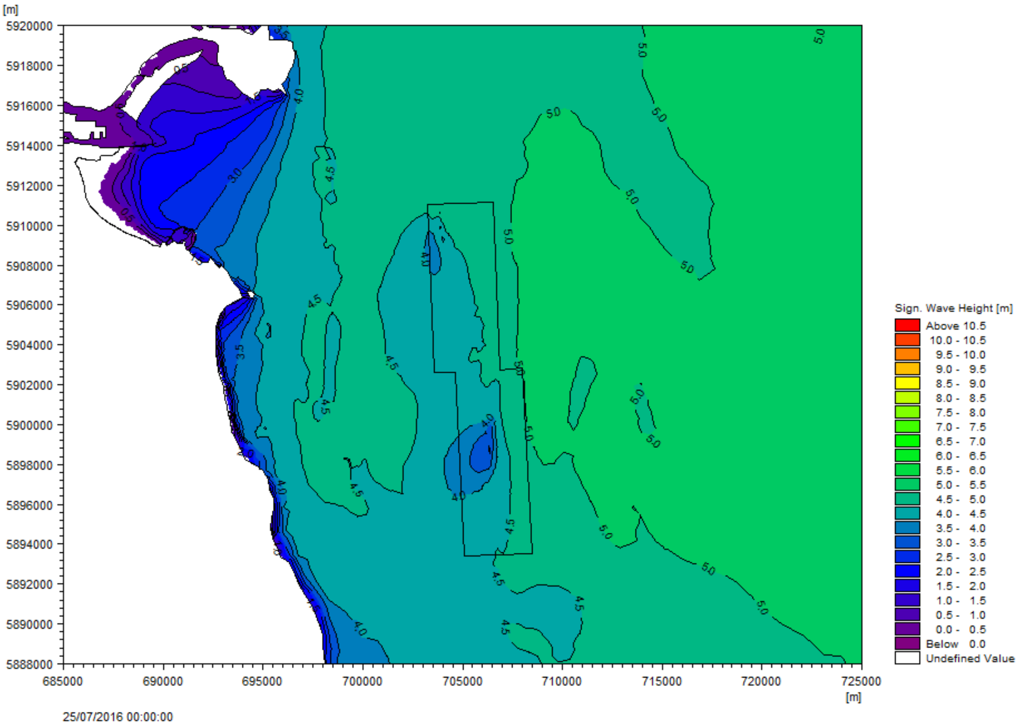


Figure A-28 H_{m0} (m), wave direction from north, 1 in 100 year scenario

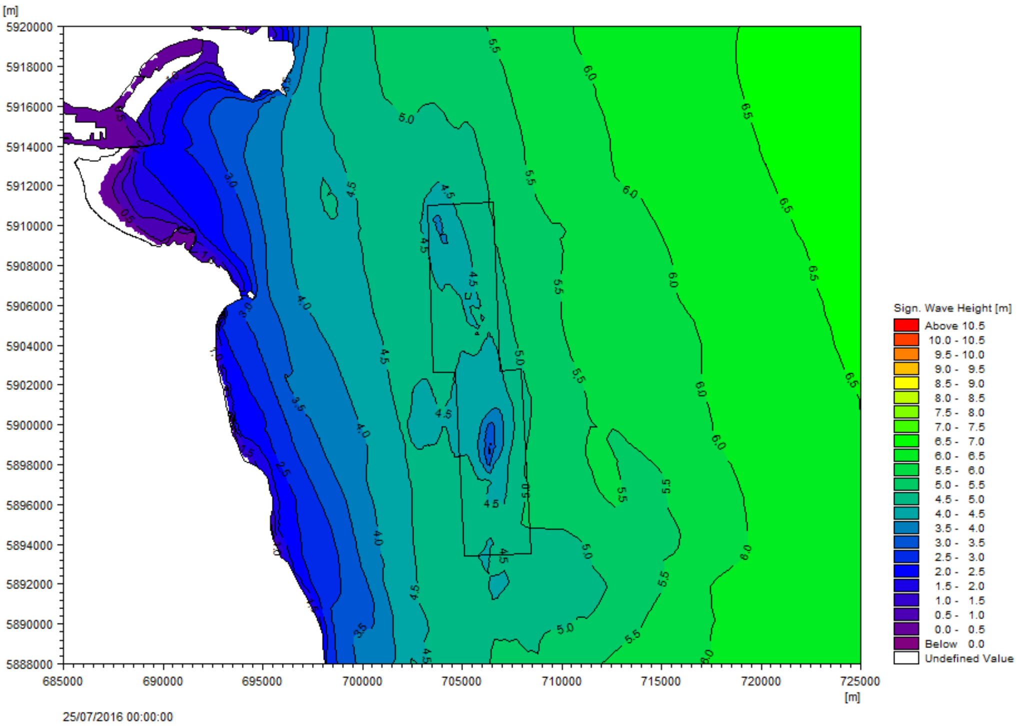


Figure A-29 H_{m0} (m), wave direction from east, 50%ile scenario

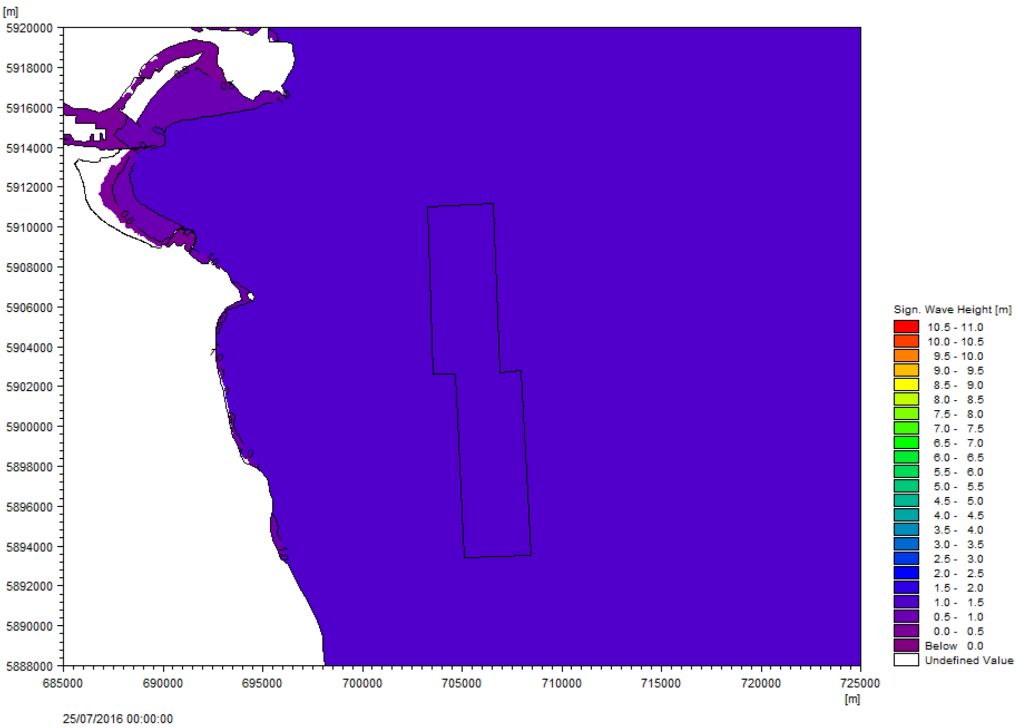


Figure A-30 H_{m0} (m), wave direction from east, 5%ile scenario

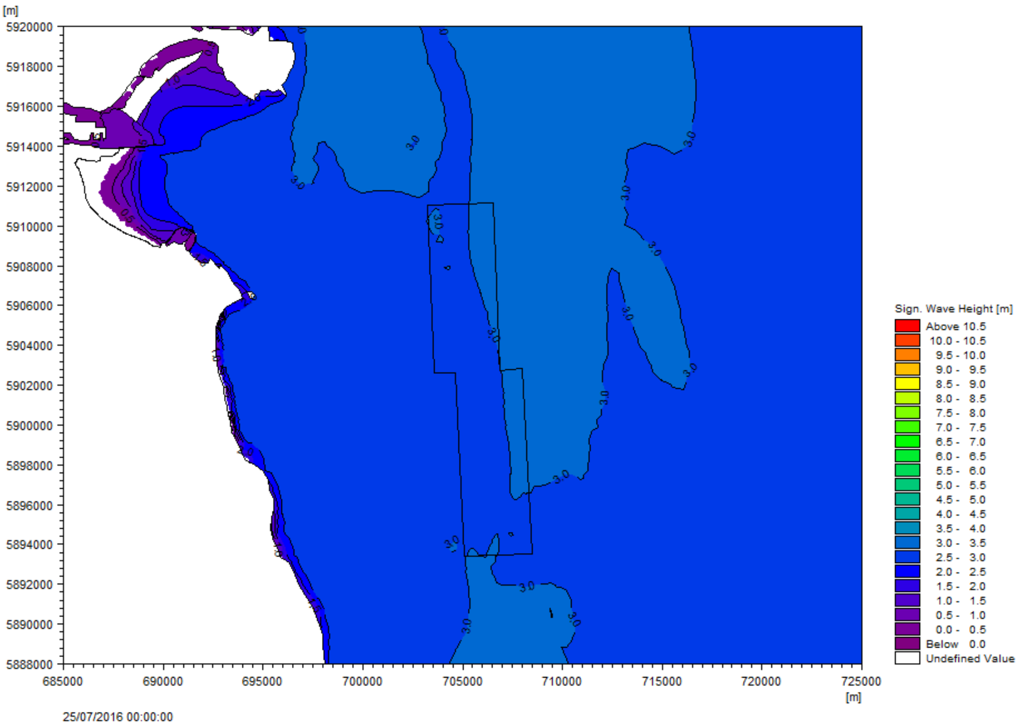


Figure A-31 H_{m0} (m), wave direction from east, 1 in 1 year scenario

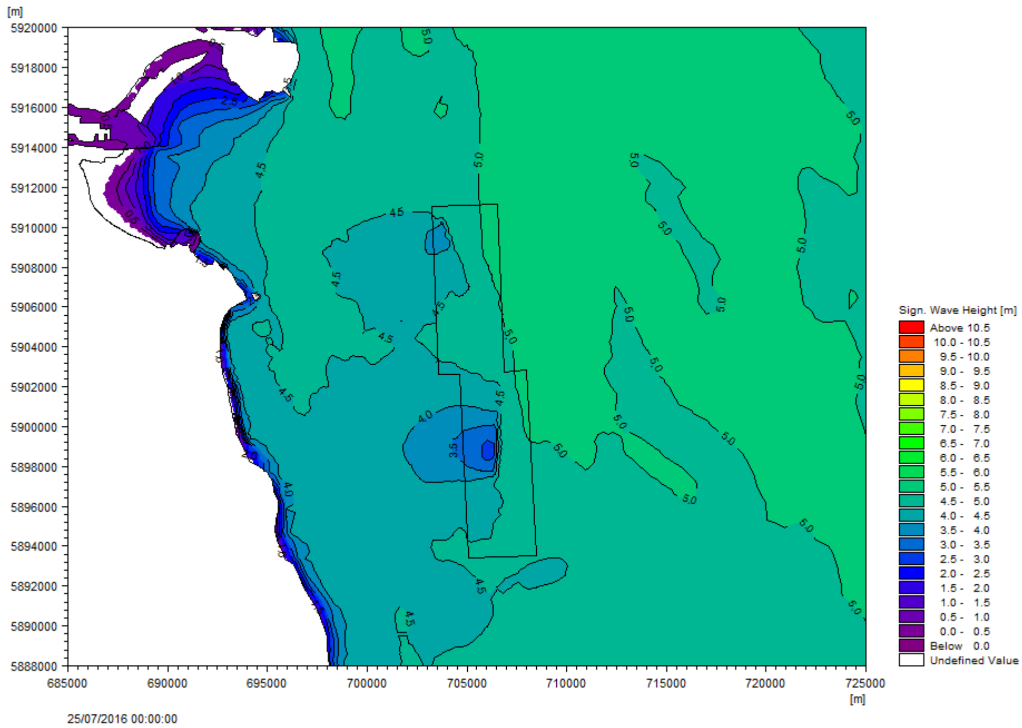


Figure A-32 H_{m0} (m), wave direction from east, 1 in 100 year scenario

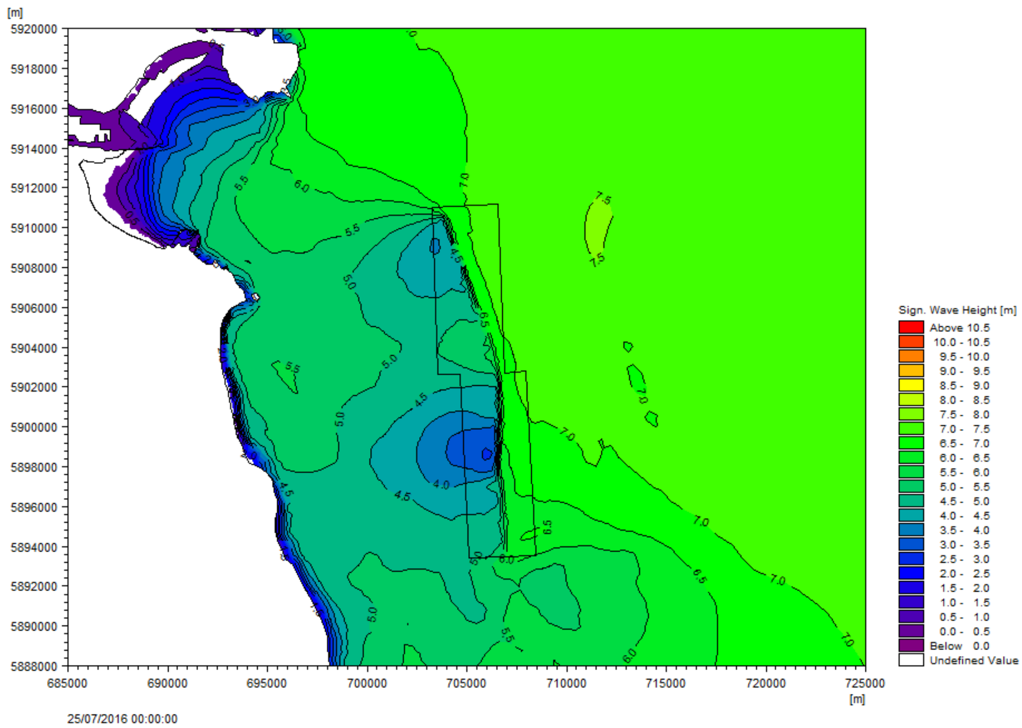


Figure A-33 H_{m0} (m), wave direction from south, 50%ile scenario

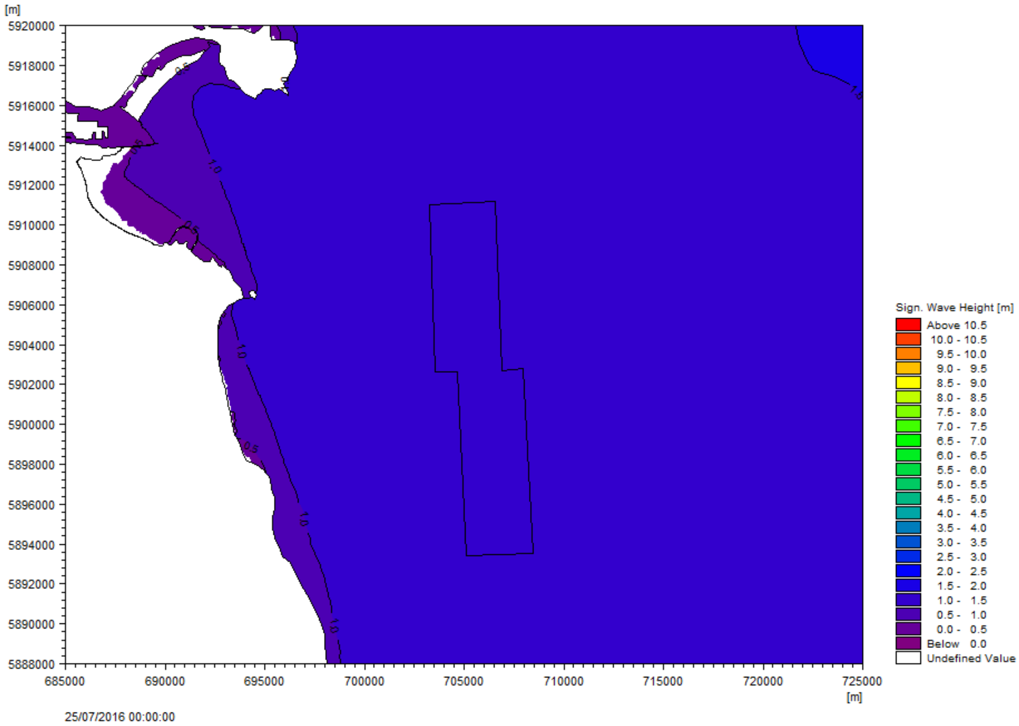


Figure A-34 H_{m0} (m), wave direction from south, 5%ile scenario

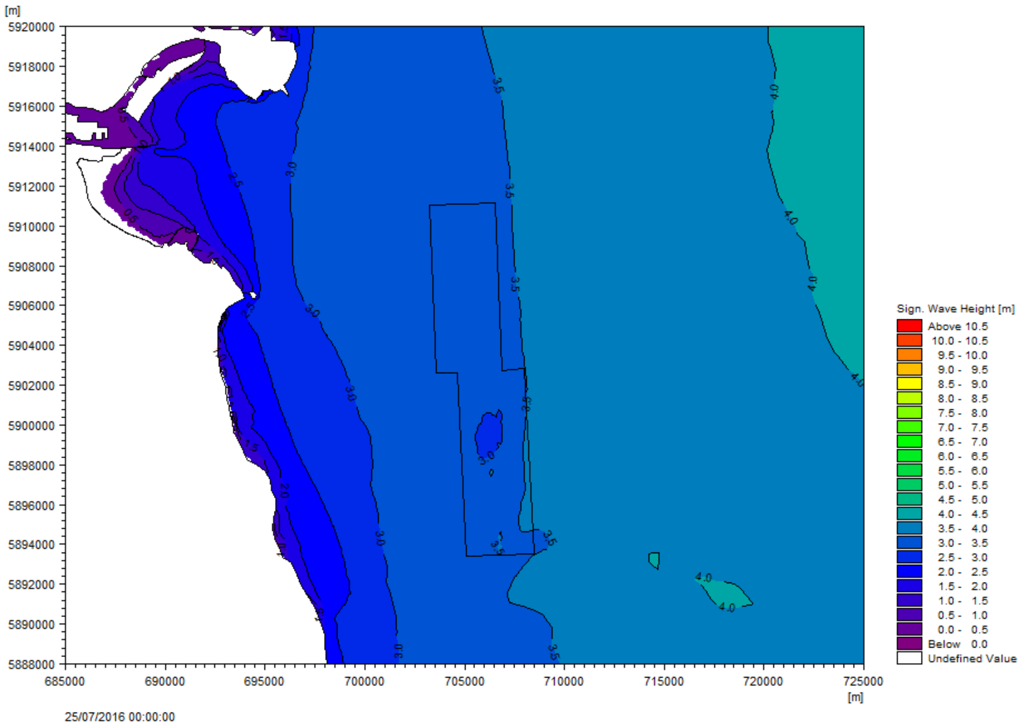


Figure A-35 H_{m0} (m), wave direction from south, 1 in 1 year scenario

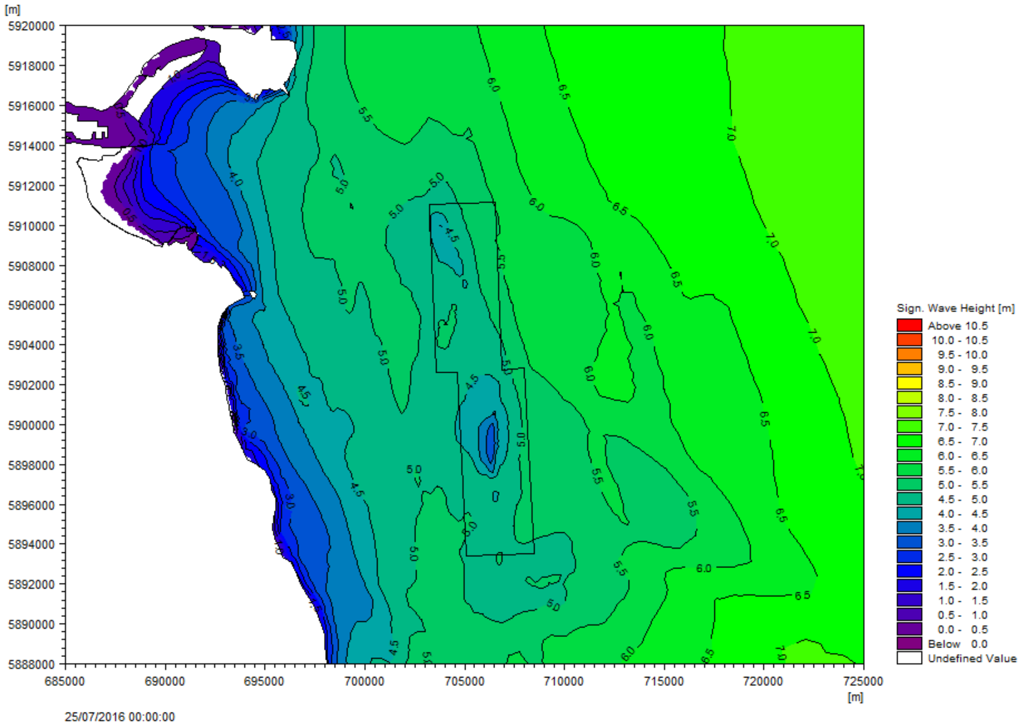


Figure A-36 H_{m0} (m), wave direction from south, 1 in 100 year scenario

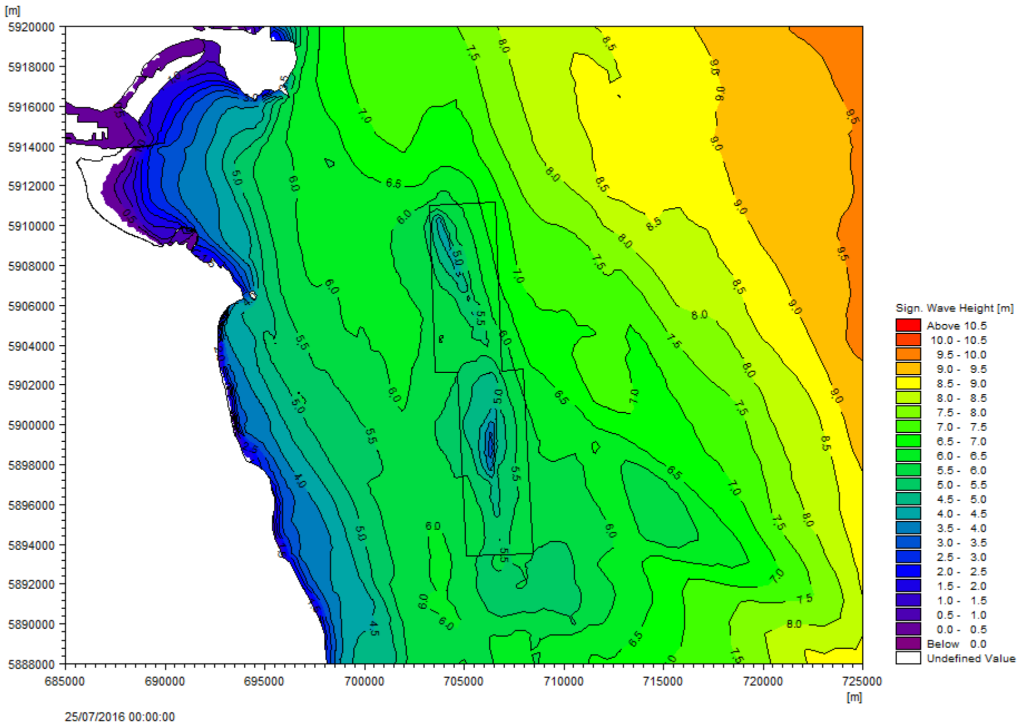


Figure A-37 H_{m0} (m), wave direction from west, 50%ile scenario

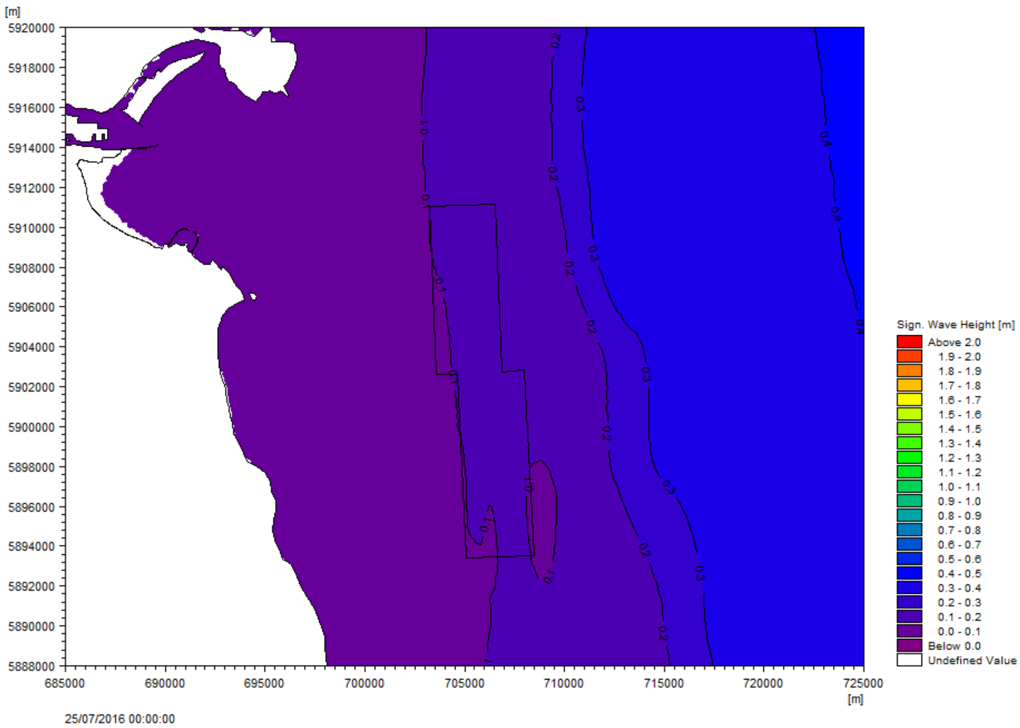


Figure A-38 H_{m0} (m), wave direction from west, 5%ile scenario

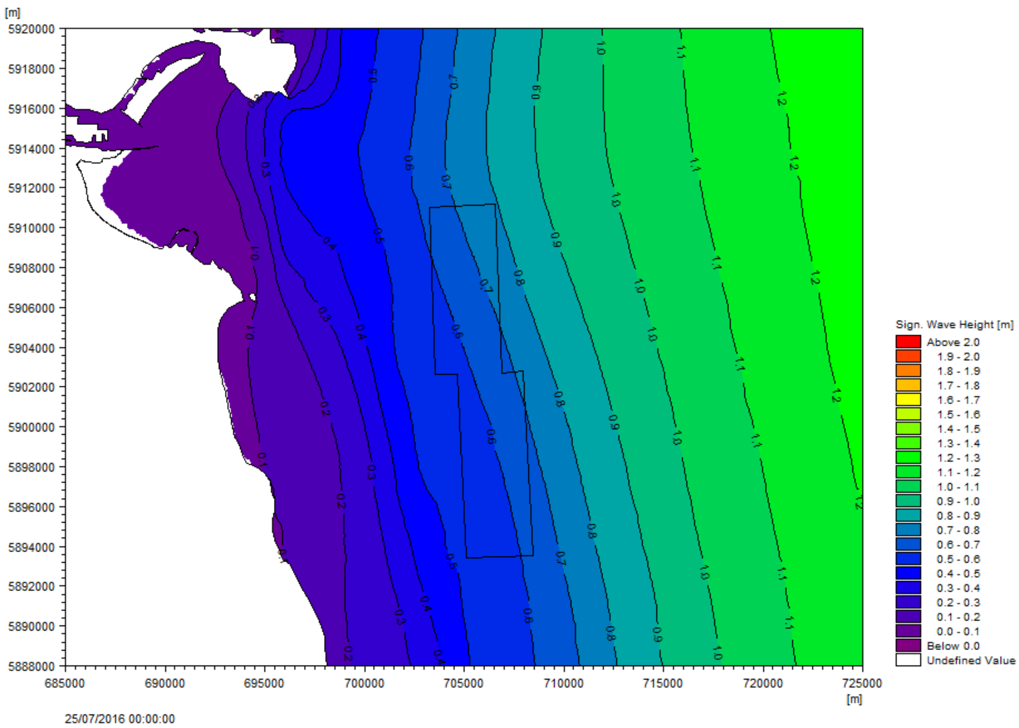


Figure A-39 H_{m0} (m), wave direction from west, 1 in 1 year scenario

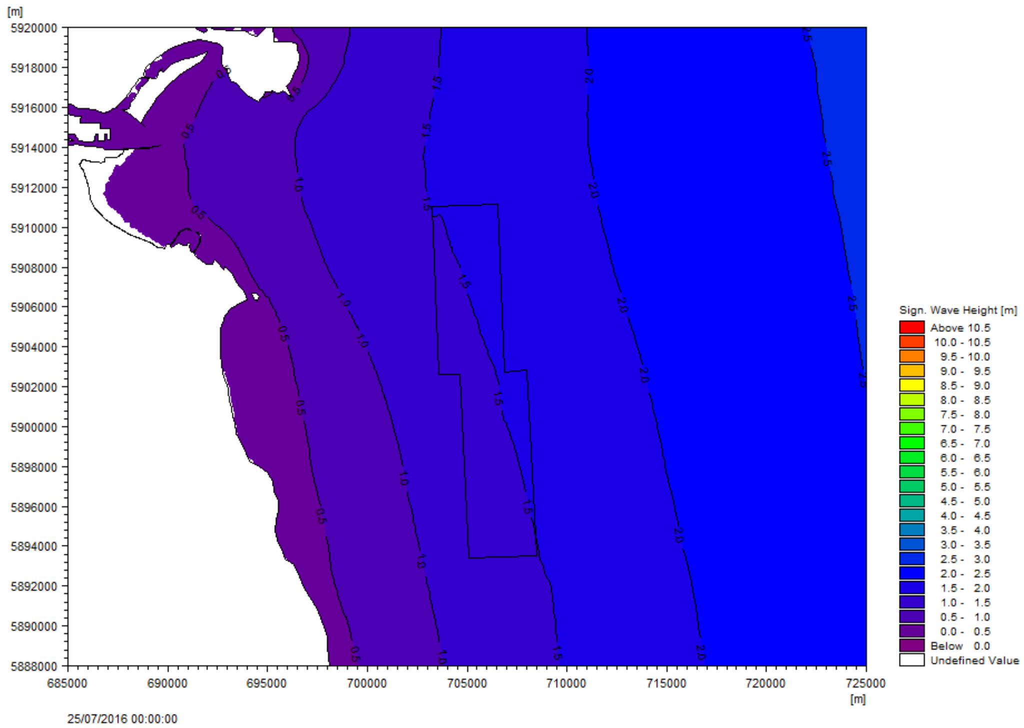
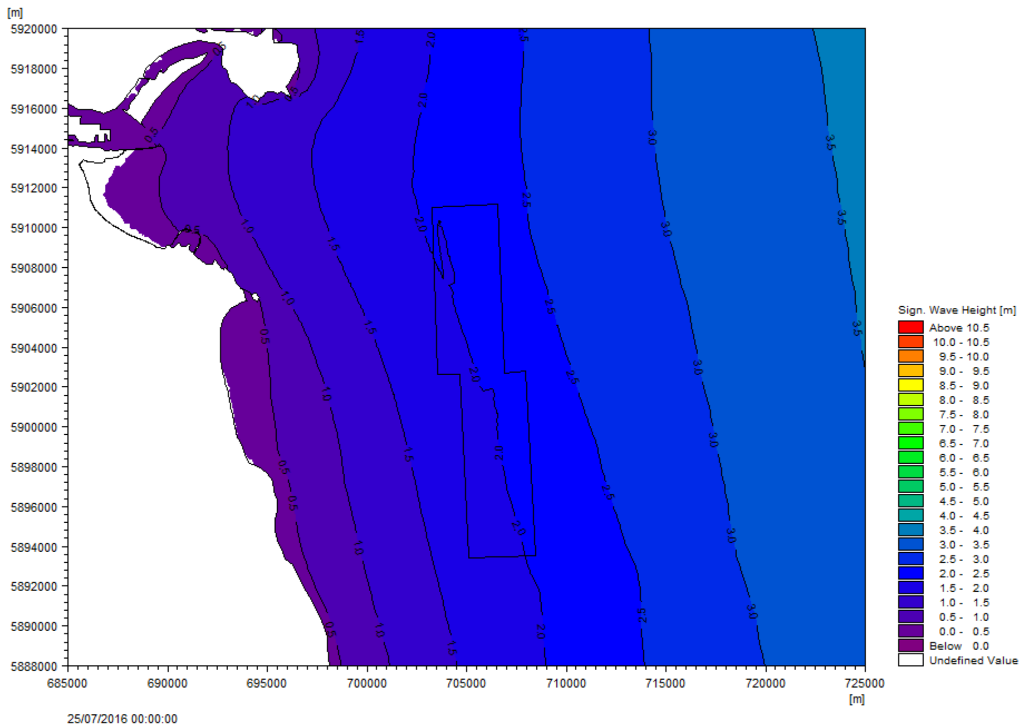


Figure A-40 H_{m0} (m), wave direction from west, 1 in 100 year scenario



A.3 DROGUE PLOTS

Figure A-41 High water drogue release for a mean spring tide (tracked over two full days).

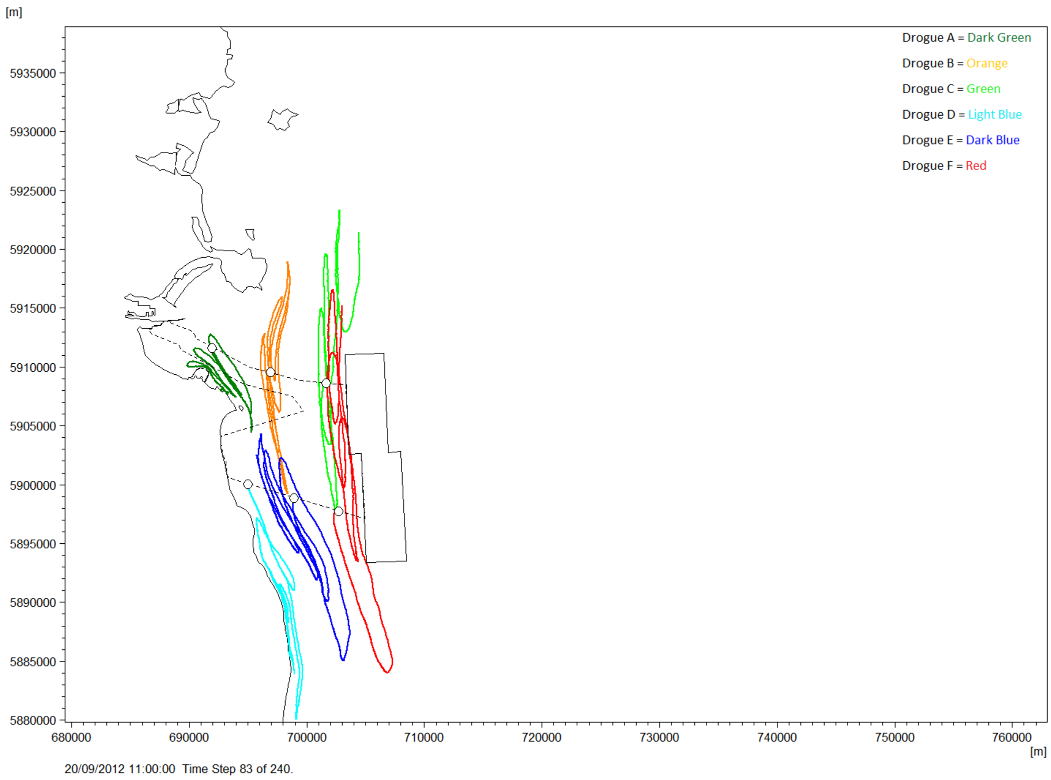


Figure A-42 Low water drogue release for a mean spring tide (tracked over two full days).

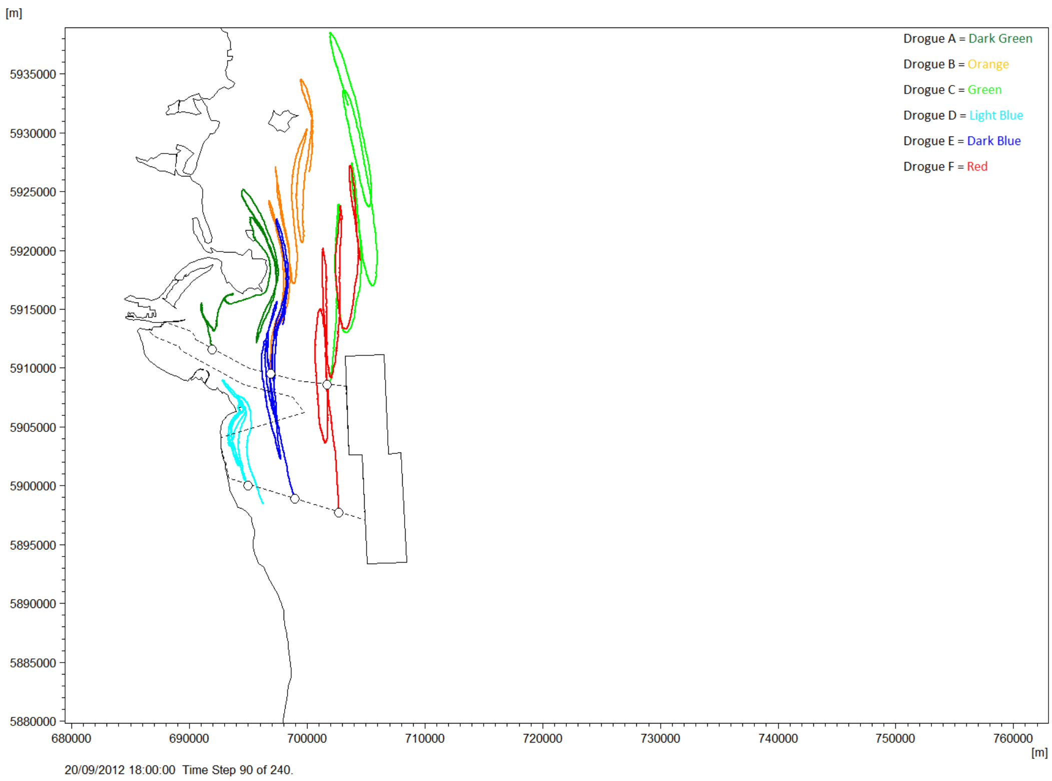


Figure A-43 High water drogue release for a mean neap tide (tracked over two full days).

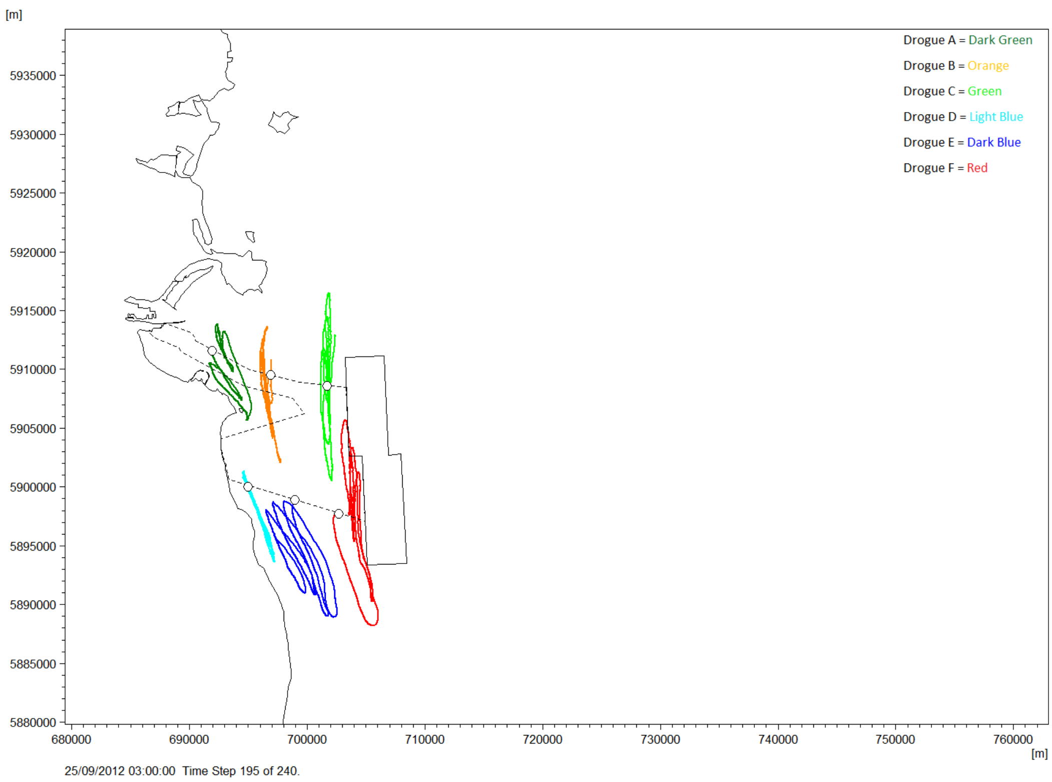
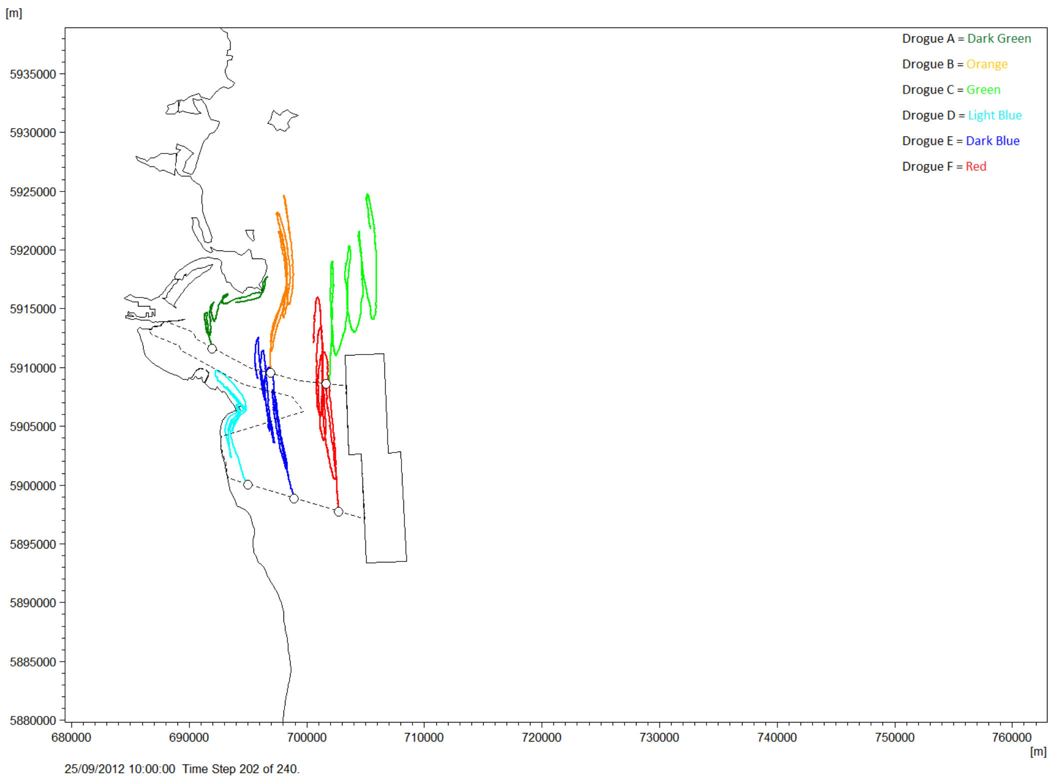


Figure A-44 Low water drogue release for a mean neap tide (tracked over two full days).



Appendix B

Modelled Wind Farm Scheme Impact Assessment Plots

B.1 HYDRODYNAMIC REGIME DIFFERENCE PLOTS

B.1.1 Water Level Difference Plots

Figure B-1 Difference in mean spring tide water level at high water

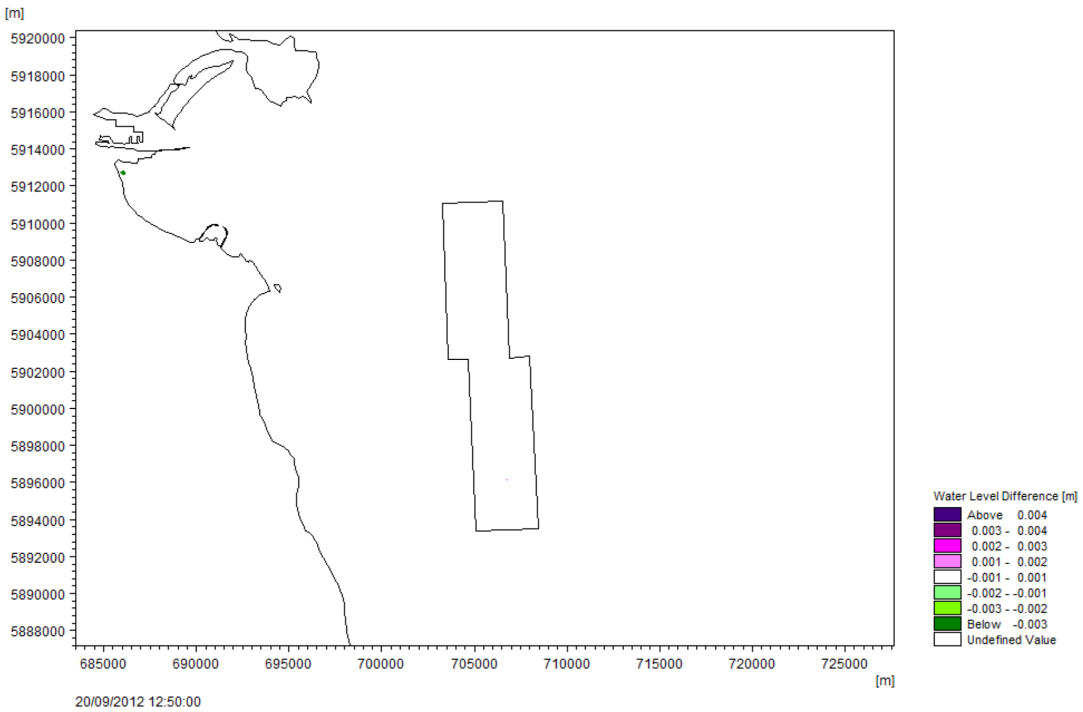


Figure B-2 Difference in mean spring tide water level at low water

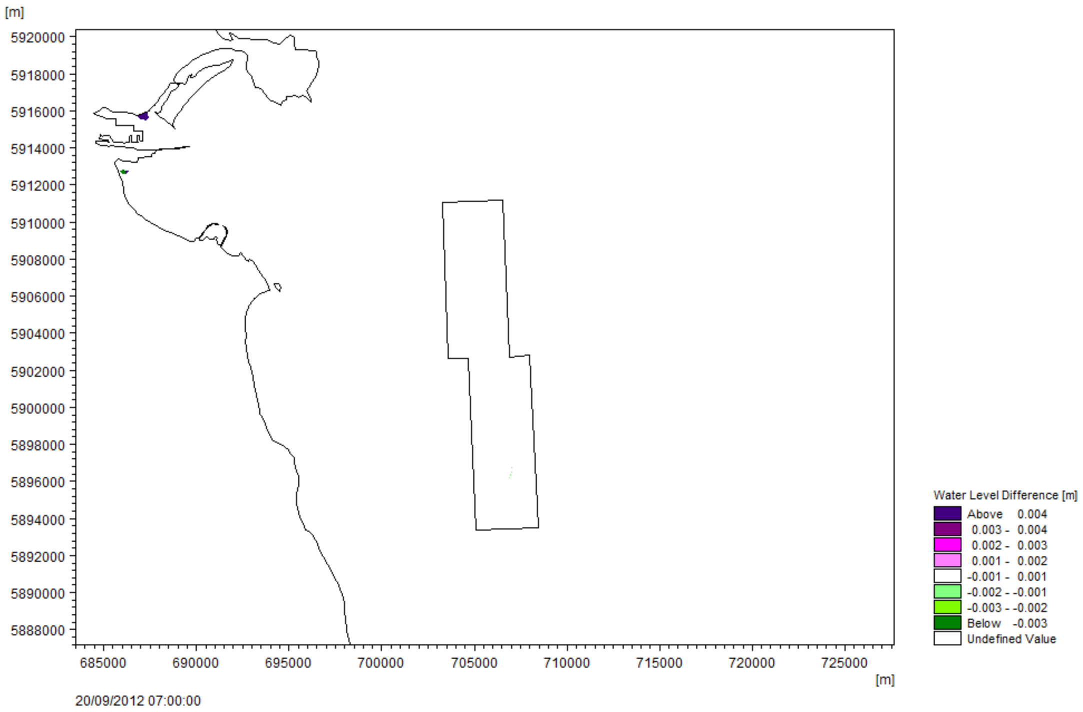


Figure B-3 Difference in mean spring tide water level at peak flood

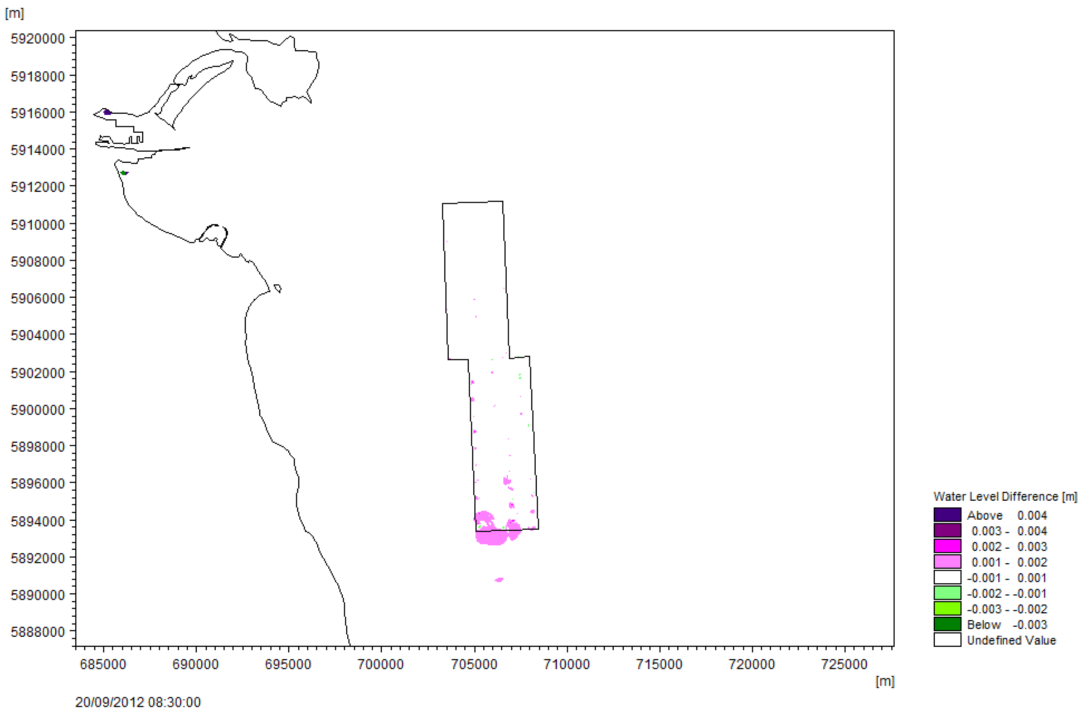


Figure B-4 Difference in mean spring tide water level at peak ebb

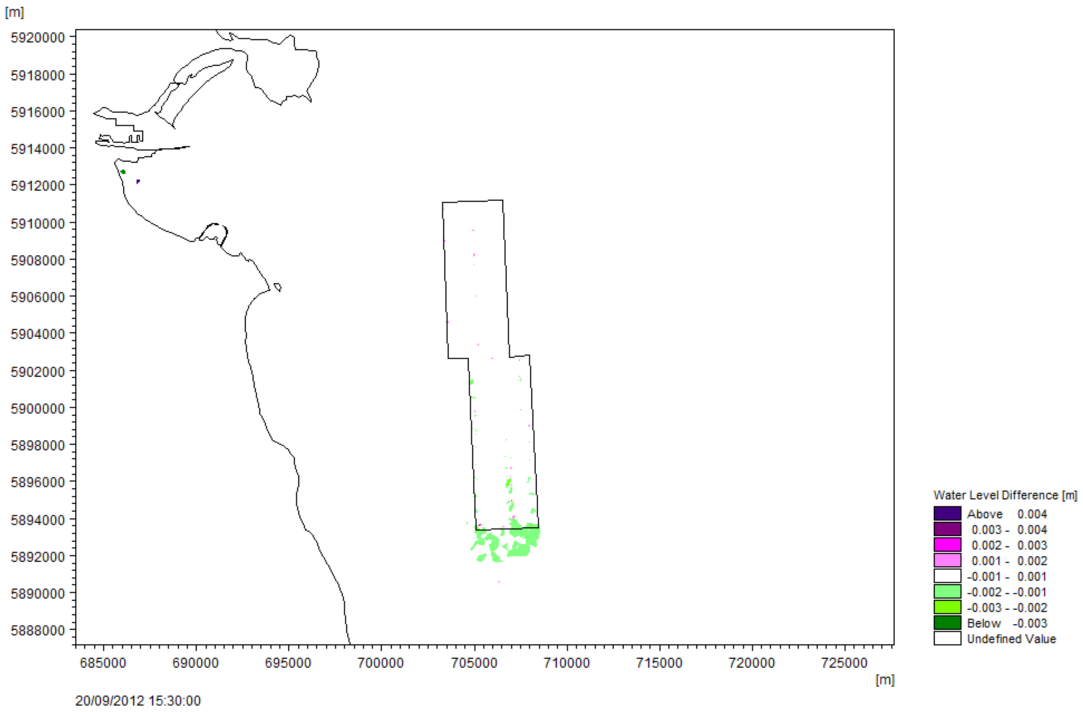


Figure B-5 Difference in mean neap tide water level at high water

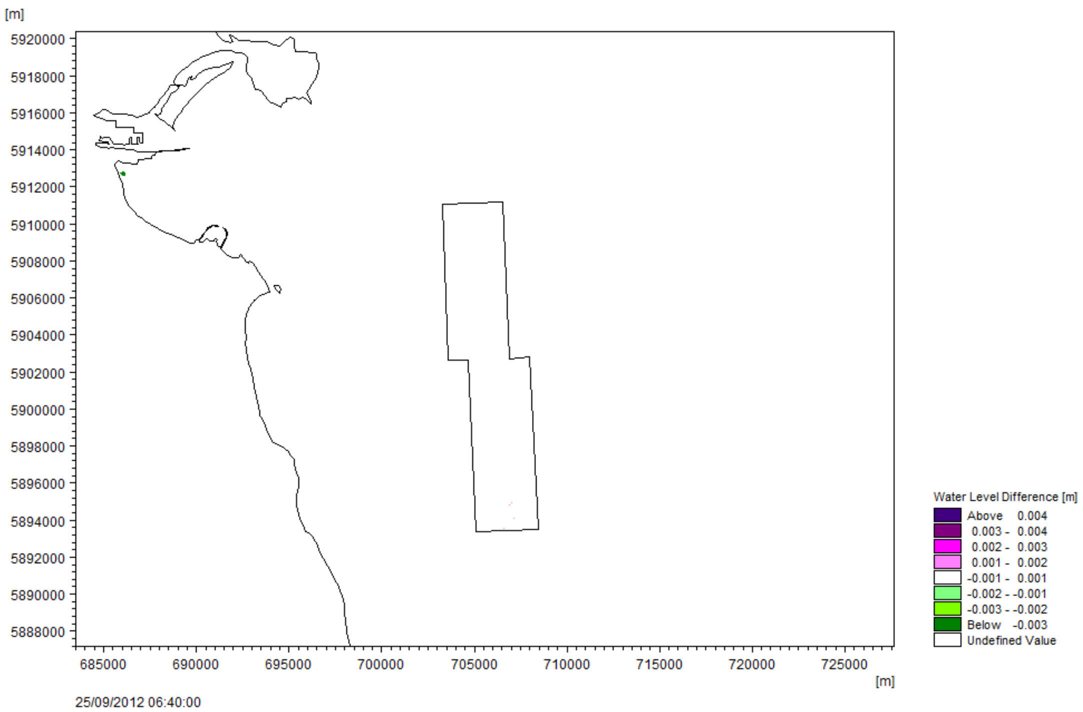


Figure B-6 Difference in mean neap tide water level at low water

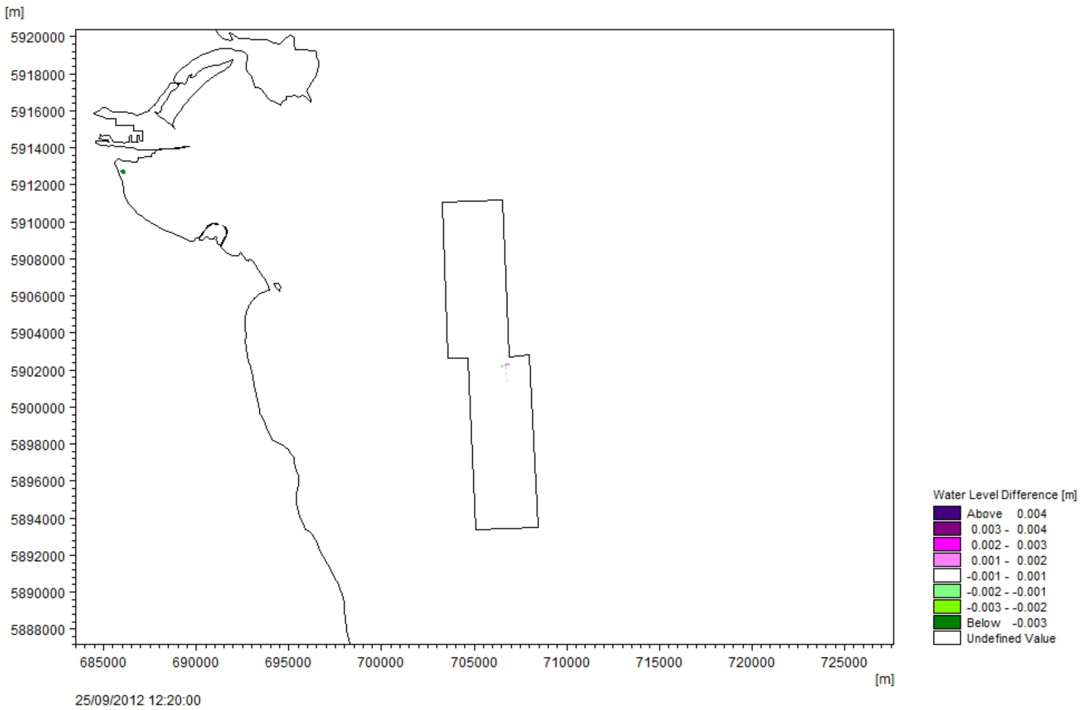


Figure B-7 Difference in mean neap tide water level at peak flood

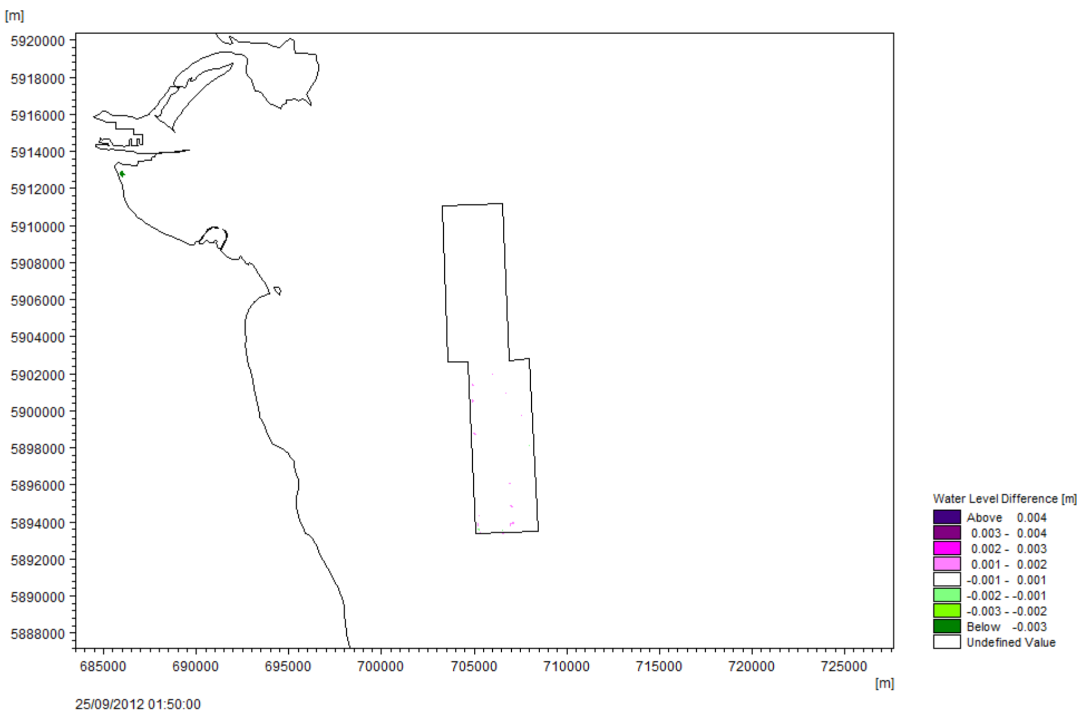
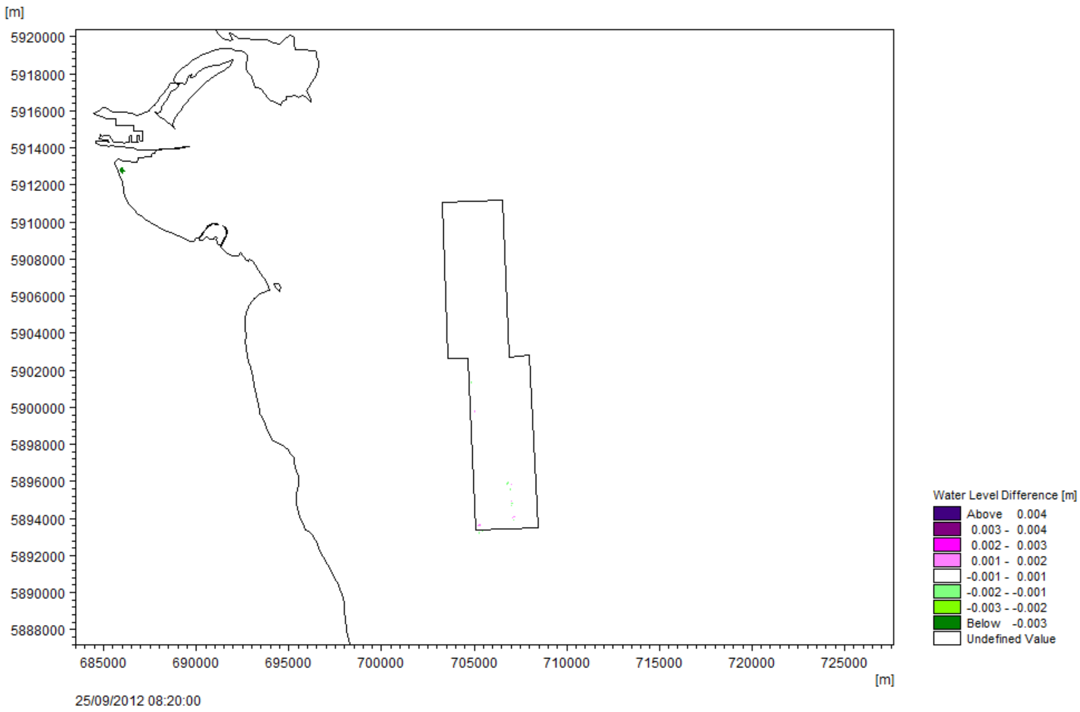


Figure B-8 Difference in mean neap tide water level at peak ebb



B.1.2 Current Speed Difference Plots

Figure B-9 Difference in mean spring tide current speed at high water

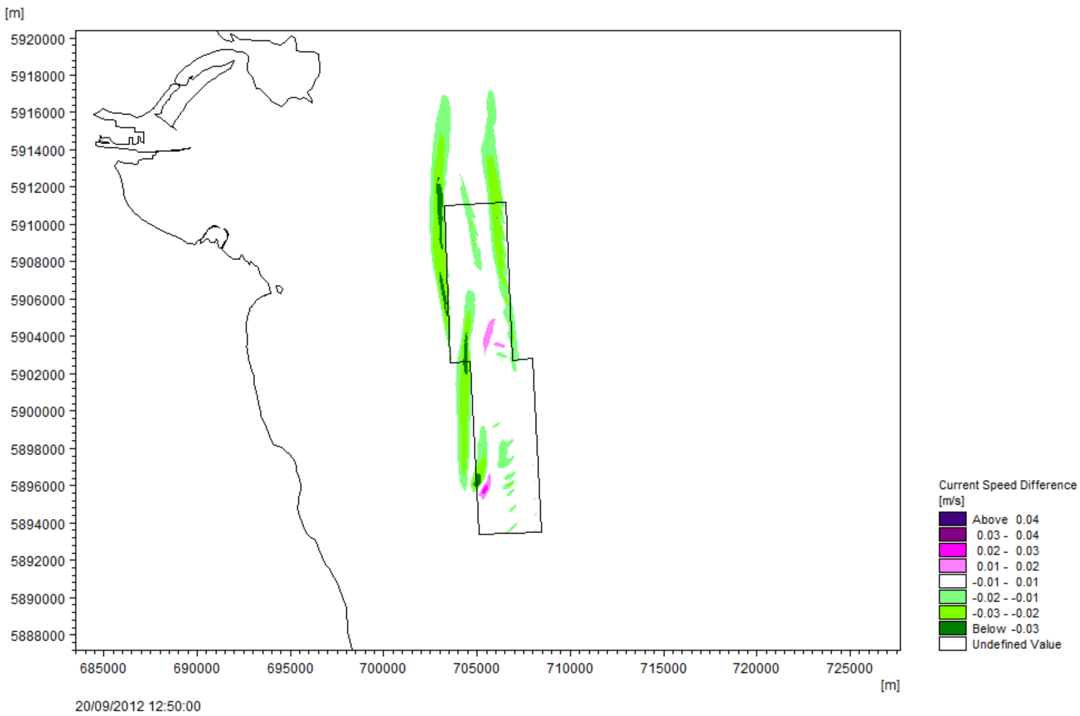


Figure B-10 Difference in mean spring tide current speed at low water

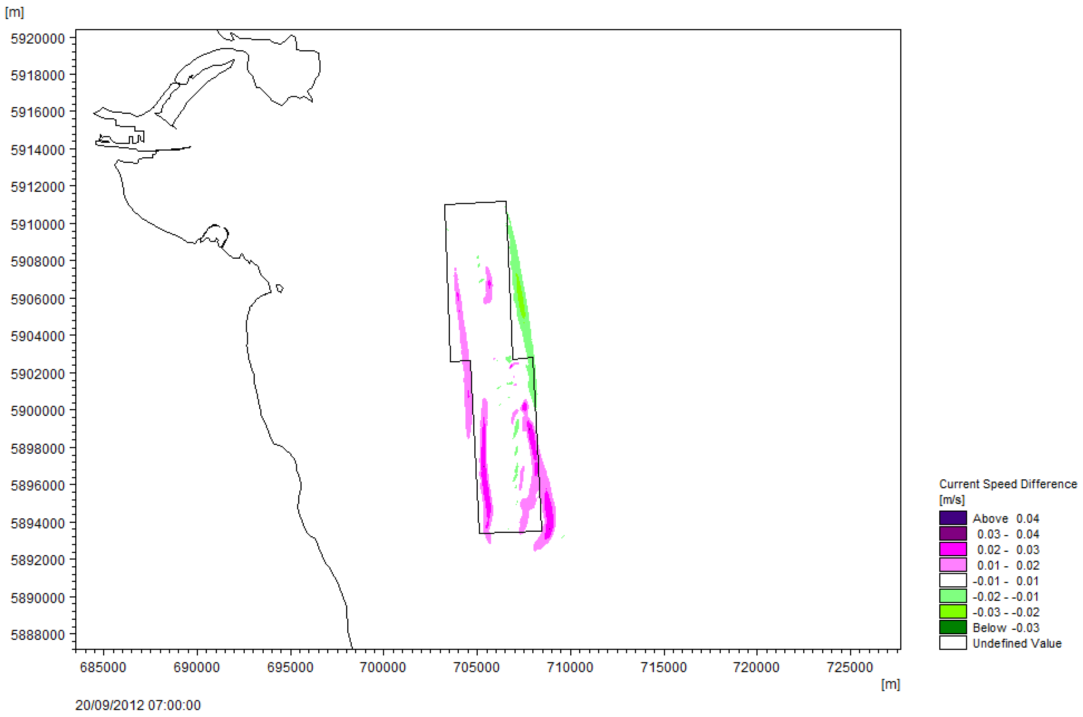


Figure B-11 Difference in mean spring tide current speed at peak flood

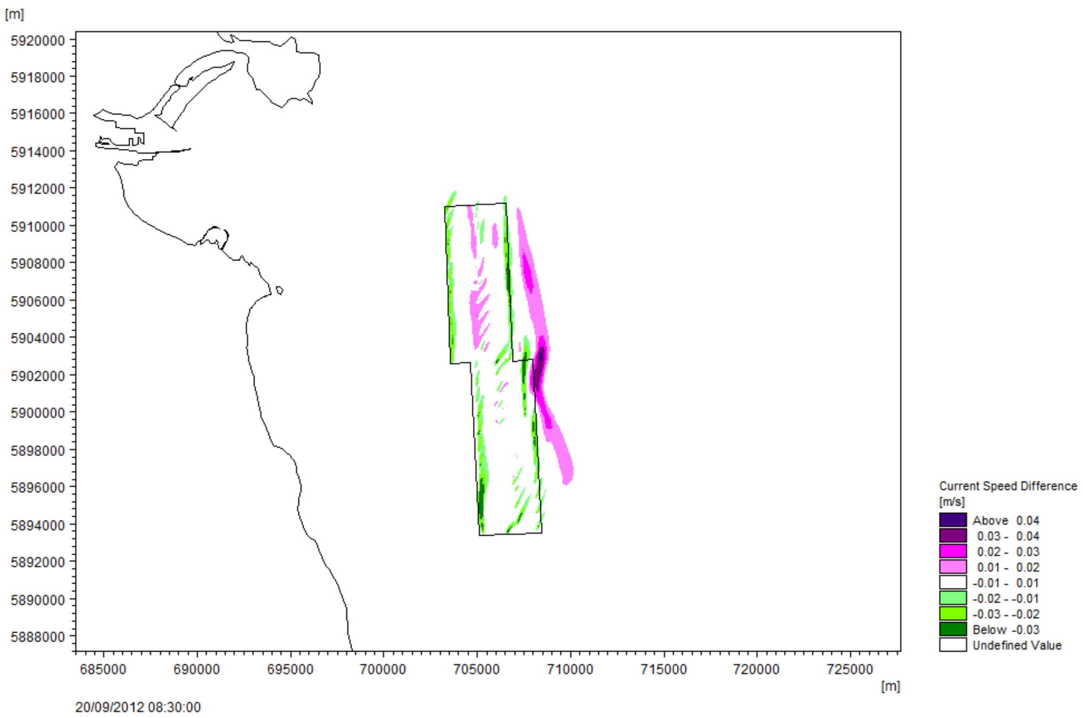


Figure B-12 Difference in mean spring tide current speed at peak ebb

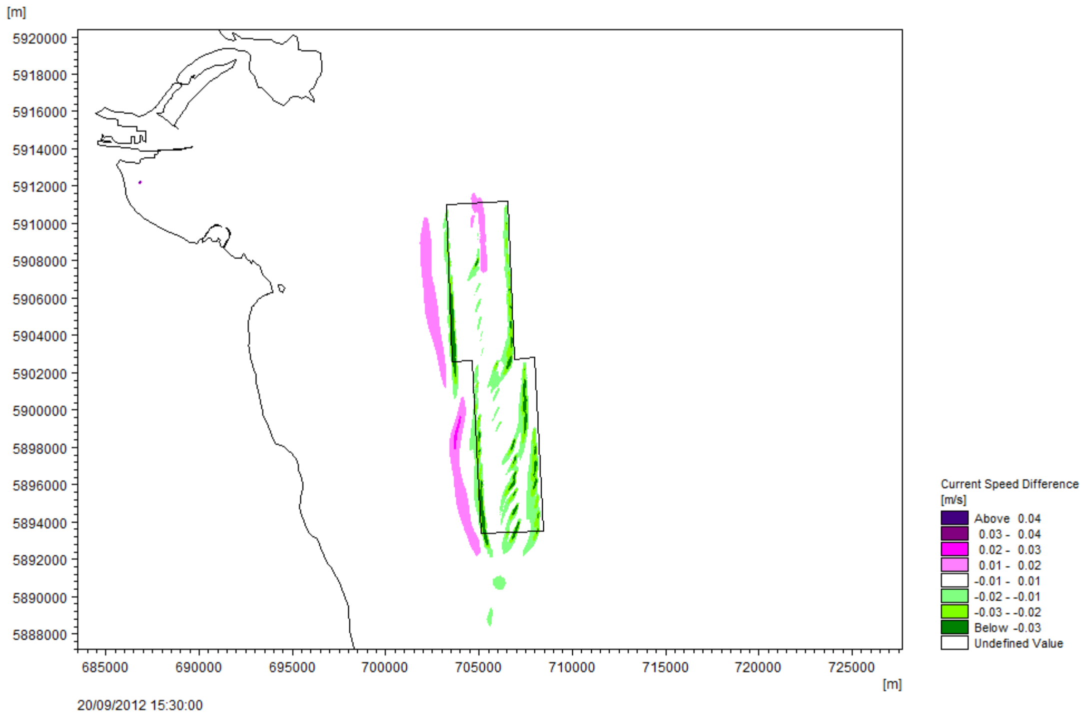


Figure B-13 Difference in mean neap tide current speed at high water

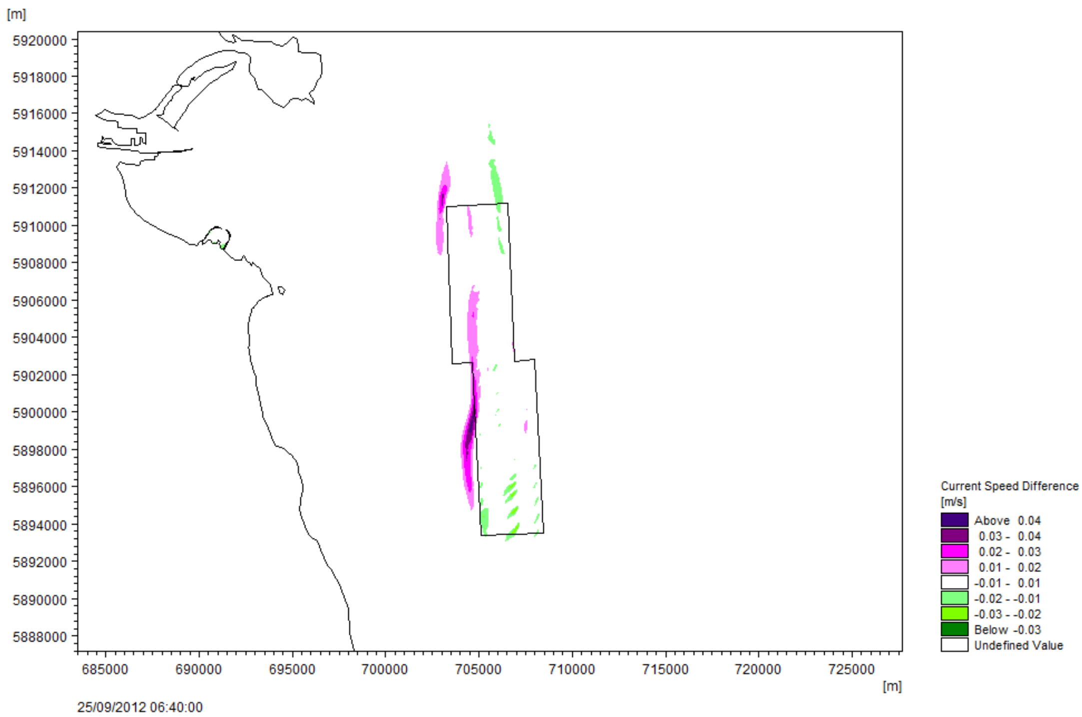


Figure B-14 Difference in mean neap tide current speed at low water

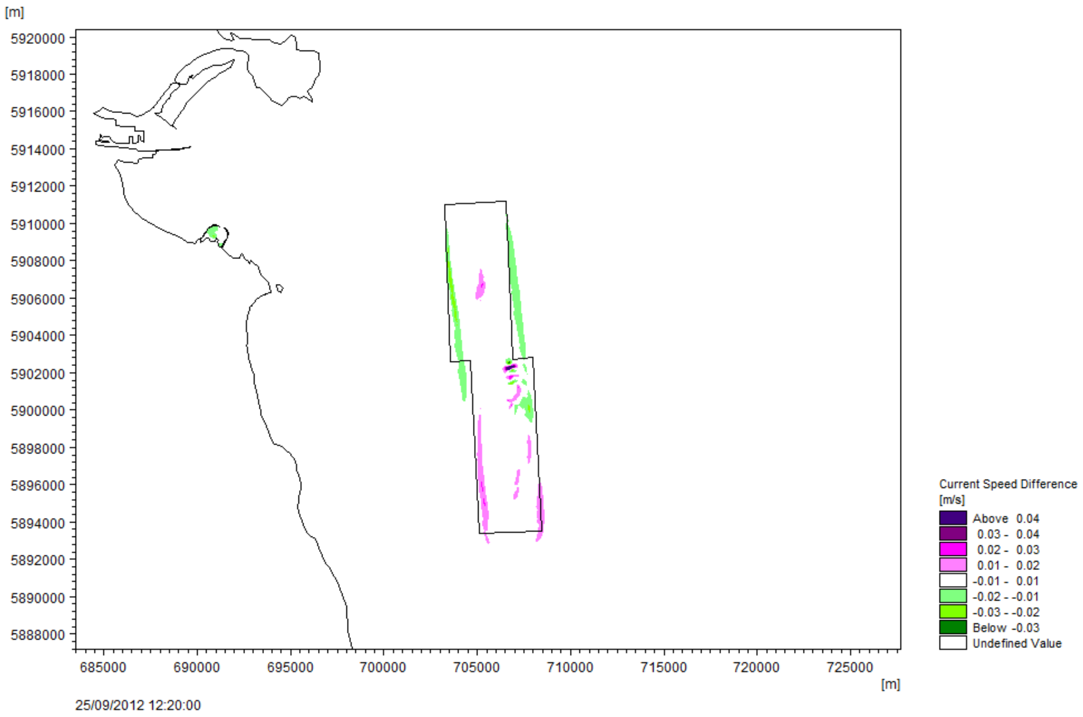


Figure B-15 Difference in mean neap tide current speed at peak flood

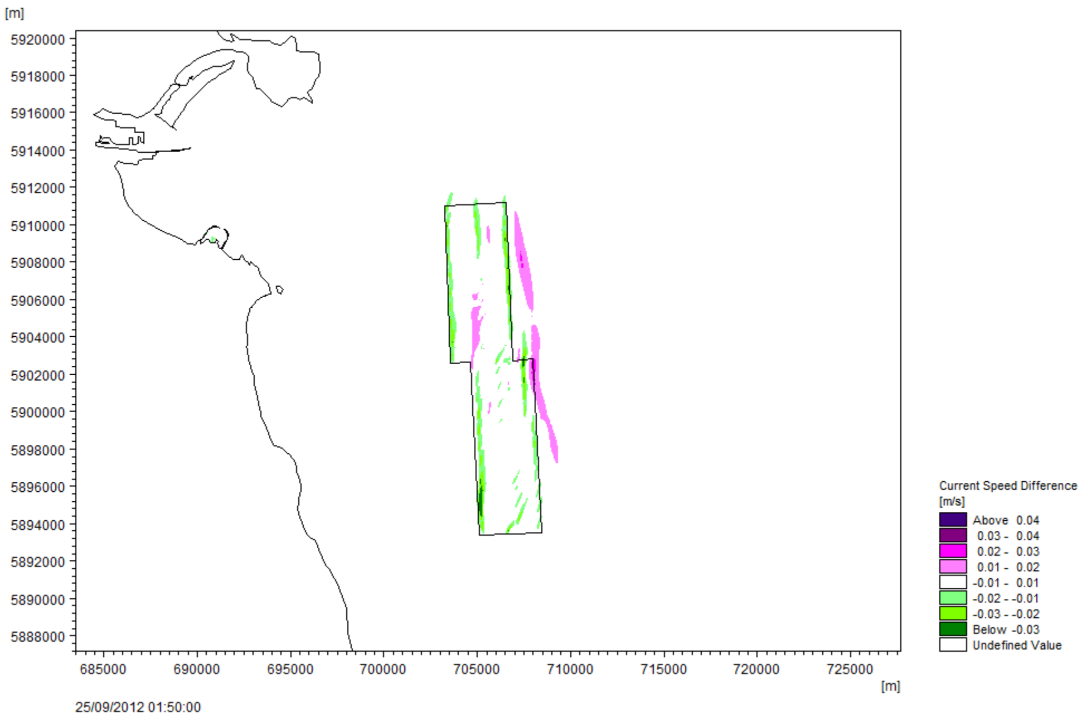
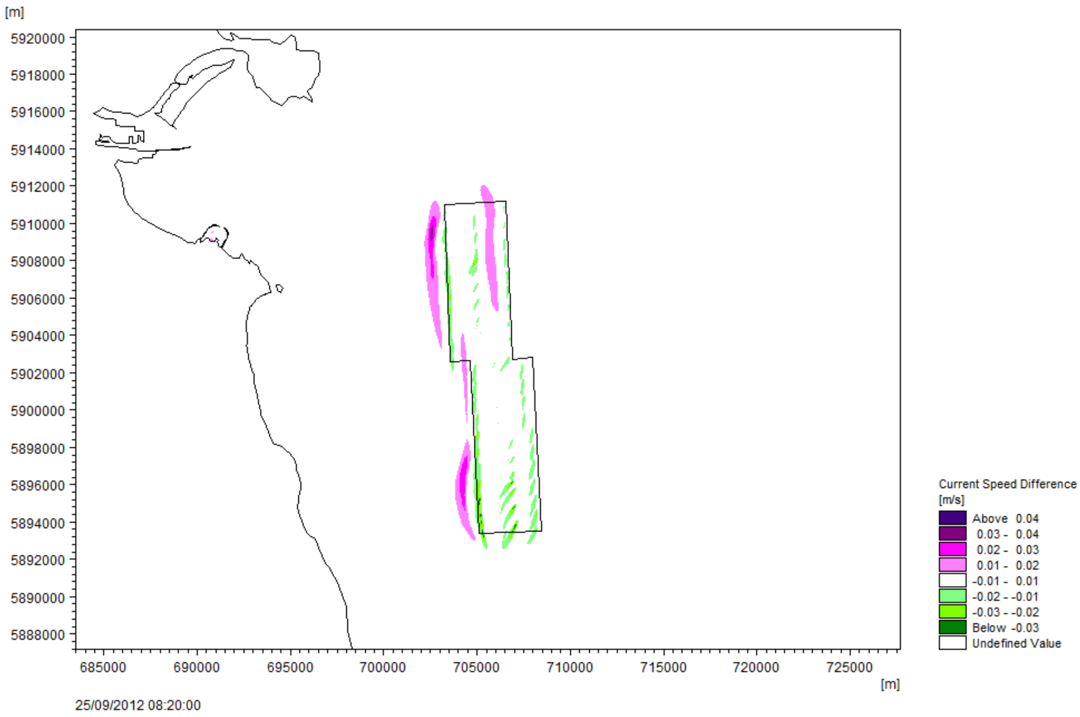


Figure B-16 Difference in mean neap tide current speed at peak ebb



B.1.3 Water Level Percentage Difference Plots

Figure B-17 Percentage difference in mean spring tide water level at high water

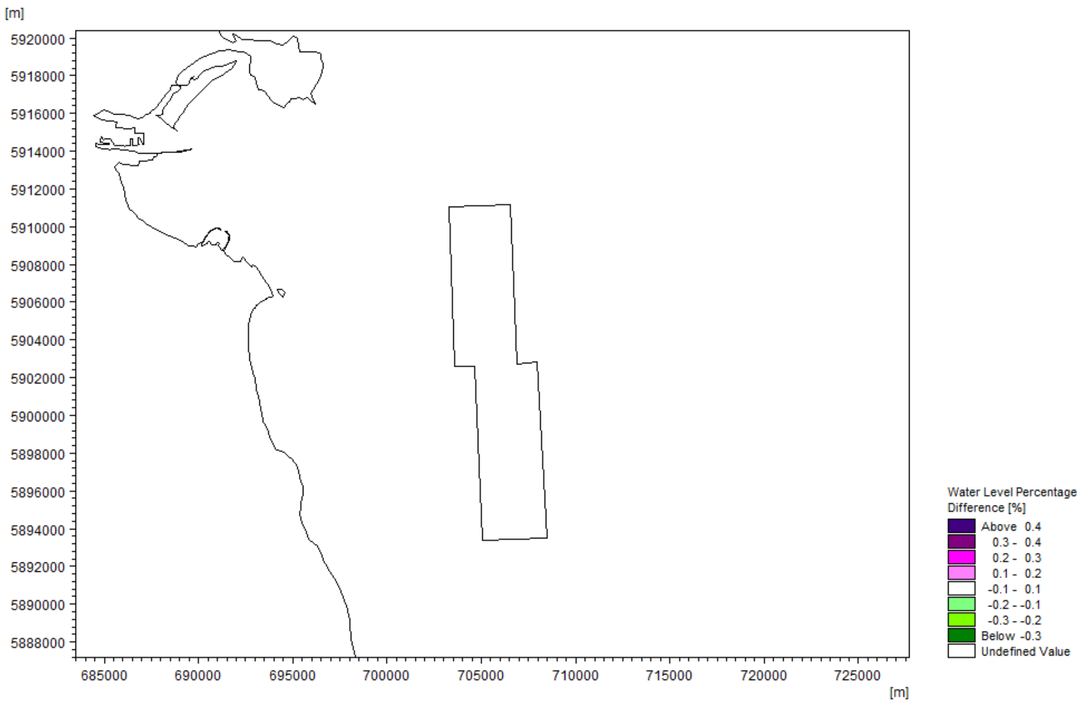


Figure B-18 Percentage difference in mean spring tide water level at low water

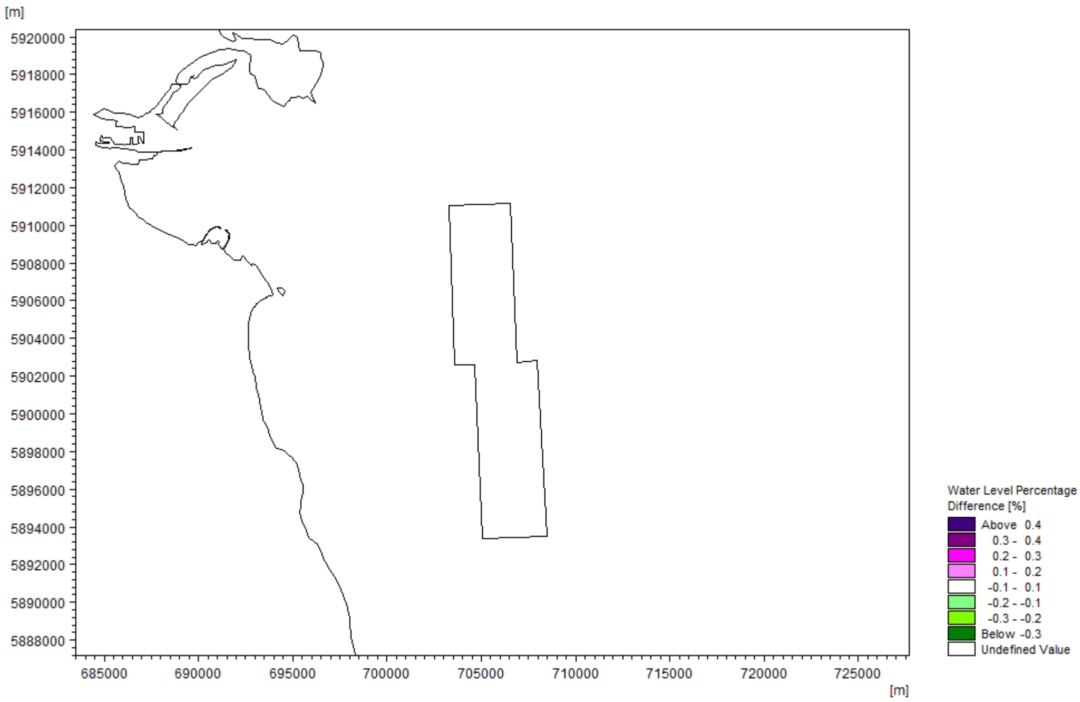


Figure B-19 Percentage difference in mean spring tide water level at peak flood

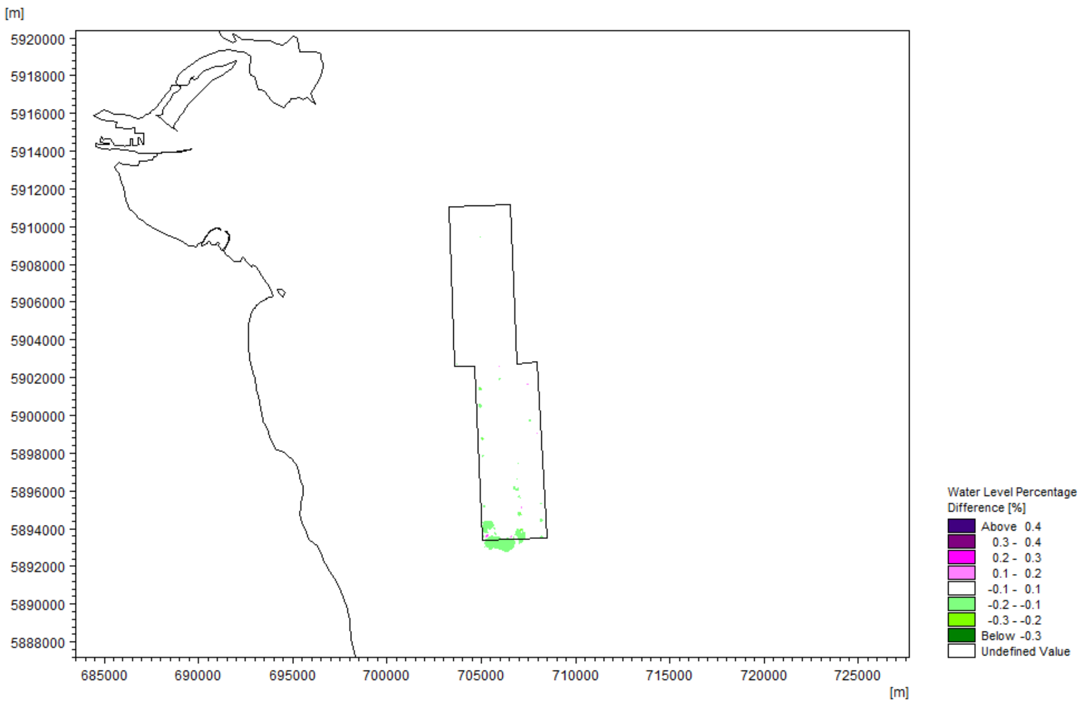


Figure B-20 Percentage difference in mean spring tide water level at peak ebb

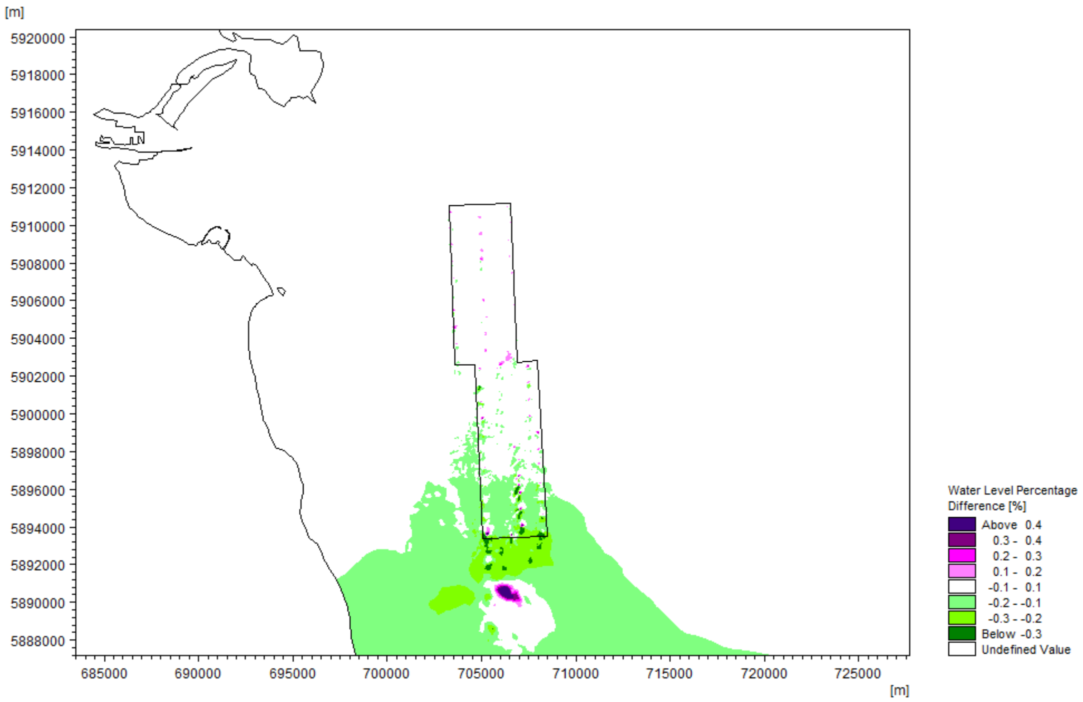


Figure B-21 Percentage difference in mean neap tide water level at high water

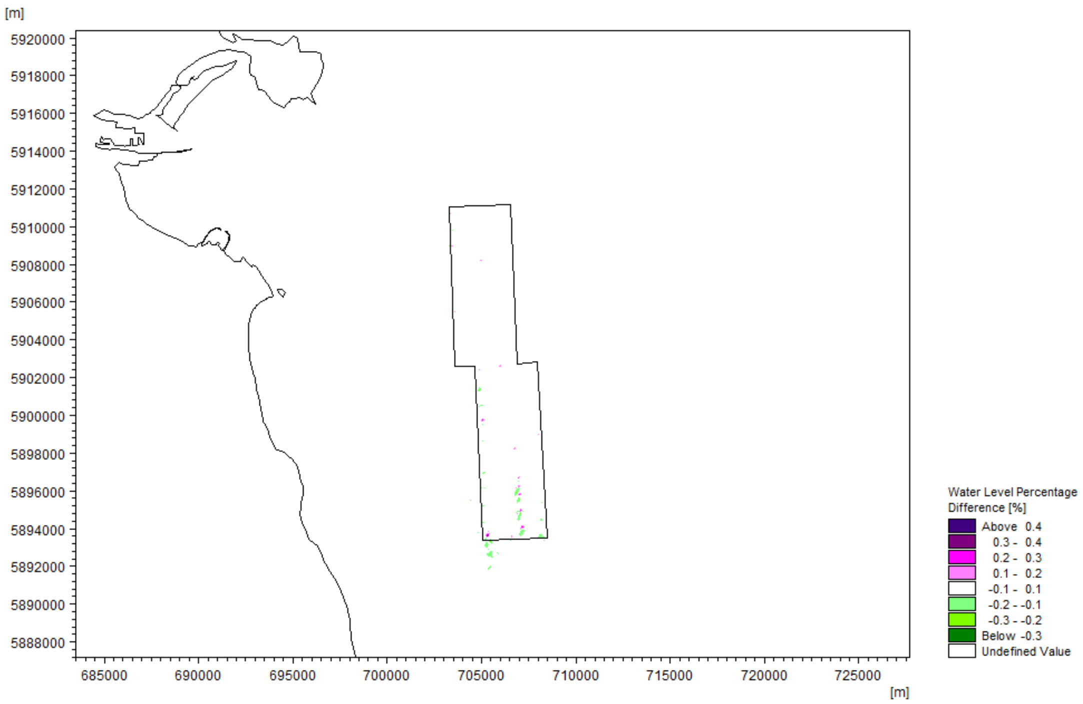


Figure B-22 Percentage difference in mean neap tide water level at low water

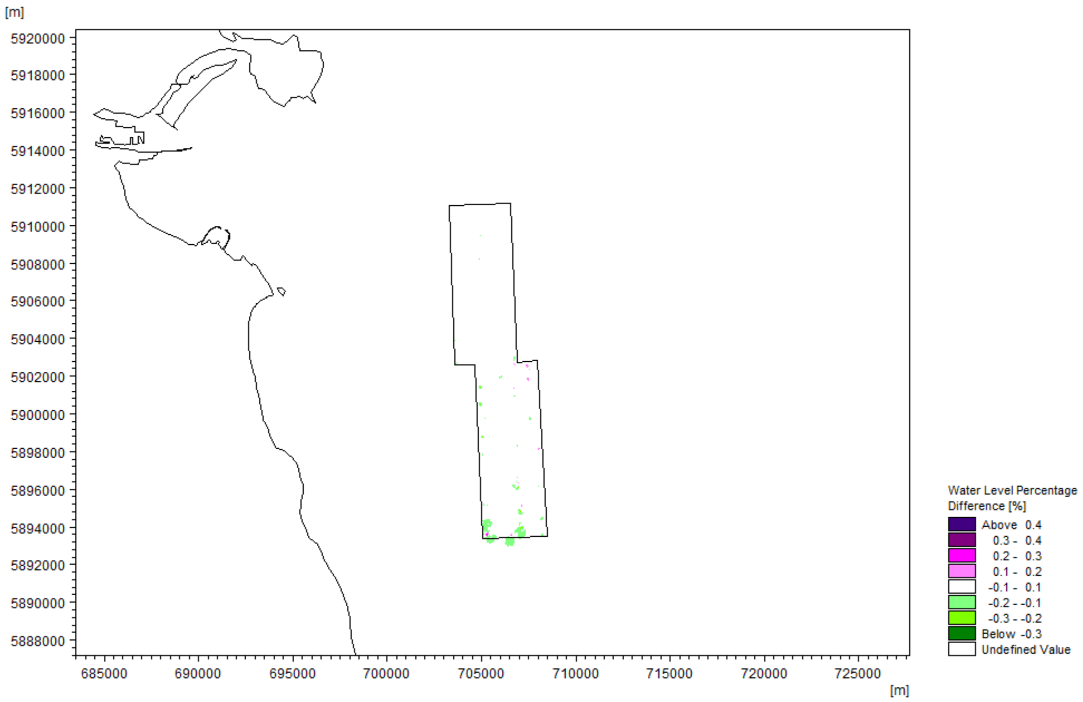


Figure B-23 Percentage difference in mean neap tide water level at peak flood

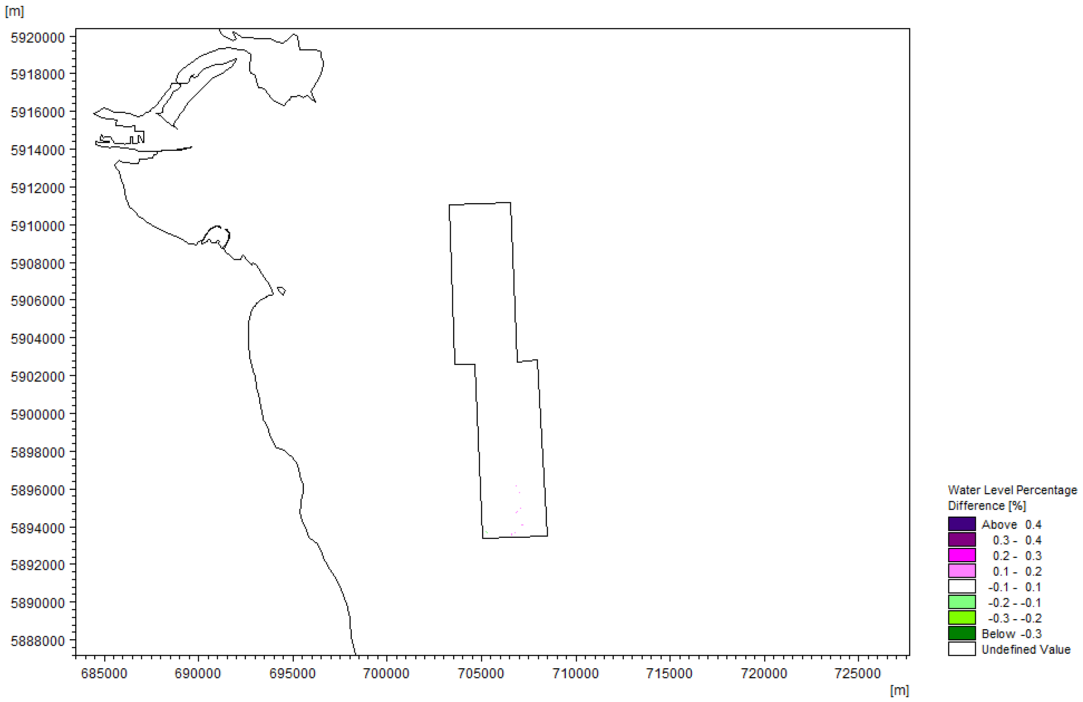
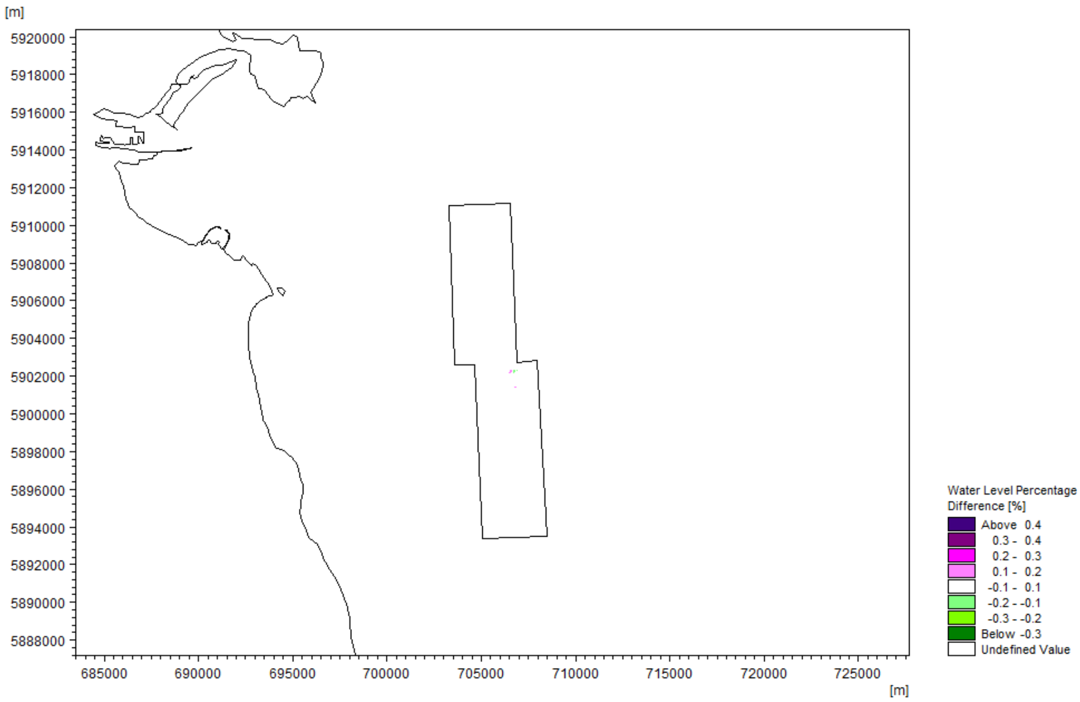


Figure B-24 Percentage difference in mean neap tide water level at peak ebb



B.1.4 Current Speed Percentage Difference Plots

Figure B-25 Percentage difference in mean spring tide current speed at high water

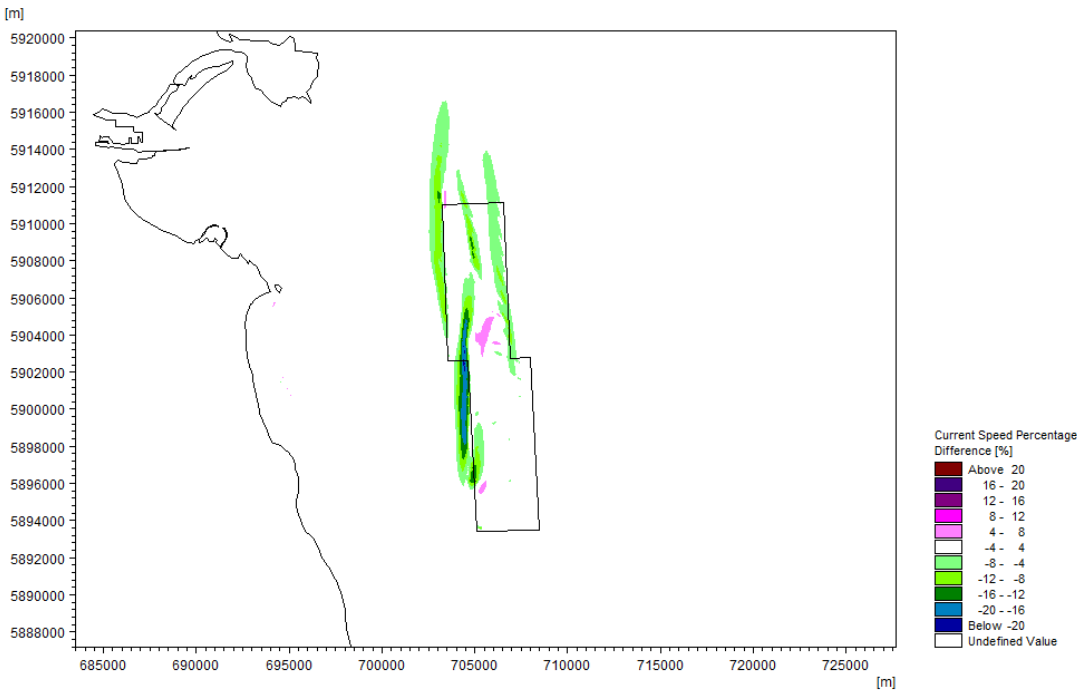


Figure B-26 Percentage difference in mean spring tide current speed at low water

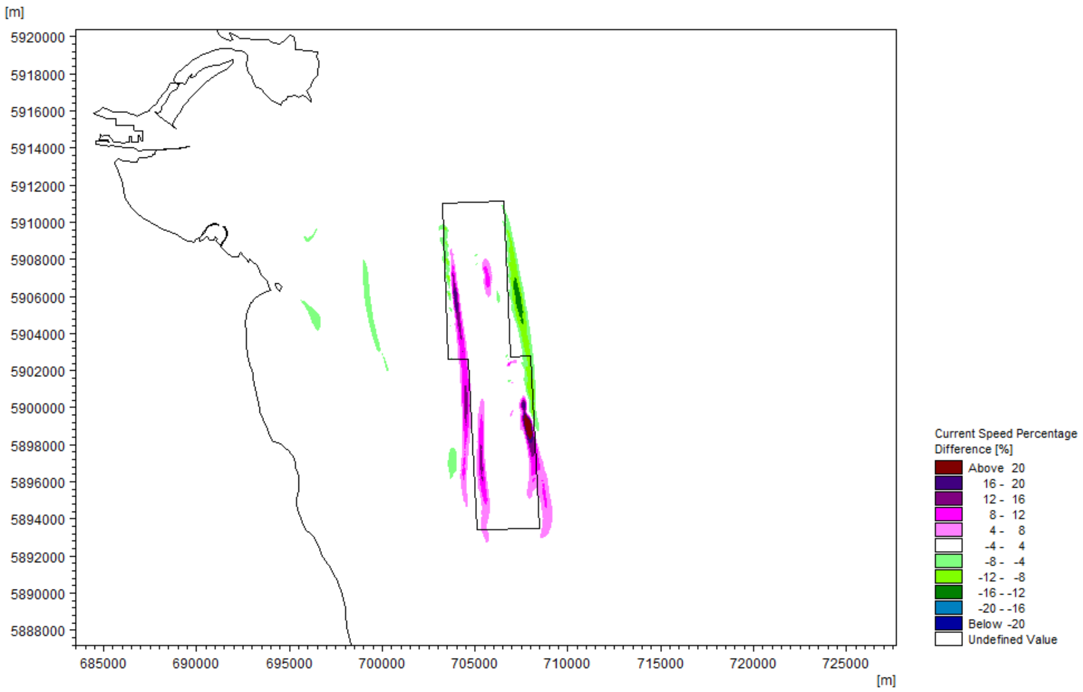


Figure B-27 Percentage difference in mean spring tide current speed at peak flood

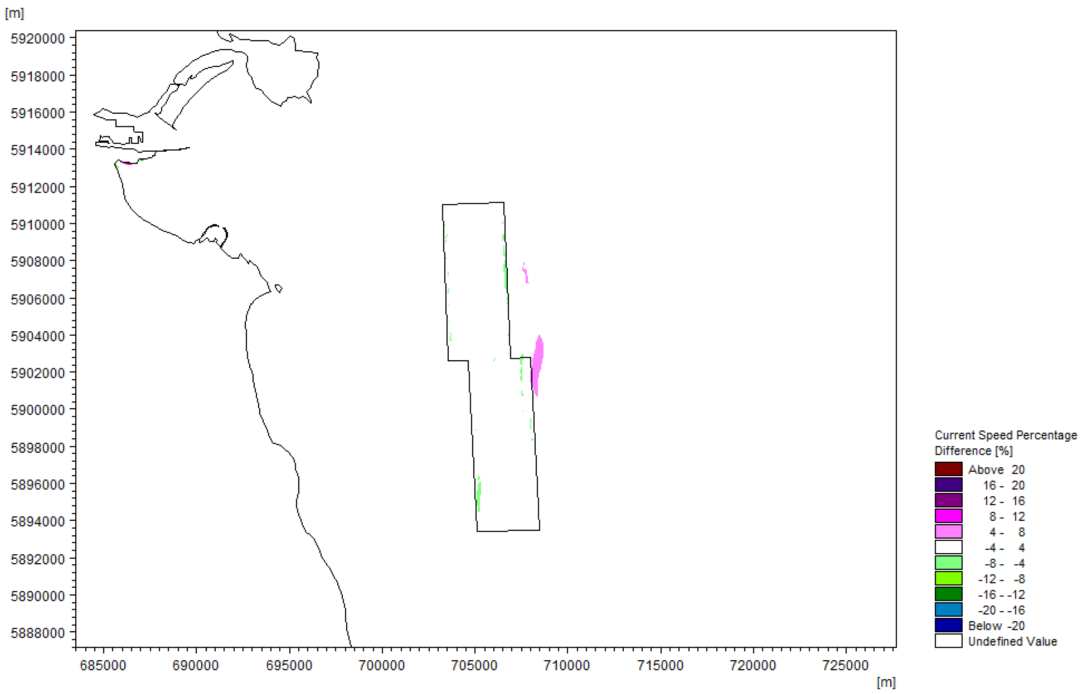


Figure B-28 Percentage difference in mean spring tide current speed at peak ebb

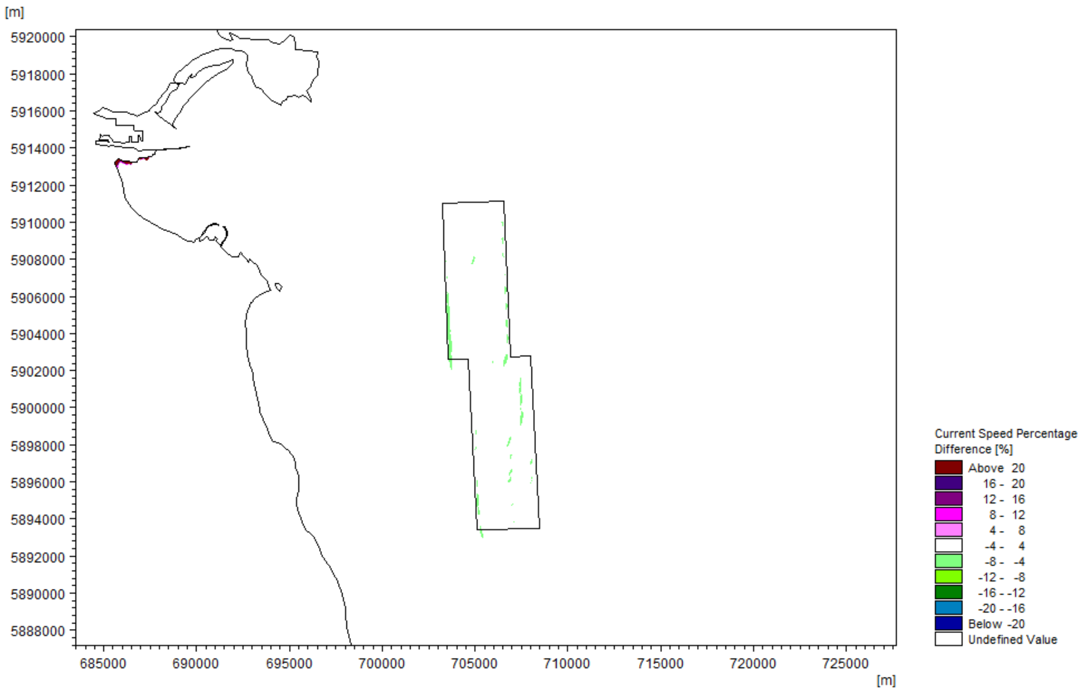


Figure B-29 Percentage difference in mean neap tide current speed at high water

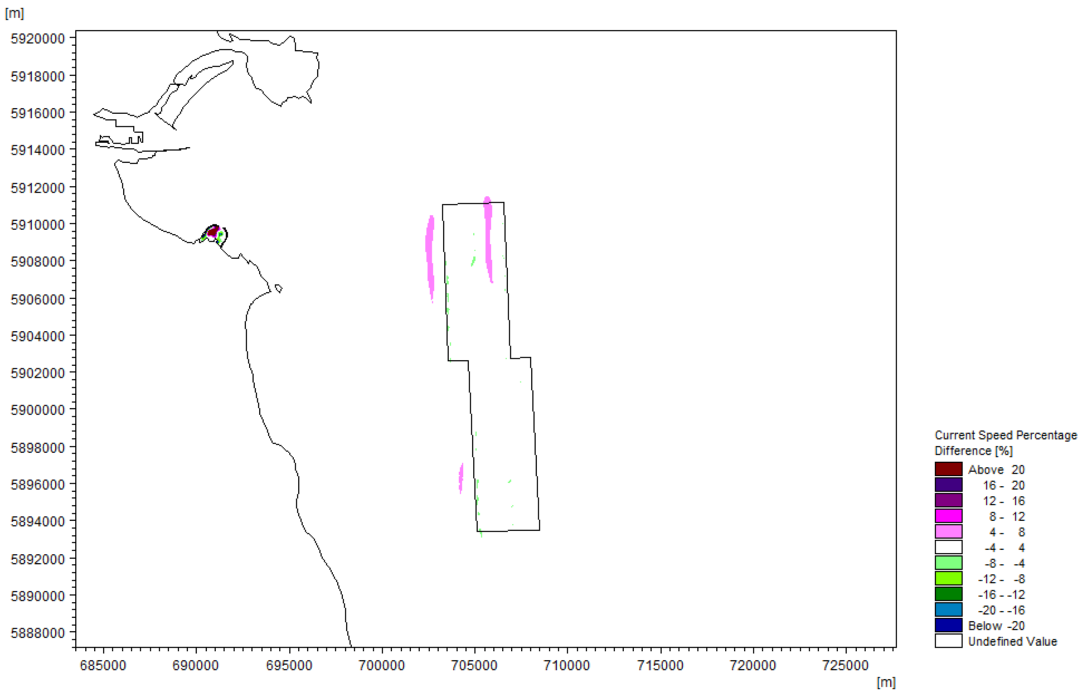


Figure B-30 Percentage difference in mean neap tide current speed at low water

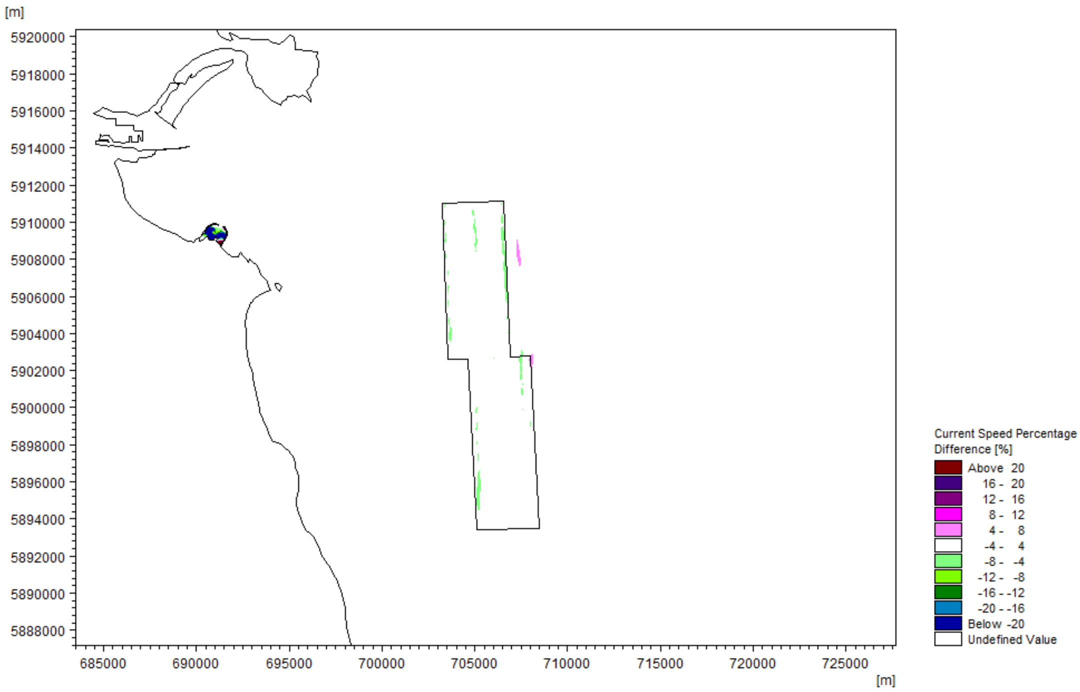


Figure B-31 Percentage difference in mean neap tide current speed at peak flood

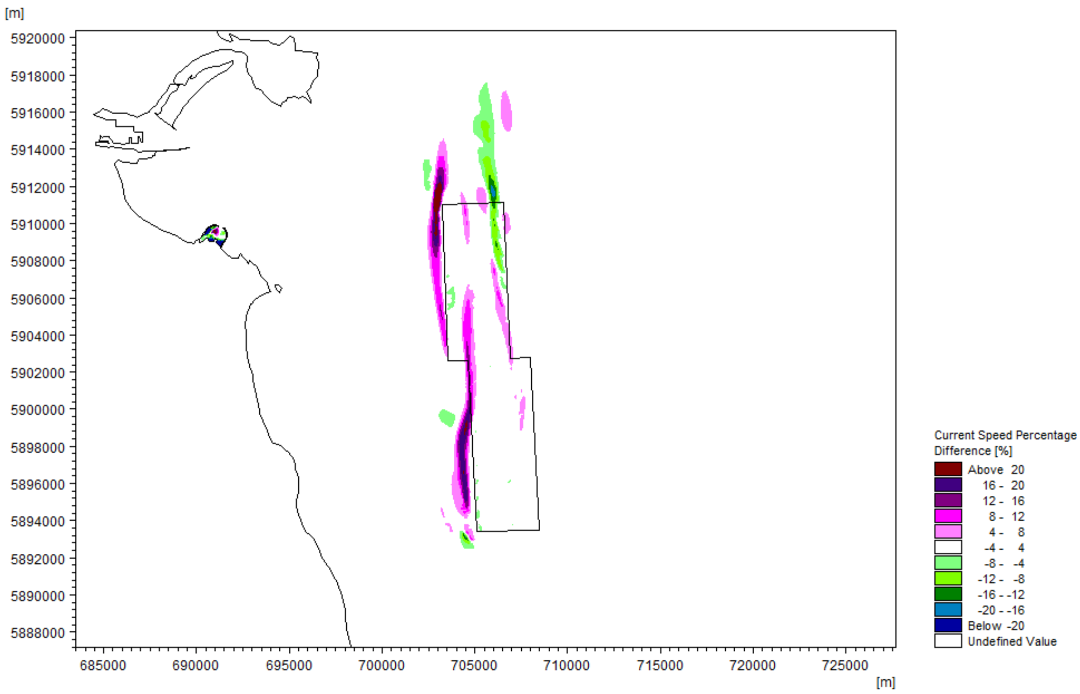
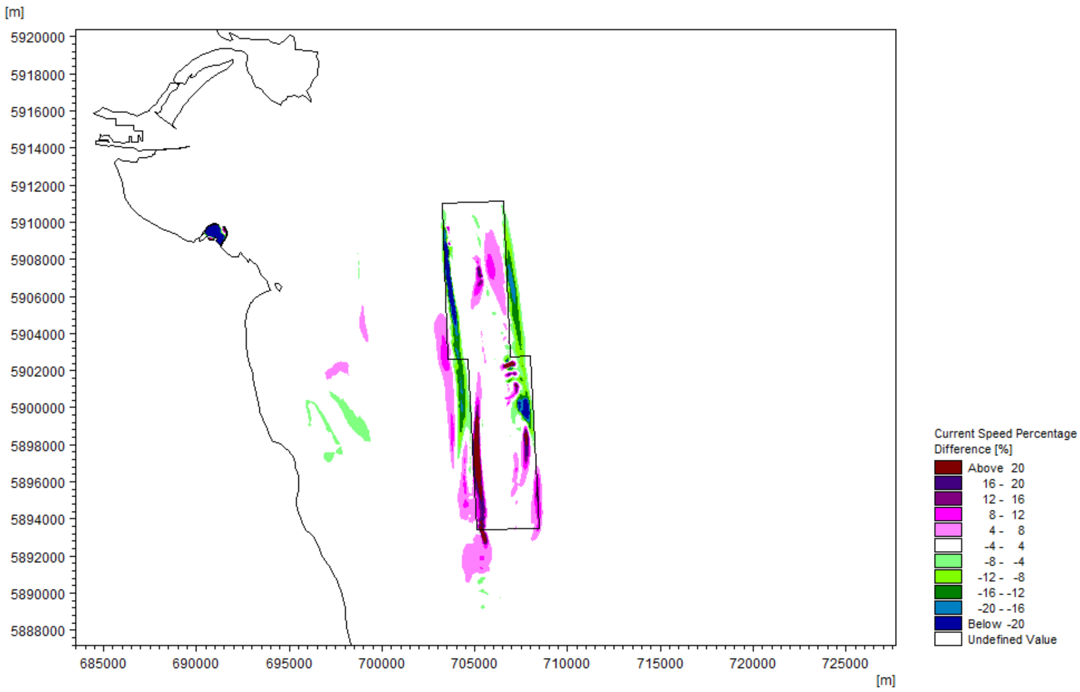


Figure B-32 Percentage difference in mean neap tide current speed at peak ebb



B.1.5 Bed Shear Stress Difference Plots

Figure B-33 Difference in mean spring tide bed shear stress speed at high water

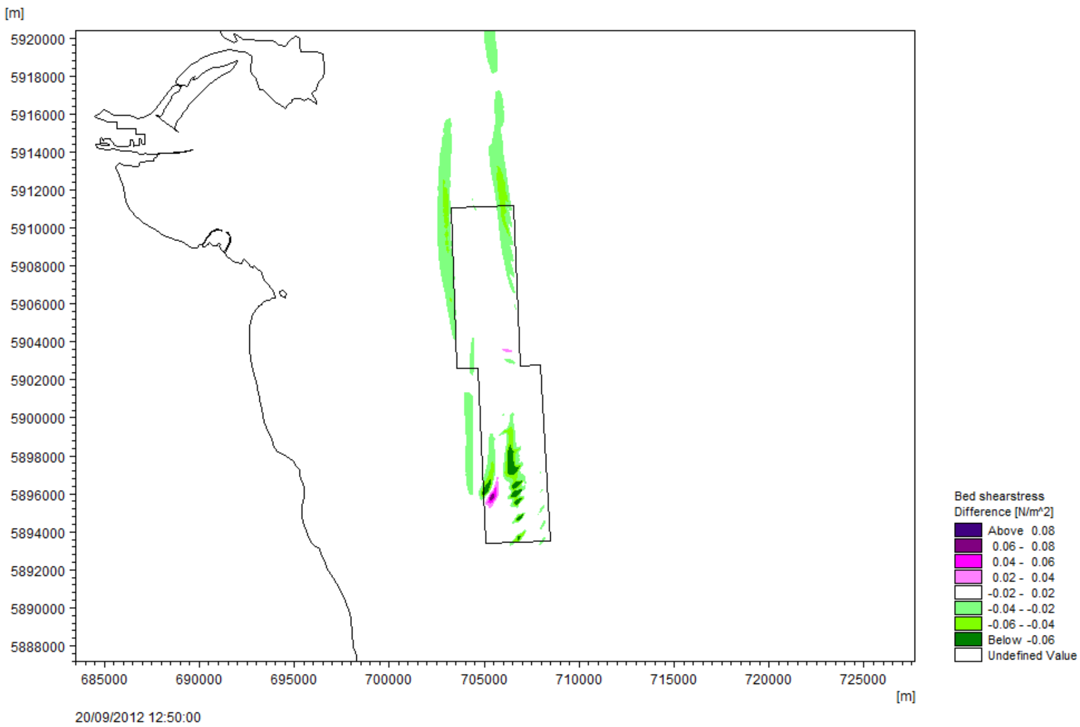


Figure B-34 Difference in mean spring tide bed shear stress speed at low water

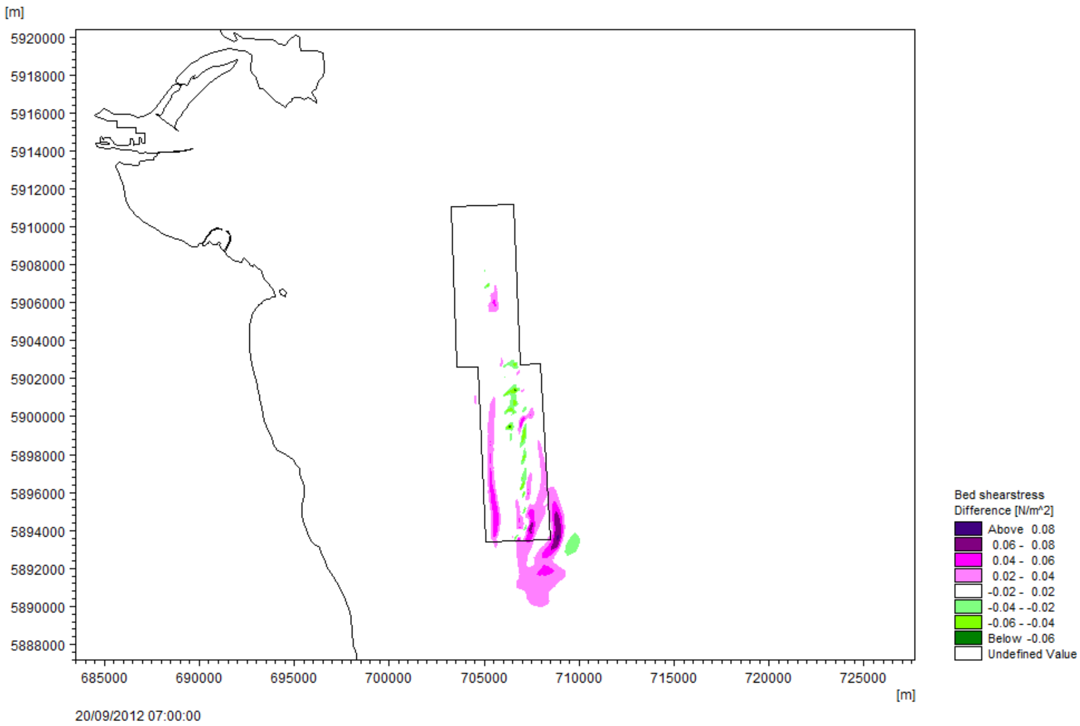


Figure B-35 Difference in mean spring tide bed shear stress speed at peak flood

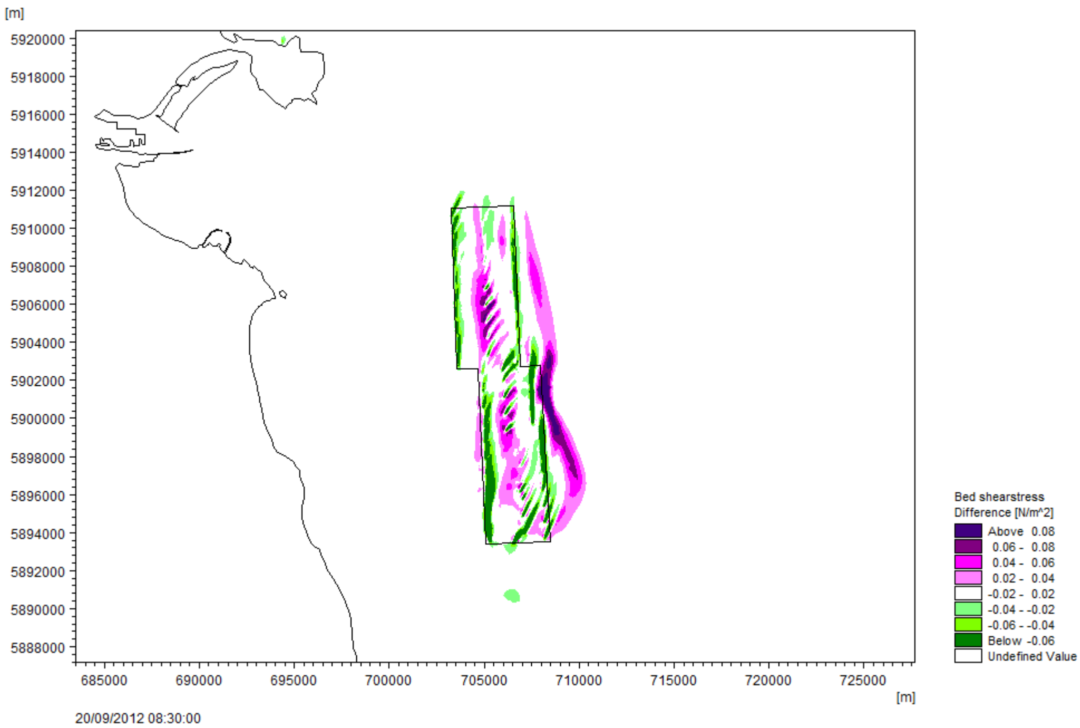


Figure B-36 Difference in mean spring tide bed shear stress speed at peak ebb

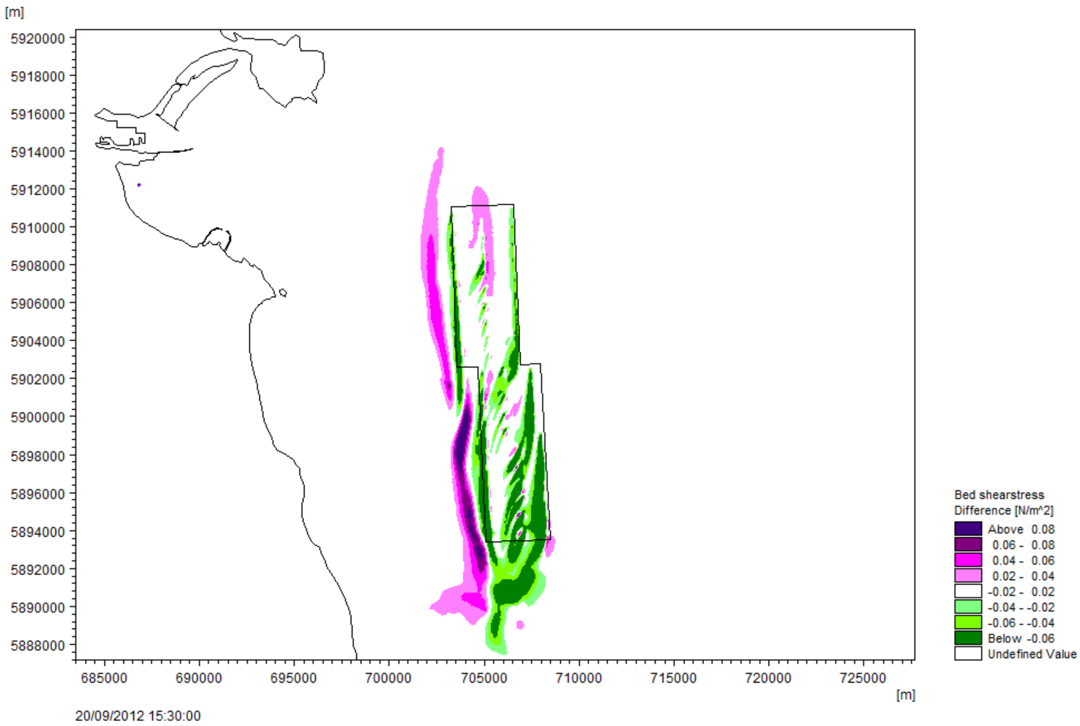


Figure B-37 Difference in mean neap tide bed shear stress speed at high water

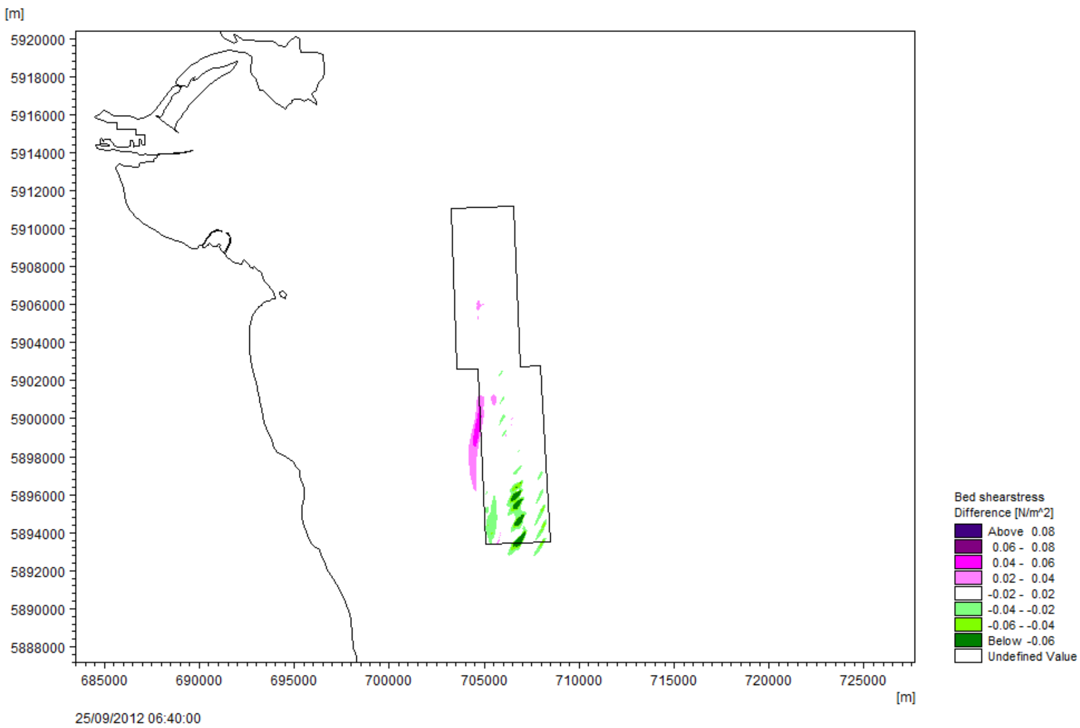


Figure B-38 Difference in mean neap tide bed shear stress speed at low water

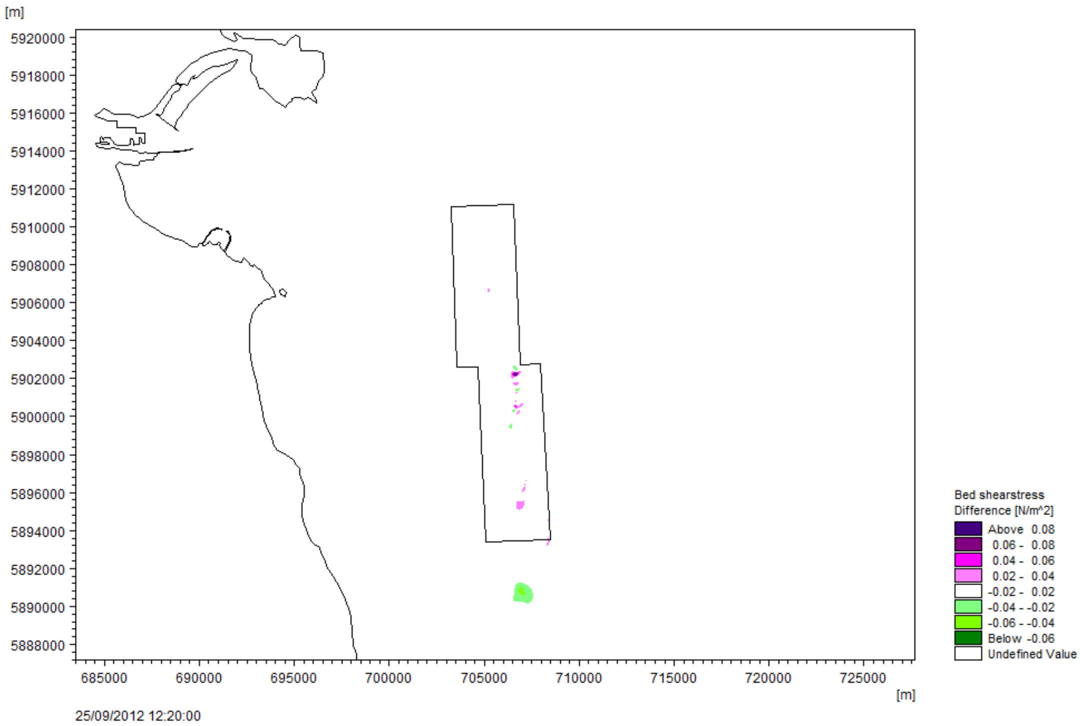


Figure B-39 Difference in mean neap tide bed shear stress speed at peak flood

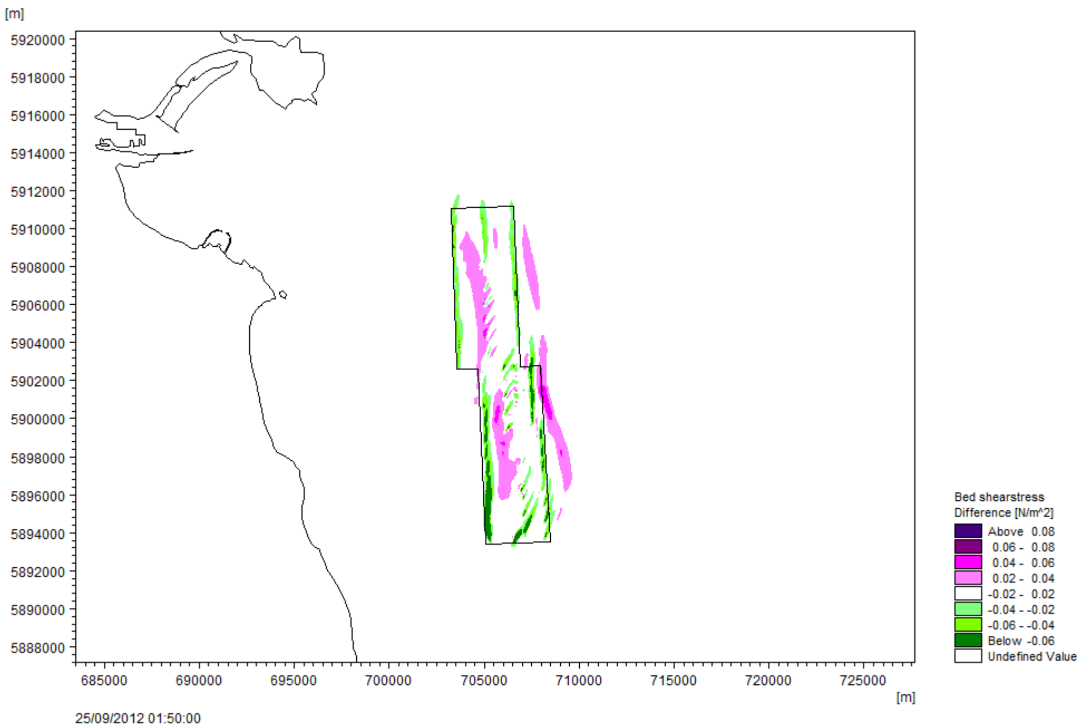
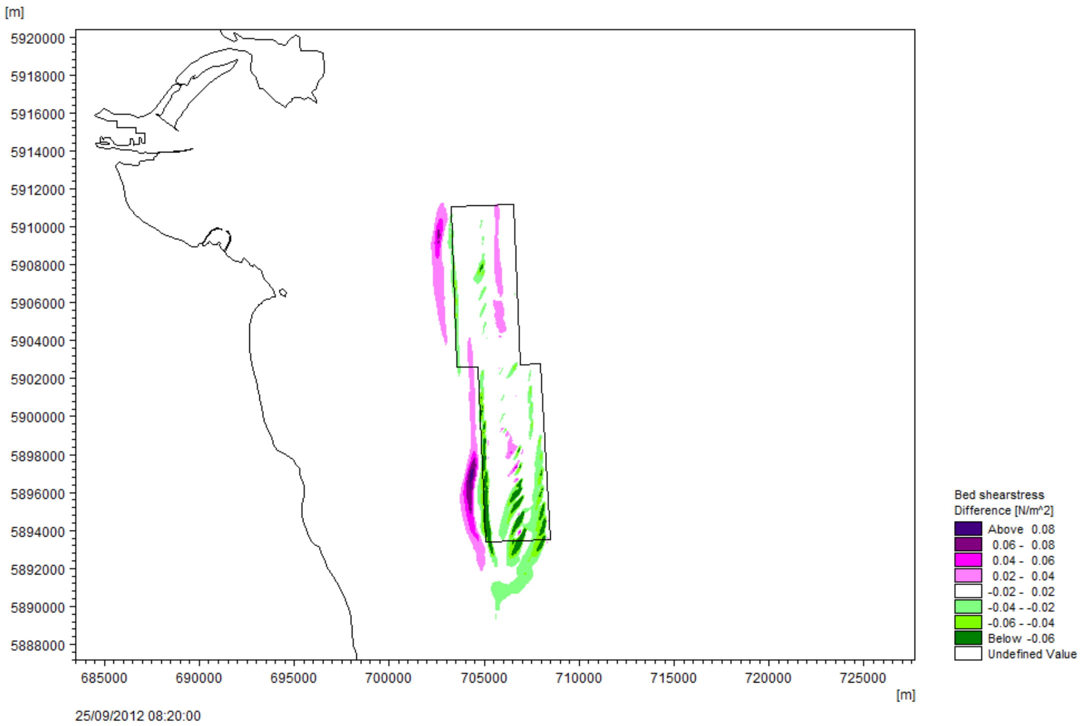


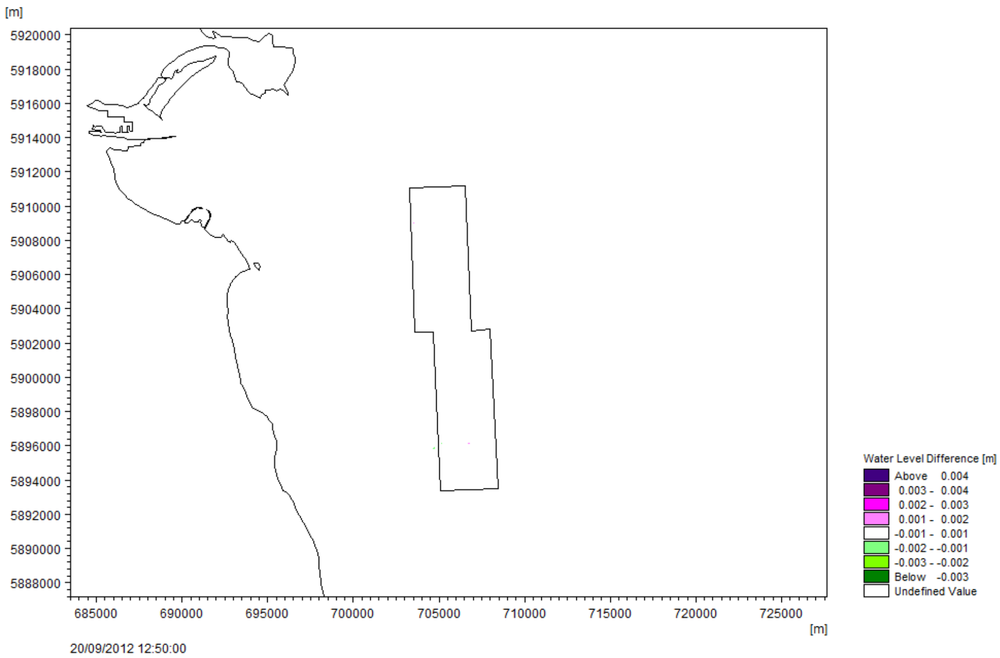
Figure B-40 Difference in mean neap tide bed shear stress speed at peak ebb



B.2 HYDRODYNAMIC REGIME DIFFERENCE PLOTS WITH FUTURE SEA LEVEL RISE

B.2.1 Water Level Difference Plots

Figure B-41 Spring tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at high water



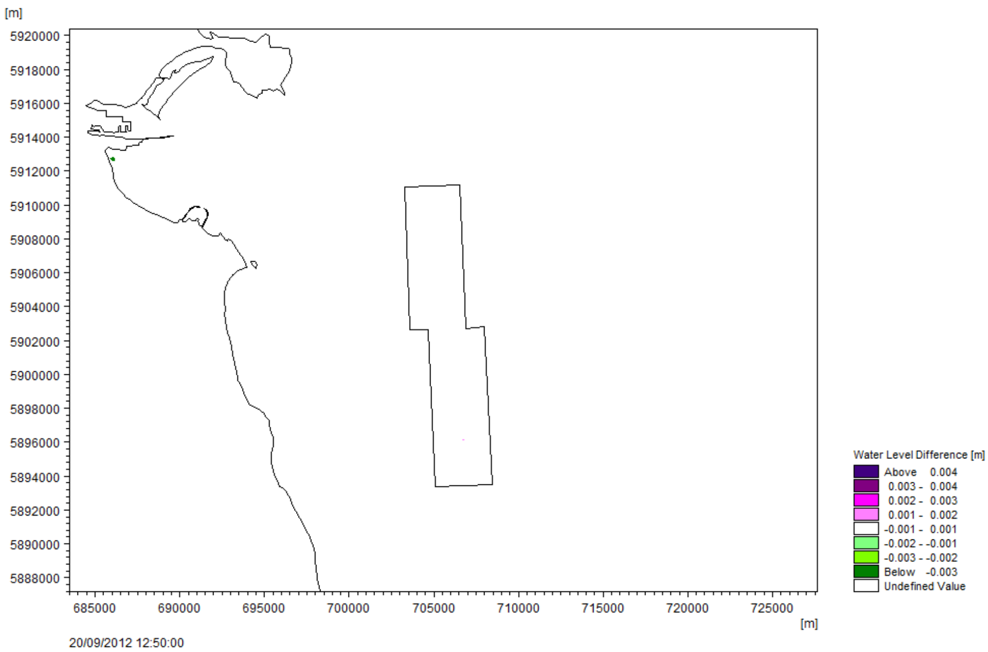
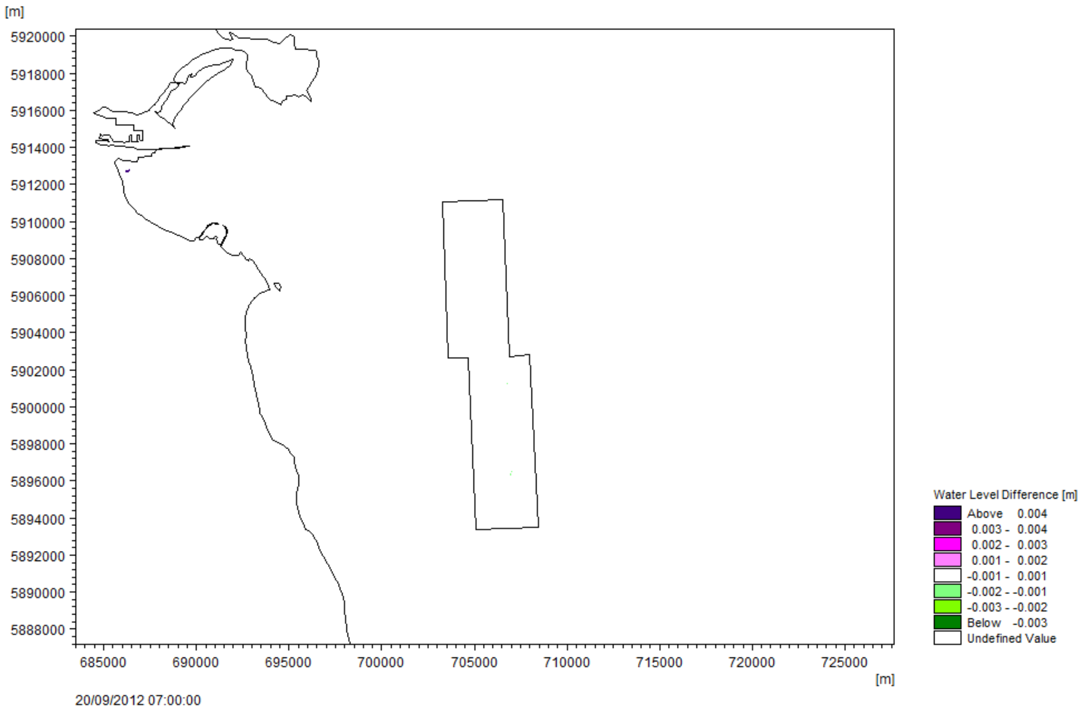


Figure B-42 Spring tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at low water



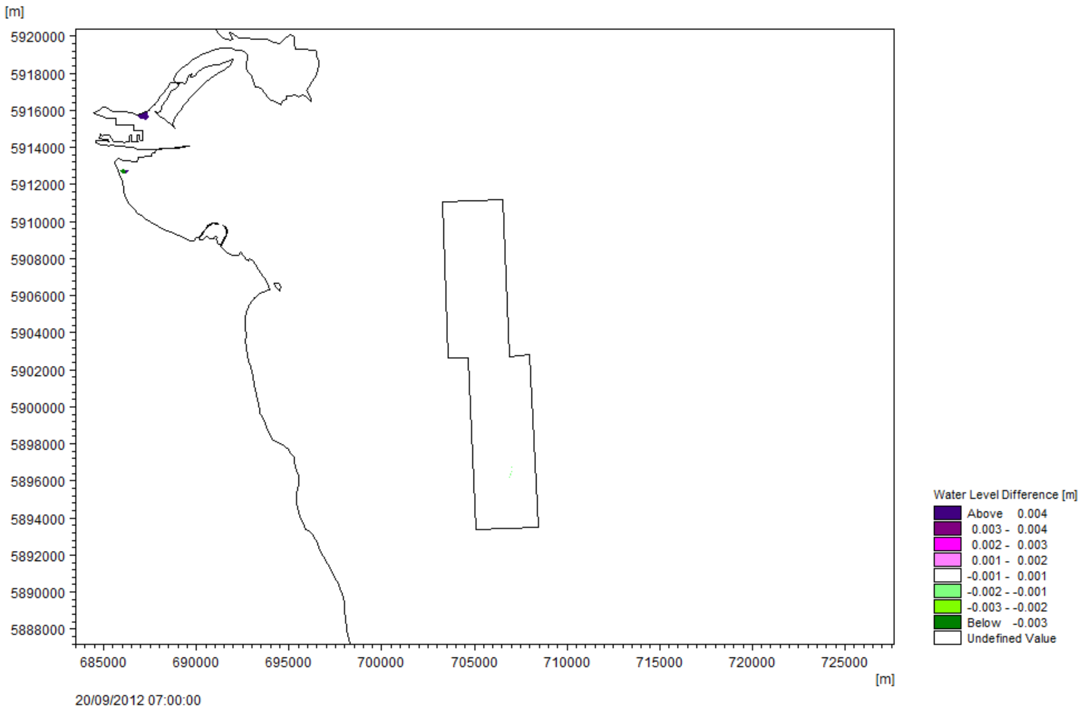
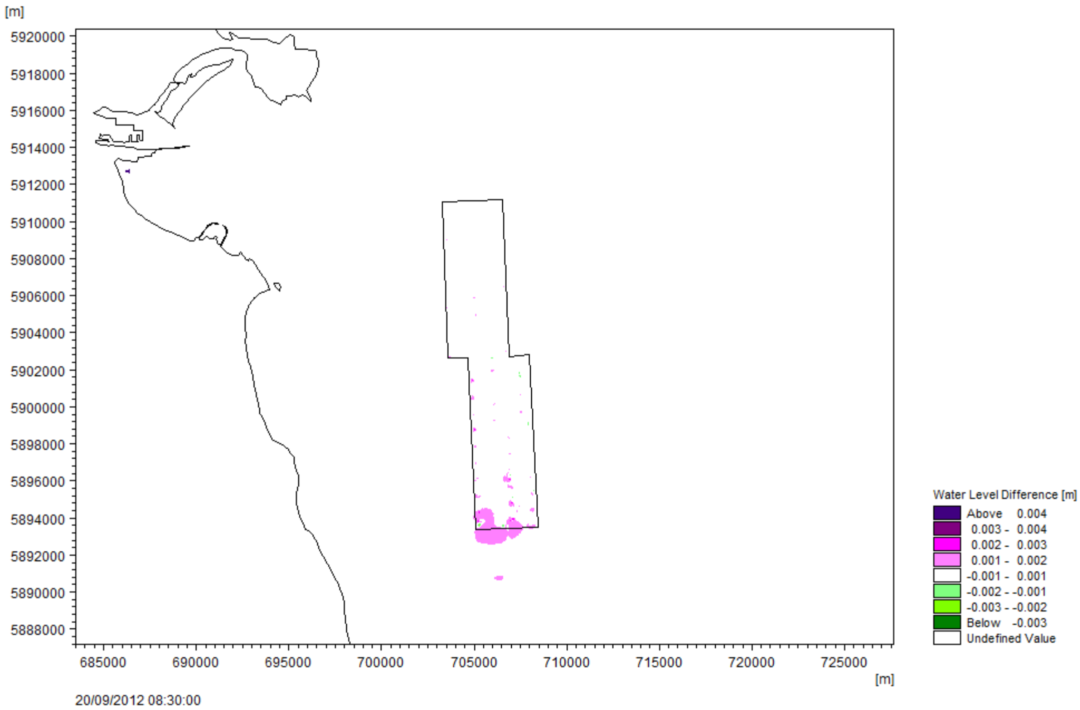


Figure B-43 pring tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak flood



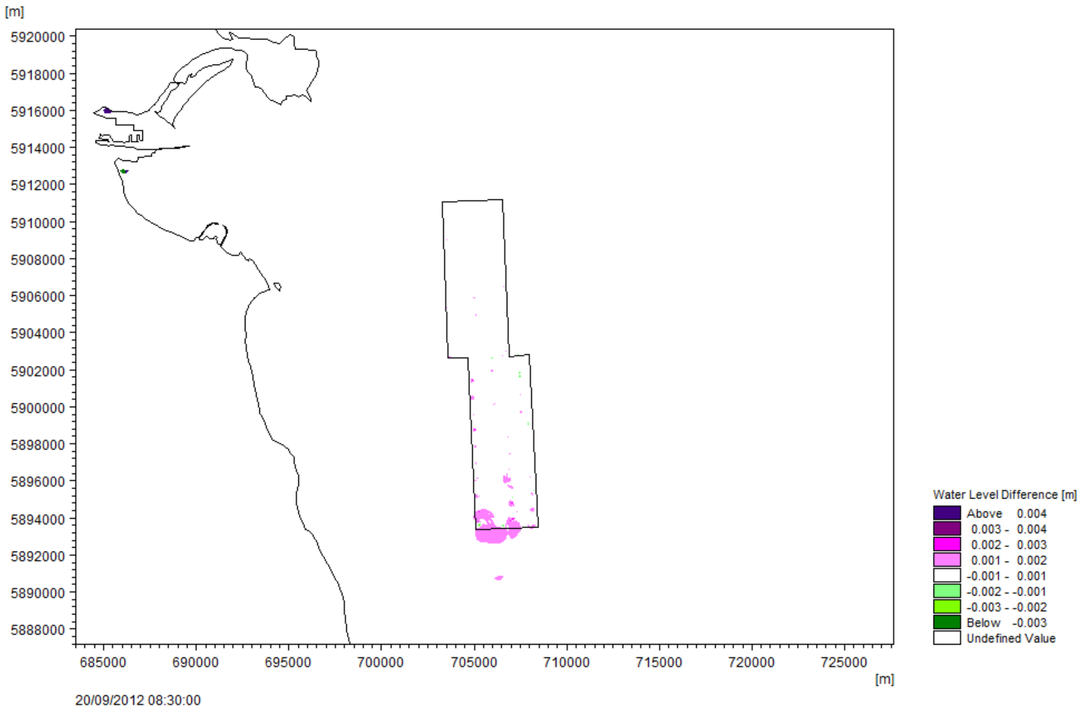
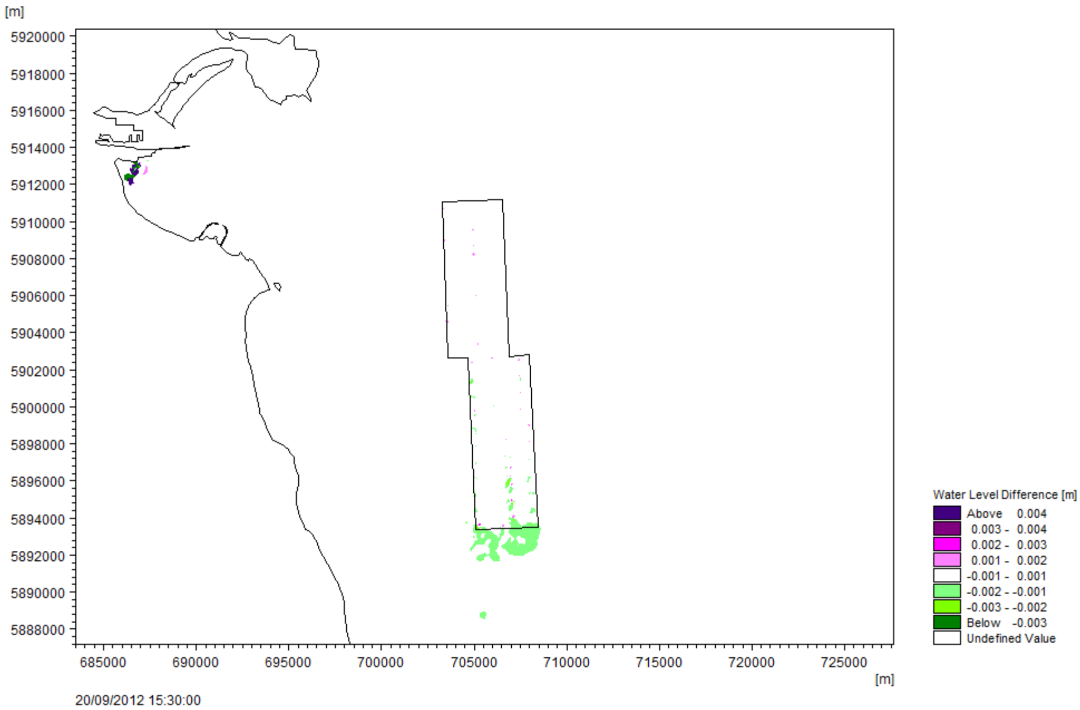


Figure B-44 Spring tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak ebb



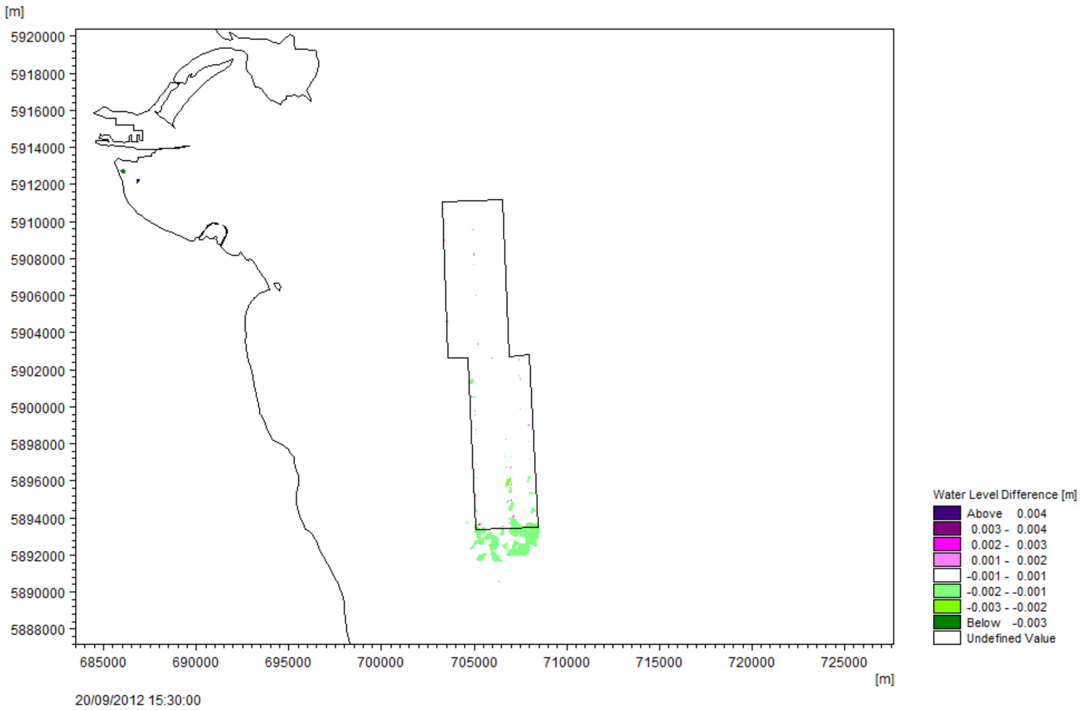
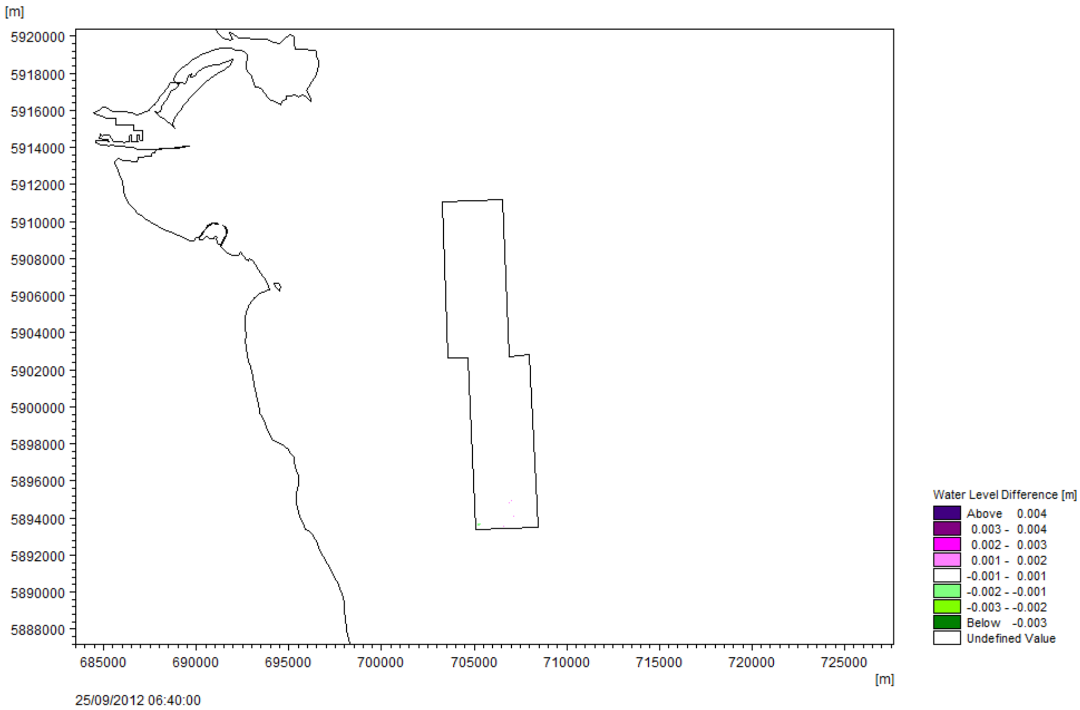


Figure B-45 Neap tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at high water



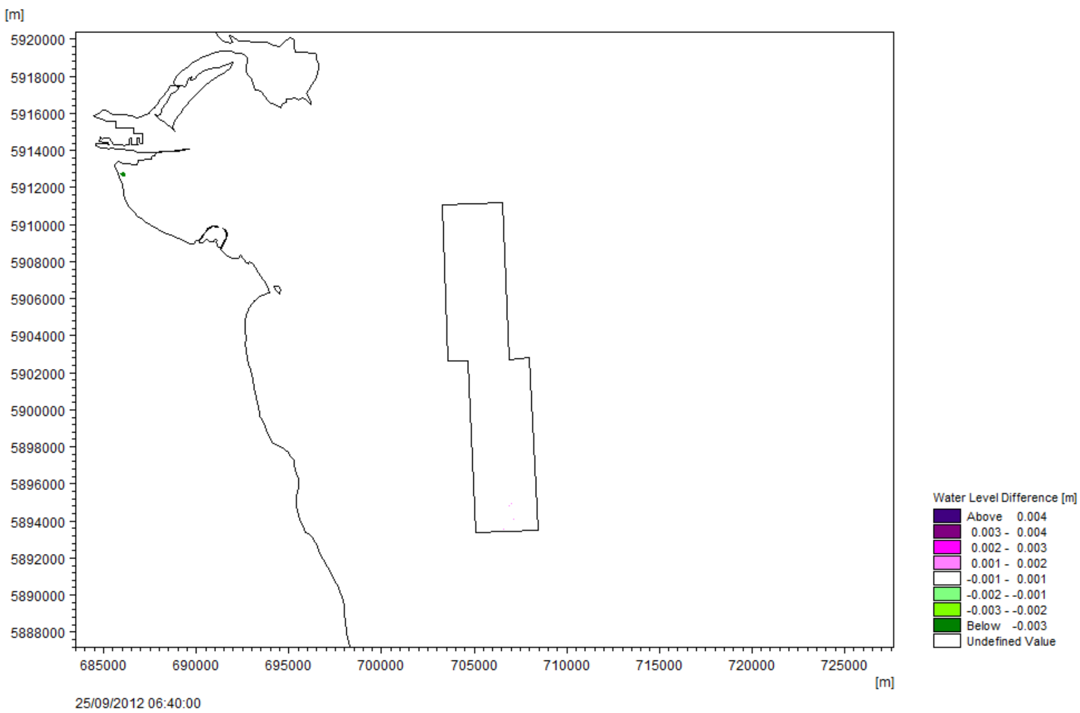
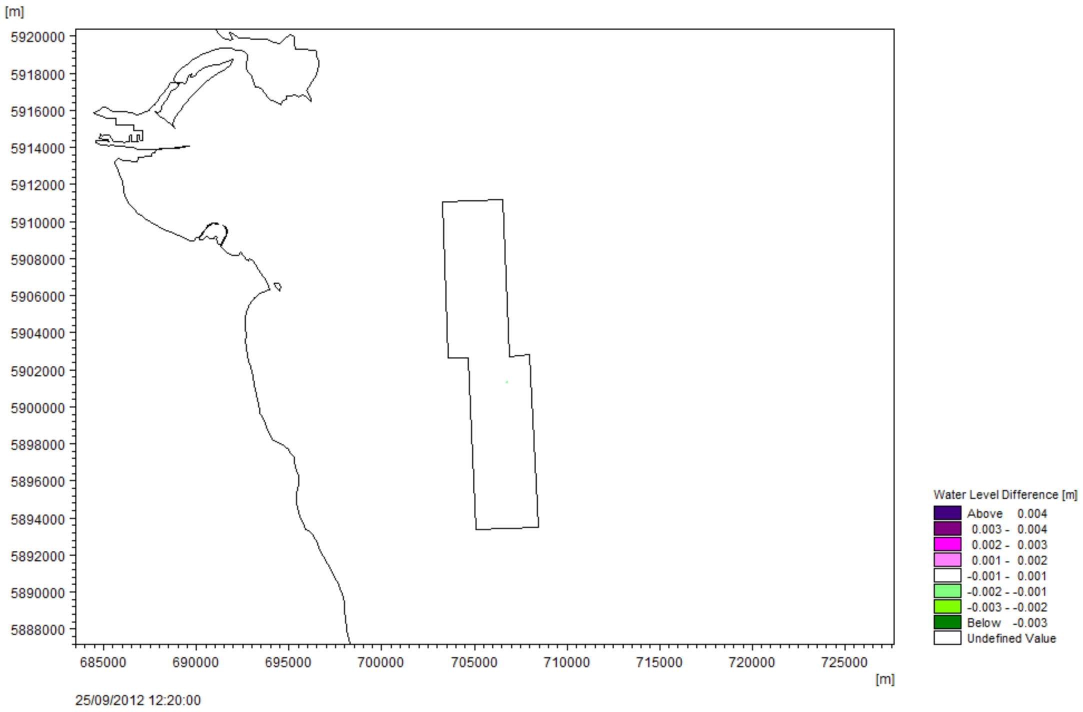


Figure B-46 Neap tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at low water



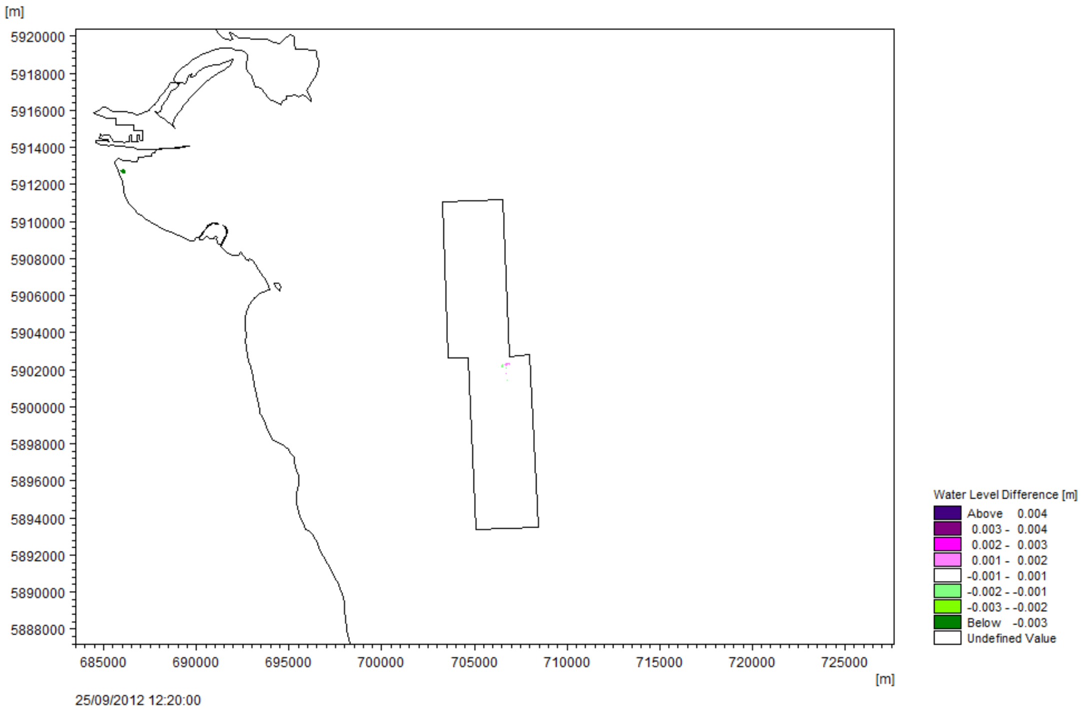
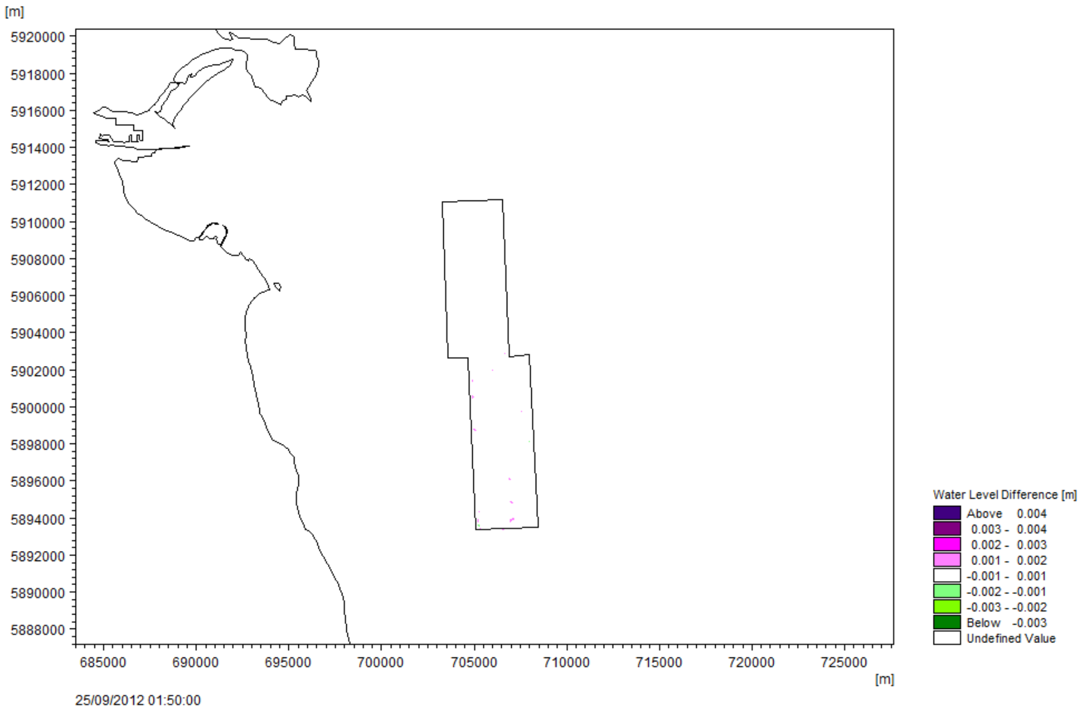


Figure B-47 Neap tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below) , at peak flood



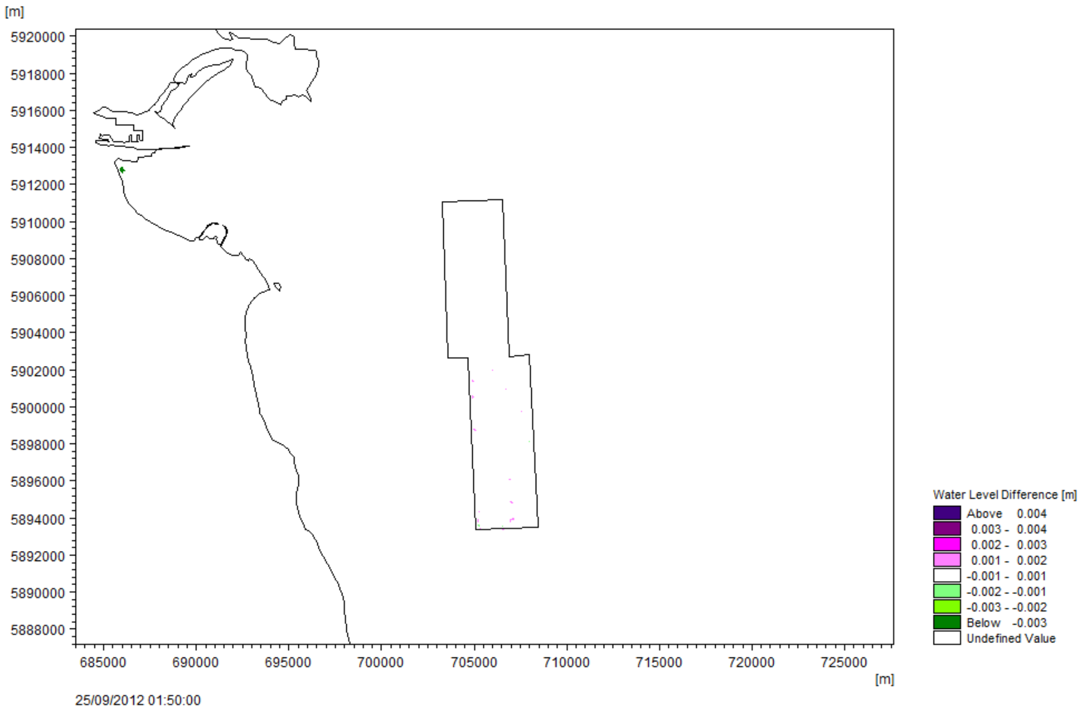
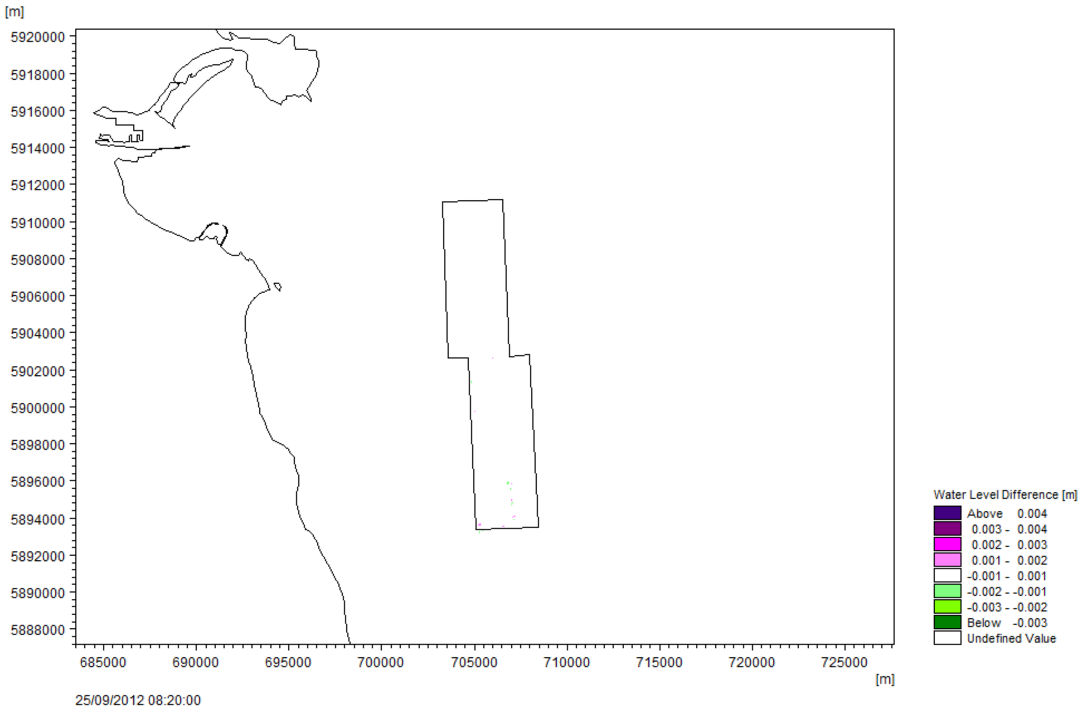
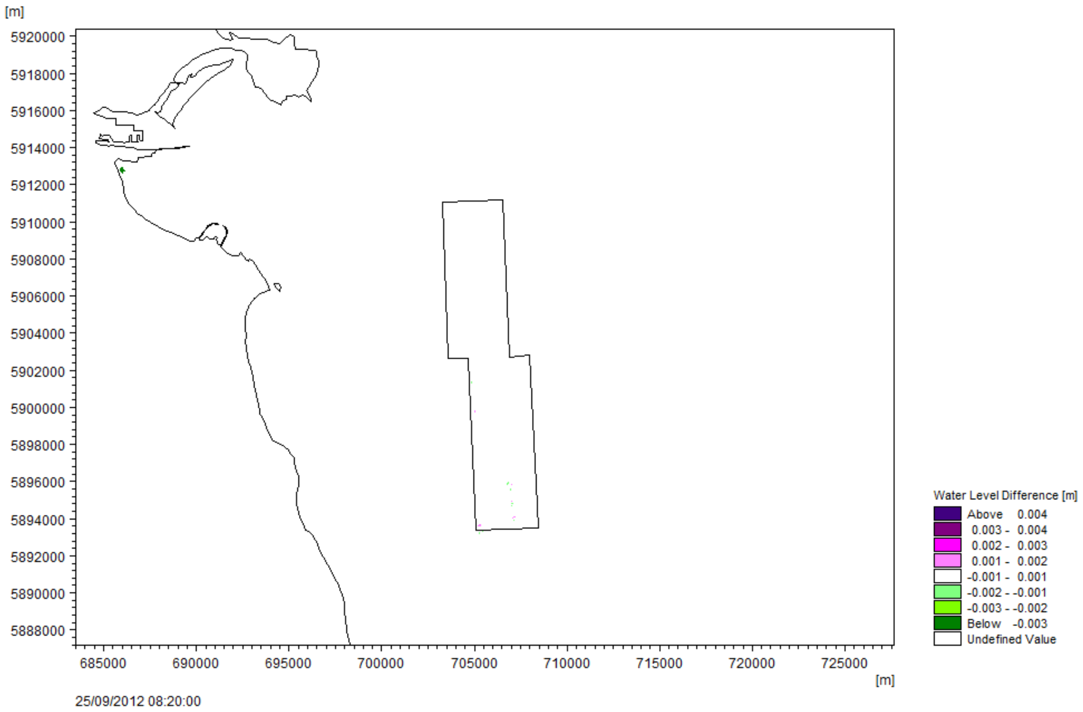


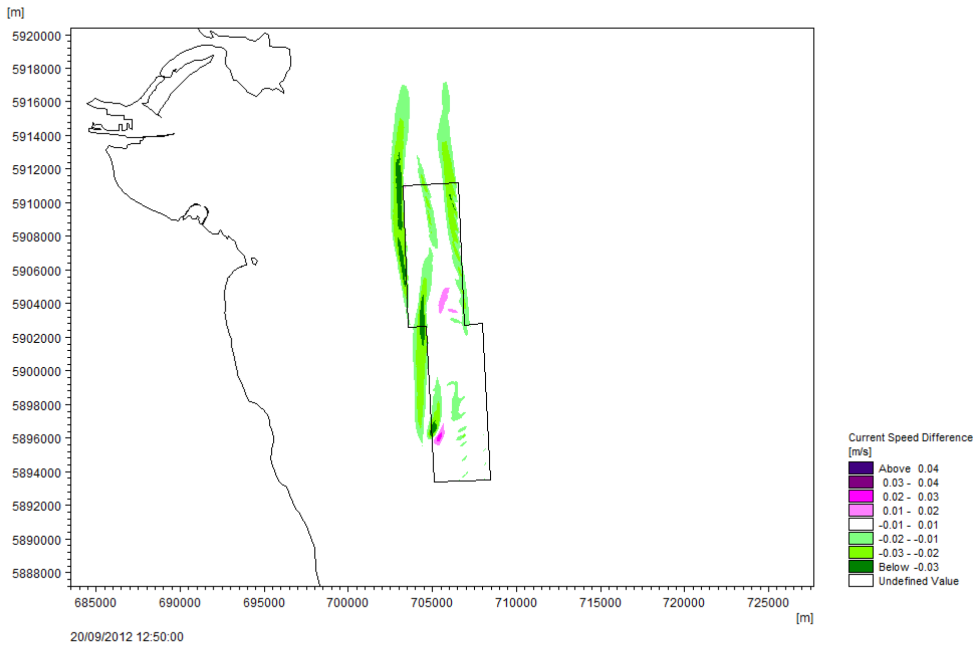
Figure B-48 Neap tide water level difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak ebb





B.2.2 Current Speed Difference Plots

Figure B-49 Spring tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at high water



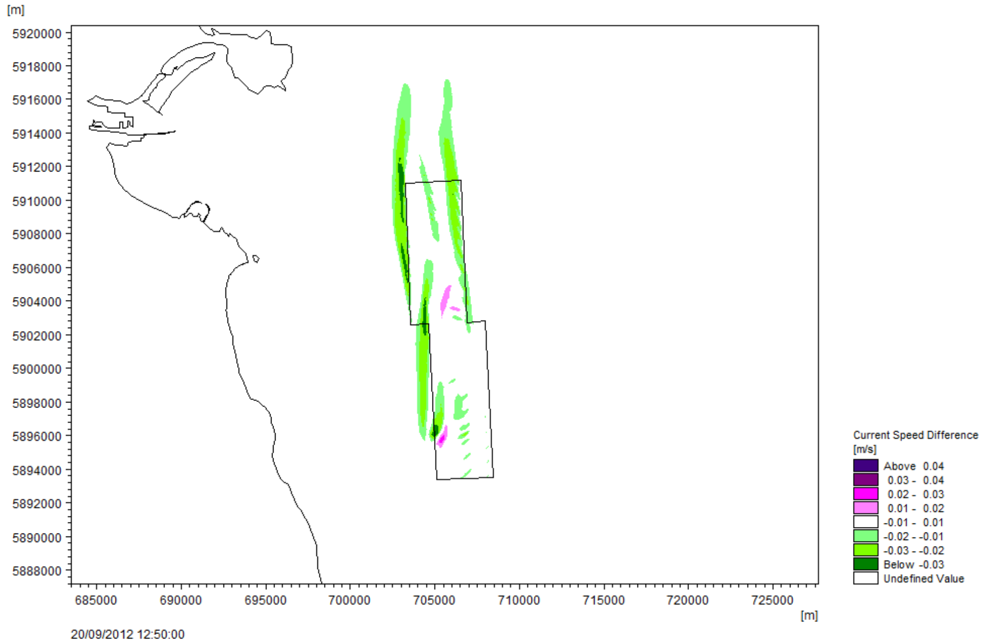
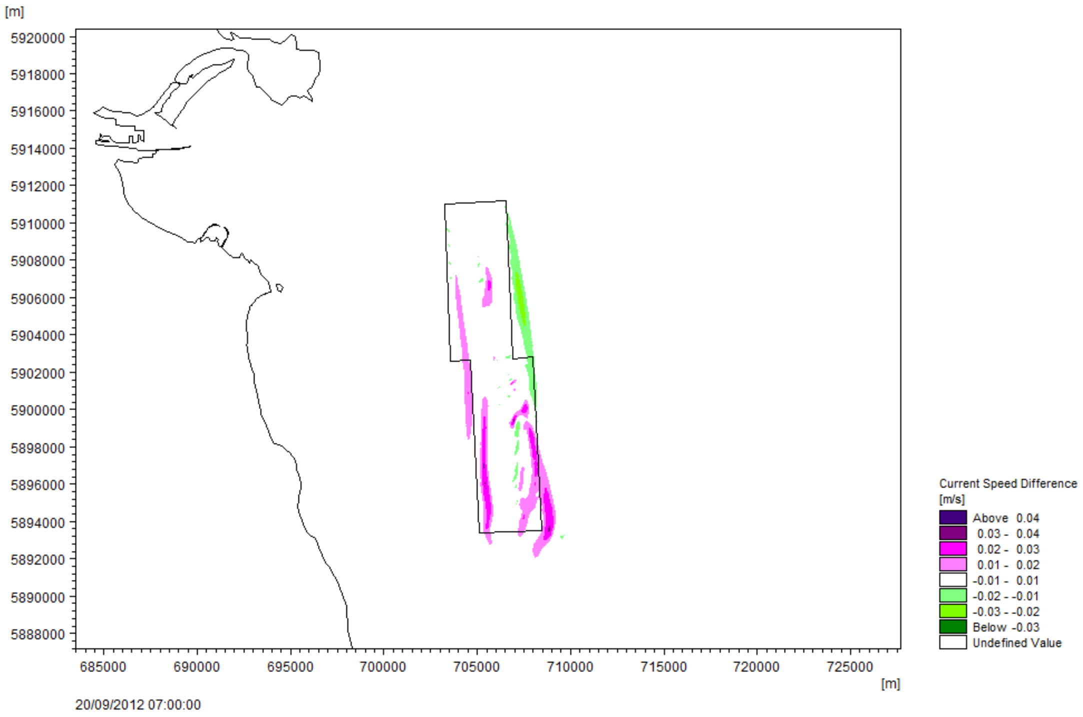


Figure B-50 Spring tide current speed difference between baseline and scheme with, sea level rise (above) and without sea level rise (below), at low water



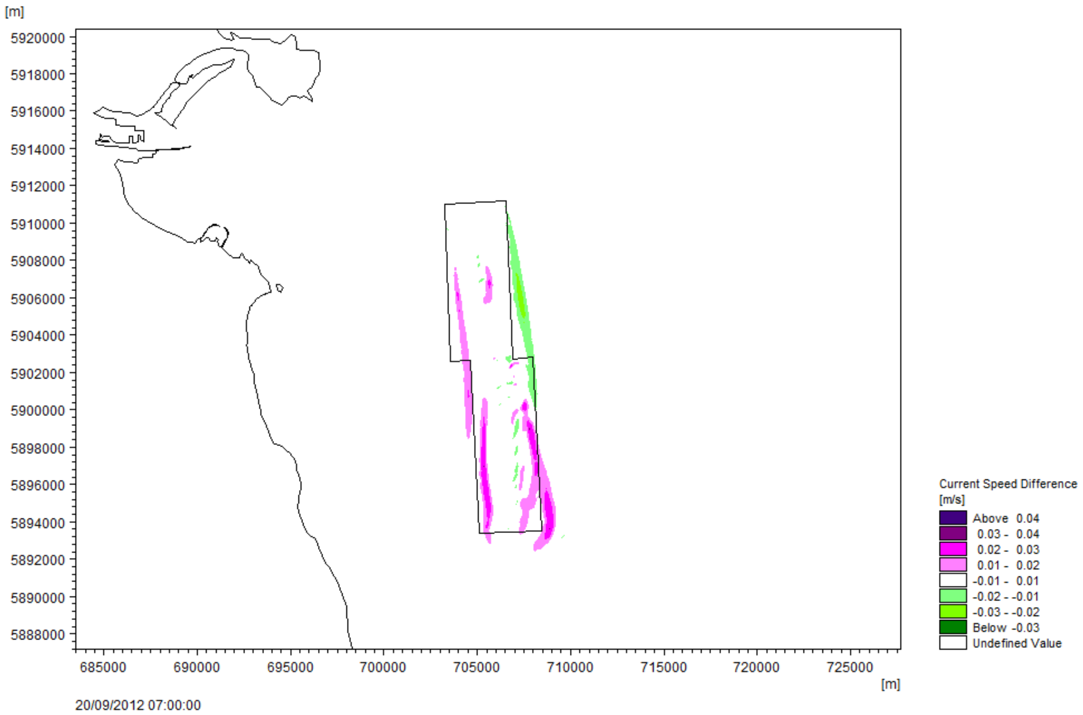
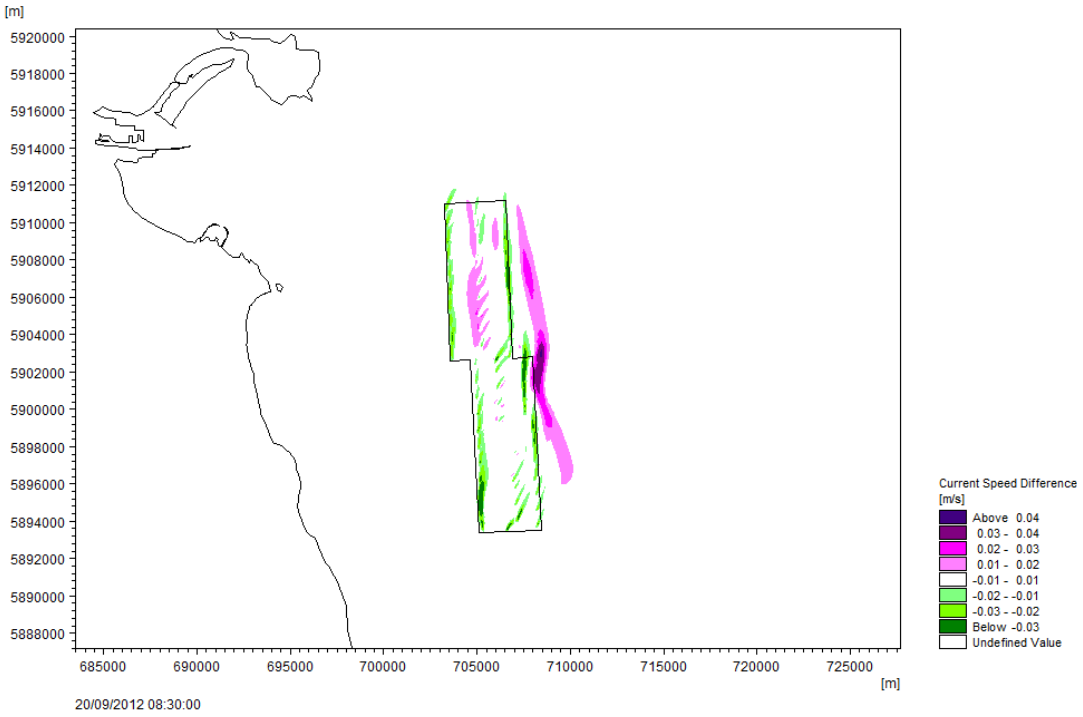


Figure B-51 Spring tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak flood



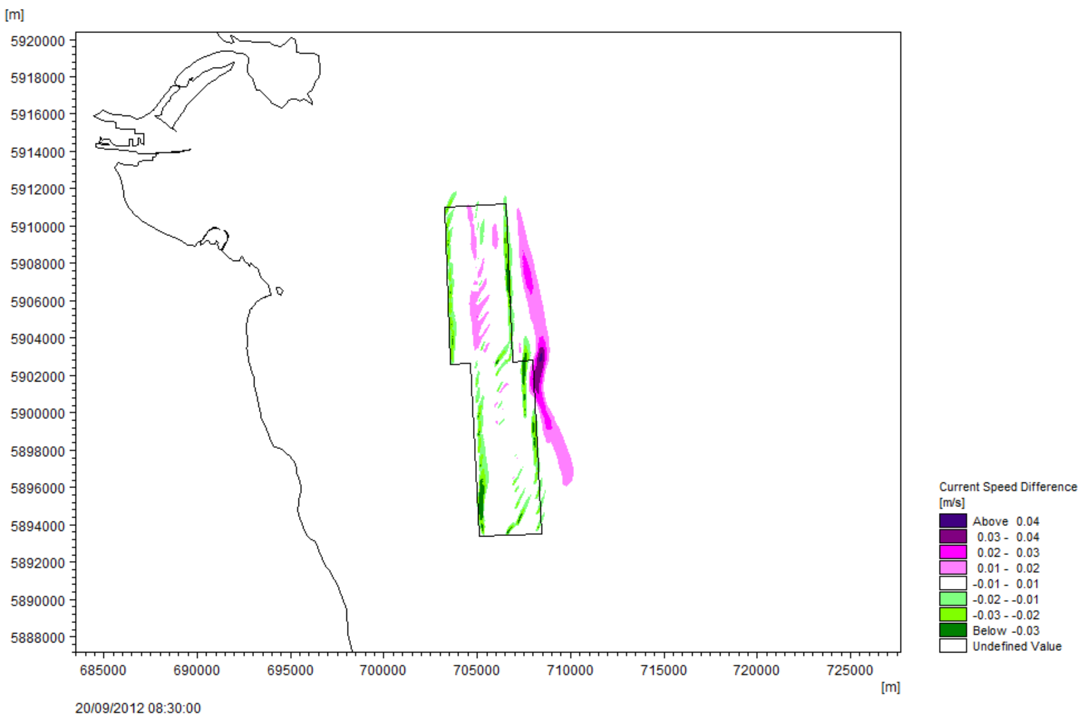
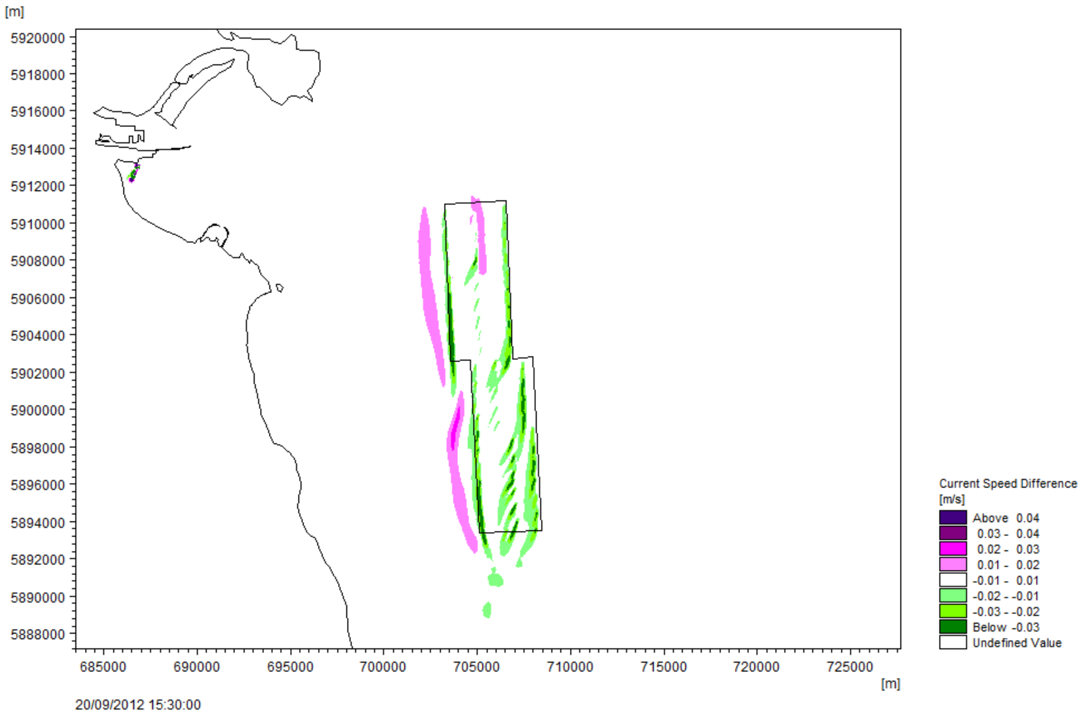


Figure B-52 Spring tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak ebb



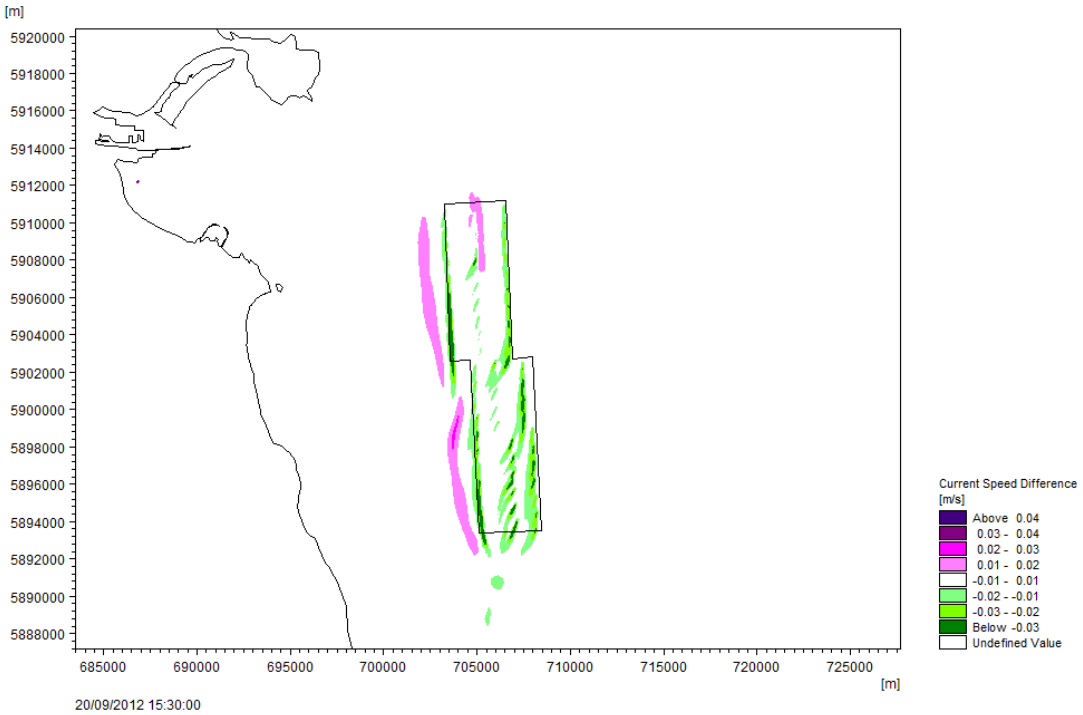
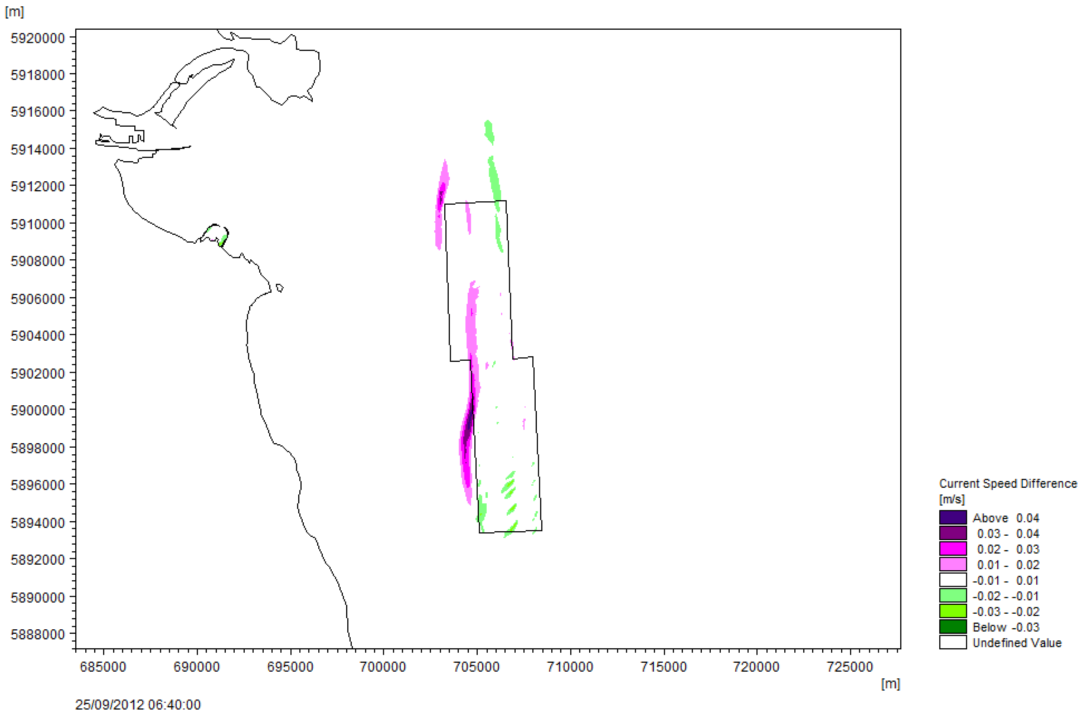


Figure B-53 Neap tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at high water



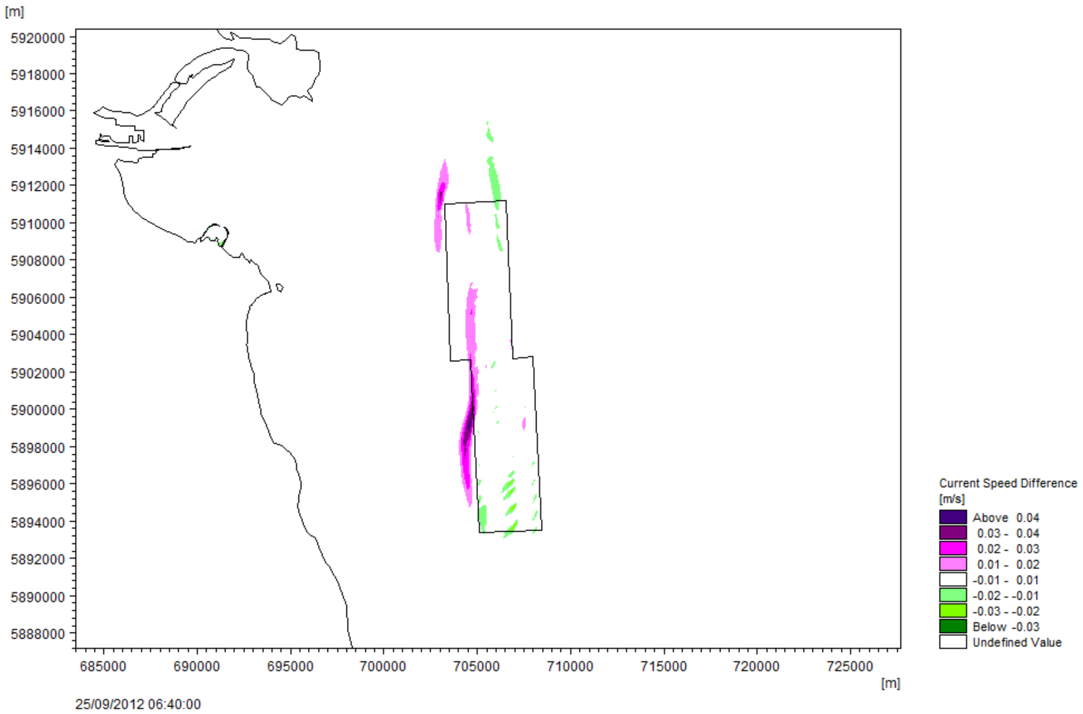
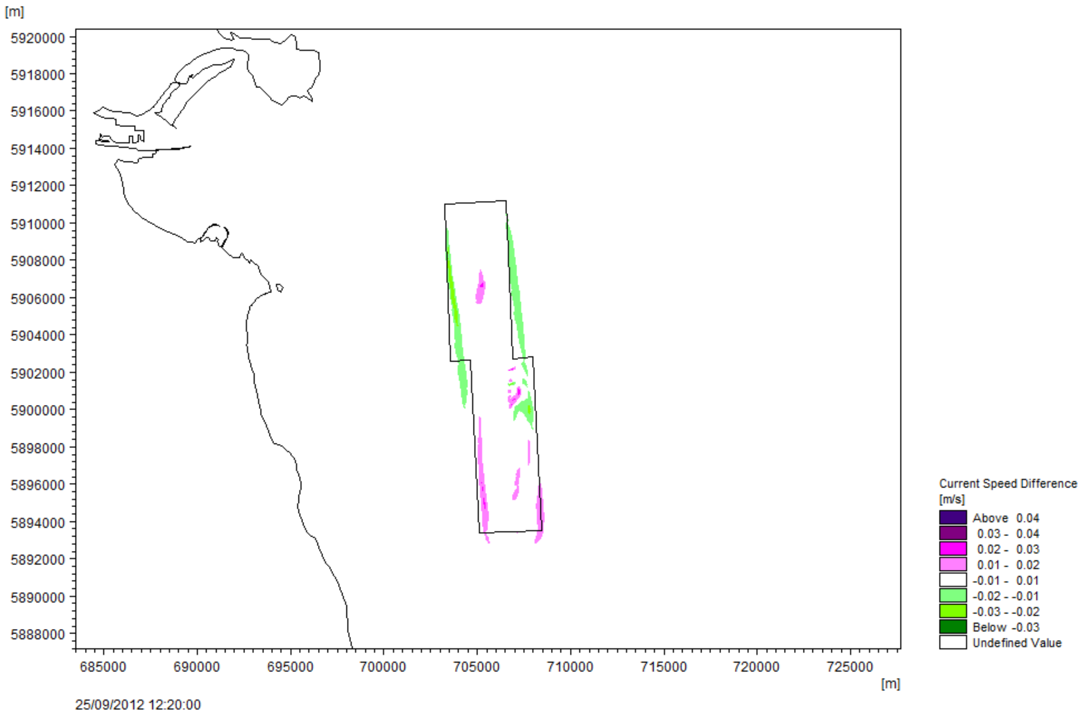


Figure B-54 Neap tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at low water



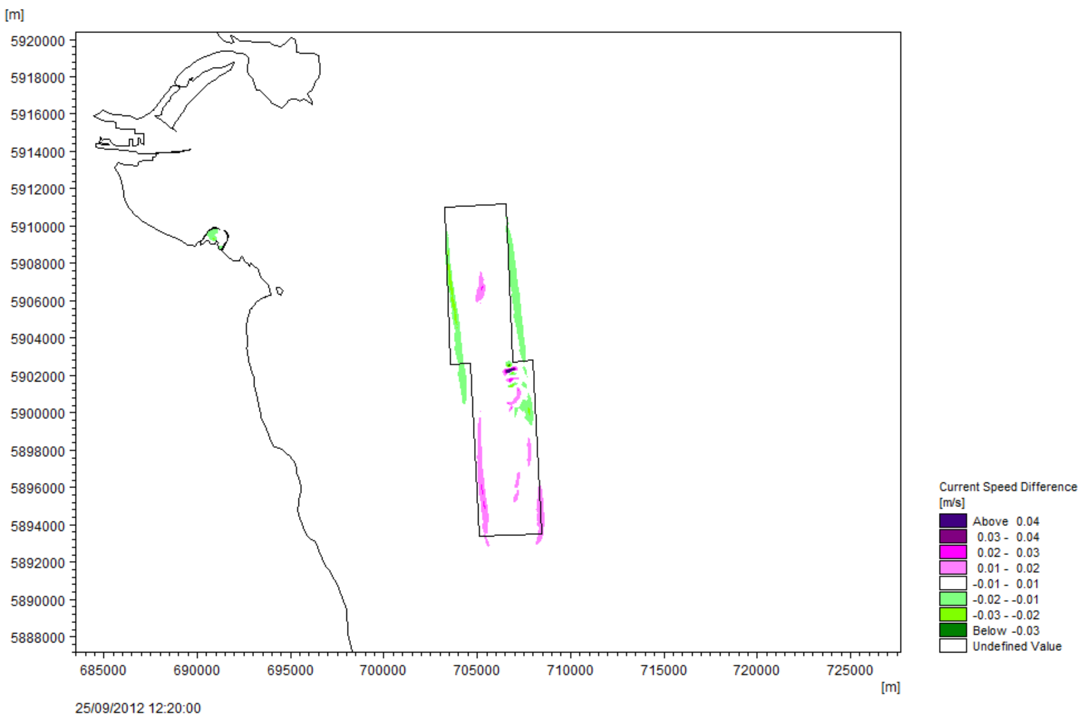
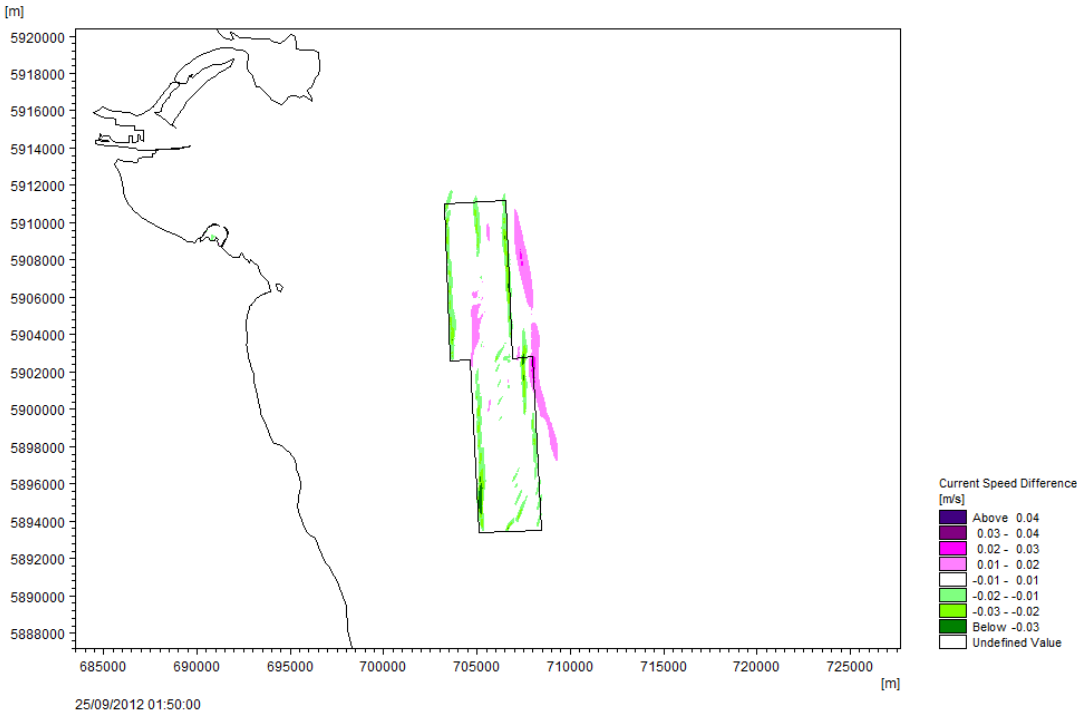


Figure B-55 Neap tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak flood



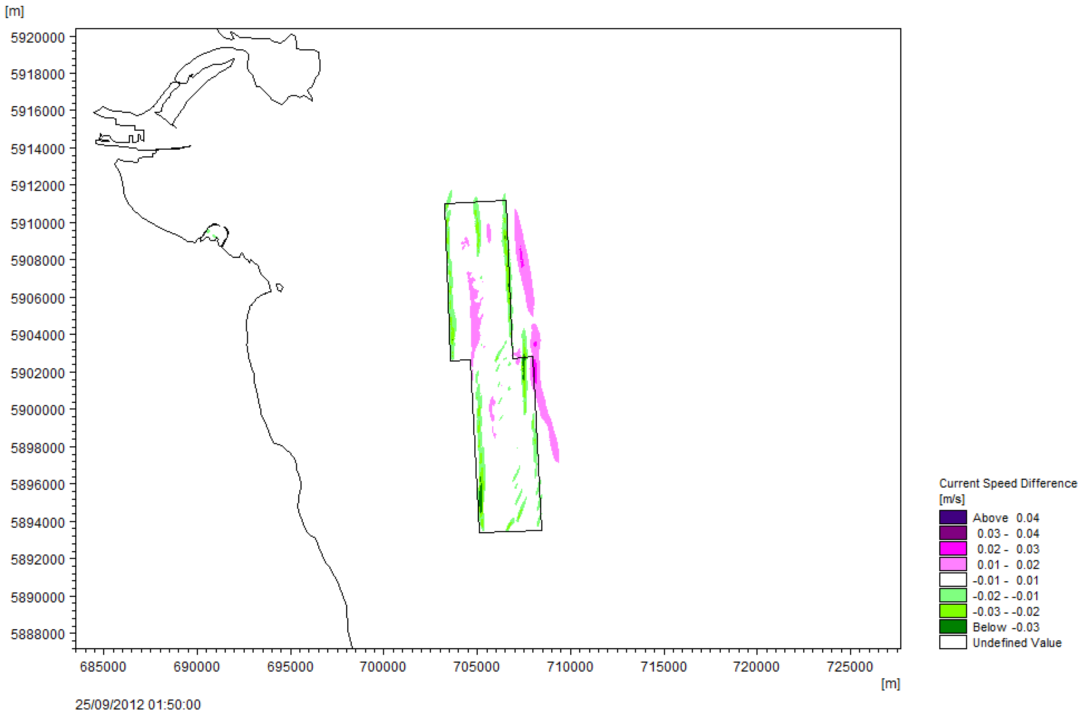
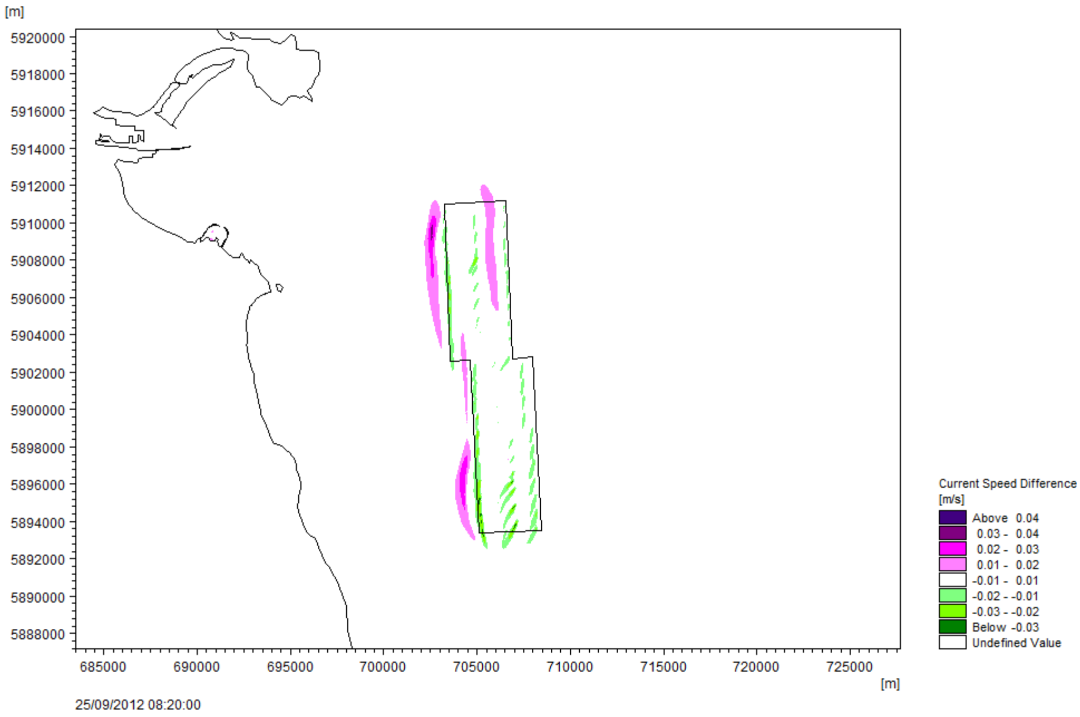
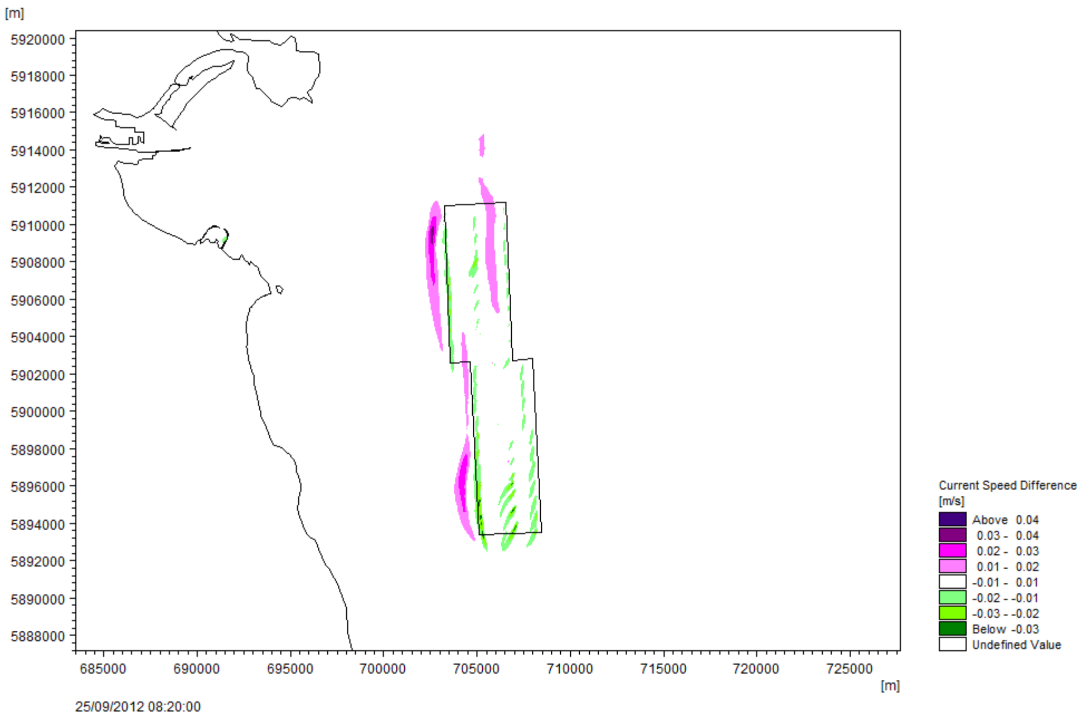


Figure B-56 Neap tide current speed difference between baseline and scheme, with sea level rise (above) and without sea level rise (below), at peak ebb





B.2.3 Significant Wave Height Difference Plots

Figure B-57 Absolute difference in H_{m0}, 50%ile condition from north (m)

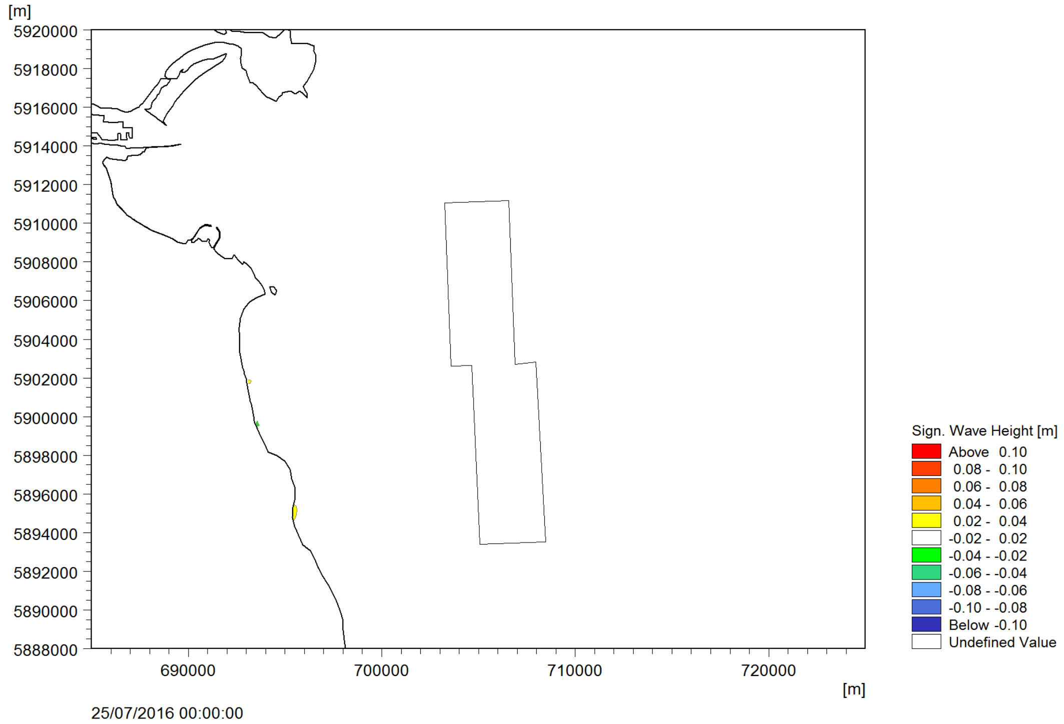


Figure B-58 Relative difference in H_{m0}, 50%ile condition from north (m)

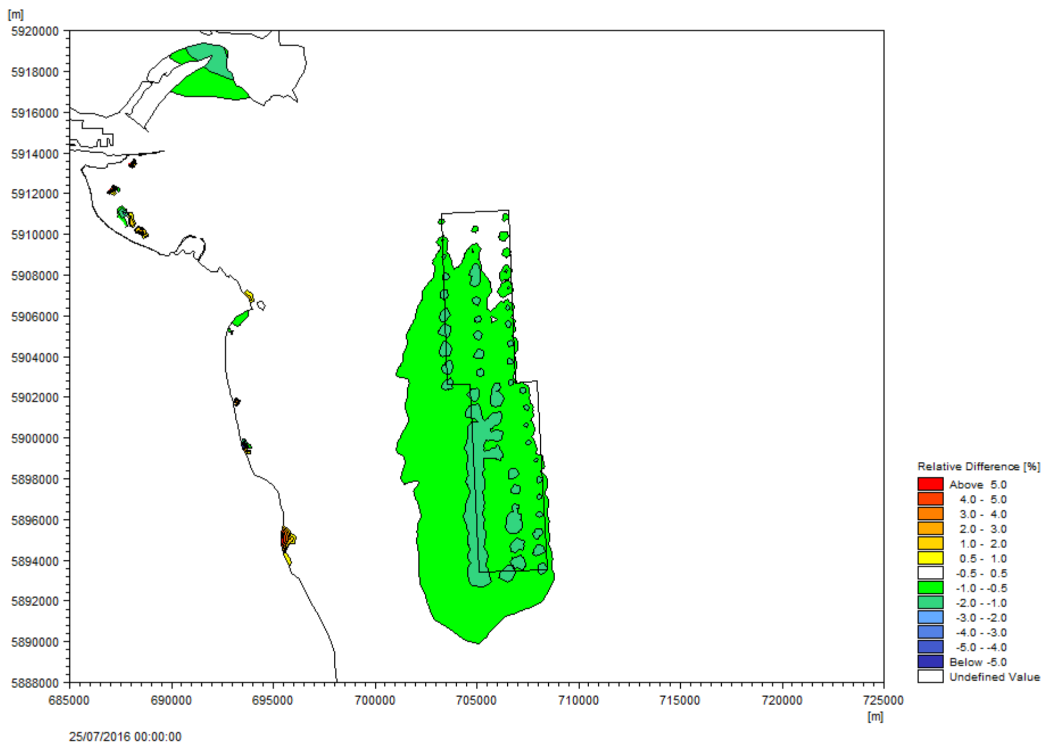


Figure B-59 Absolute difference in H_{m0}, 5%ile condition from north (m)

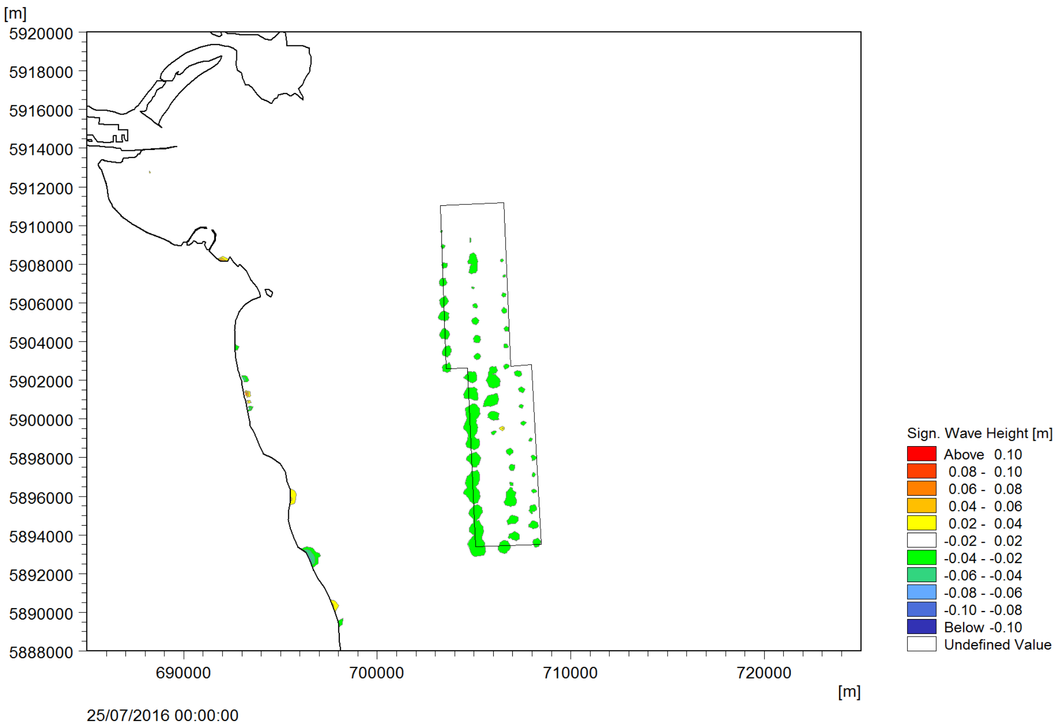


Figure B-60 Relative difference in H_{m0}, 5%ile condition from north (m)

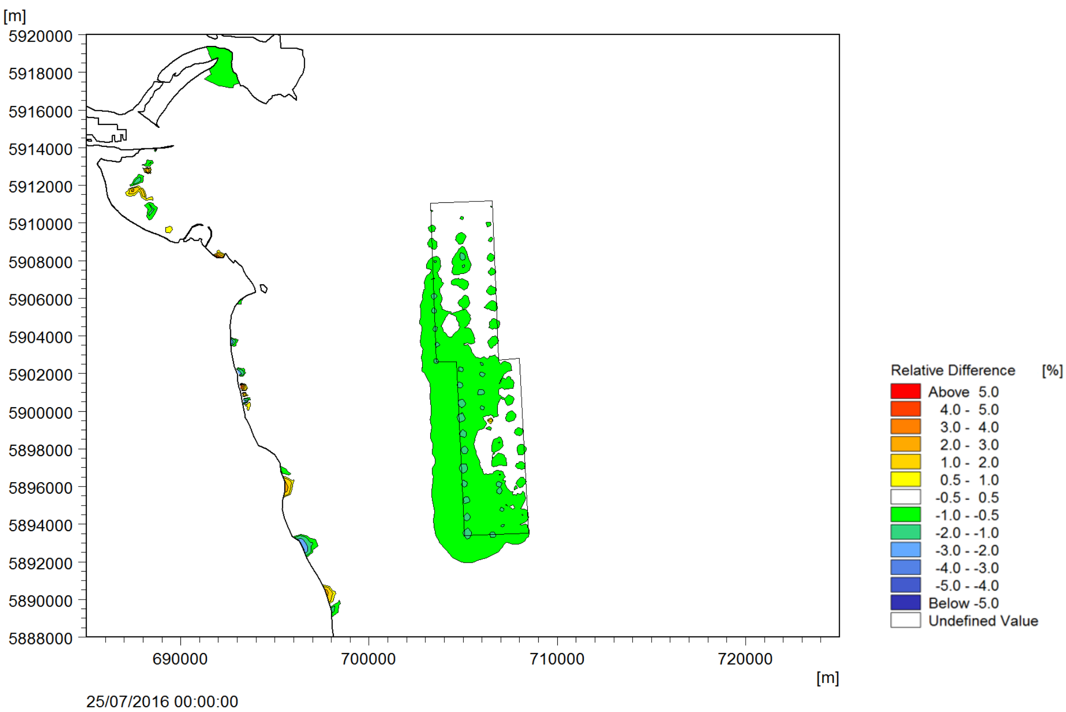


Figure B-61 Absolute difference in H_{m0}, 1 in 1 year condition from north (m)

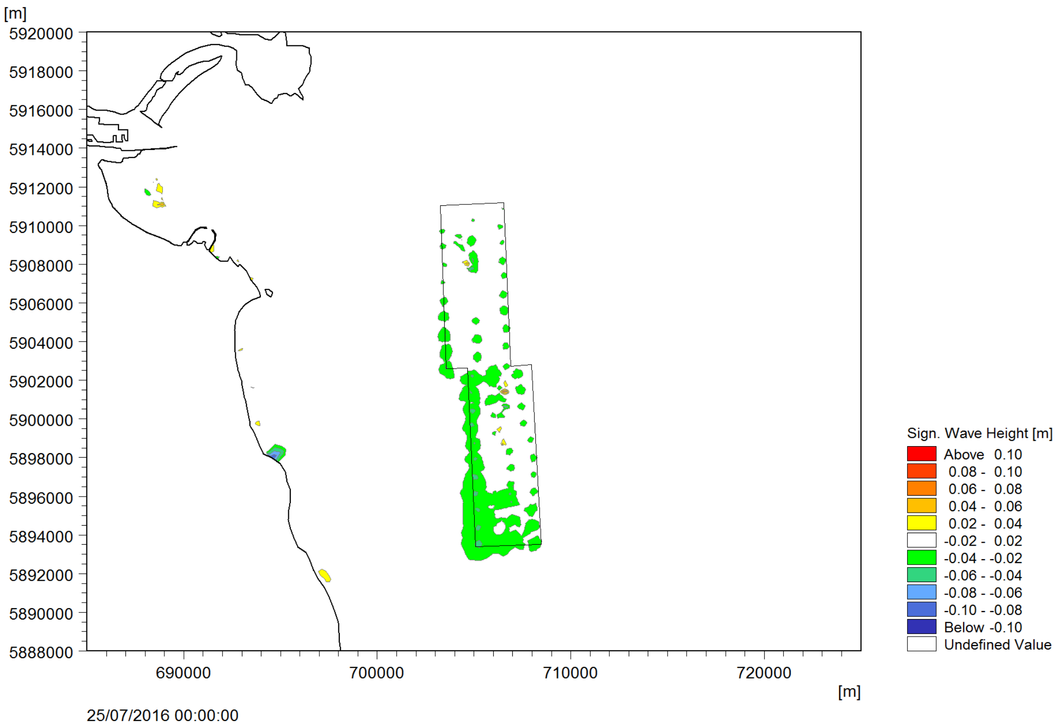


Figure B-62 Relative difference in H_{m0}, 1 in 1 year condition from north (m)

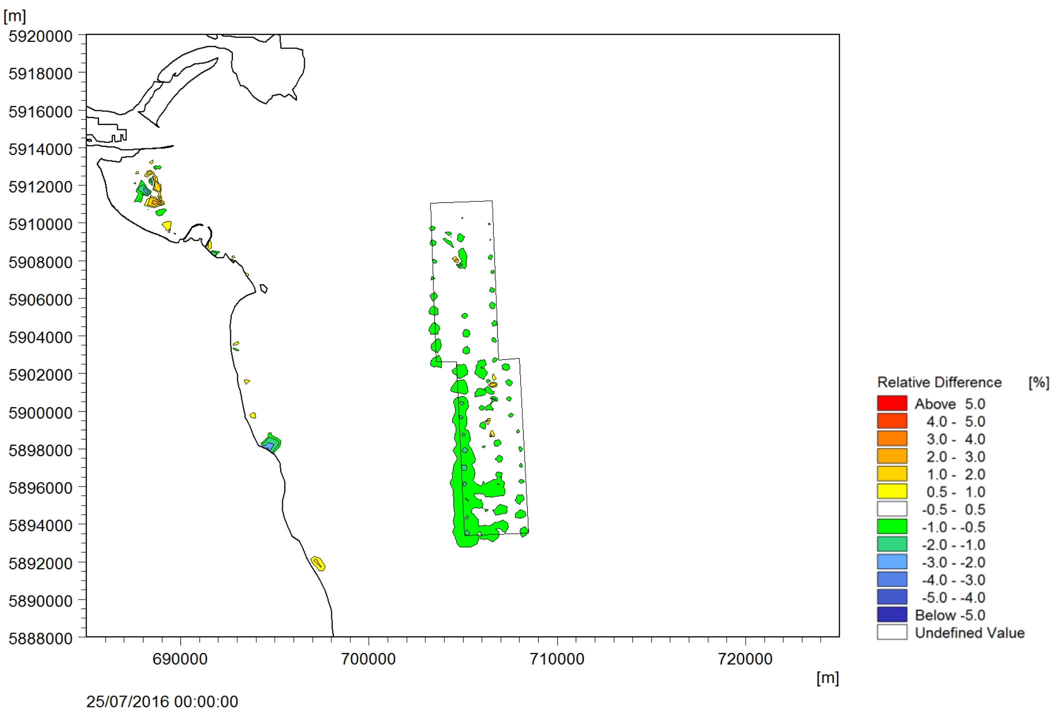


Figure B-63 Absolute difference in H_{m0}, 1 in 100 year condition from north (m)

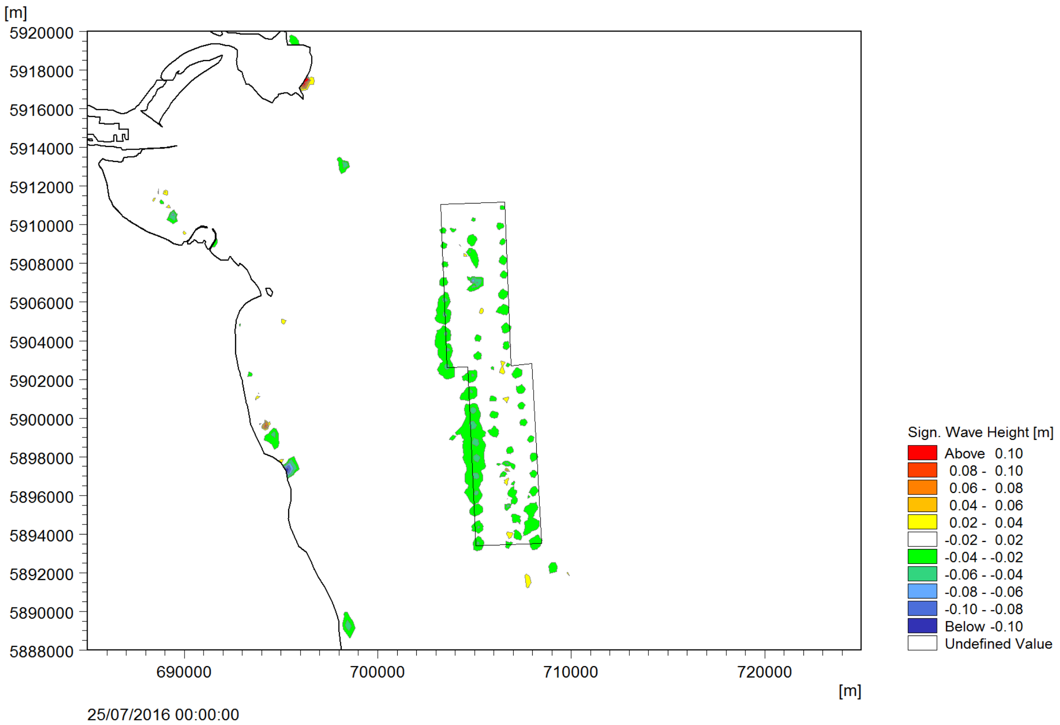


Figure B-64 Relative difference in H_{m0}, 1 in 100 year condition from north (m)

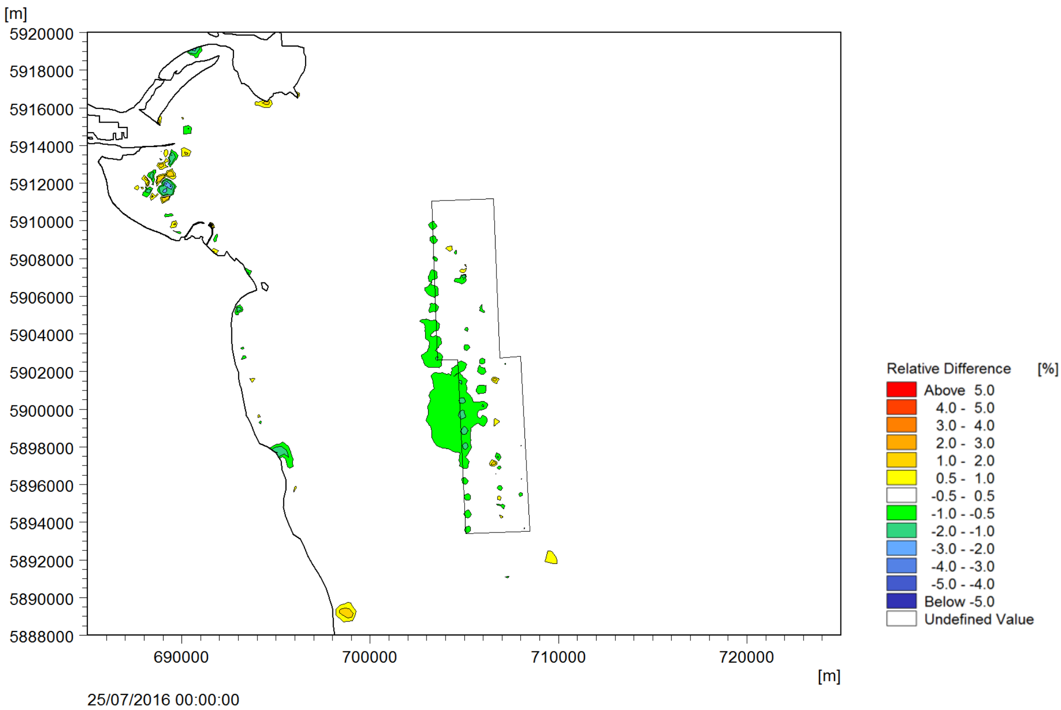


Figure B-65 Absolute difference in H_{m0}, 50%ile condition from east (m)

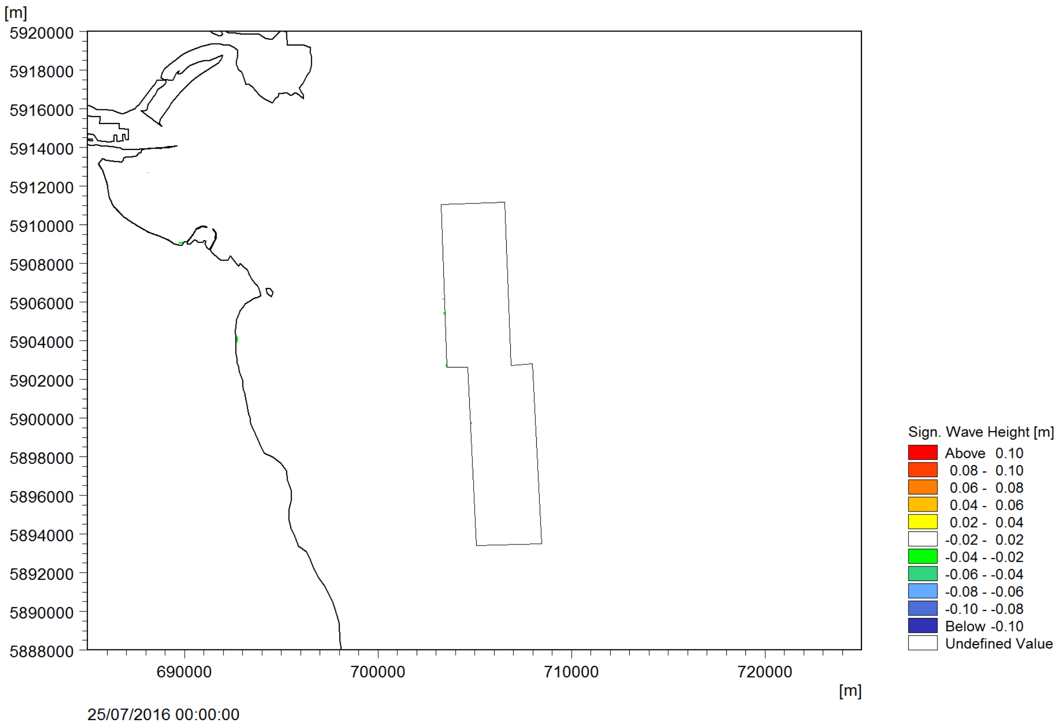


Figure B-66 Relative difference in H_{m0}, 50%ile condition from east (m)

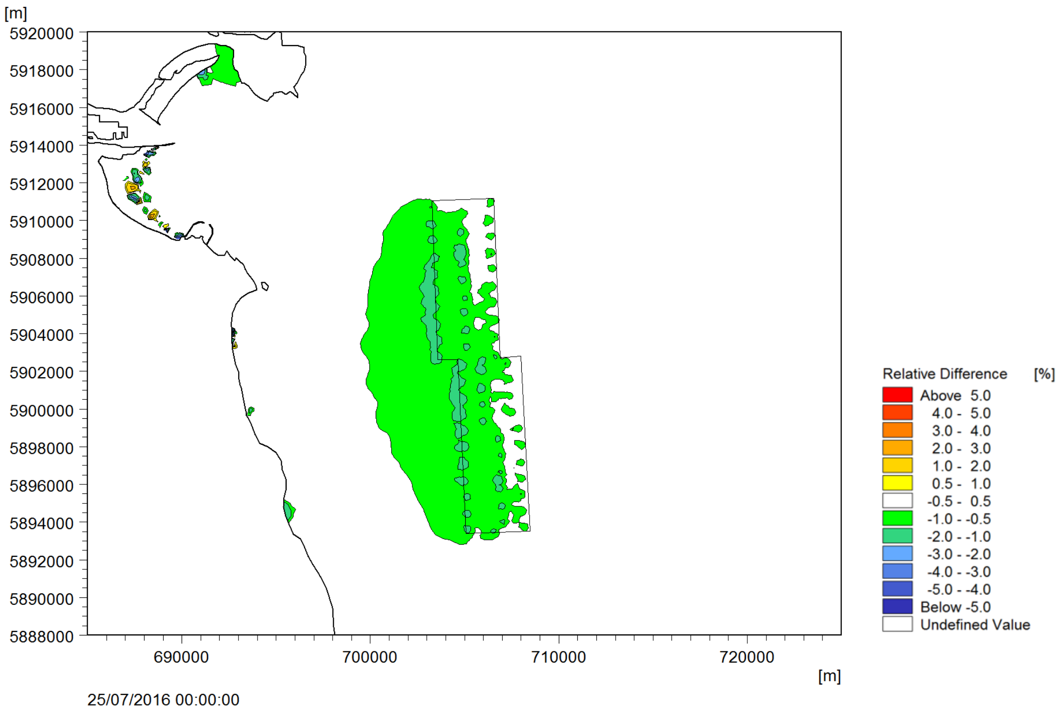


Figure B-67 Absolute difference in H_{m0}, 5%ile condition from east (m)

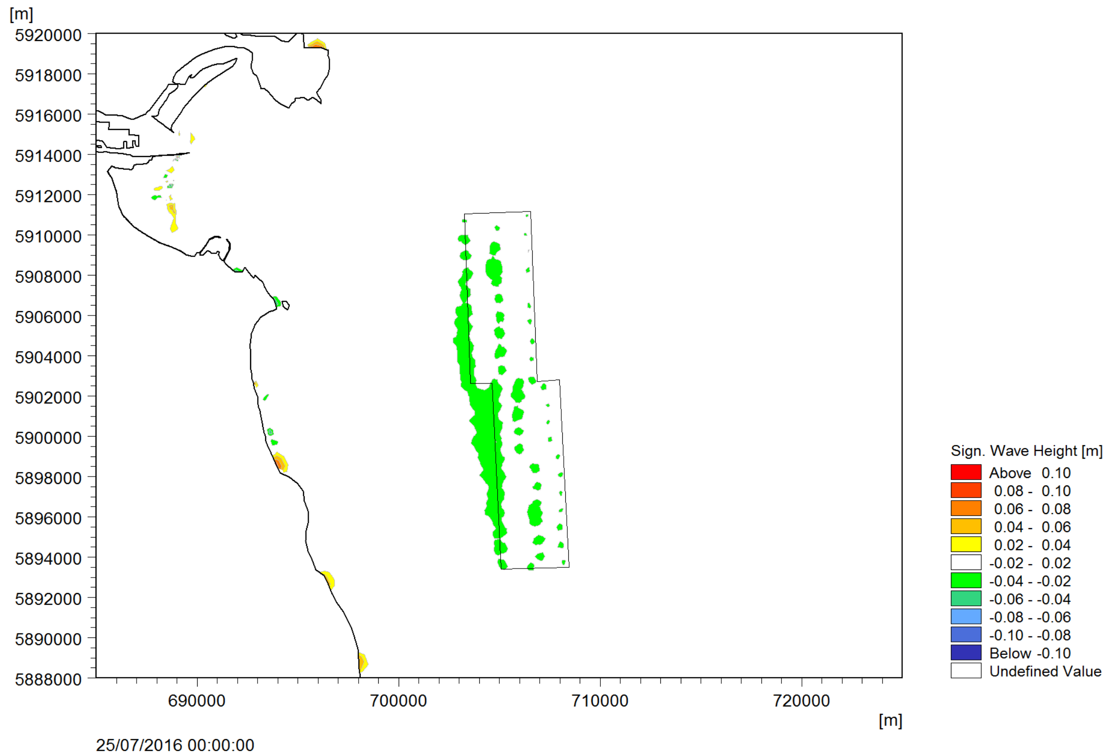


Figure B-68 Relative difference in H_{m0}, 5%ile condition from east (m)

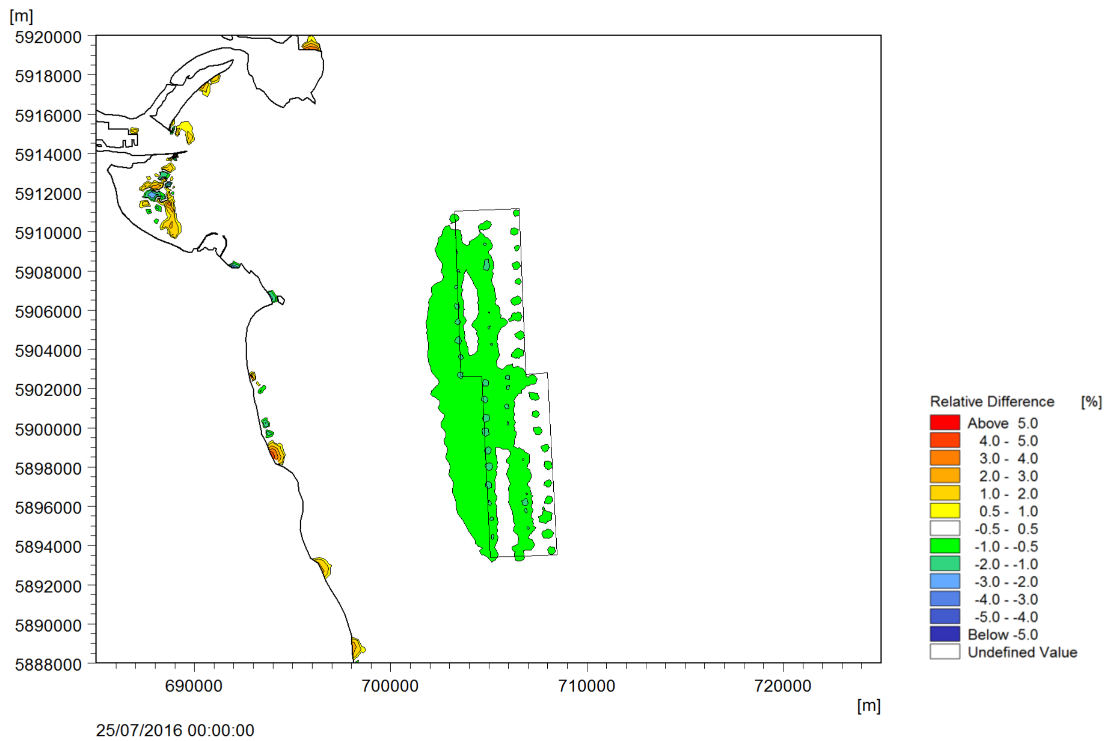


Figure B-69 Absolute difference in H_{m0}, 1 in 1 year condition from east (m)

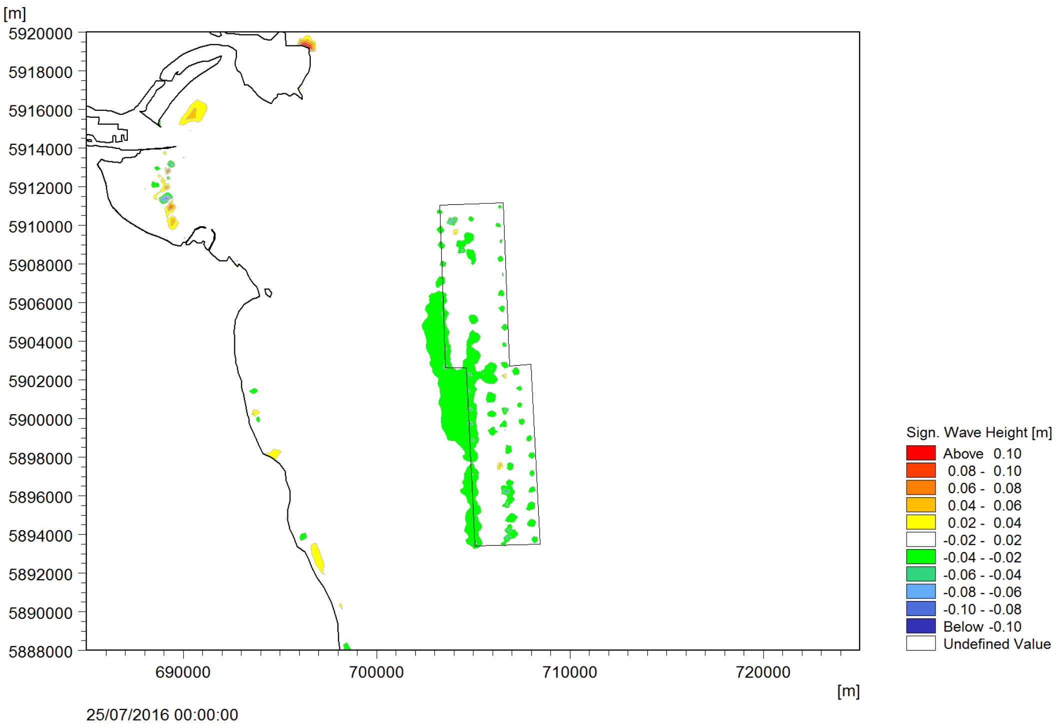


Figure B-70 Relative difference in H_{m0}, 1 in 1 year condition from east (m)

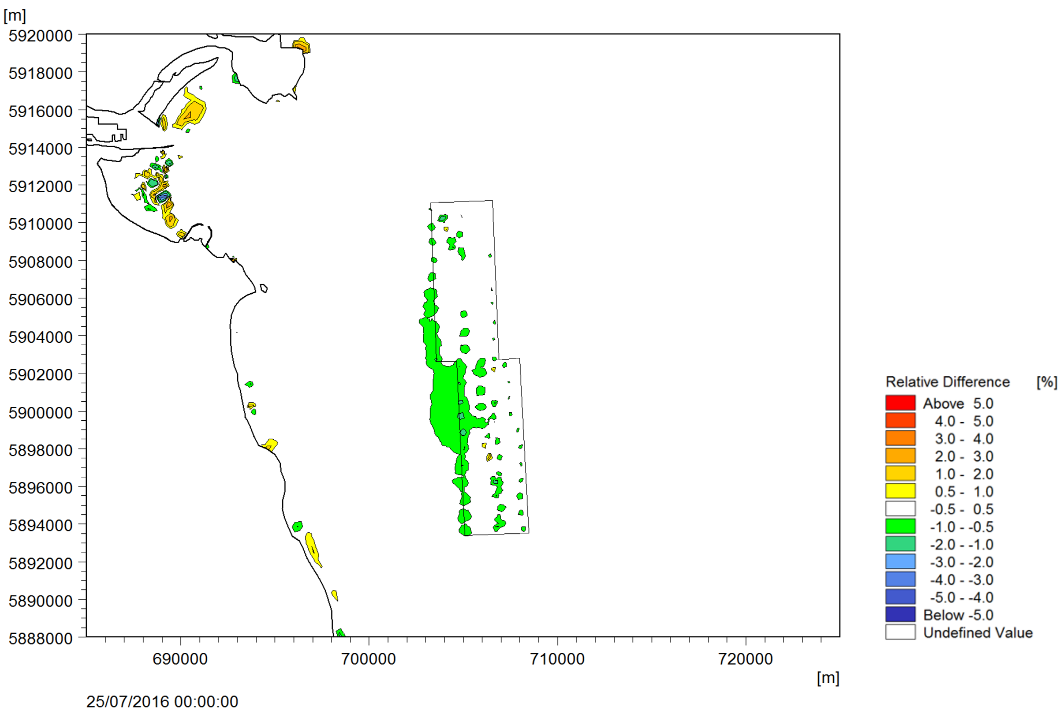


Figure B-71 Absolute difference in H_{m0}, 1 in 100 year condition from east (m)

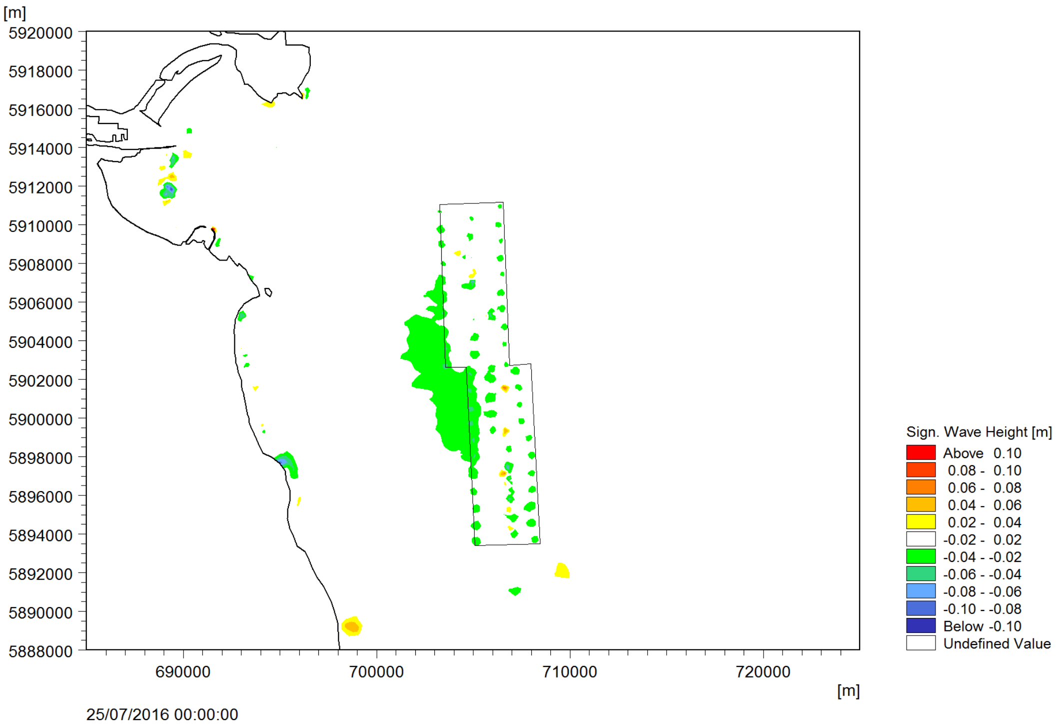


Figure B-72 Relative difference in H_{m0}, 1 in 100 year condition from east (m)

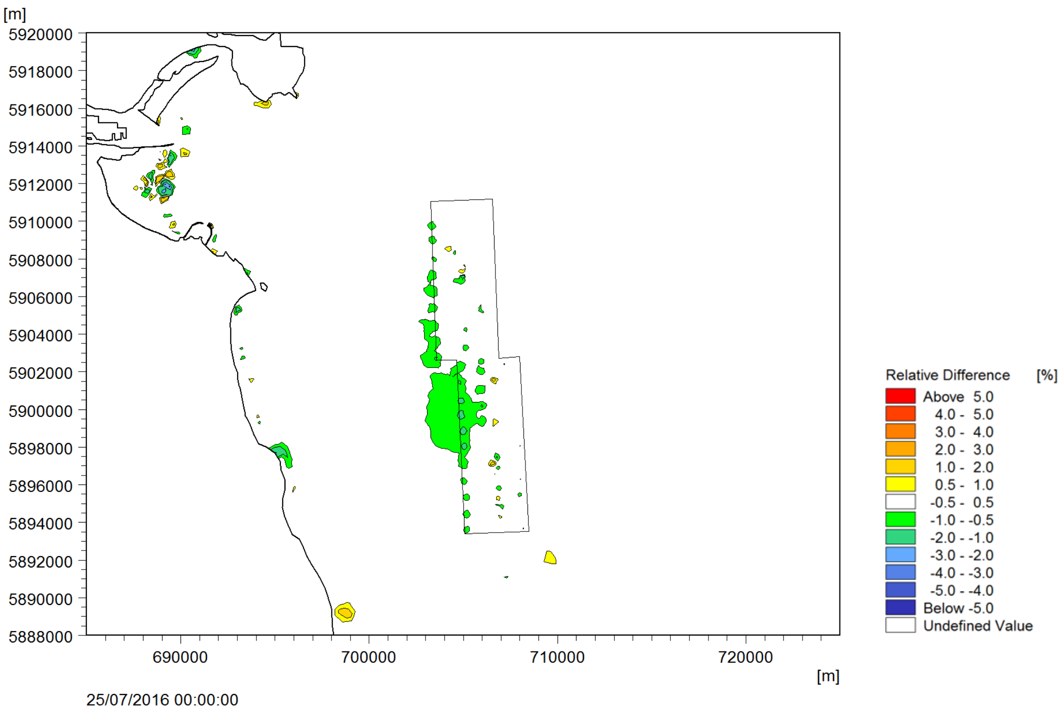


Figure B-73 Absolute difference in H_{m0}, 50%ile condition from south (m)

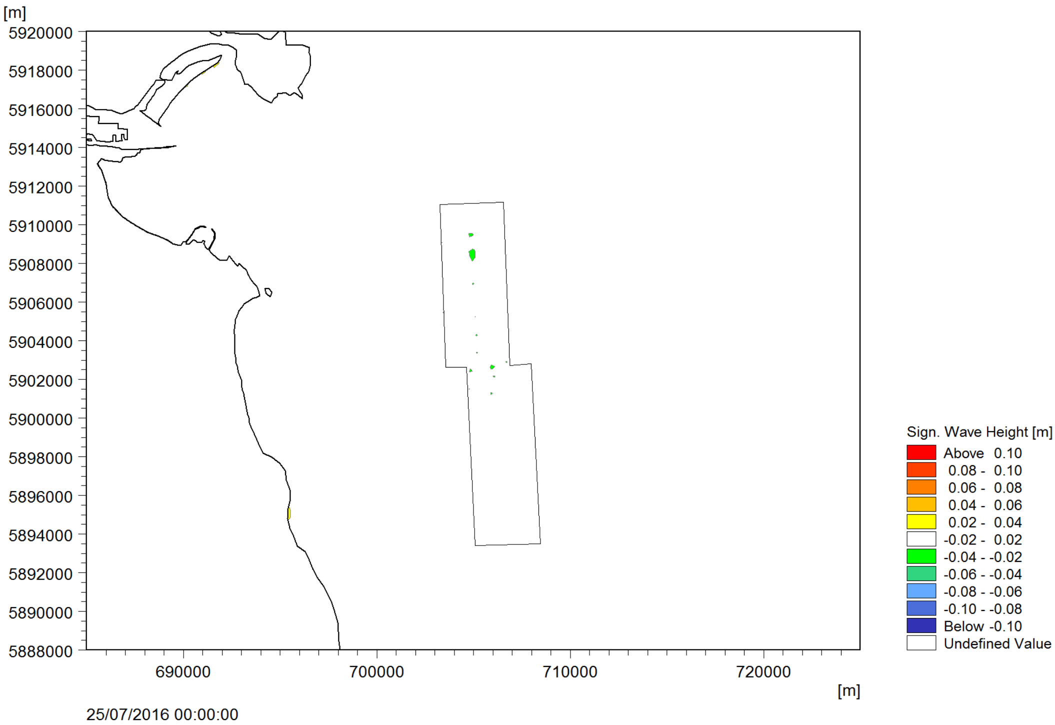


Figure B-74 Relative difference in H_{m0}, 50%ile condition from south (m)

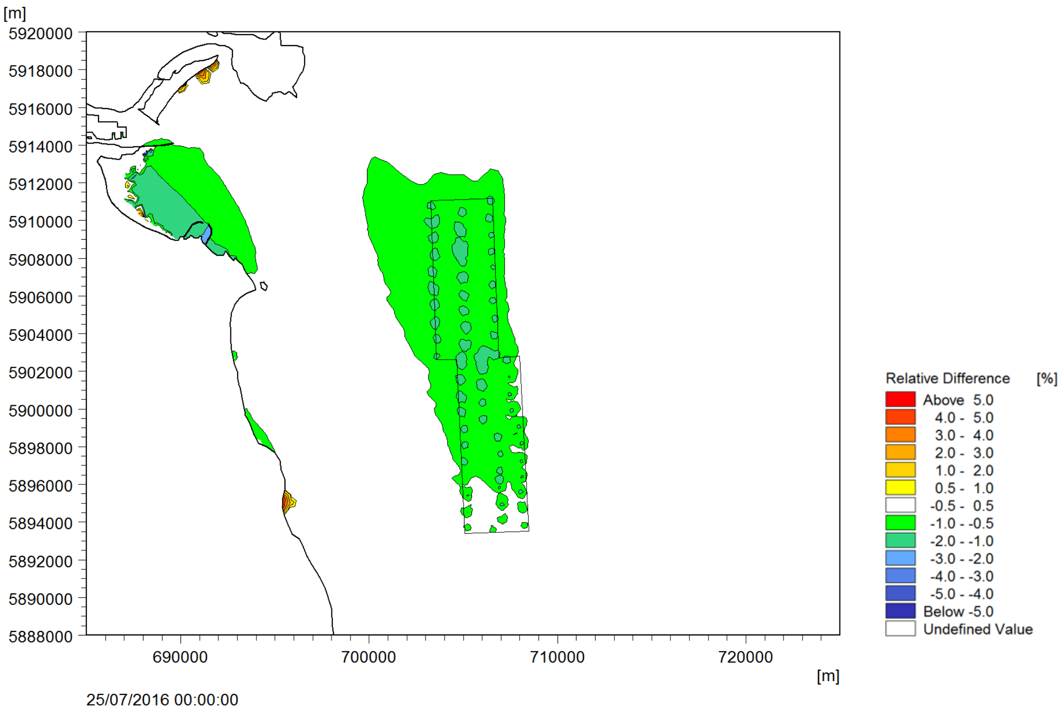


Figure B-75 Absolute difference in H_{m0}, 5%ile condition from south (m)

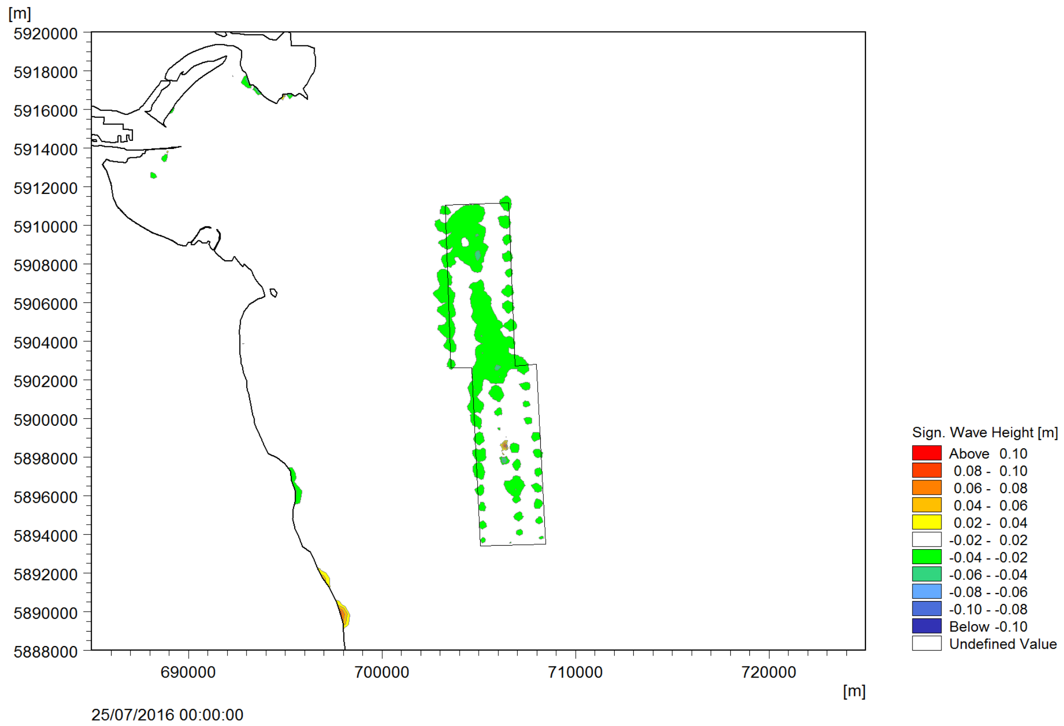


Figure B-76 Relative difference in H_{m0}, 5%ile condition from south (m)

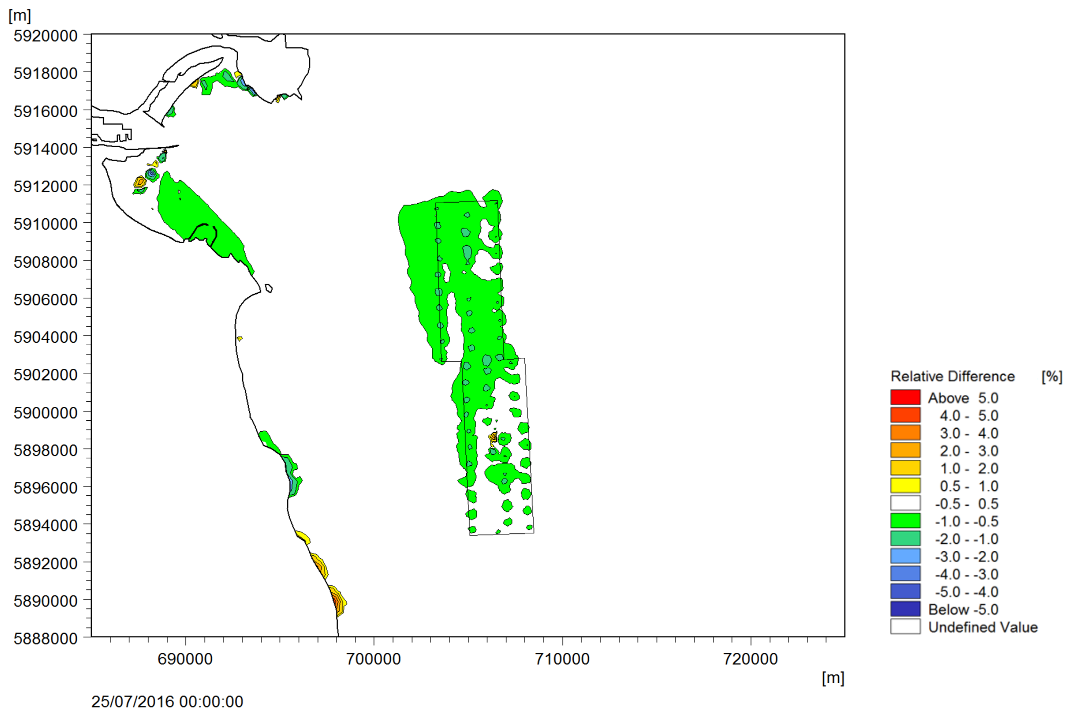


Figure B-77 Absolute difference in H_{m0}, 1 in 1 year condition from south (m)

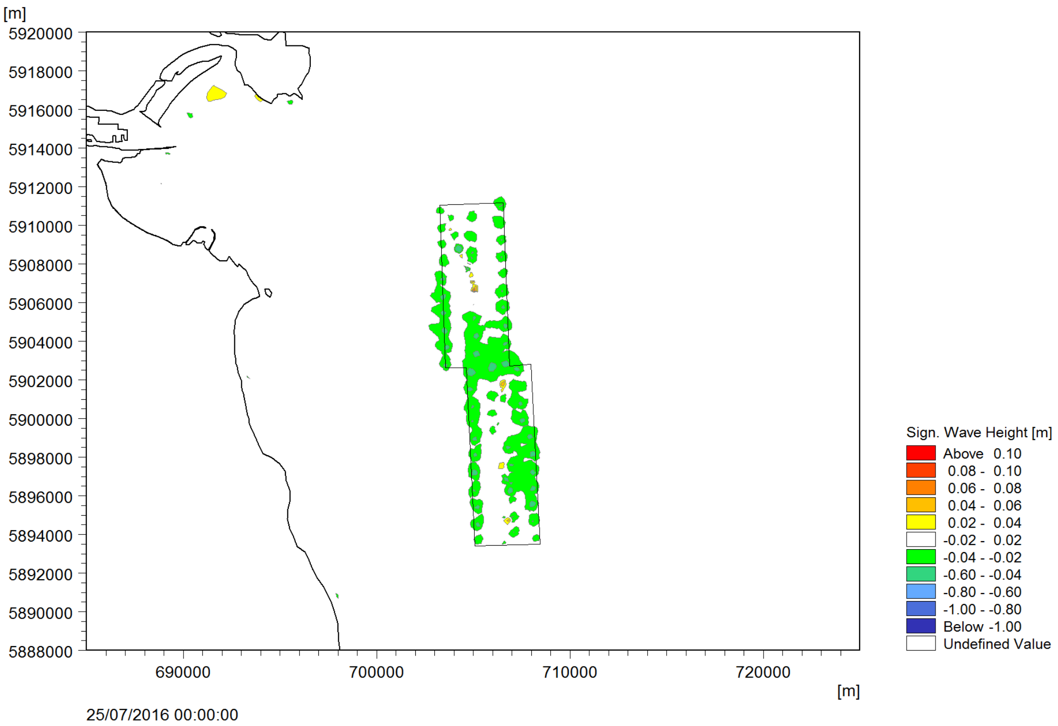


Figure B-78 Relative difference in H_{m0}, 1 in 1 year condition from south (m)

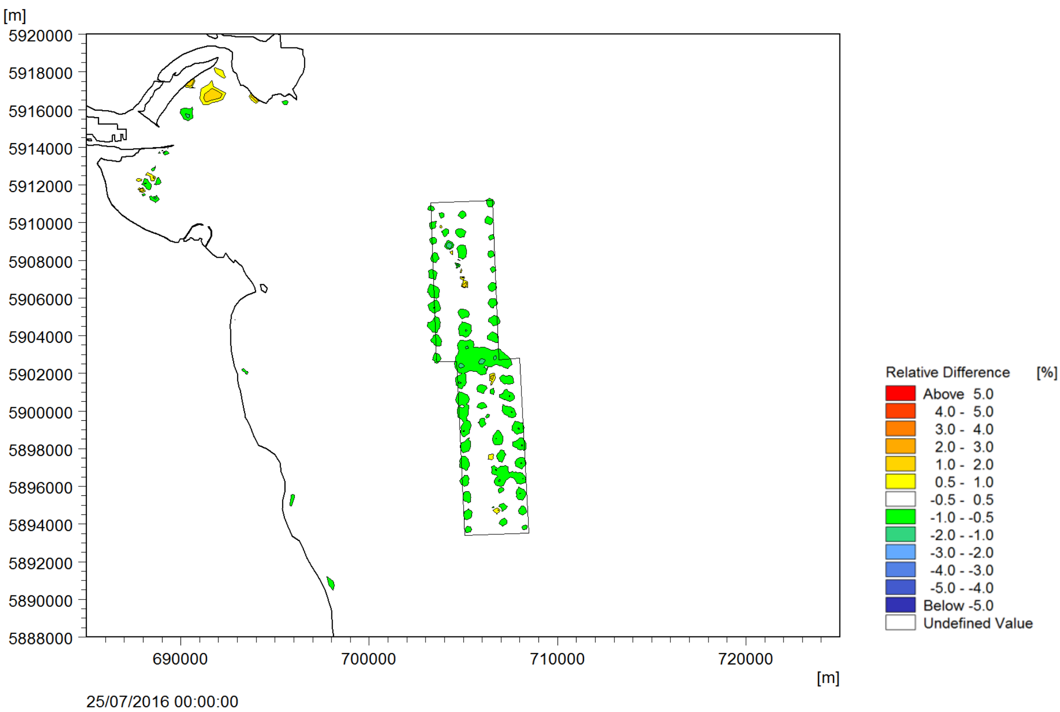


Figure B-79 Absolute difference in H_{m0}, 1 in 100 year condition from south (m)

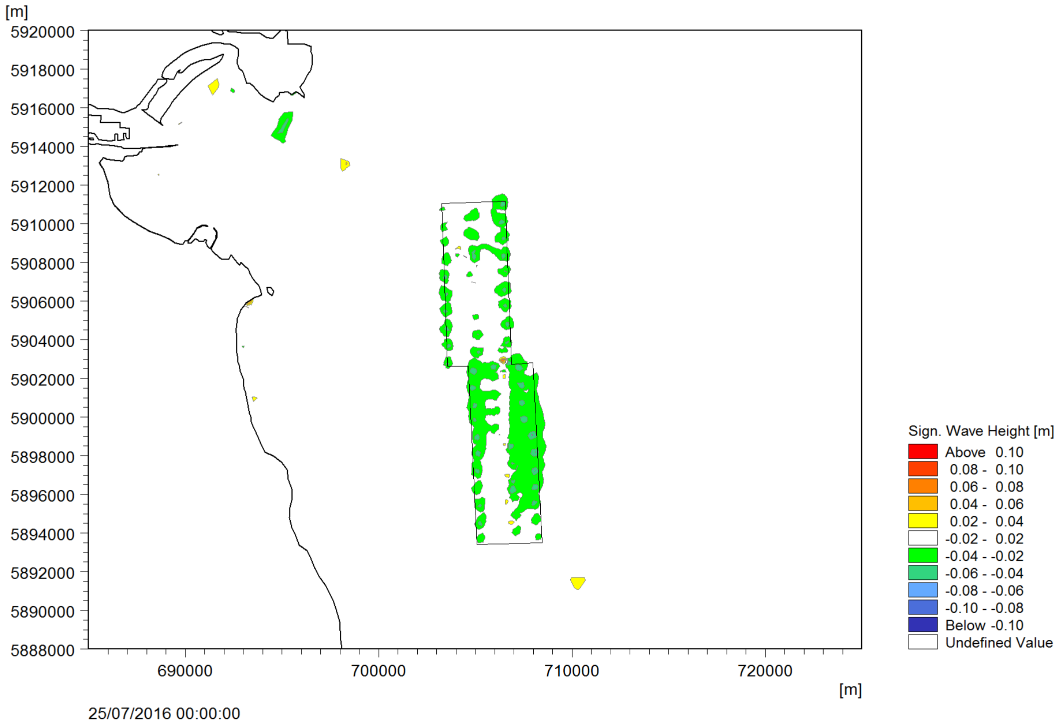


Figure B-80 Relative difference in H_{m0}, 1 in 100 year condition from south (m)

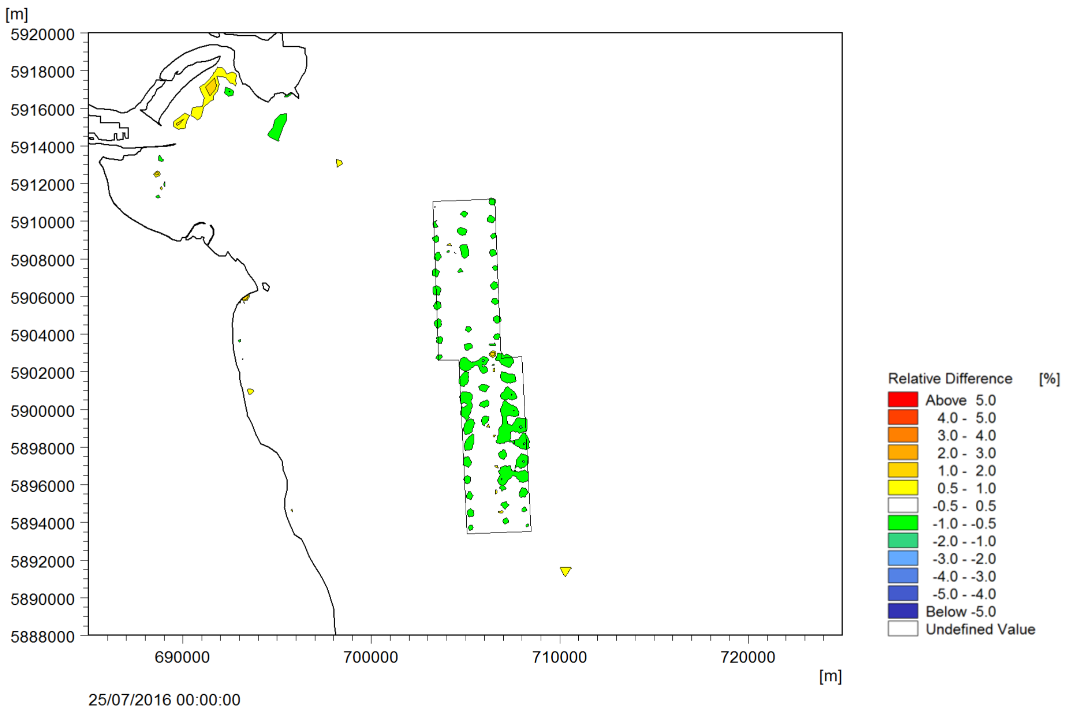


Figure B-81 Absolute difference in H_{m0}, 50%ile condition from west (m)

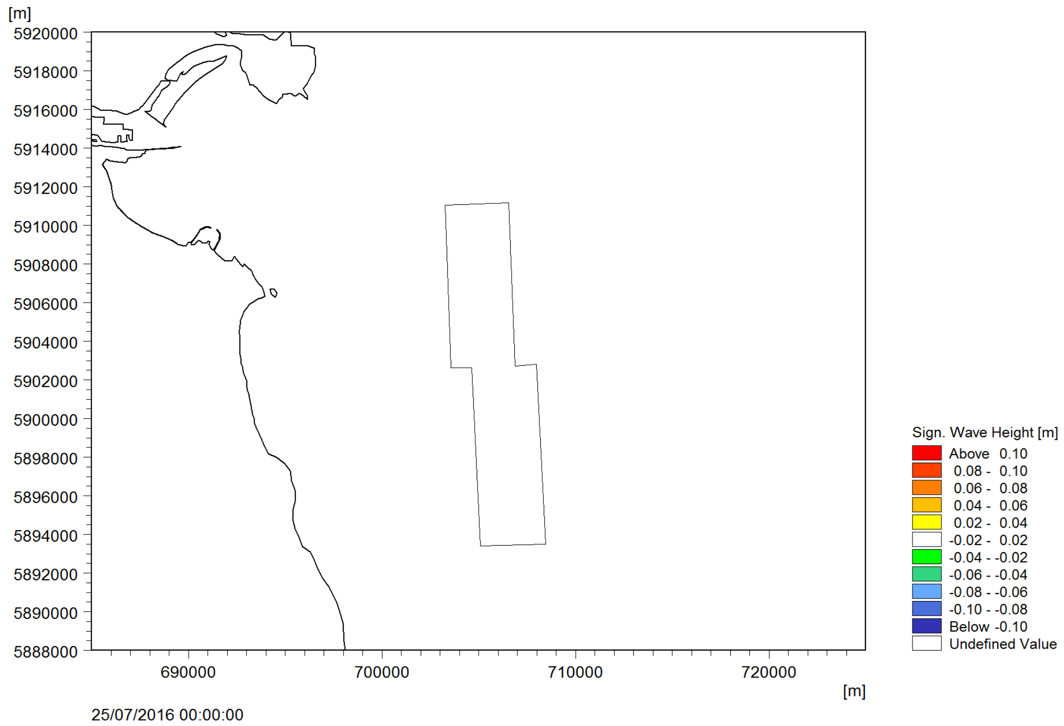


Figure B-82 Relative difference in H_{m0}, 50%ile condition from west (m)

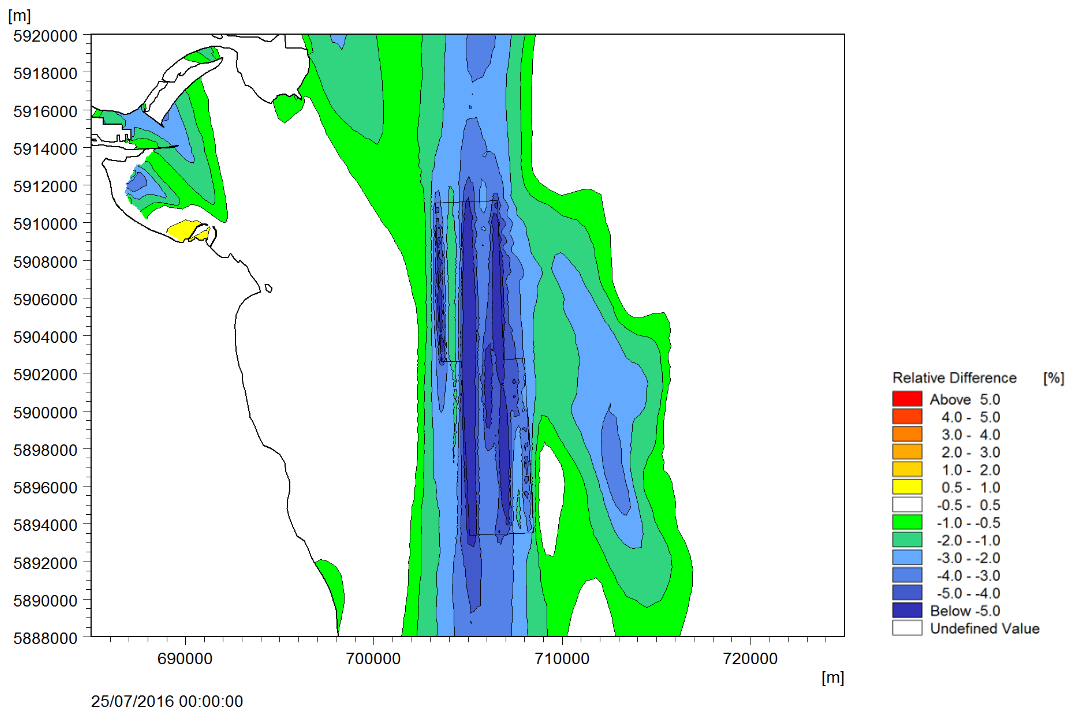


Figure B-83 Absolute difference in H_{m0}, 5%ile condition from west (m)

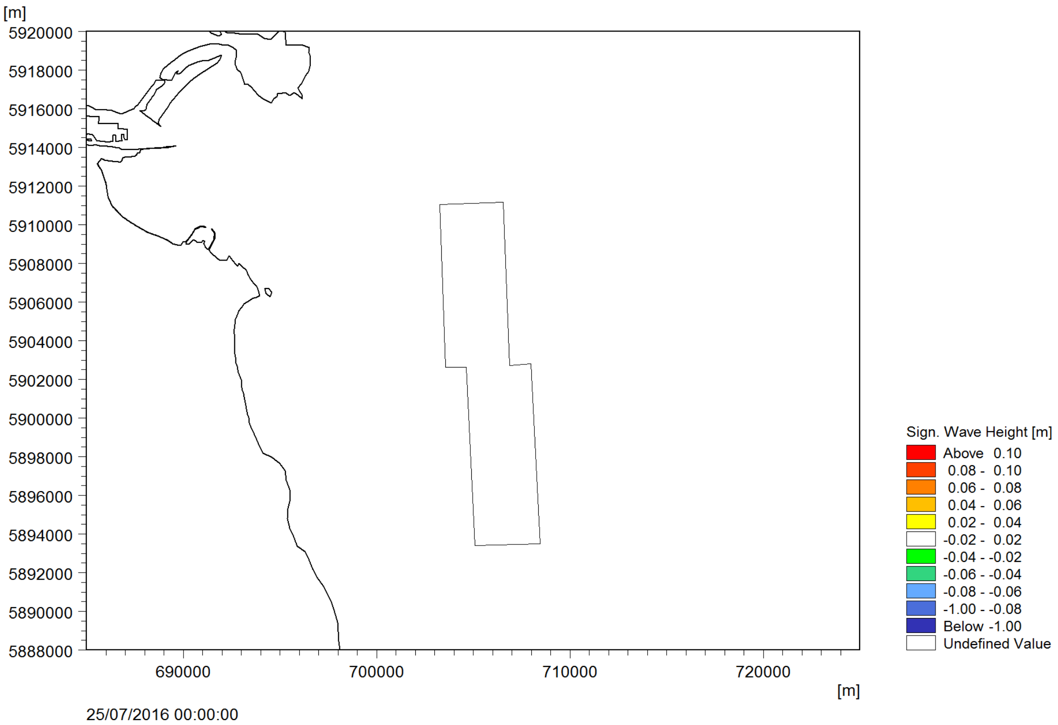


Figure B-84 Relative difference in H_{m0}, 5%ile condition from west (m)

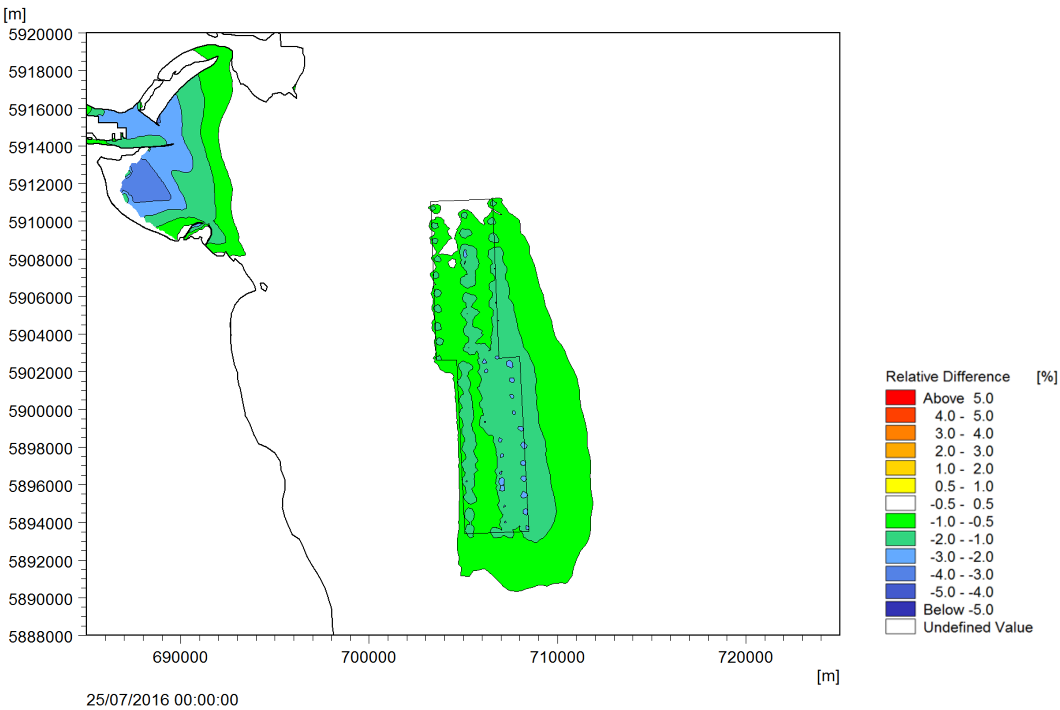


Figure B-85 Absolute difference in H_{m0}, 1 in 1 year condition from west (m)

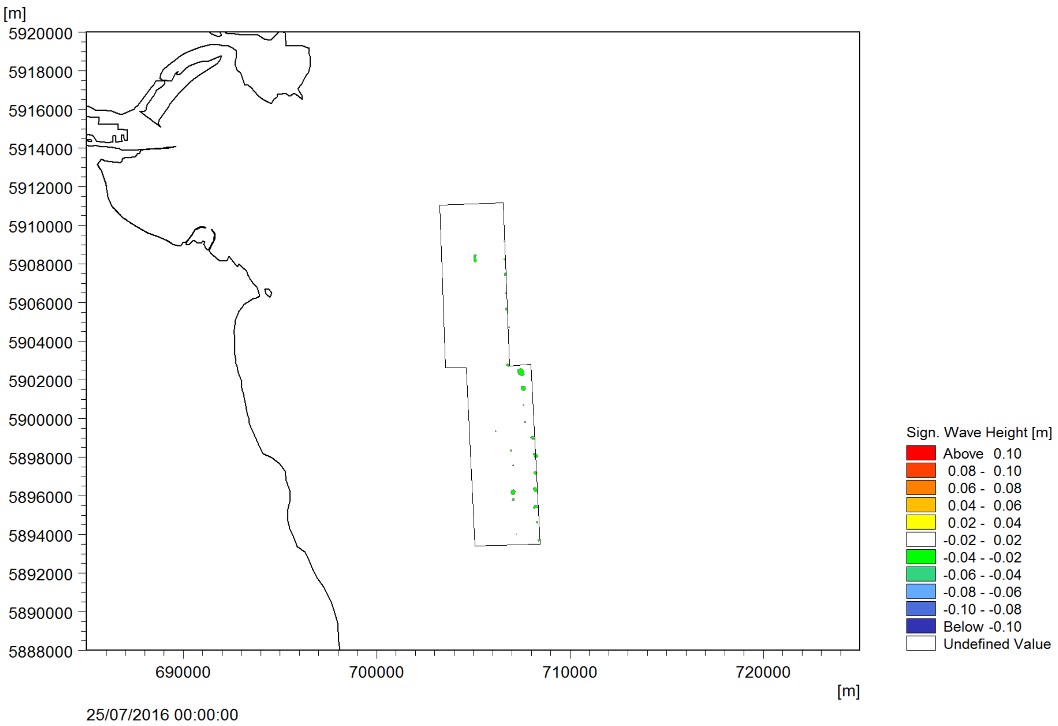


Figure B-86 Relative difference in H_{m0}, 1 in 1 year condition from west (m)

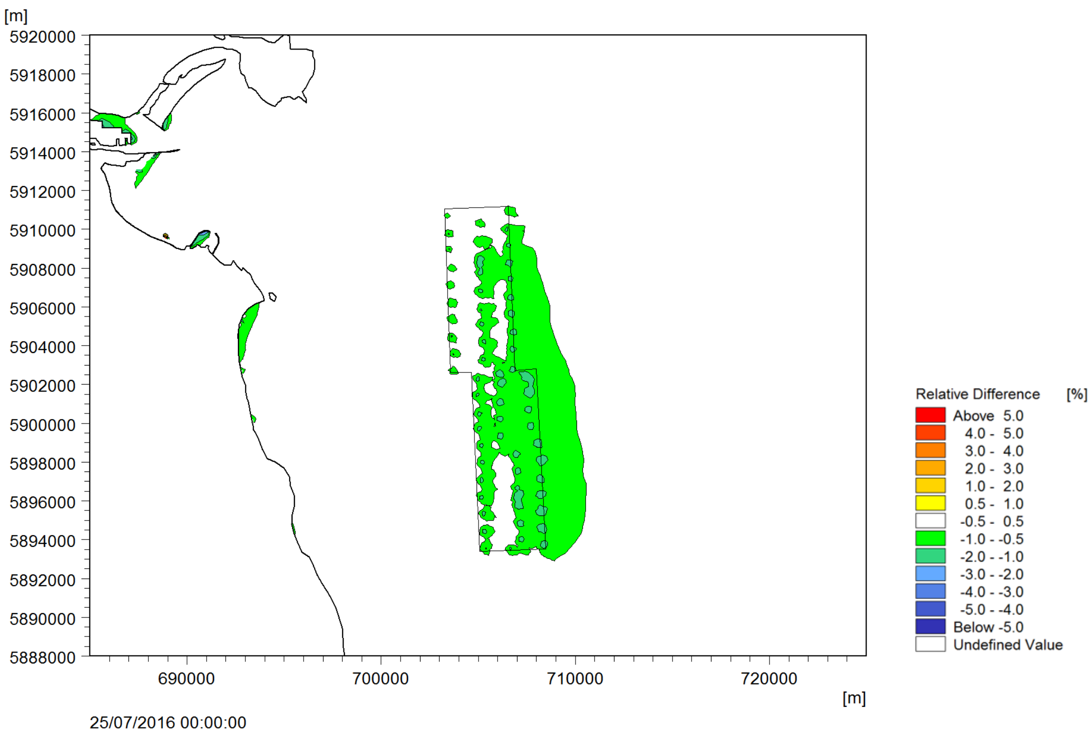


Figure B-87 Absolute difference in H_{m0}, 1 in 100 year condition from west (m)

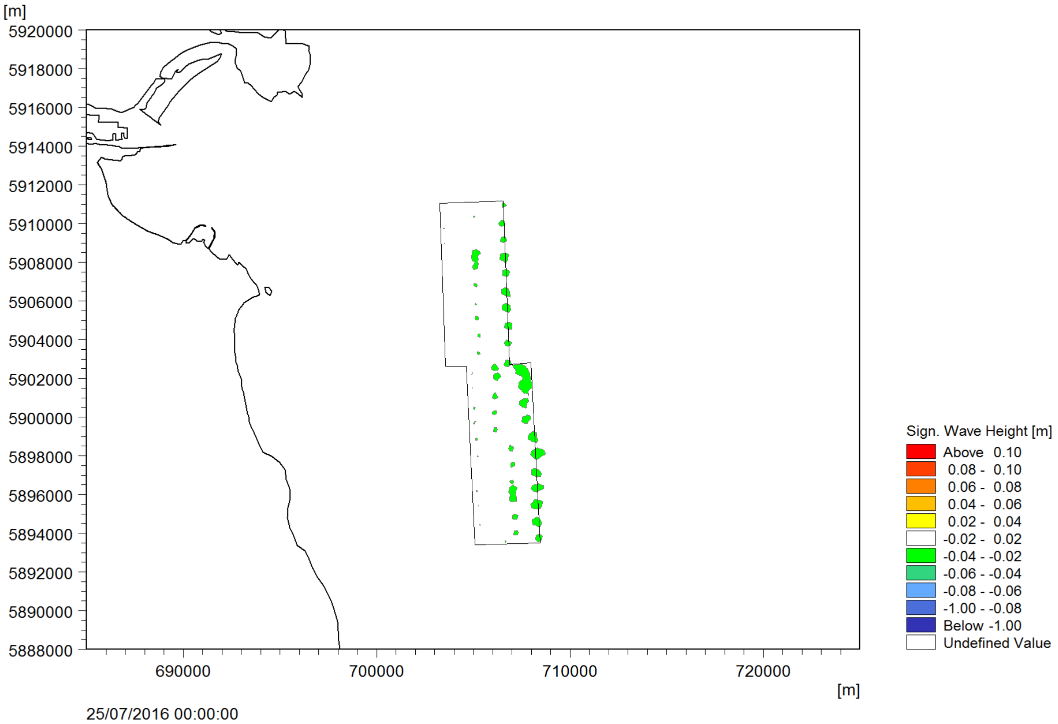


Figure B-88 Relative difference in H_{m0}, 1 in 100 year condition from west (m)

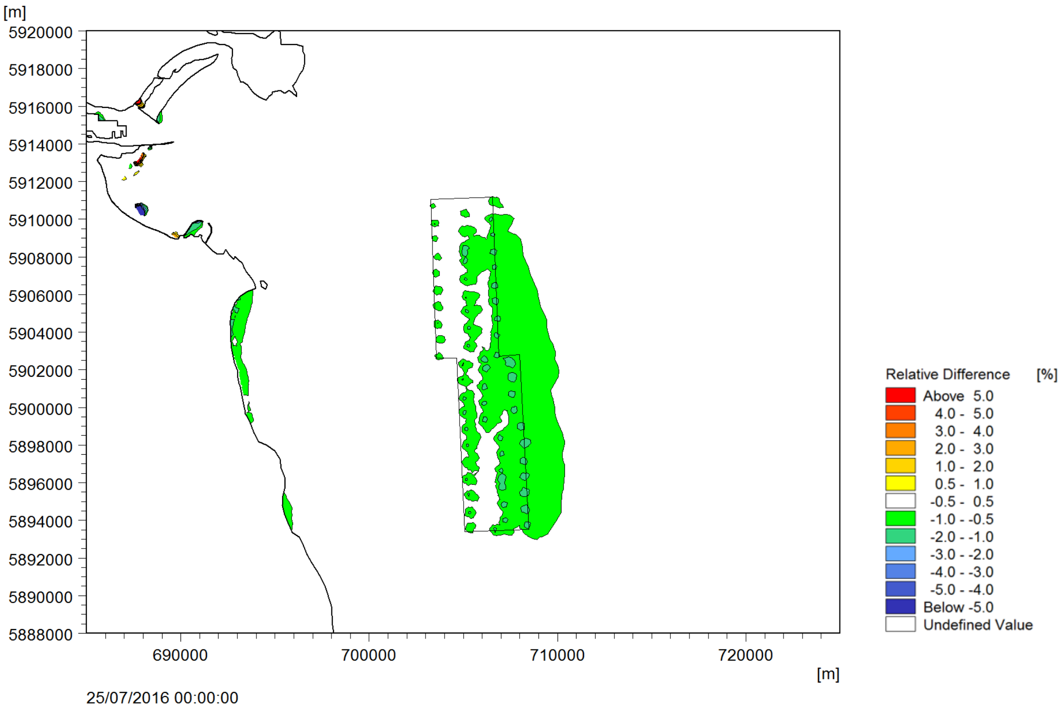
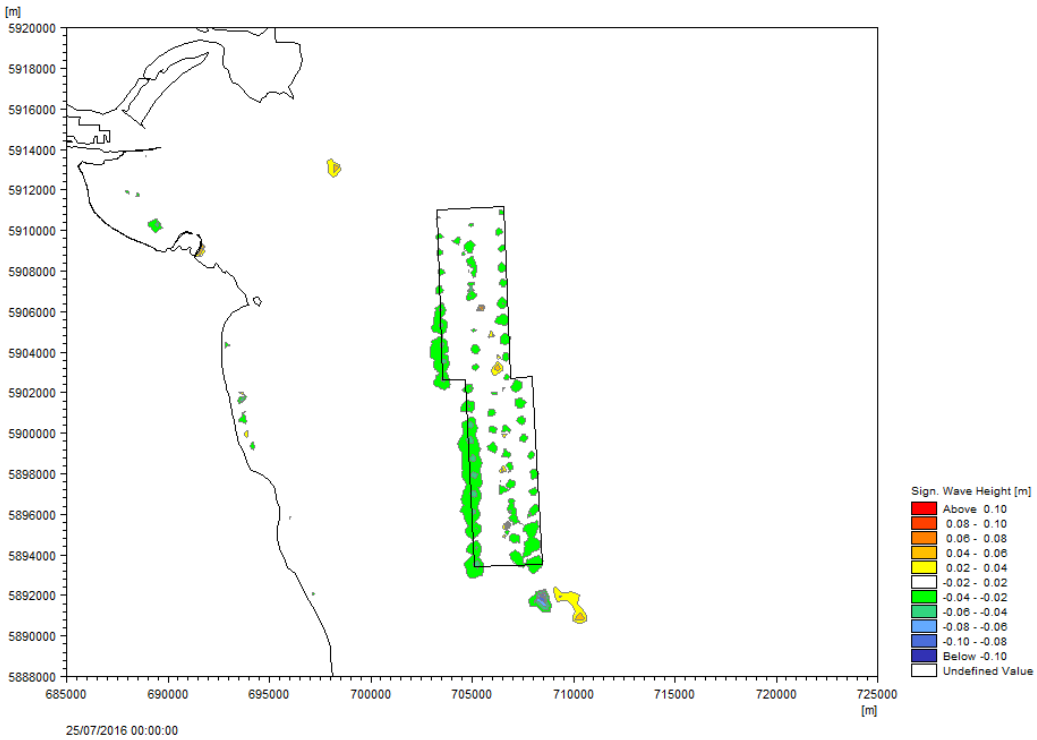


Figure B-89 Absolute difference in H_{m0}, 1 in 100 year condition between baseline and scheme including SLR (above) and without SLR (below), from north (m)



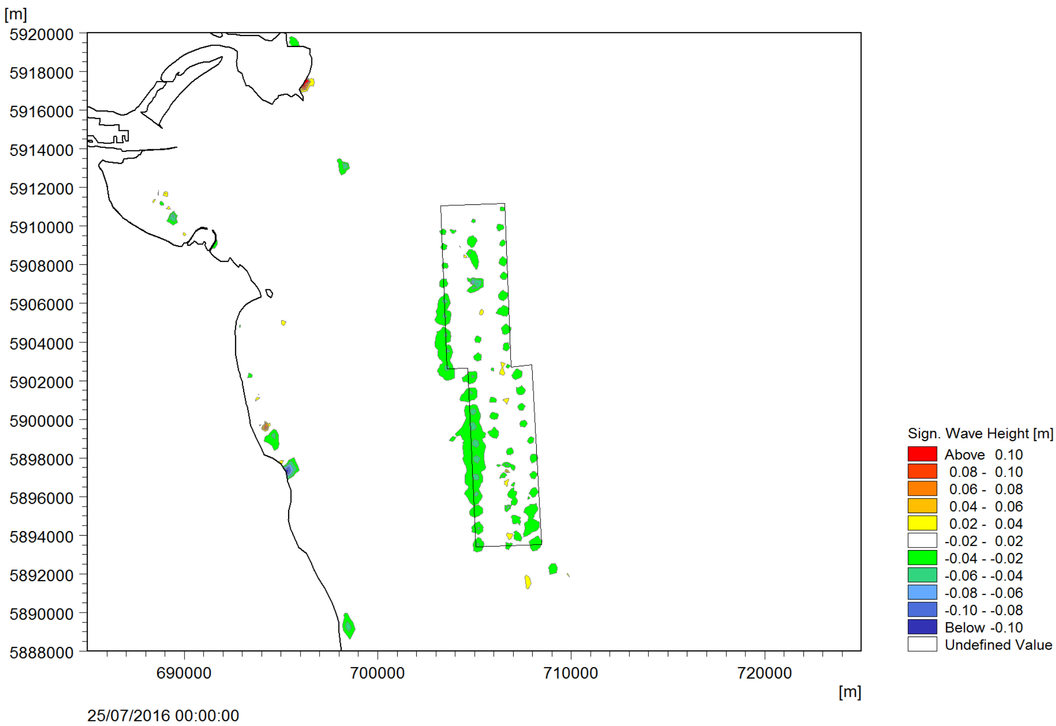
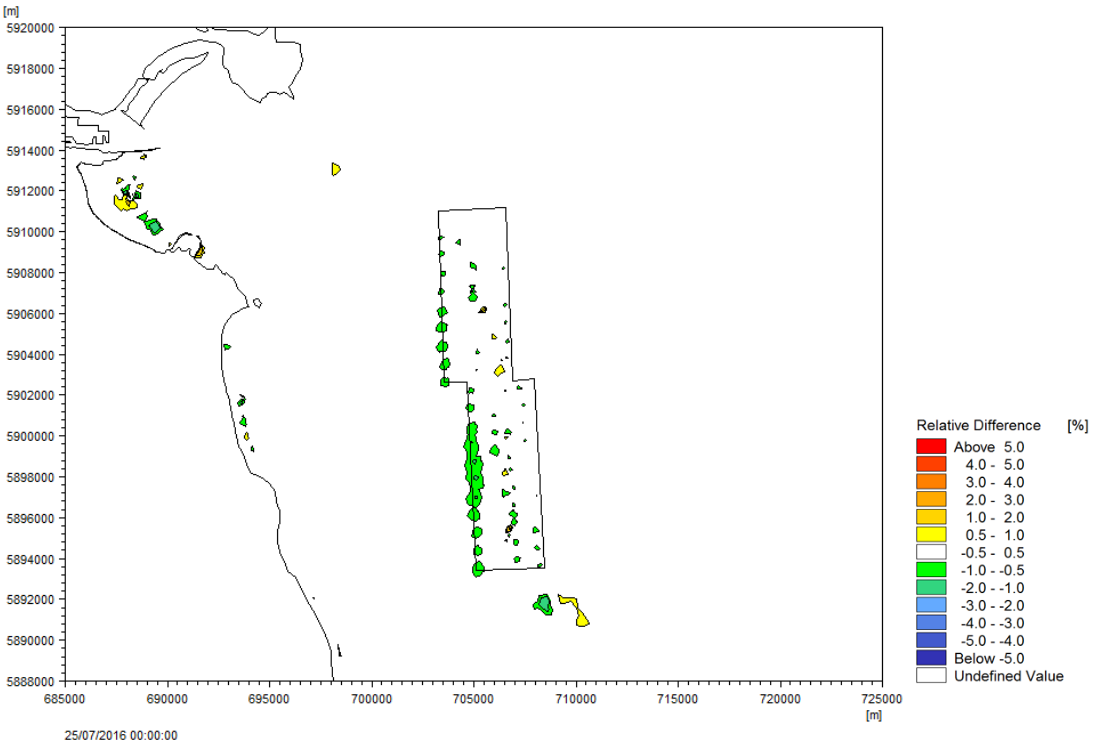


Figure B-90 Relative difference in H_{m0}, 1 in 100 year condition between baseline and scheme including SLR (above) and without SLR (below), from north (%)



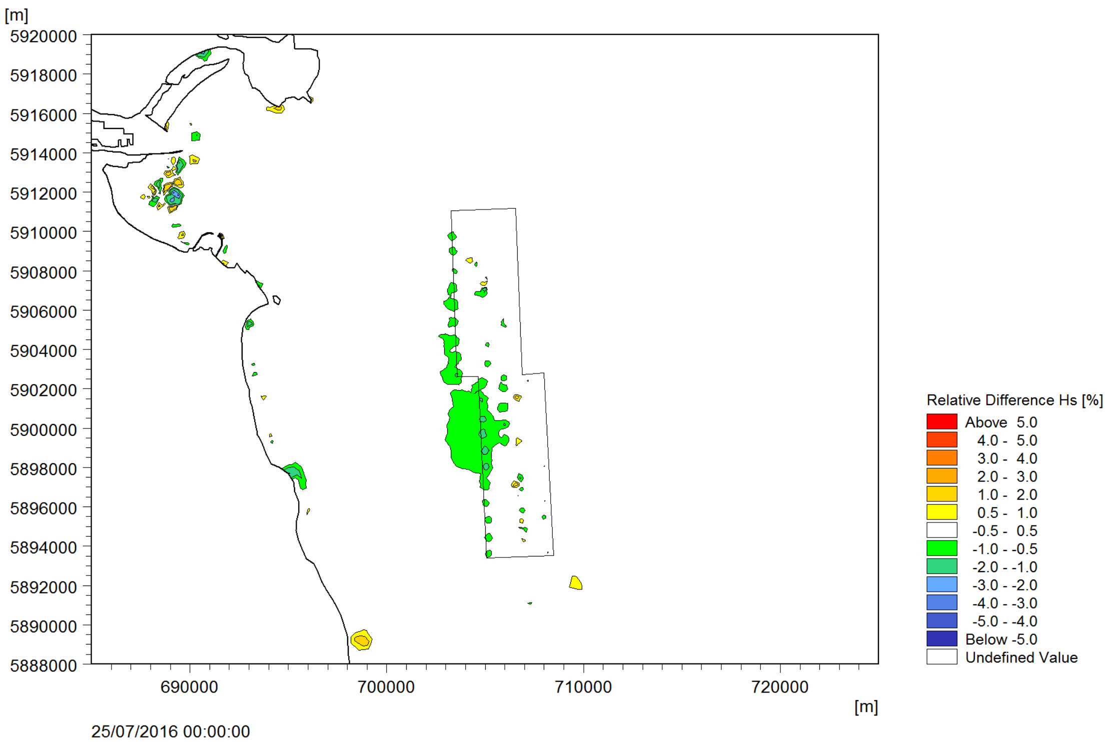
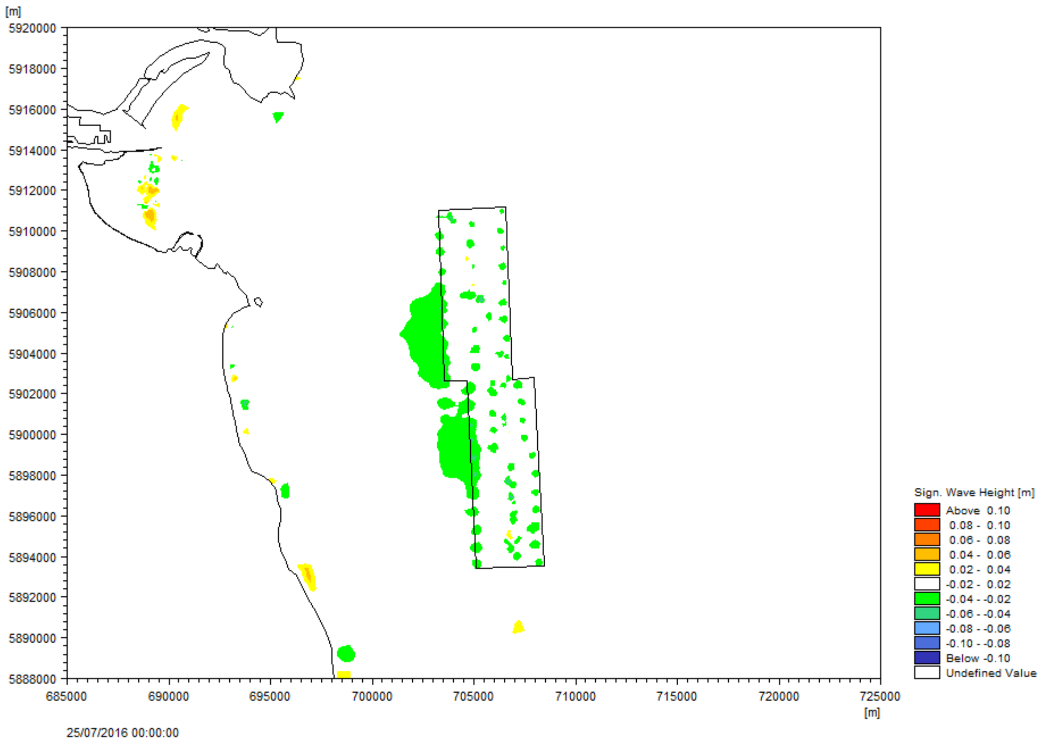


Figure B-91 Absolute difference in H_{m0}, 1 in 100 year condition between baseline and scheme including SLR (above) and without SLR (below), from east (m)



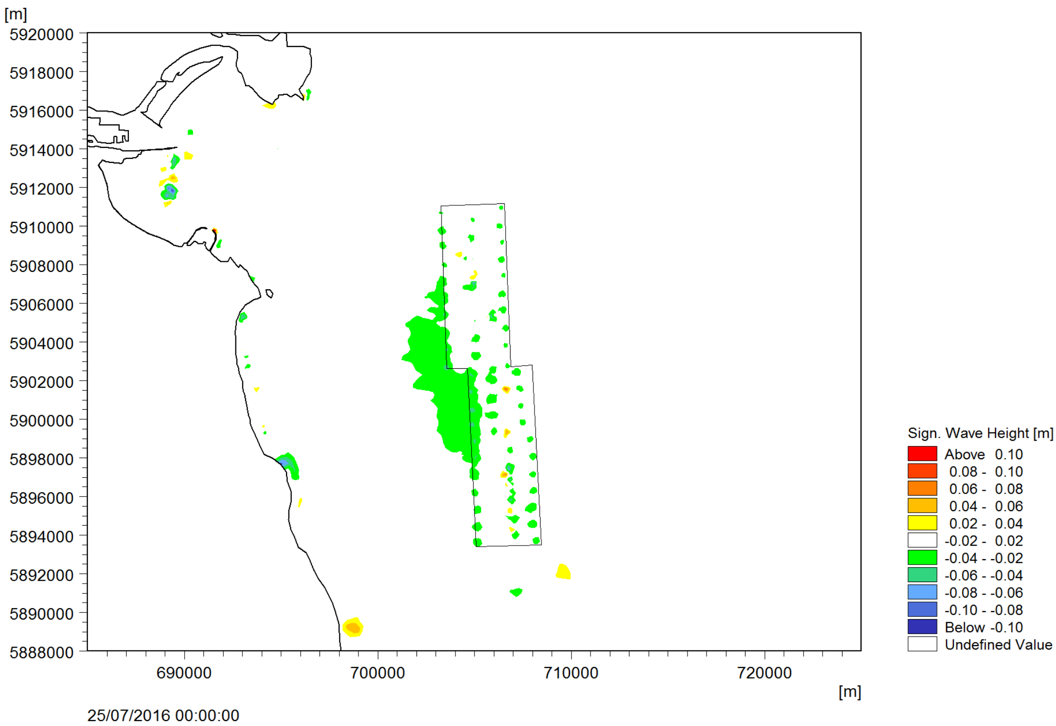
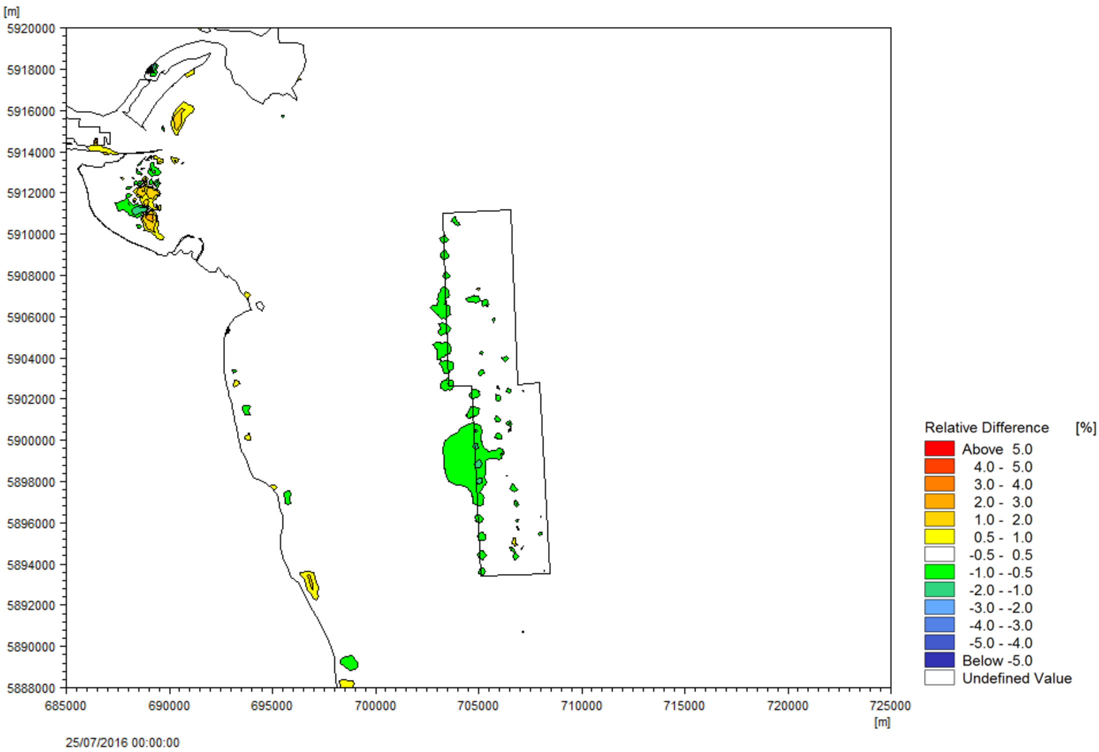


Figure B-92 Relative difference in H_{m0}, 1 in 100 year condition between baseline and scheme including SLR (above) and without SLR (below), from east (%)



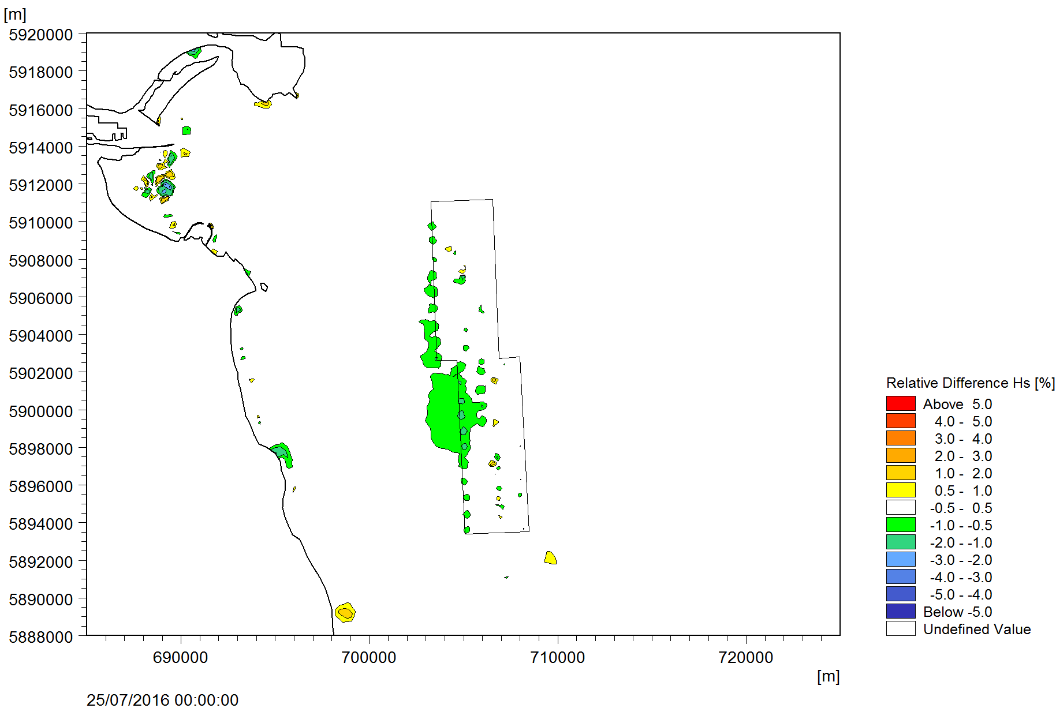
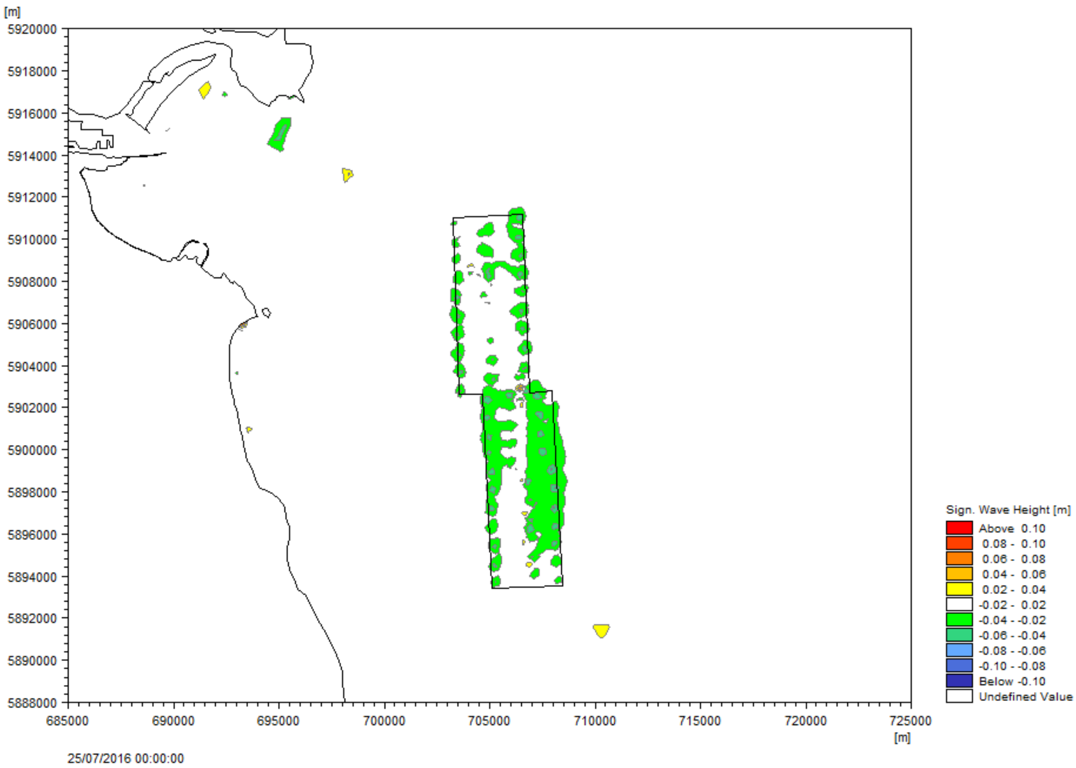


Figure B-93 Absolute difference in H_{m0}, 1 in 100 year condition between baseline and scheme including SLR (above) and without SLR (below), from south (m)



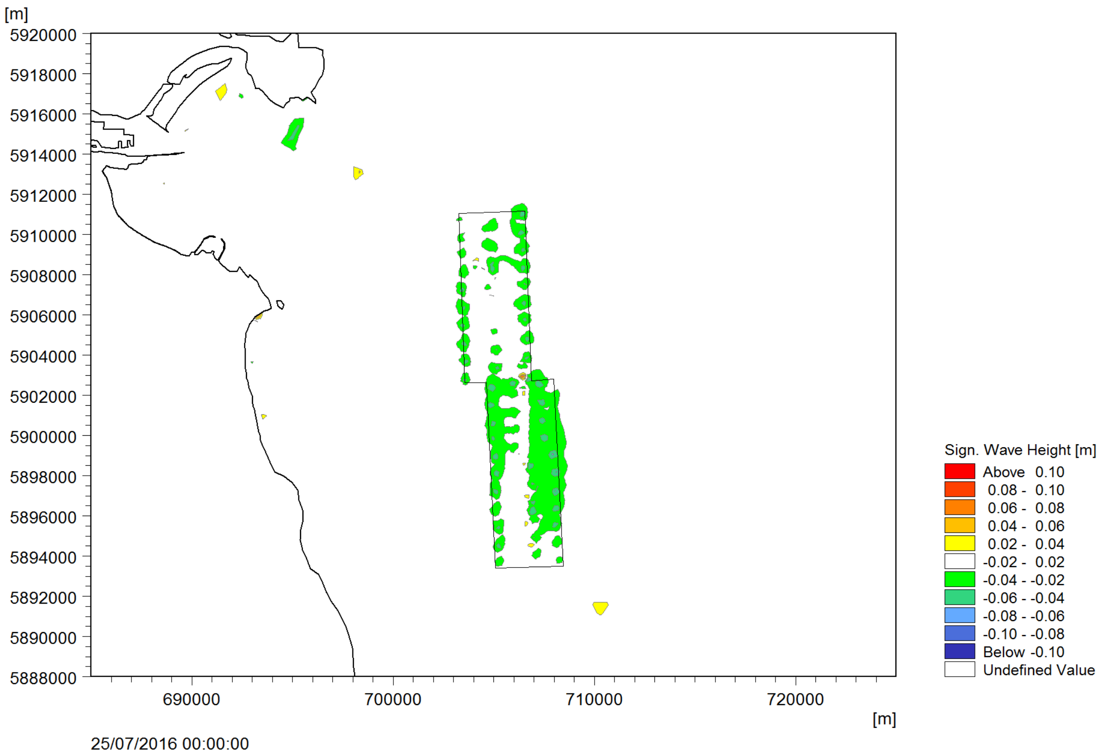
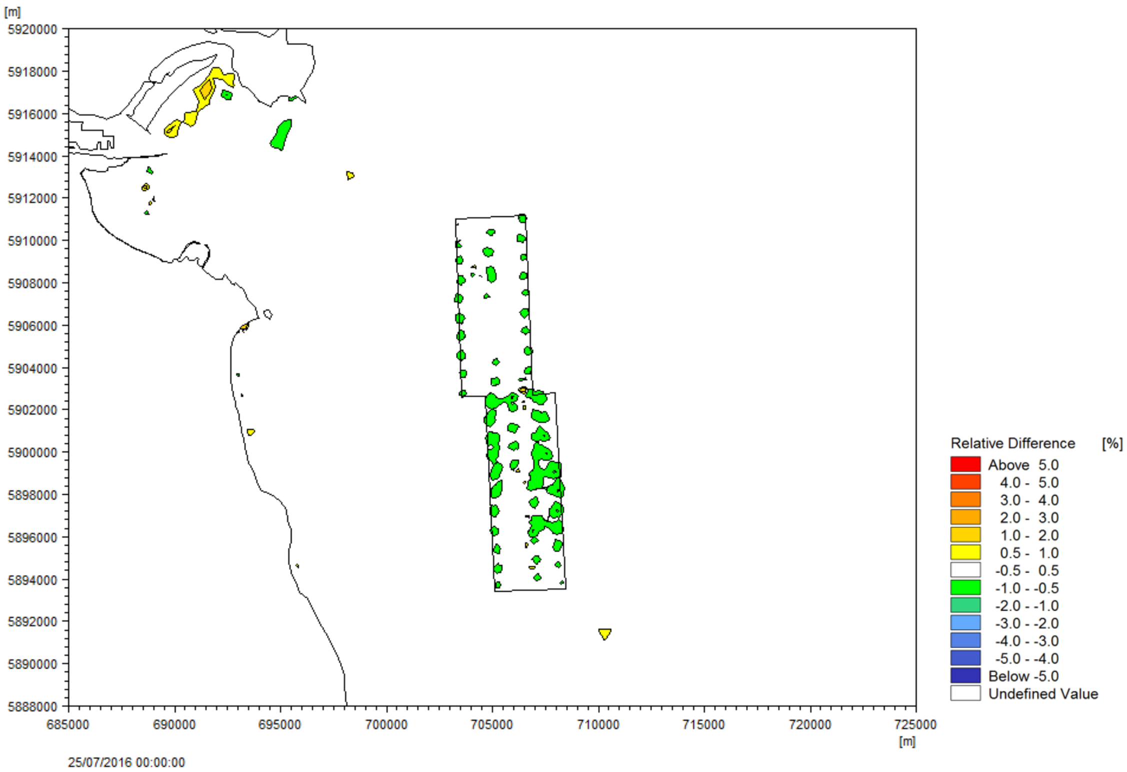
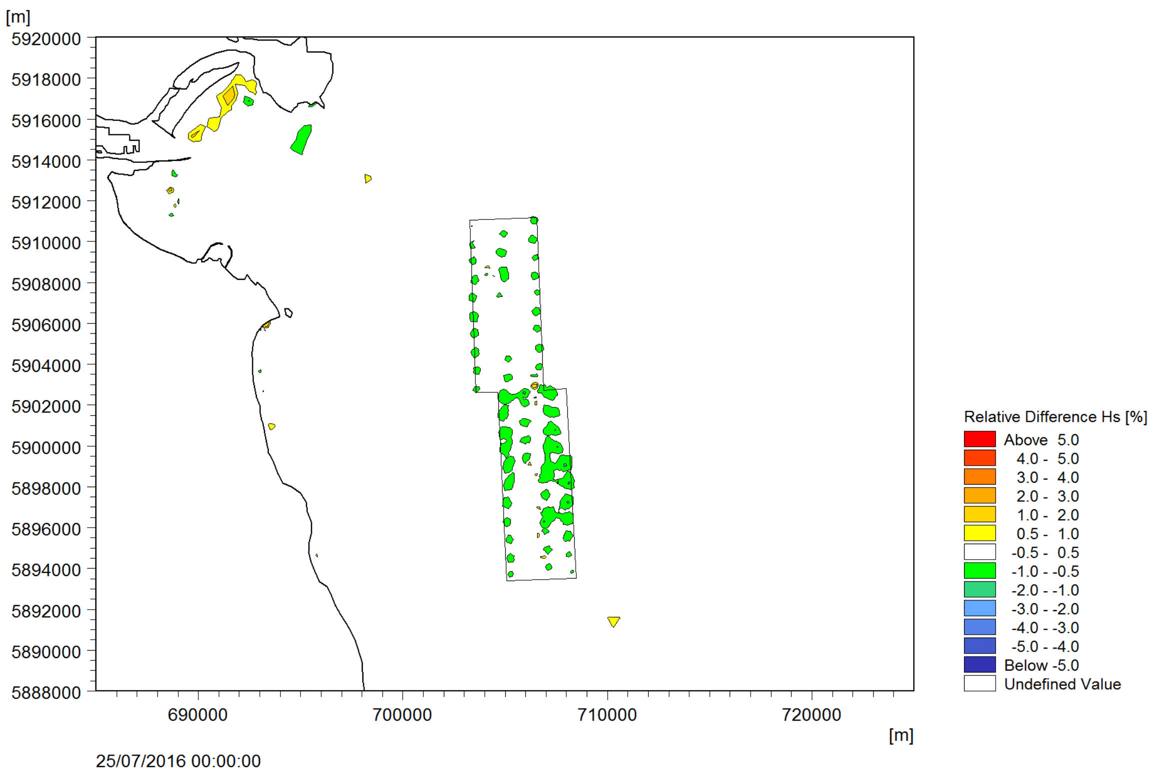


Figure B-94 Relative difference in H_{m0}, 1 in 100 year condition between baseline and scheme including SLR (above) and without SLR (below), from south (%)





Appendix C

Seabed Disturbance Sediment Modelling

C.1 SEABED PREPARATIONS AROUND FOUNDATIONS

C.1.1 Suspended Sediment Concentrations

Figure C-1 +0 hour after release of all sediment – north scenario, spring tide

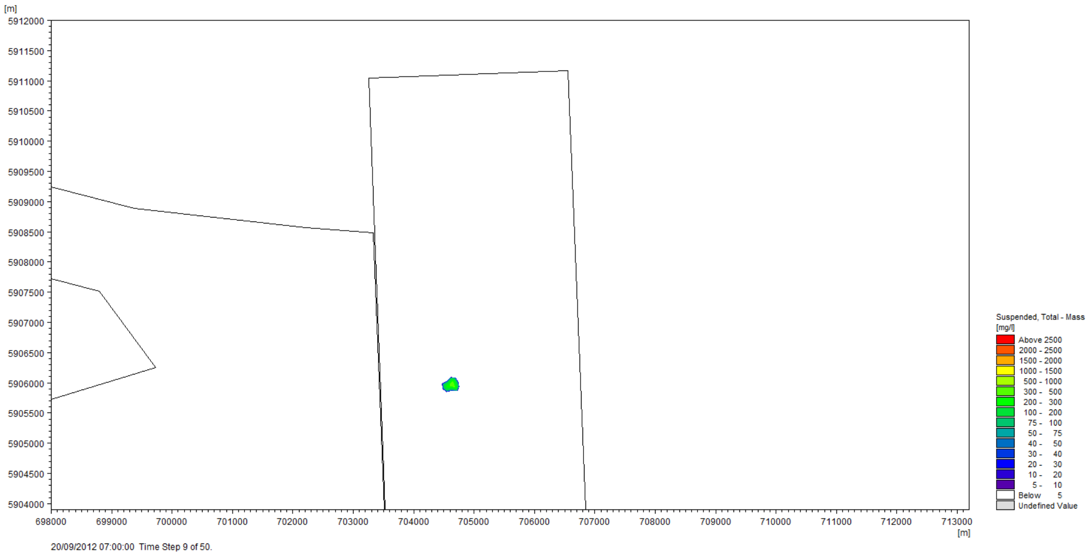


Figure C-2 +0 hours after release of all sediment – north scenario, neap tide

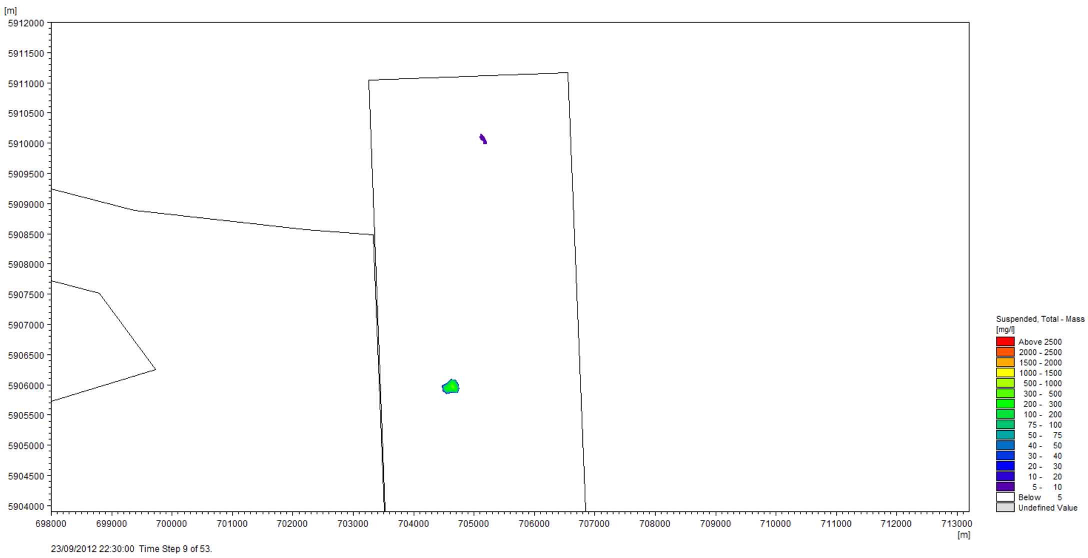


Figure C-3 +0 hours after release of all sediment – south scenario, spring tide

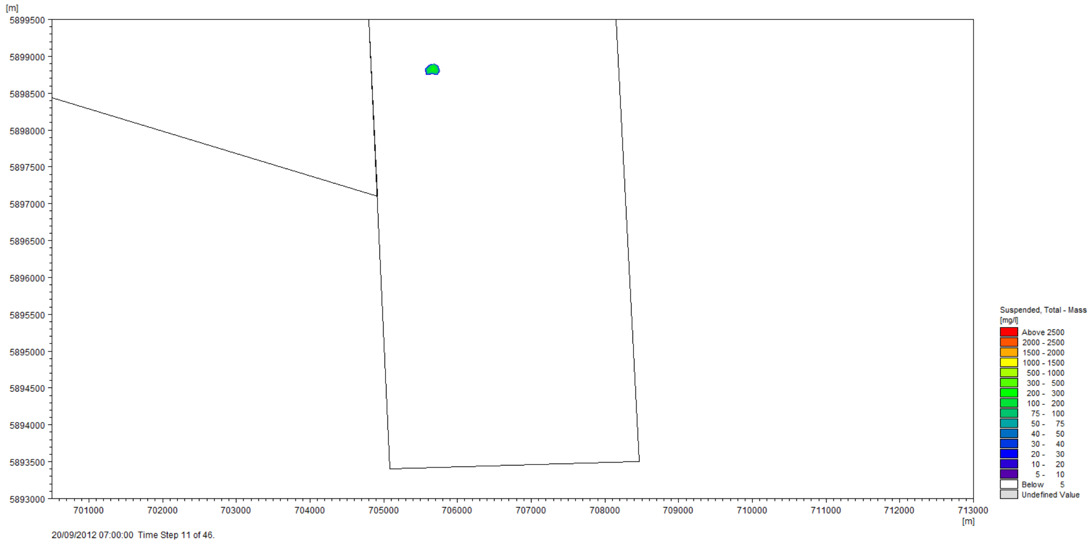
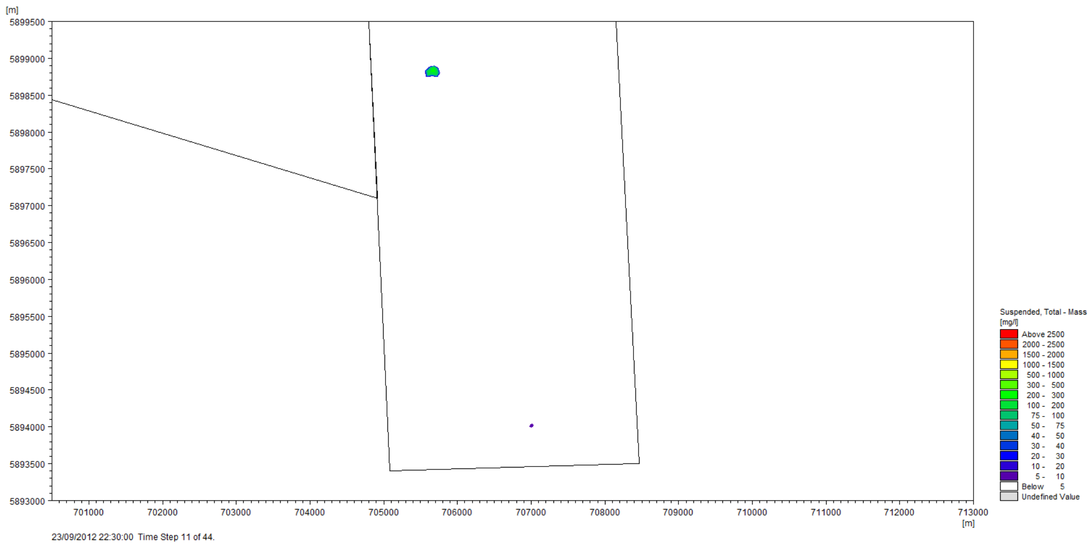


Figure C-4 +0 hours after release of all sediment – south scenario, neap tide



C.1.2 Sediment Deposition Thickness

Figure C-5 Deposition thickness – north scenario, spring tide

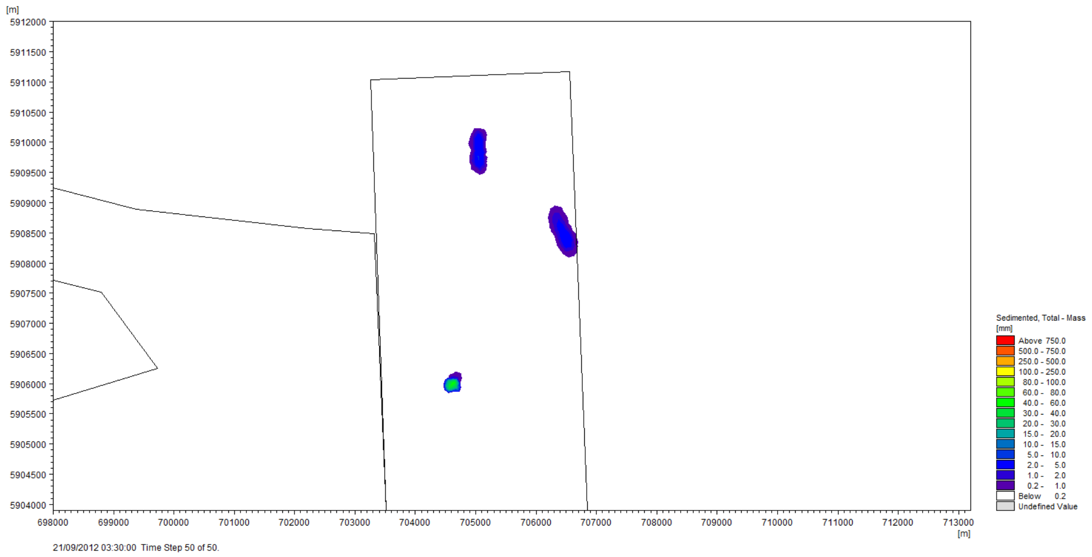


Figure C-6 Deposition thickness –north scenario, neap tide

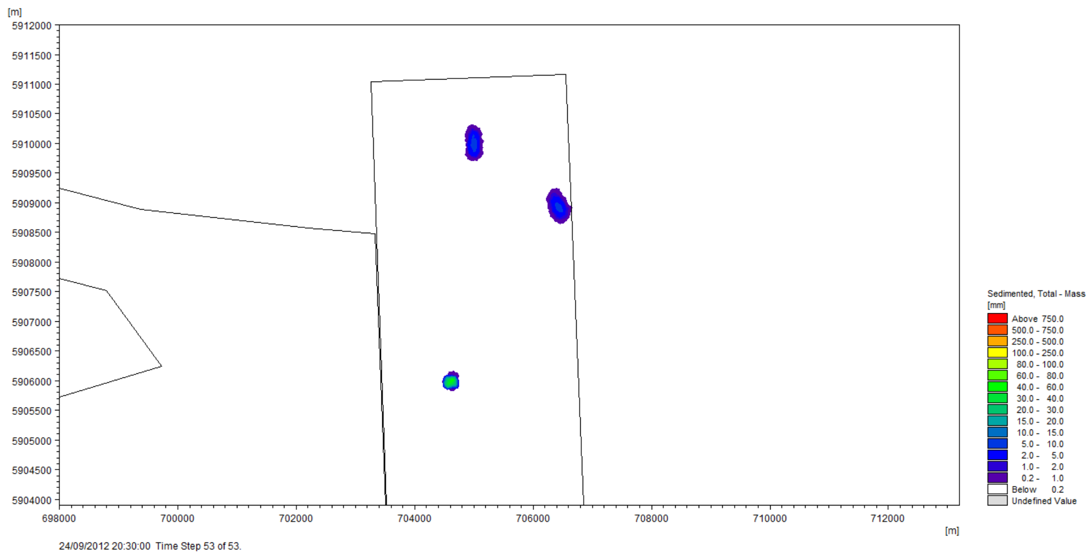


Figure C-7 Deposition thickness – south scenario, spring tide

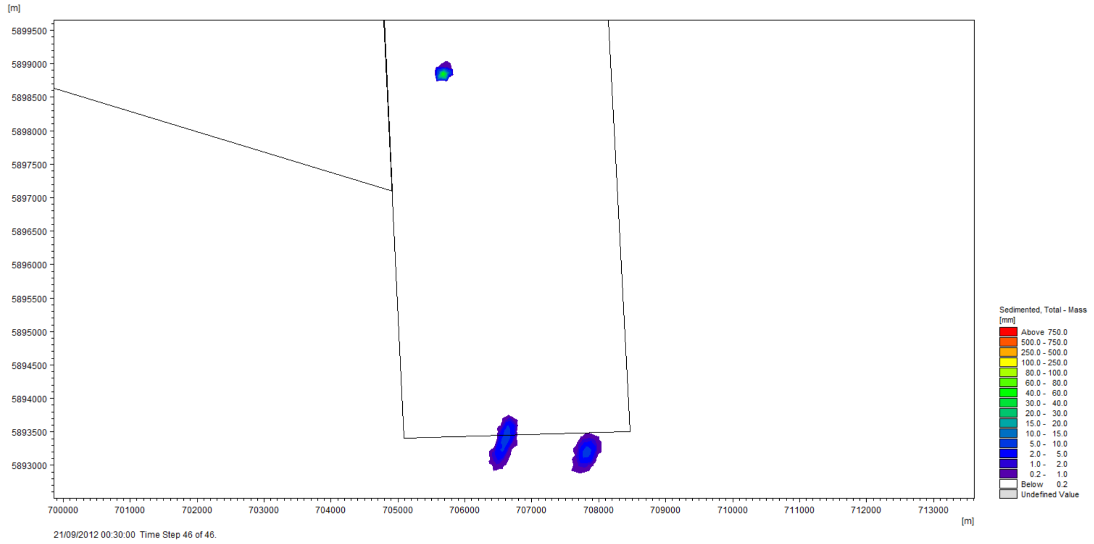
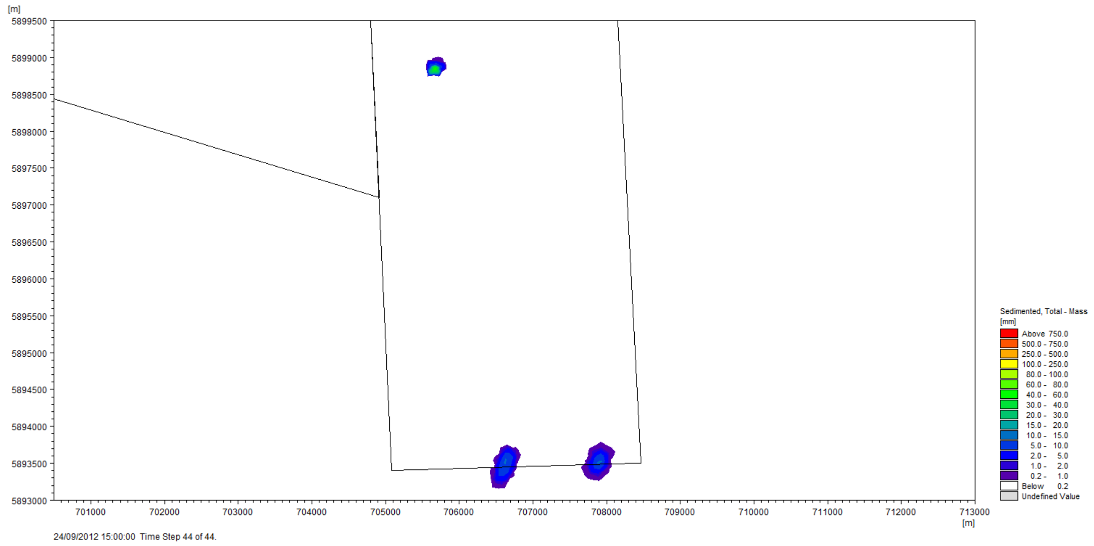


Figure C-8 Deposition thickness – south scenario, neap tide



C.2 DRILLING OF FOUNDATION PILES

C.2.1 Suspended Sediment Concentrations

Figure C-9 Suspended sediment concentrations 11 hours after the start of sediment release - spring tide scenario

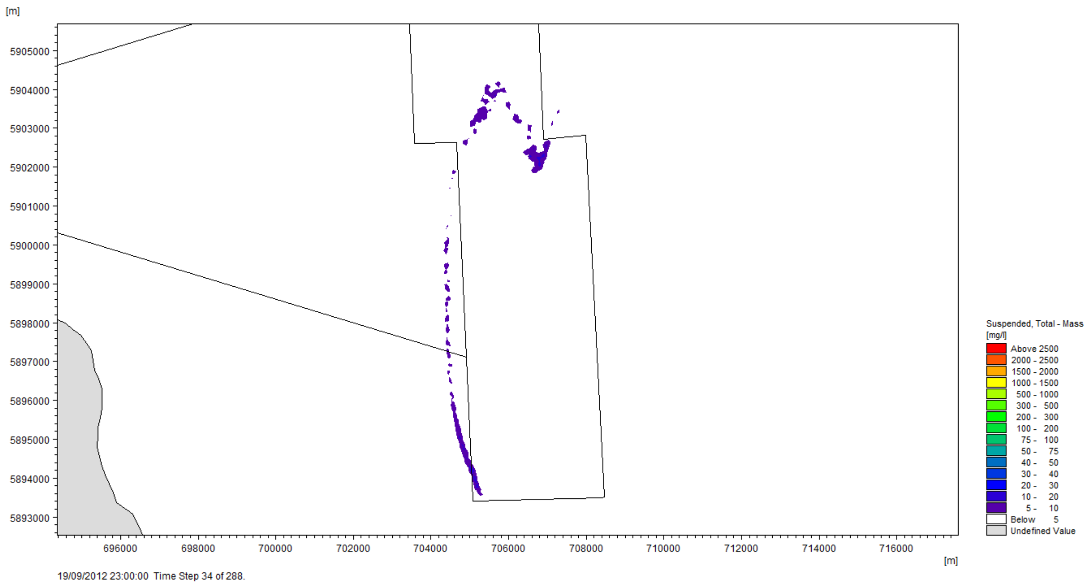


Figure C-10 +0 hours after release of all sediment – spring tide scenario

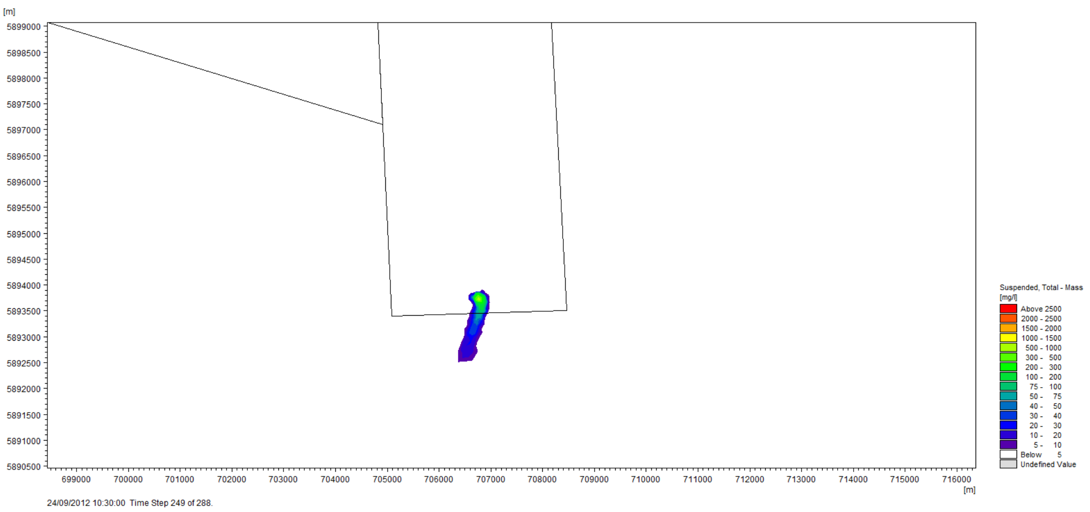
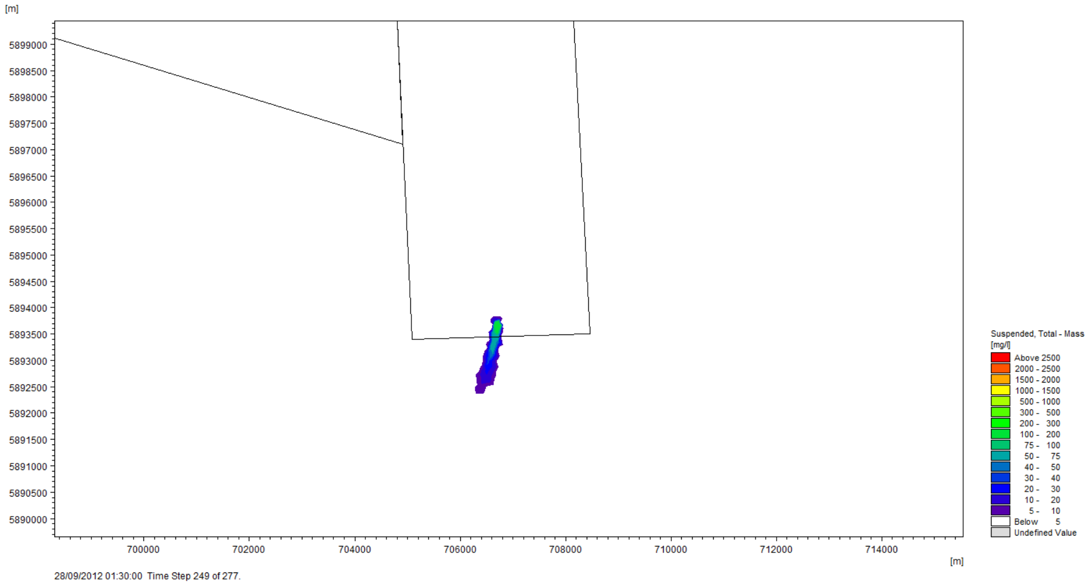


Figure C-11 +0 hours after release of all sediment – neap tide scenario



C.2.2 Sediment Deposition Thickness

Figure C-12 Deposition thickness – spring tide scenario

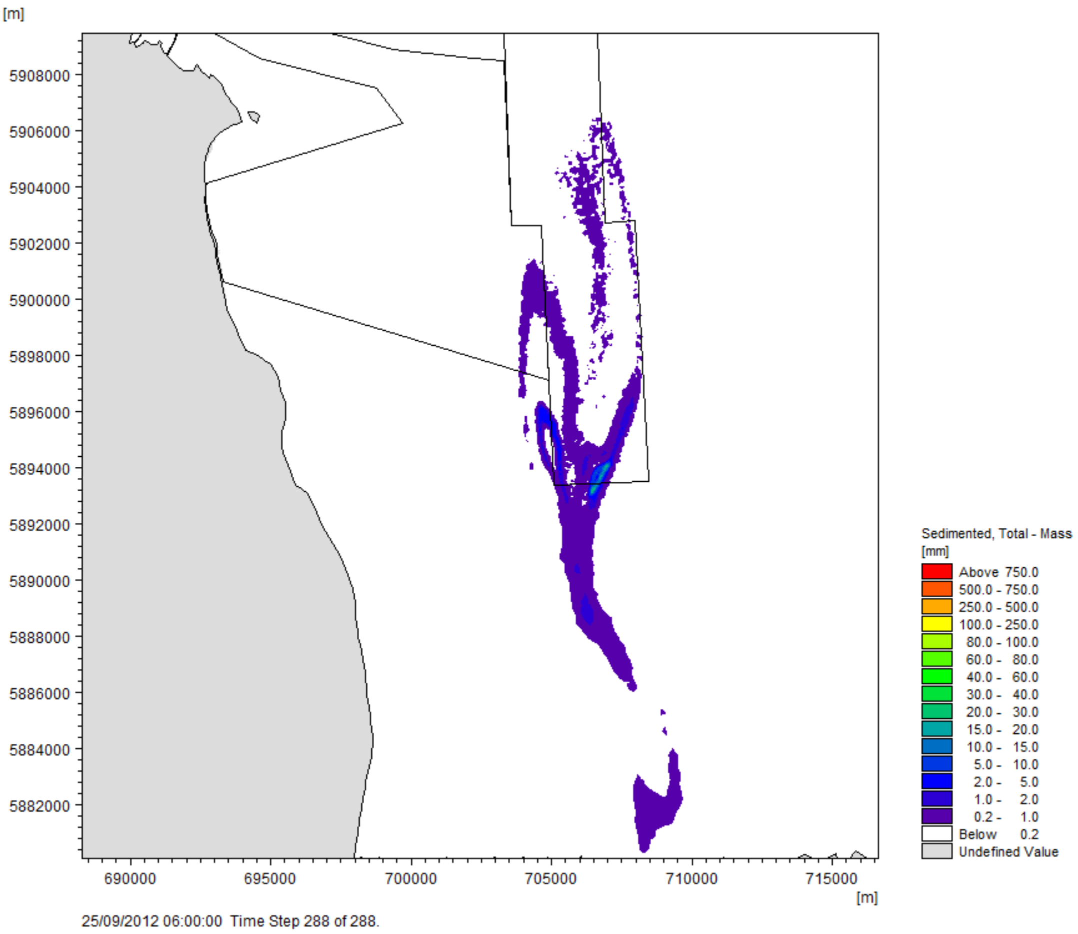
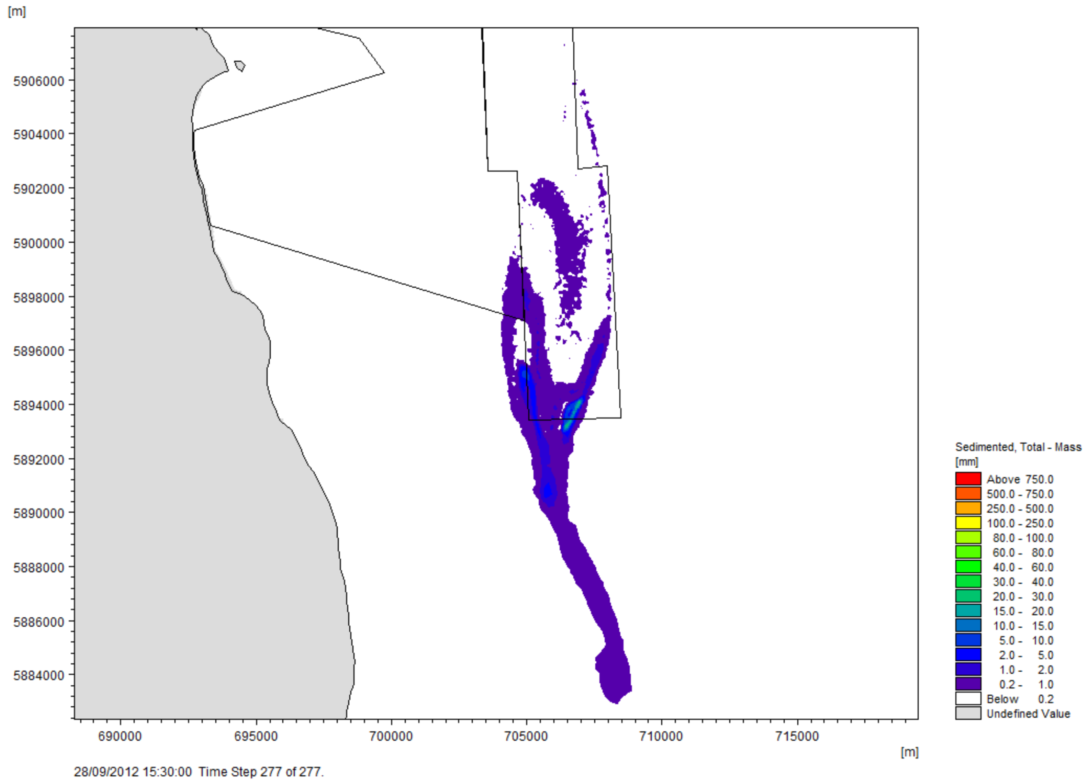


Figure C-13 Deposition thickness – neap tide scenario



C.3 PRE-CONSTRUCTION SWEEPING OF CABLE ROUTES – INTER-ARRAY CABLES

C.3.1 Suspended Sediment Concentrations

Figure C-14 +0 hours after release of all sediment – north scenario, spring tide

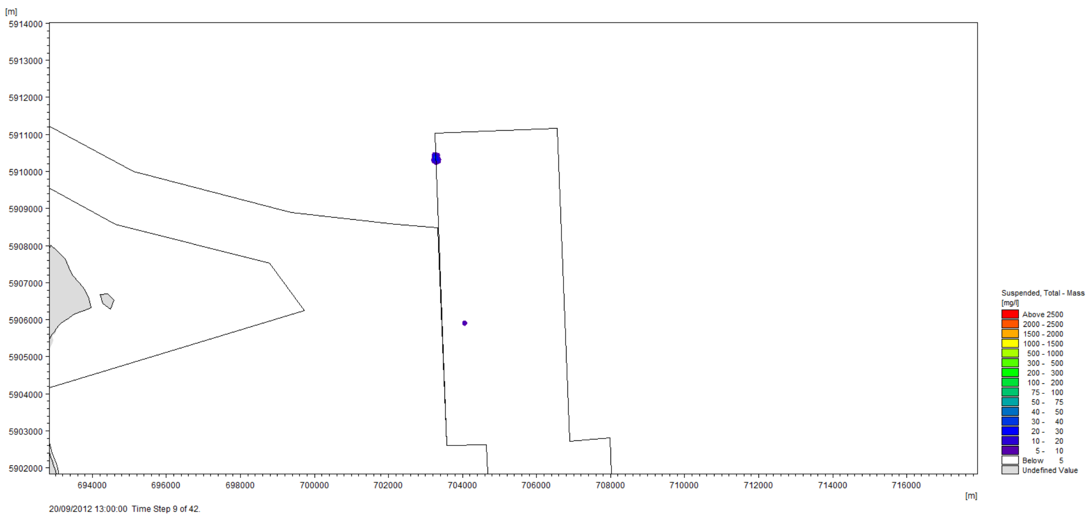


Figure C-15 +0 hours after release of all sediment – north scenario, neap tide

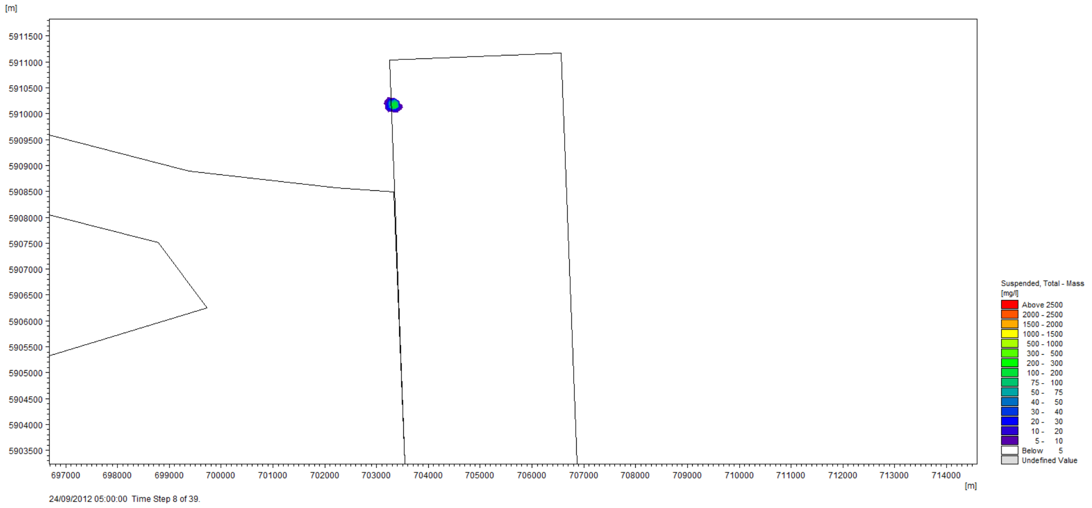


Figure C-16 +0 hours after release of all sediment – south scenario, spring tide

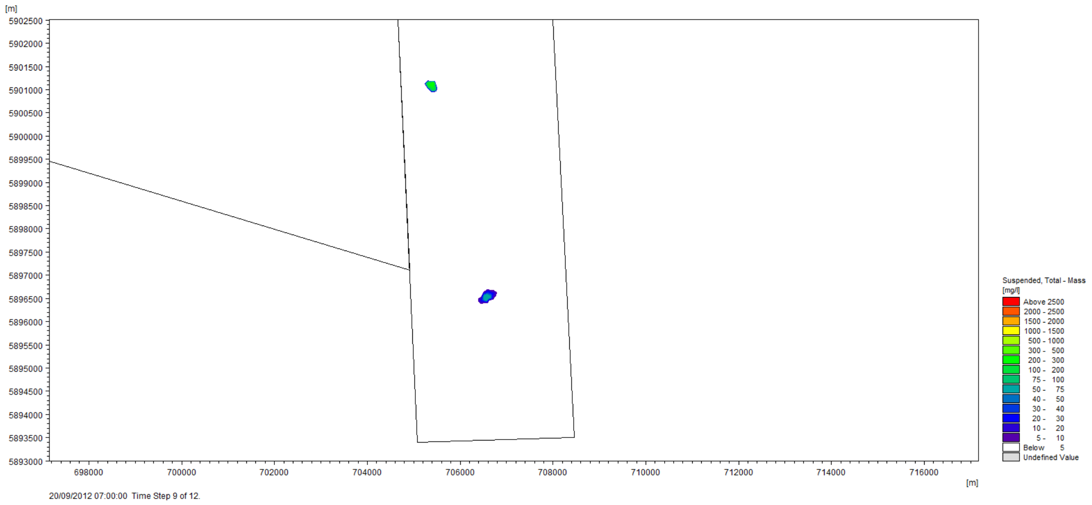
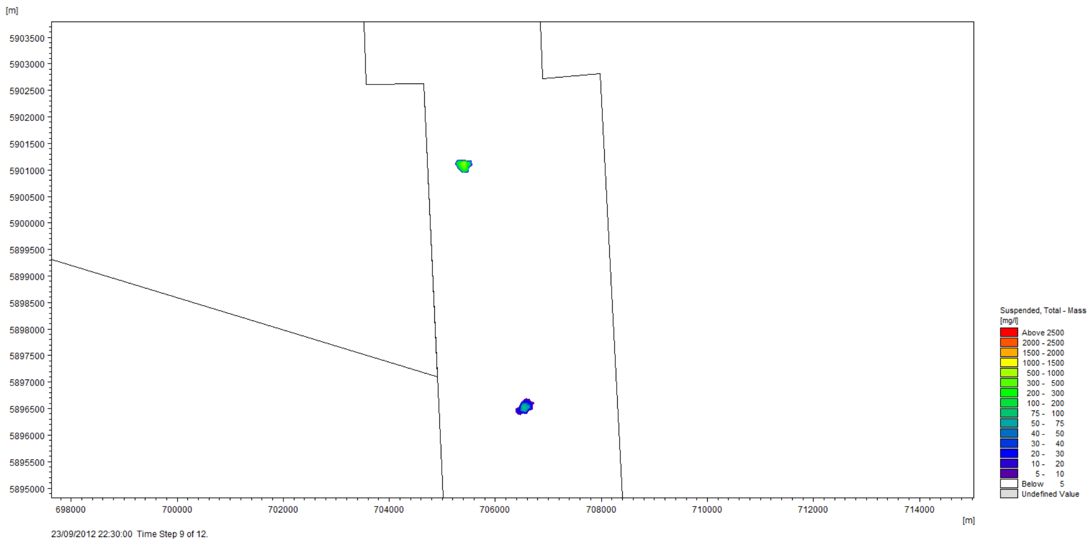


Figure C-17 +0 hours after release of all sediment – south scenario, neap tide



C.3.2 Sediment Deposition Thickness

Figure C-18 Deposition thickness – north scenario, spring tide

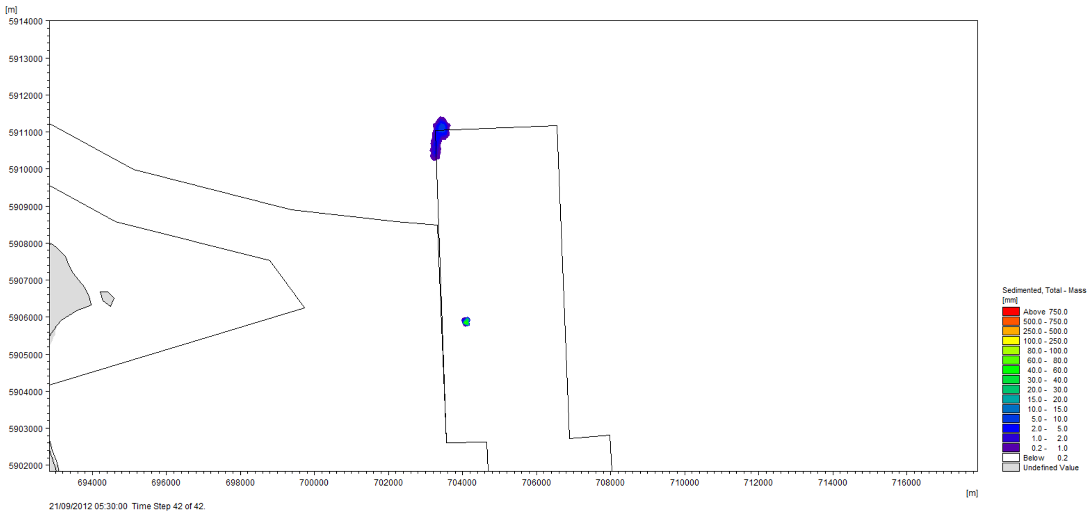


Figure C-19 Deposition thickness – north scenario, neap tide

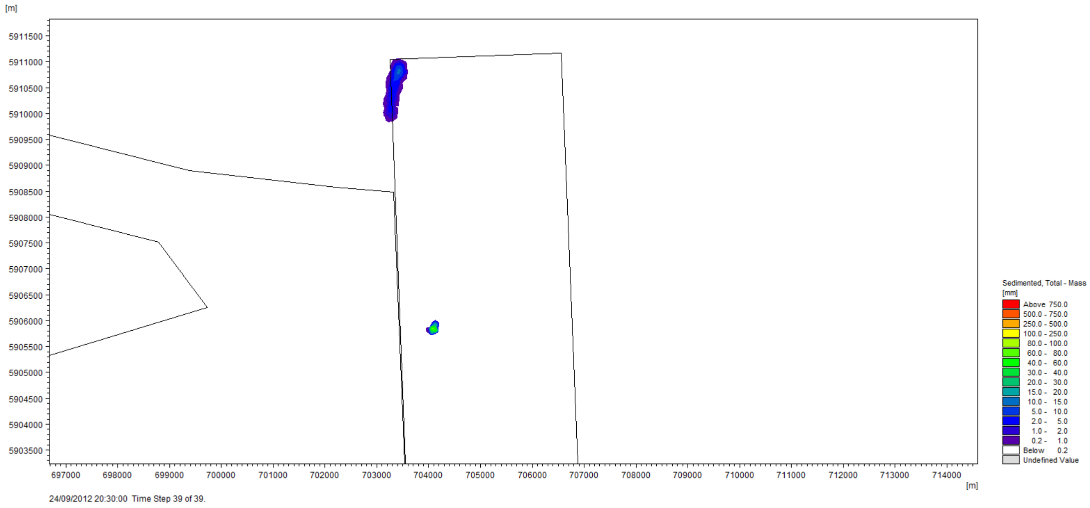


Figure C-20 Deposition thickness – south scenario, spring tide

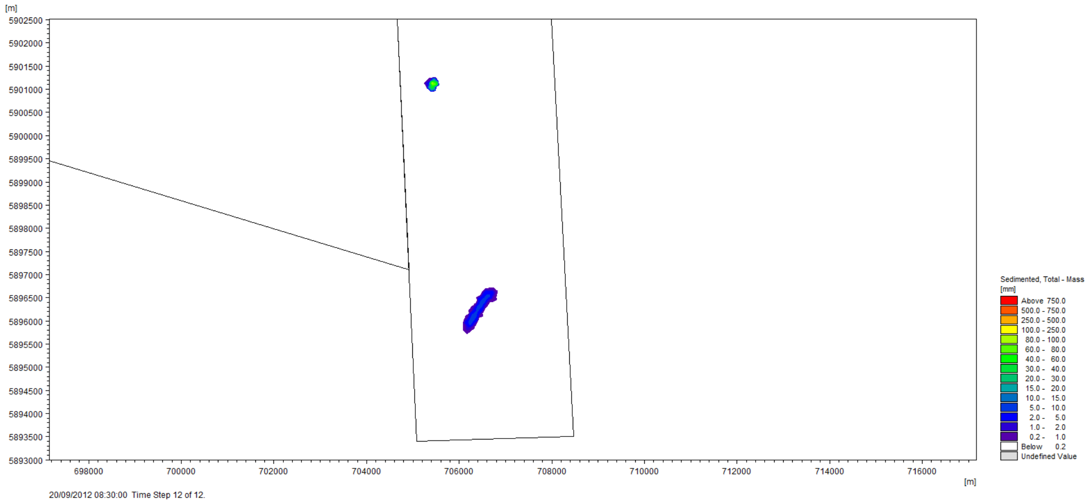
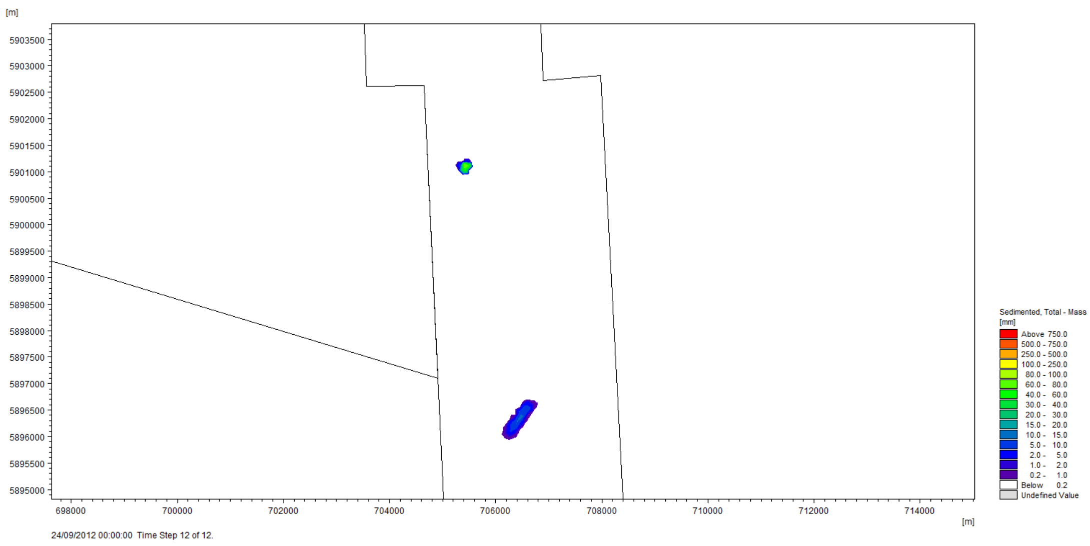


Figure C-21 Deposition thickness – south scenario, neap tide



C.4 PRE-CONSTRUCTION SWEEPING OF CABLE ROUTES – EXPORT CABLE ROUTE

C.4.1 Suspended Sediment Concentrations

Figure C-22 +1 hours after start of sediment release – Section 5 scenario, spring tide

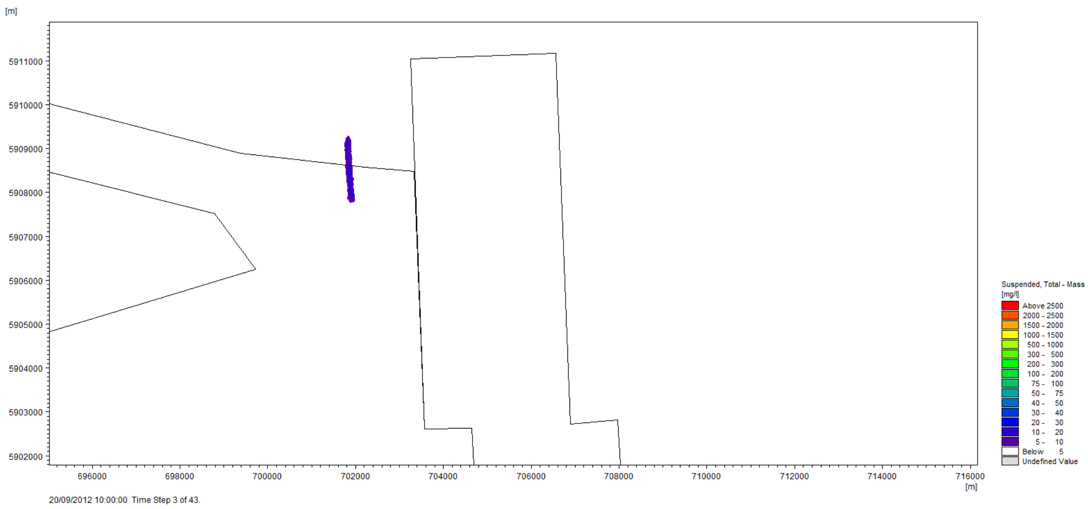


Figure C-23 +1 hours after start of sediment release – Section 5 scenario, neap tide

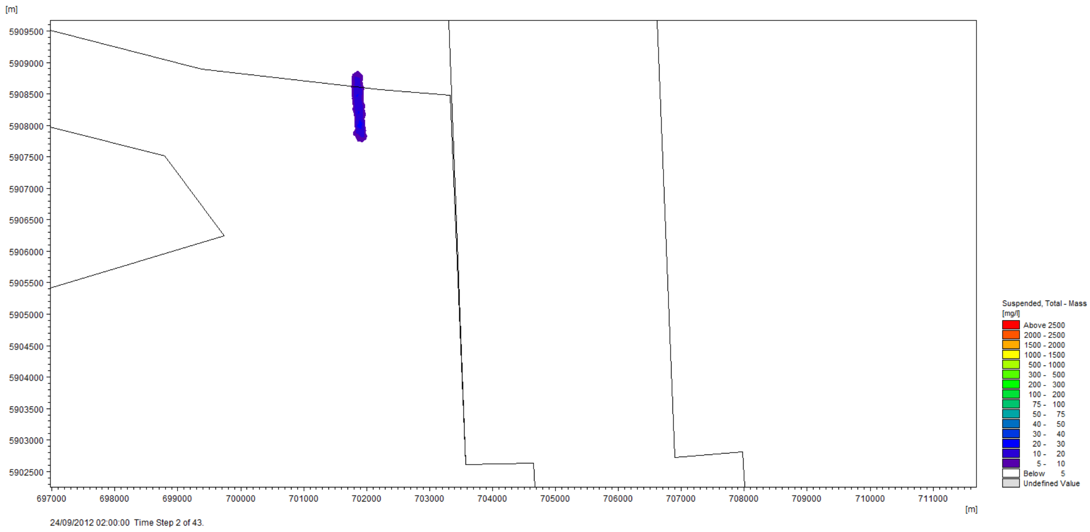


Figure C-24 +0 hours after release of all sediment – Section 8 scenario, spring tide

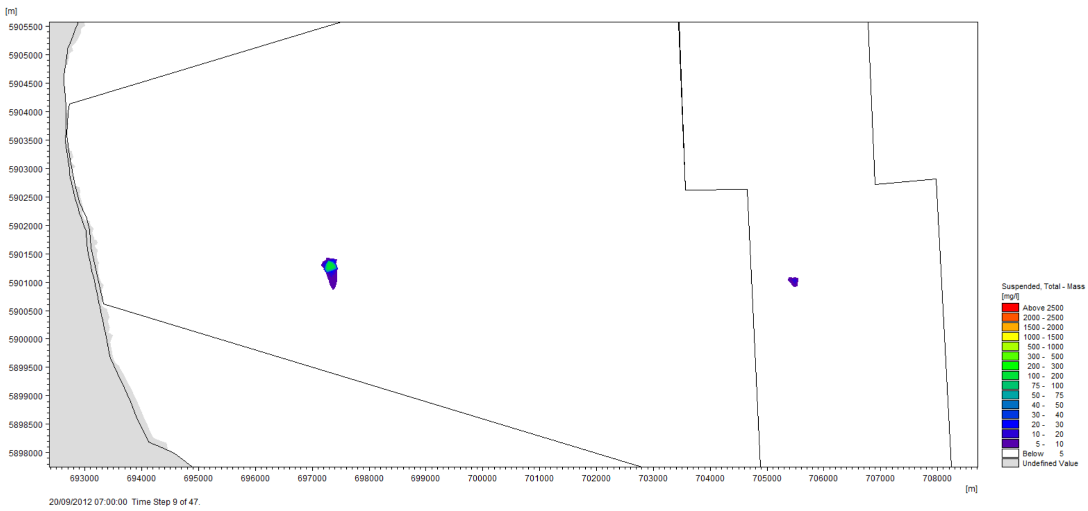


Figure C-25 +0 hours after release of all sediment – Section 8 scenario, neap tide

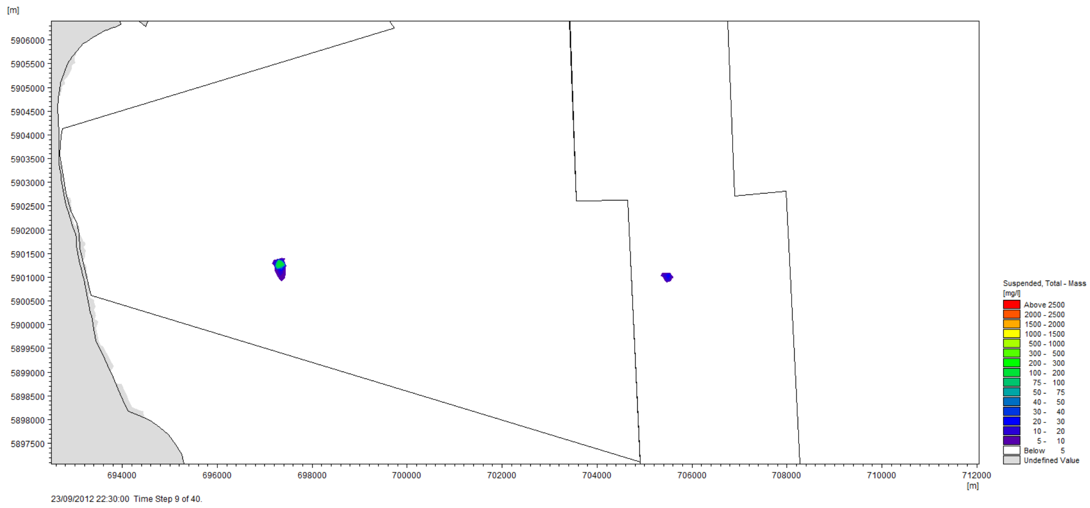


Figure C-26 +1 hours after start of sediment release – Section 11 scenario, spring tide

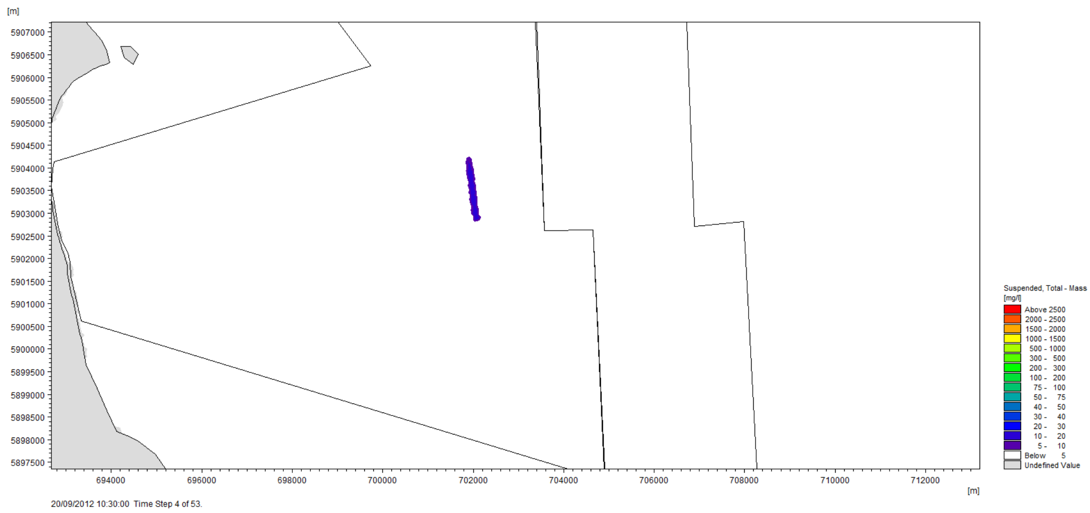
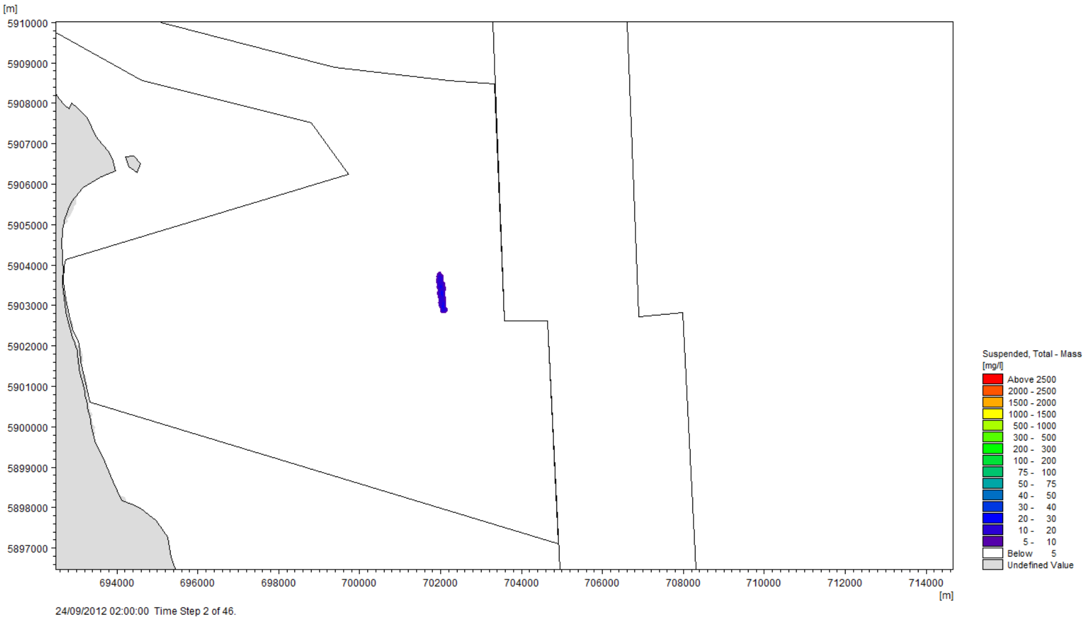


Figure C-27 +1 hours after start of sediment release – Section 11 scenario, neap tide



C.4.2 Sediment Deposition Thickness

Figure C-28 Deposition thickness, Section 5 scenario, spring tide

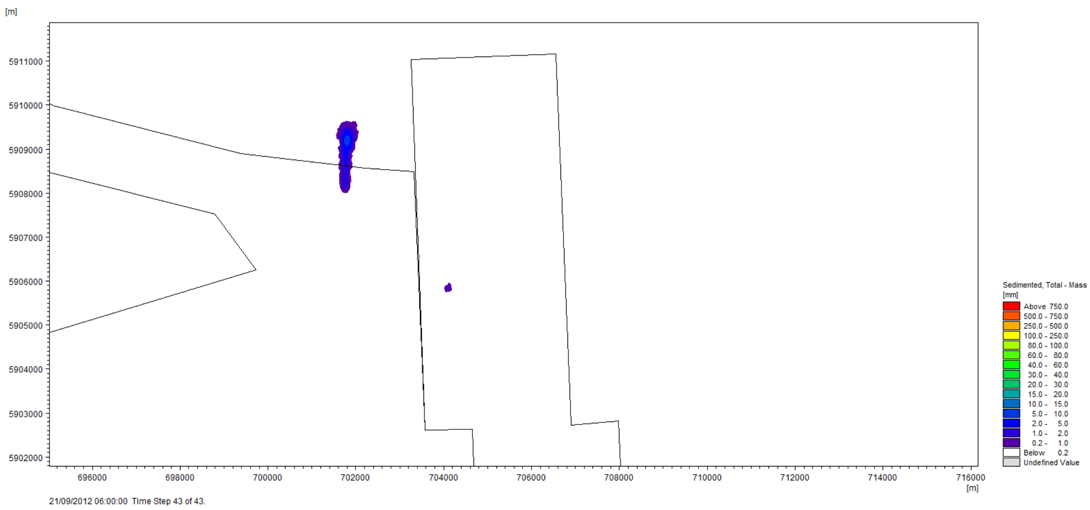


Figure C-29 Deposition thickness, Section 5 scenario, neap tide

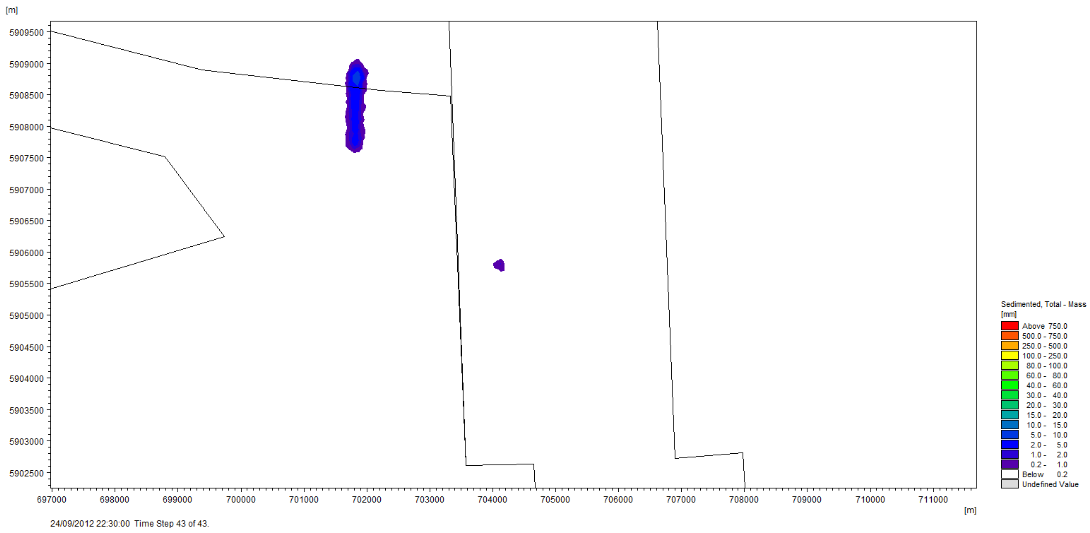


Figure C-30 Deposition thickness, Section 8 scenario, spring tide

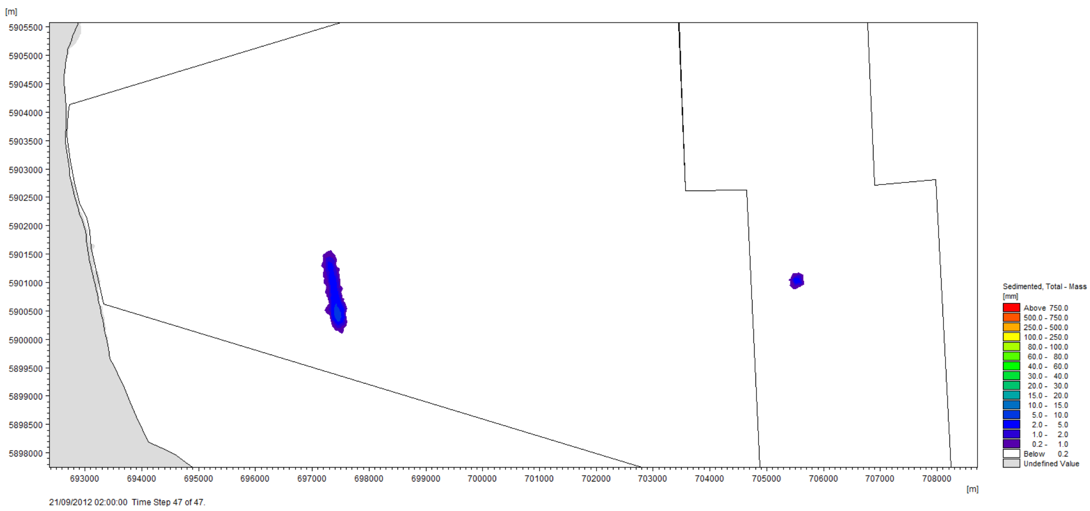


Figure C-31 Deposition thickness, Section 8 scenario, neap tide

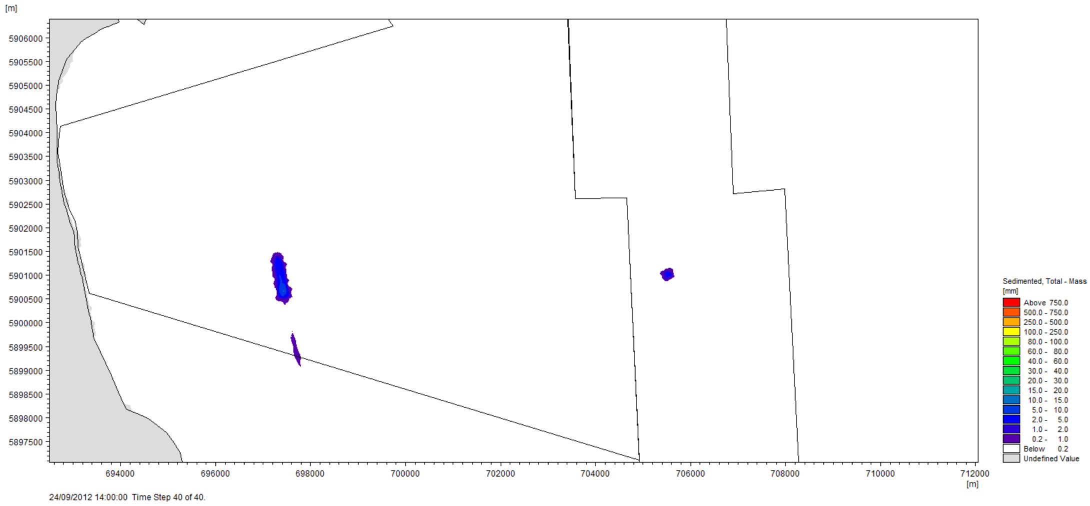


Figure C-32 Deposition thickness, Section 11 scenario, spring tide

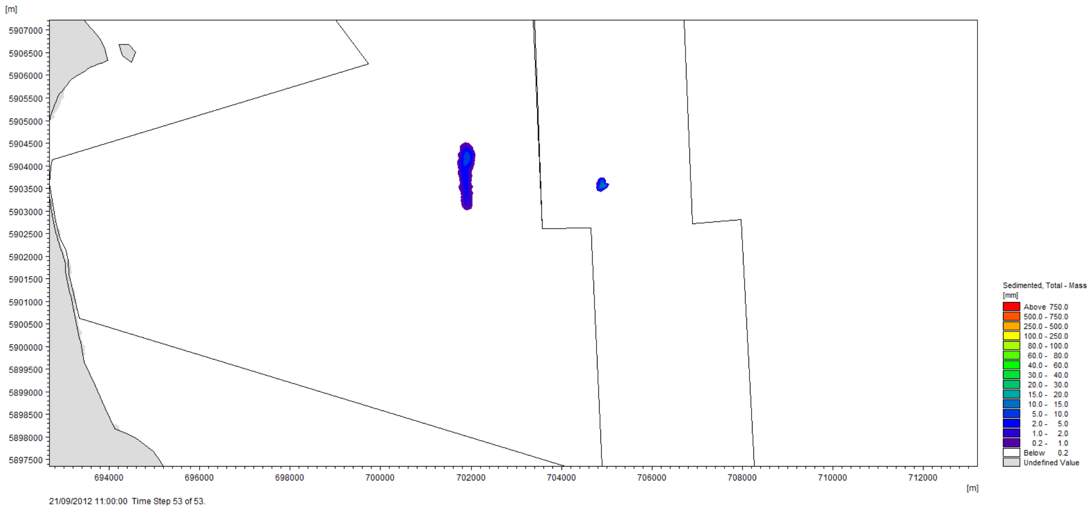
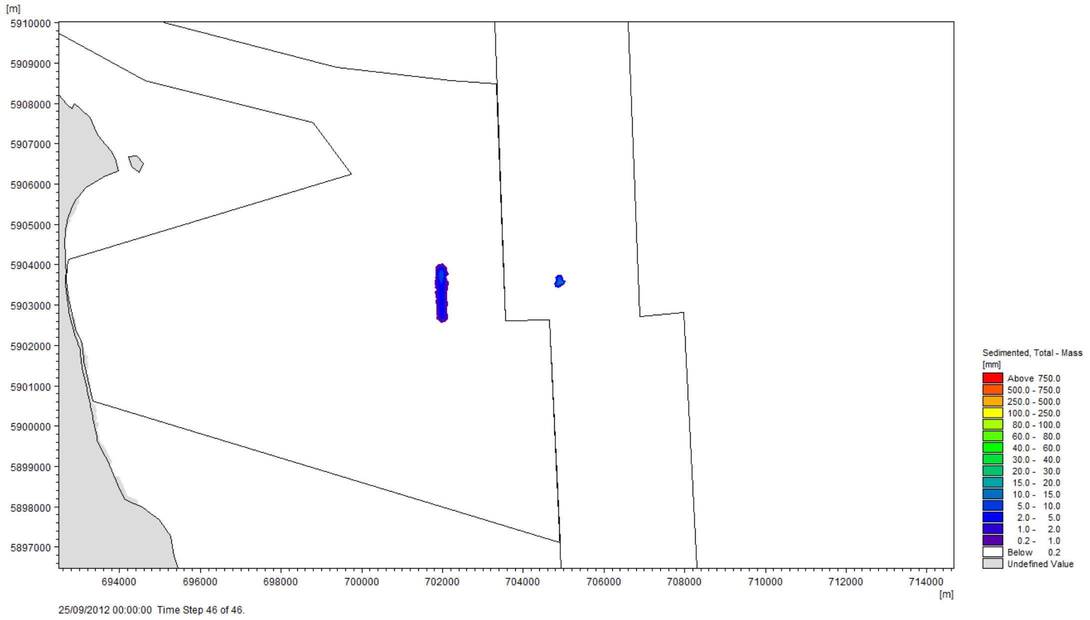


Figure C-33 Deposition thickness, Section 11 scenario, neap tide



C.5 CABLE TRENCHING – INTER-ARRAY CABLES

C.5.1 Suspended Sediment Concentrations

Figure C-34 +2 hours after start of sediment release – Line 1 scenario, neap tide

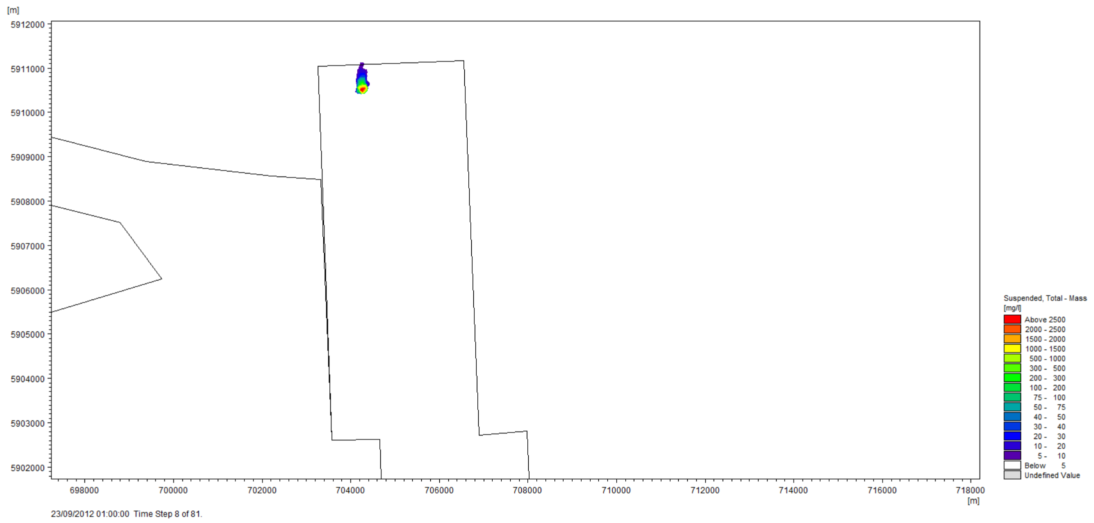


Figure C-35 +0 hours after release of all sediment – Line 1 scenario, spring tide

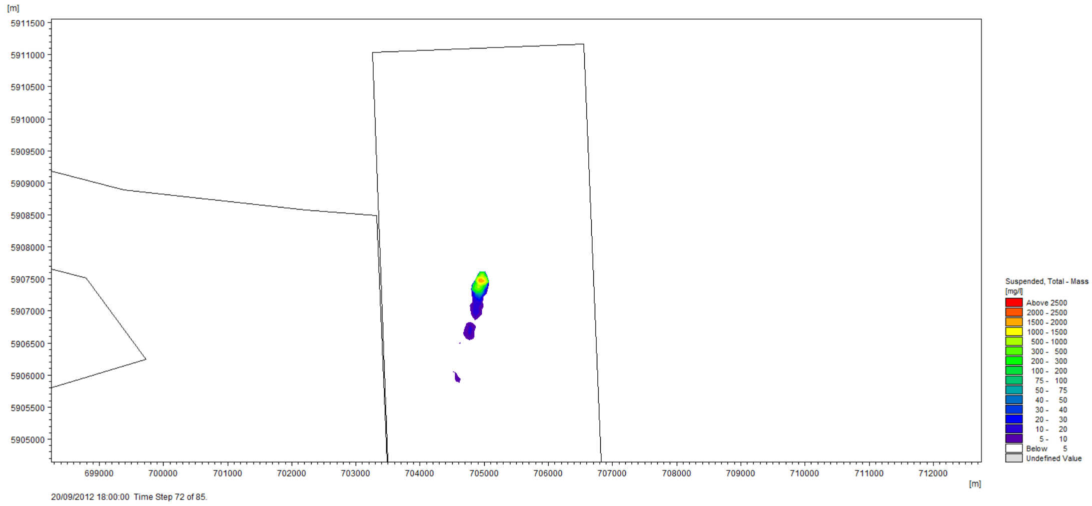


Figure C-36 +0 hours after release of all sediment – Line 2 scenario, spring tide

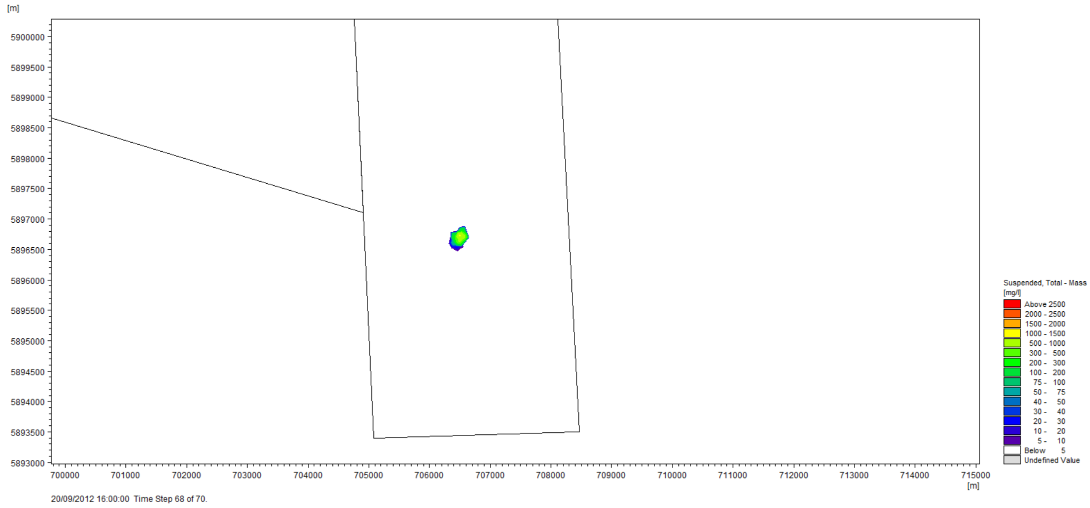
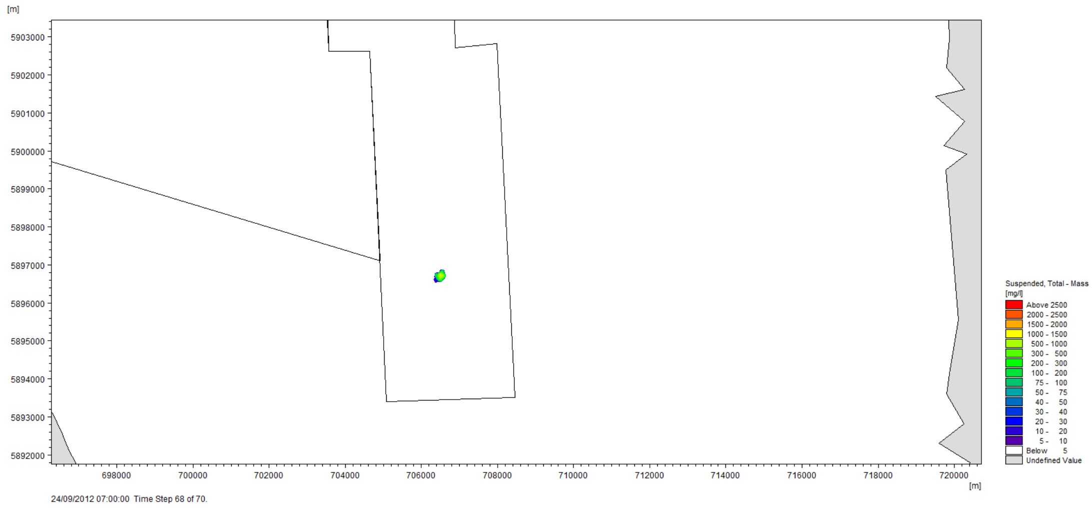


Figure C-37 +0 hours after release of all sediment – Line 2 scenario, neap tide



C.5.2 Sediment Deposition Thickness

Figure C-38 Deposition thickness, Line 1 scenario, spring tide

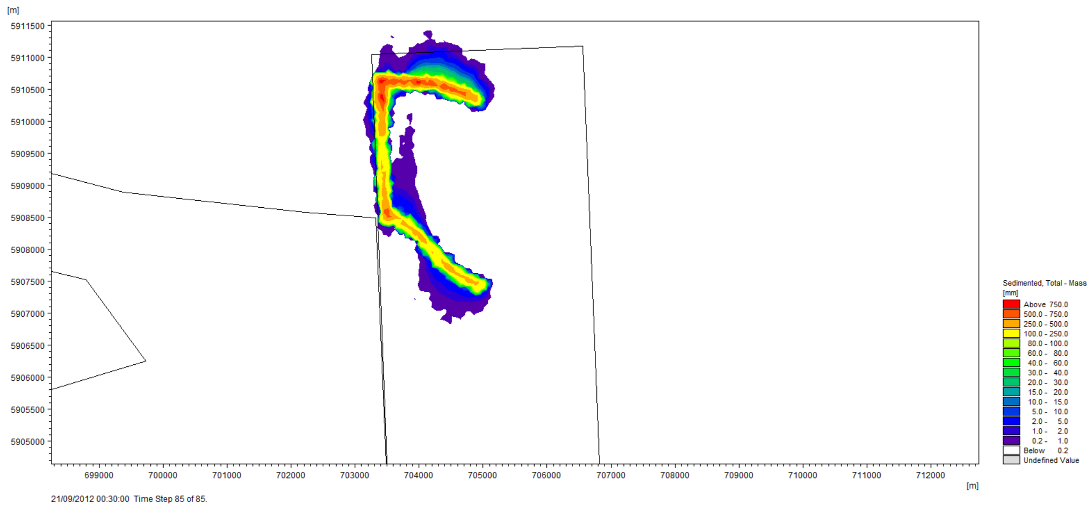


Figure C-39 Deposition thickness, Line 1 scenario, neap tide

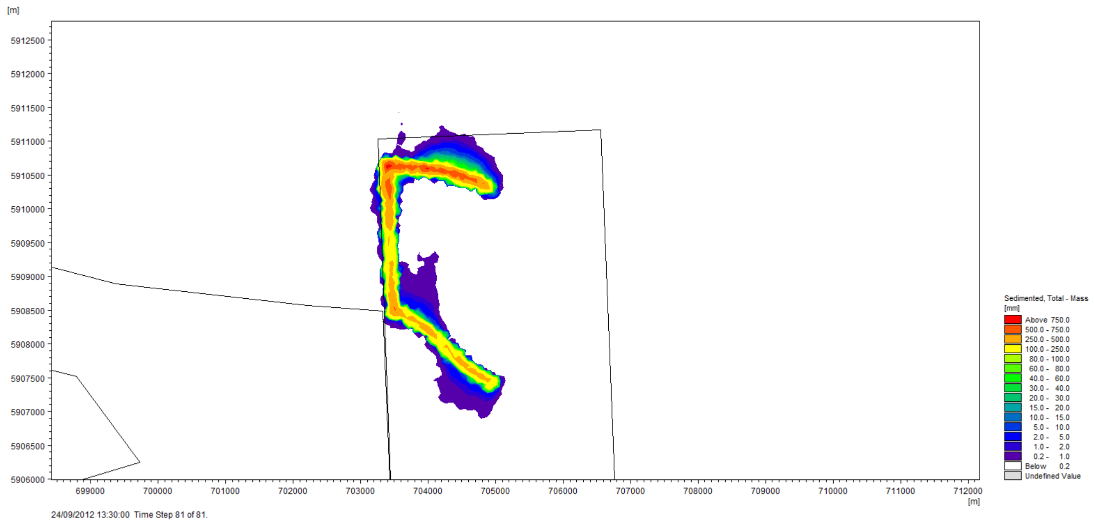


Figure C-40 Deposition thickness, Line 2 scenario, spring tide

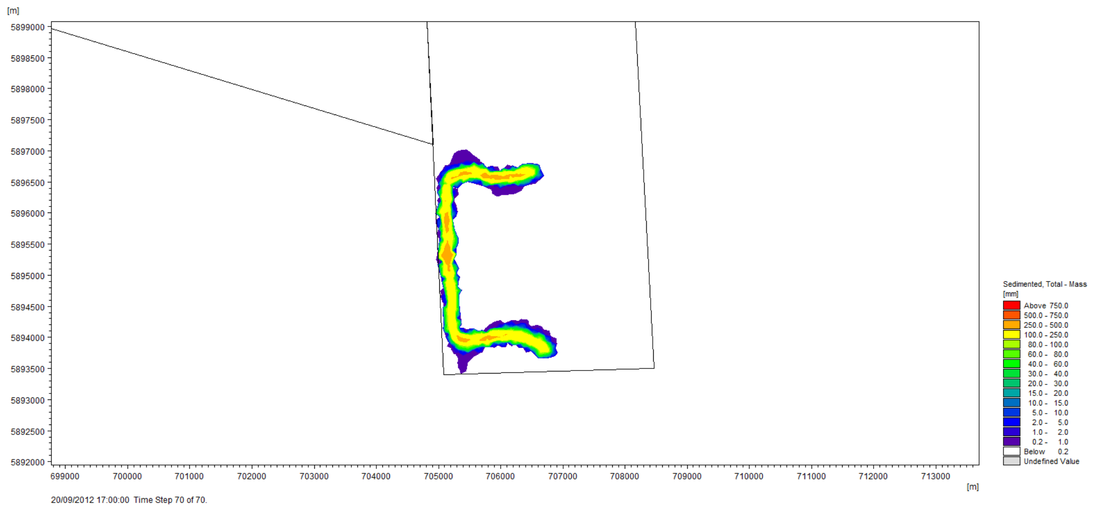
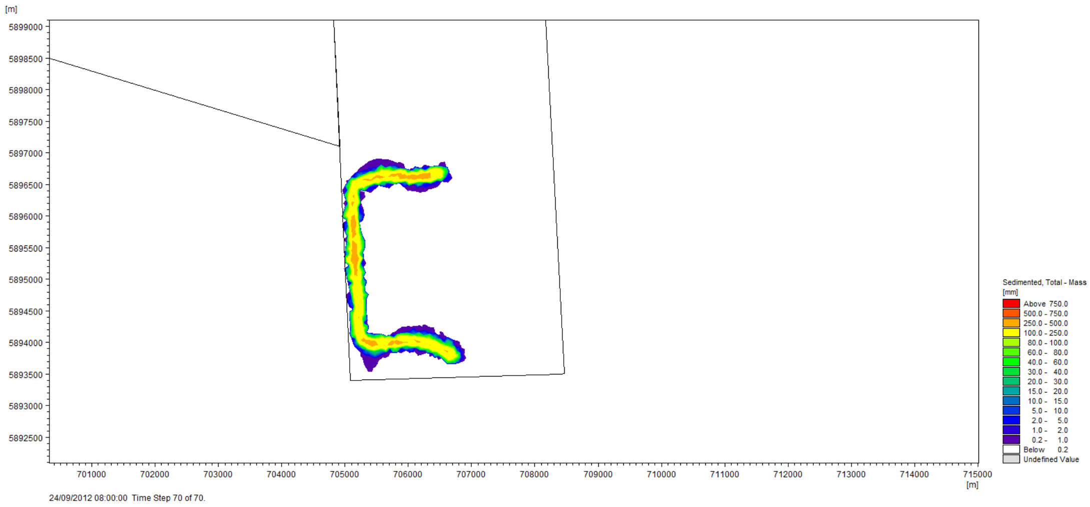


Figure C-41 Deposition thickness, Line 2 scenario, neap tide



C.6 CABLE TRENCHING – EXPORT CABLE ROUTE

C.6.1 Suspended Sediment Concentrations

Figure C-42 +1 hours after start of sediment release – Section 1 scenario, spring tide

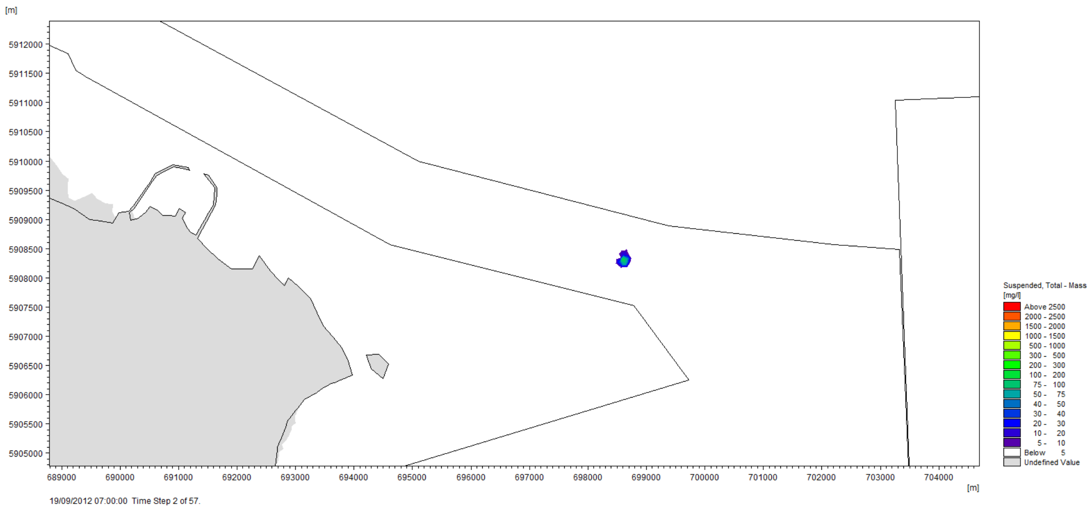


Figure C-43 +1 hours after start of sediment release – Section 1 scenario, neap tide

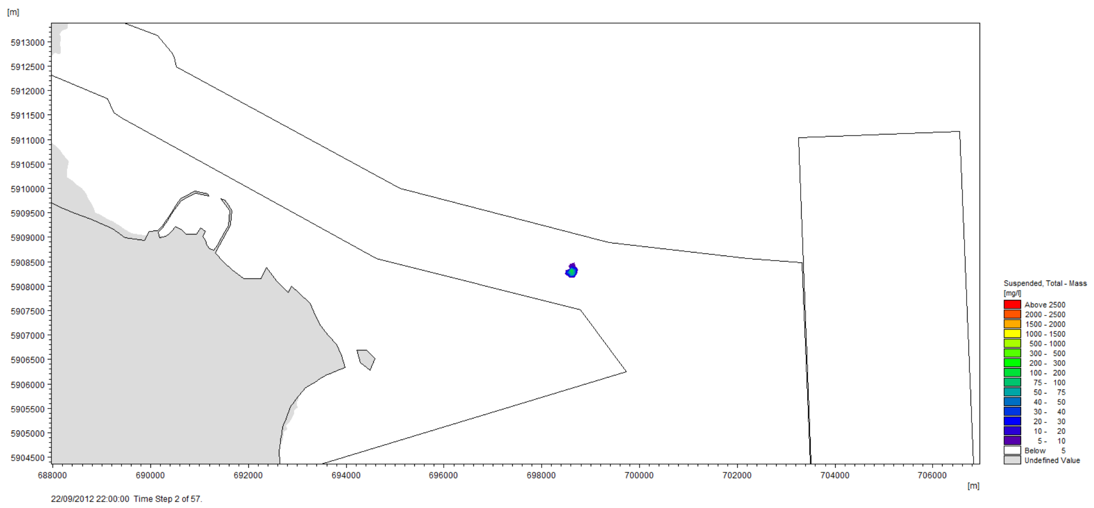


Figure C-44 +2 hours after start of sediment release – Section 2 scenario, spring tide

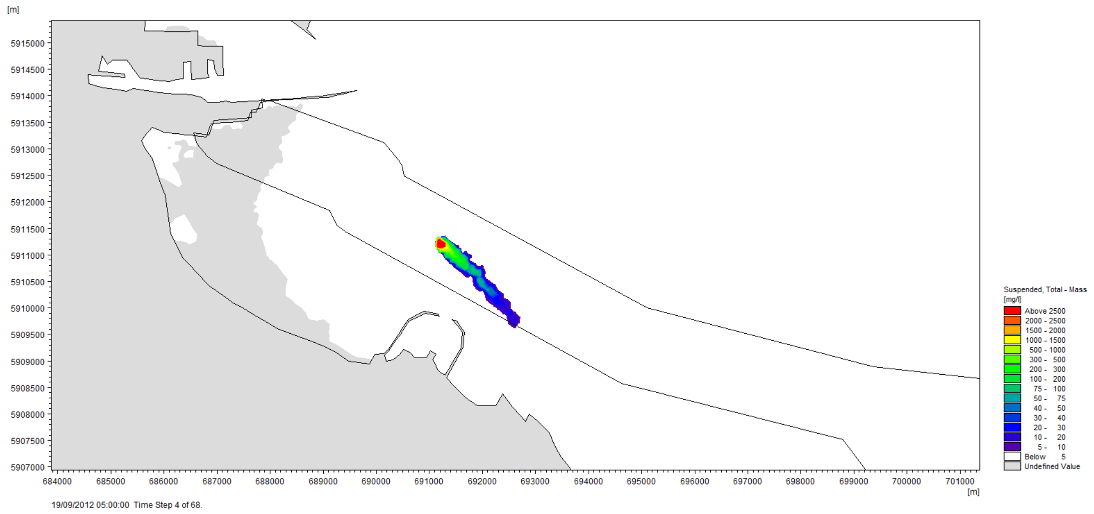


Figure C-45 +2 hours after start of sediment release – Section 2 scenario, neap tide

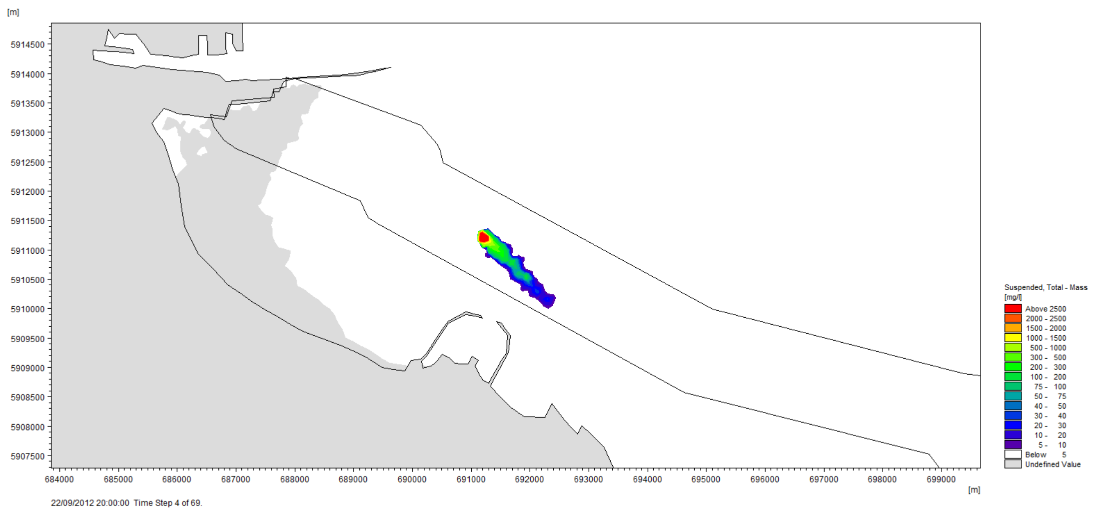


Figure C-46 +0 hours after release of all sediment – Section 3 scenario, spring tide

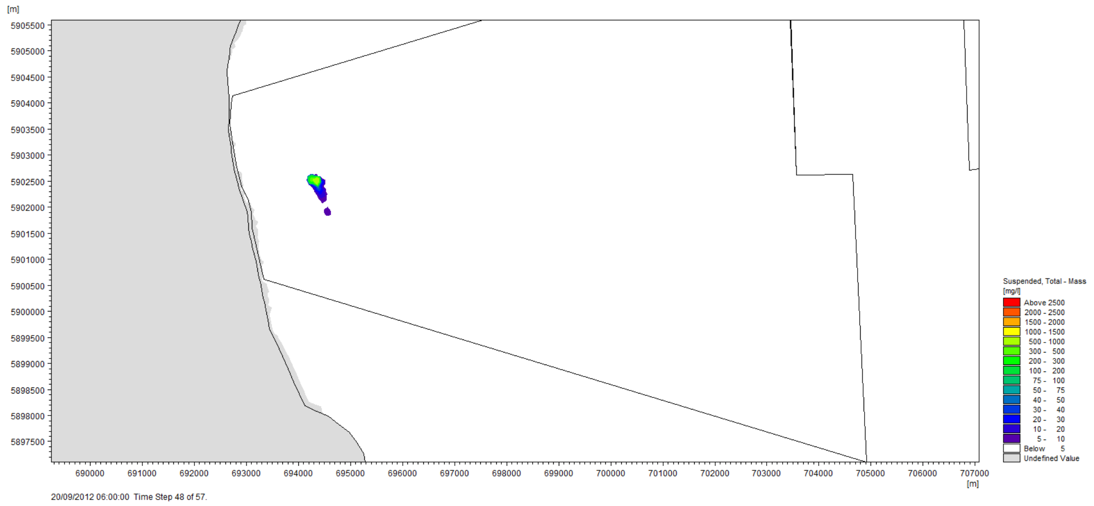
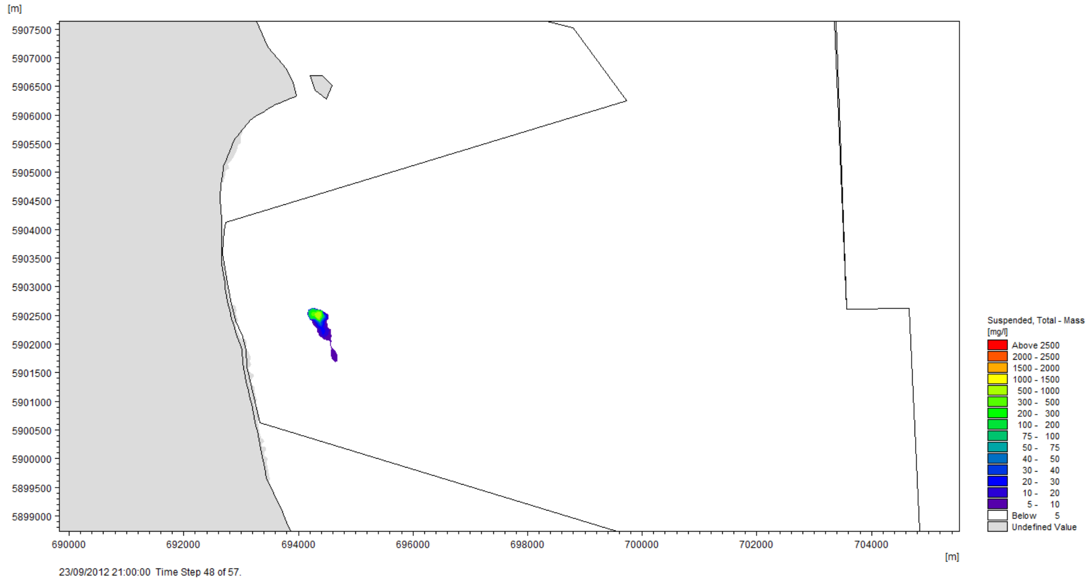


Figure C-47 +0 hours after release of all sediment – Section 3 scenario, neap tide



C.6.2 Sediment Deposition Thickness

Figure C-48 Deposition thickness, Section 1 scenario, spring tide

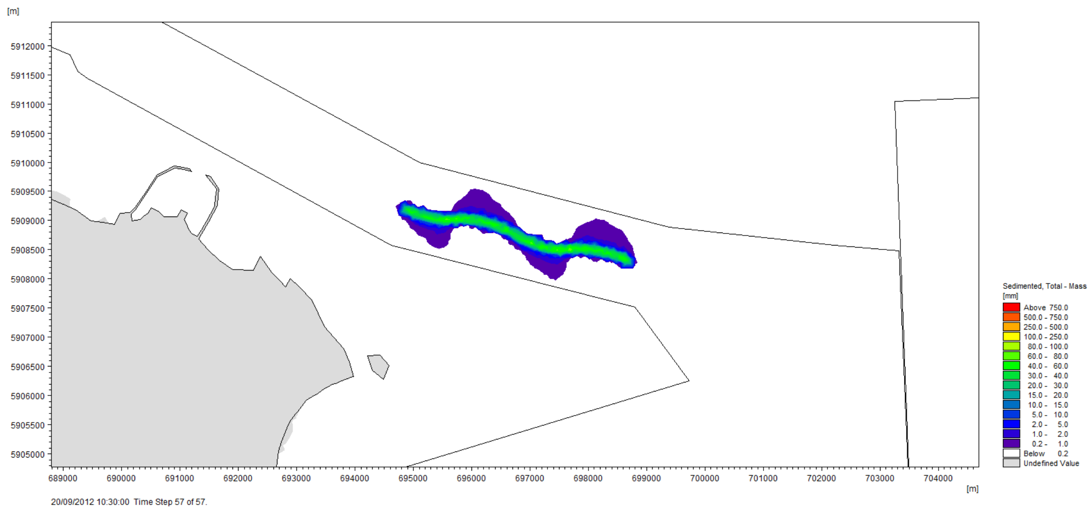


Figure C-49 Deposition thickness, Section 1 scenario, neap tide

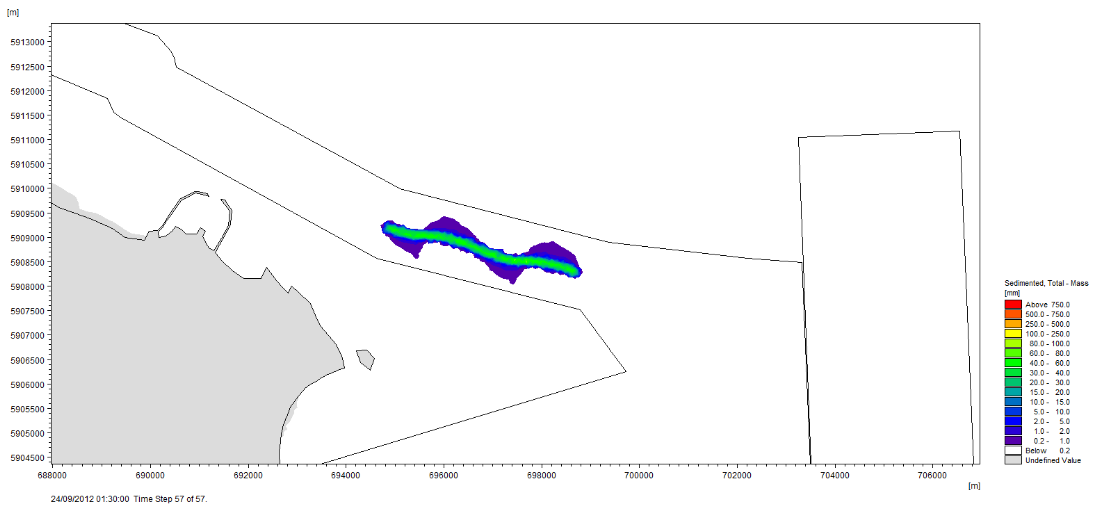


Figure C-50 Deposition thickness, Section 2 scenario, spring tide

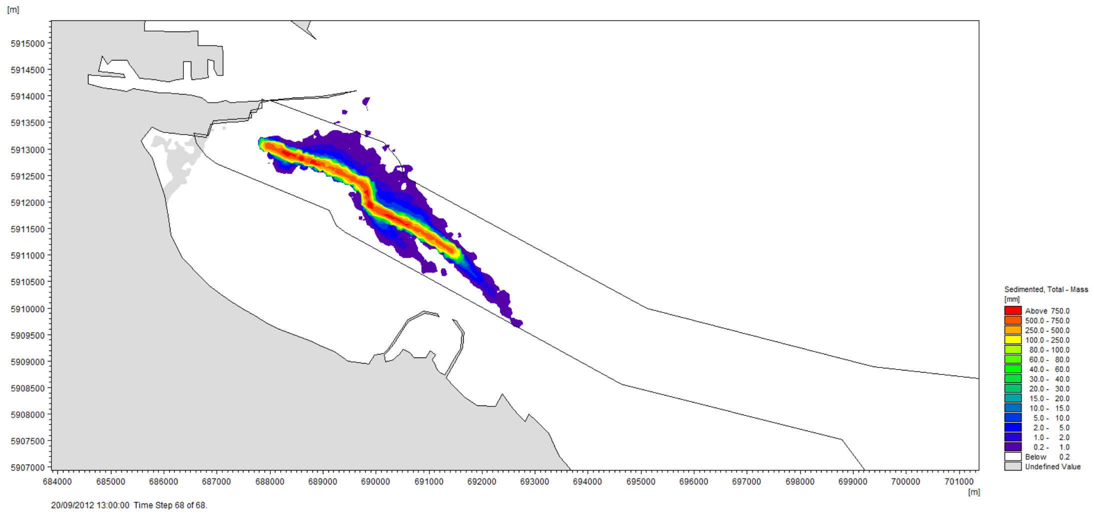


Figure C-51 Deposition thickness, Section 2 scenario, neap tide

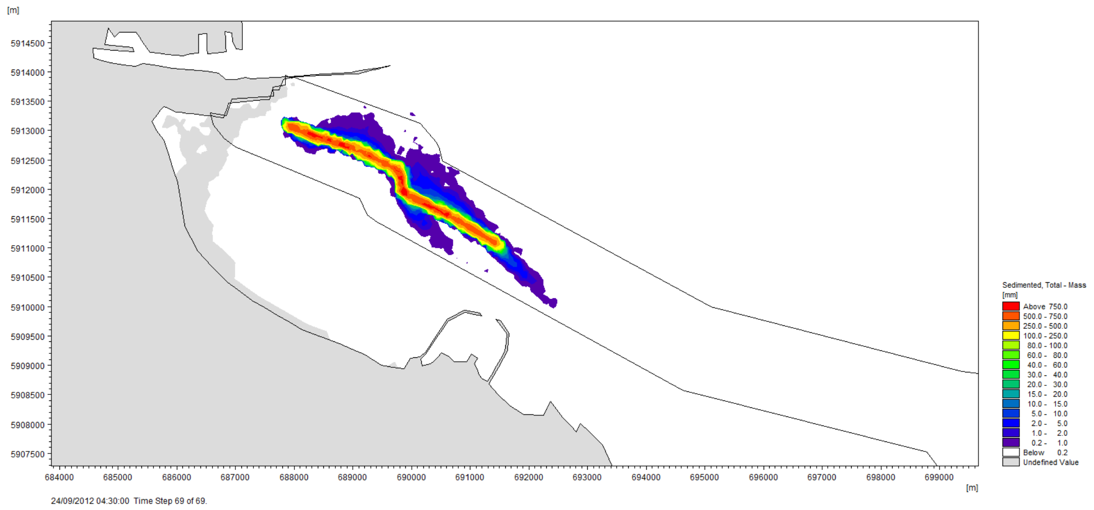


Figure C-52 Deposition thickness, Section 3 scenario, spring tide

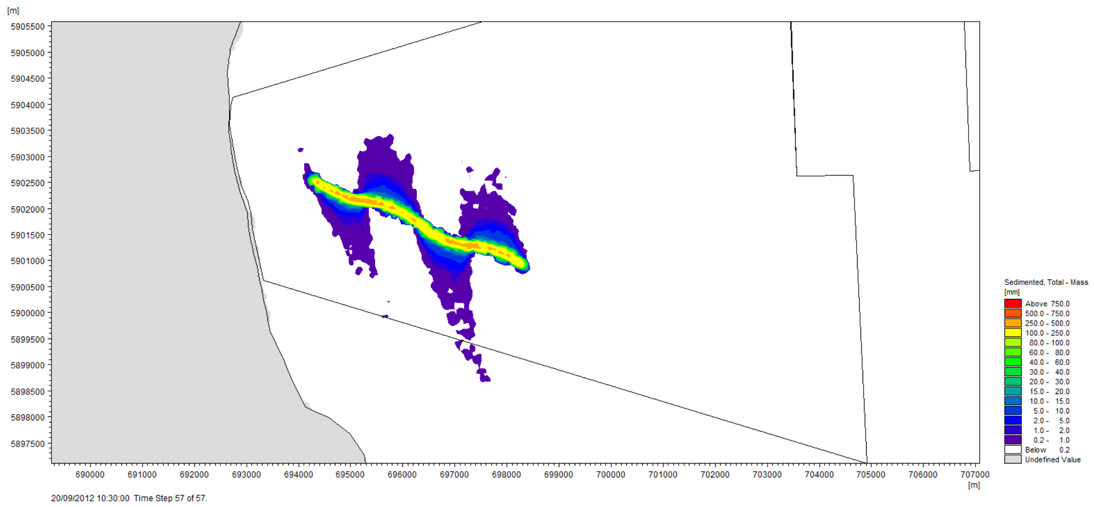
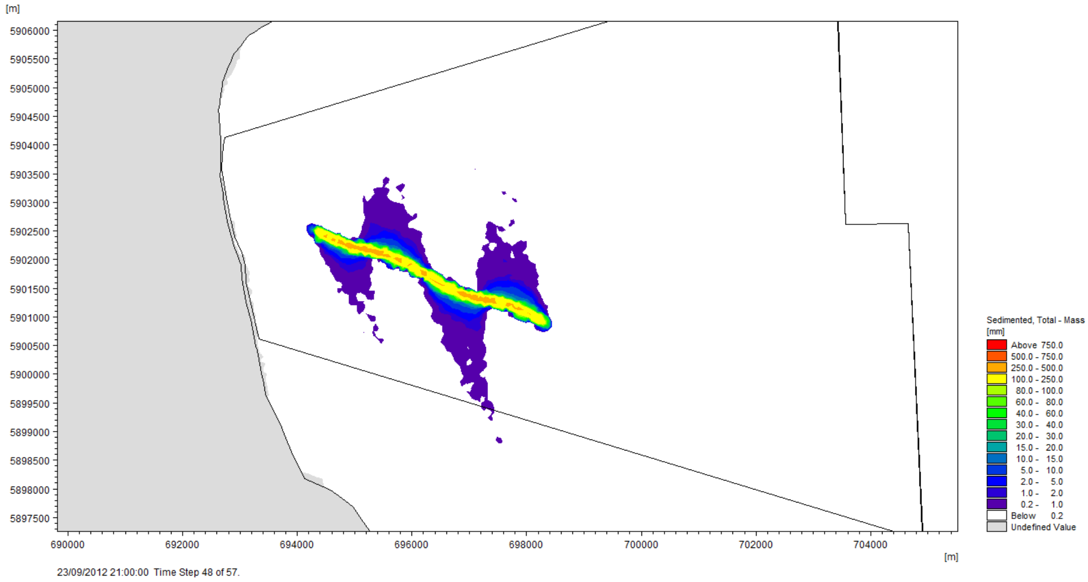


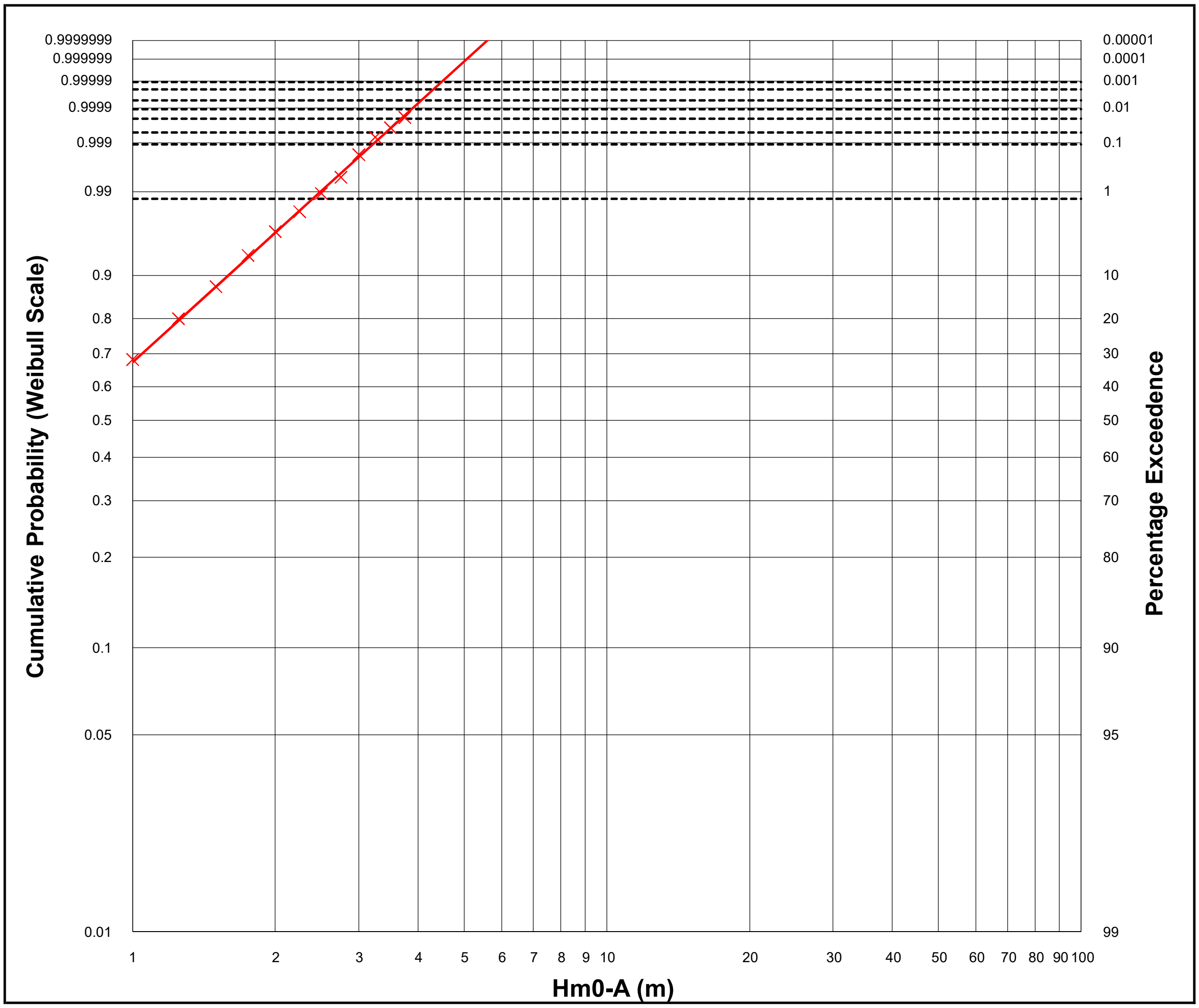
Figure C-53 Deposition thickness, Section 3 scenario, neap tide



Appendix D

Extreme Value Analysis Plots

Dublin Array Offshore Wind Farm



Extrapolations:
(Significant Wave Height, 60 min)

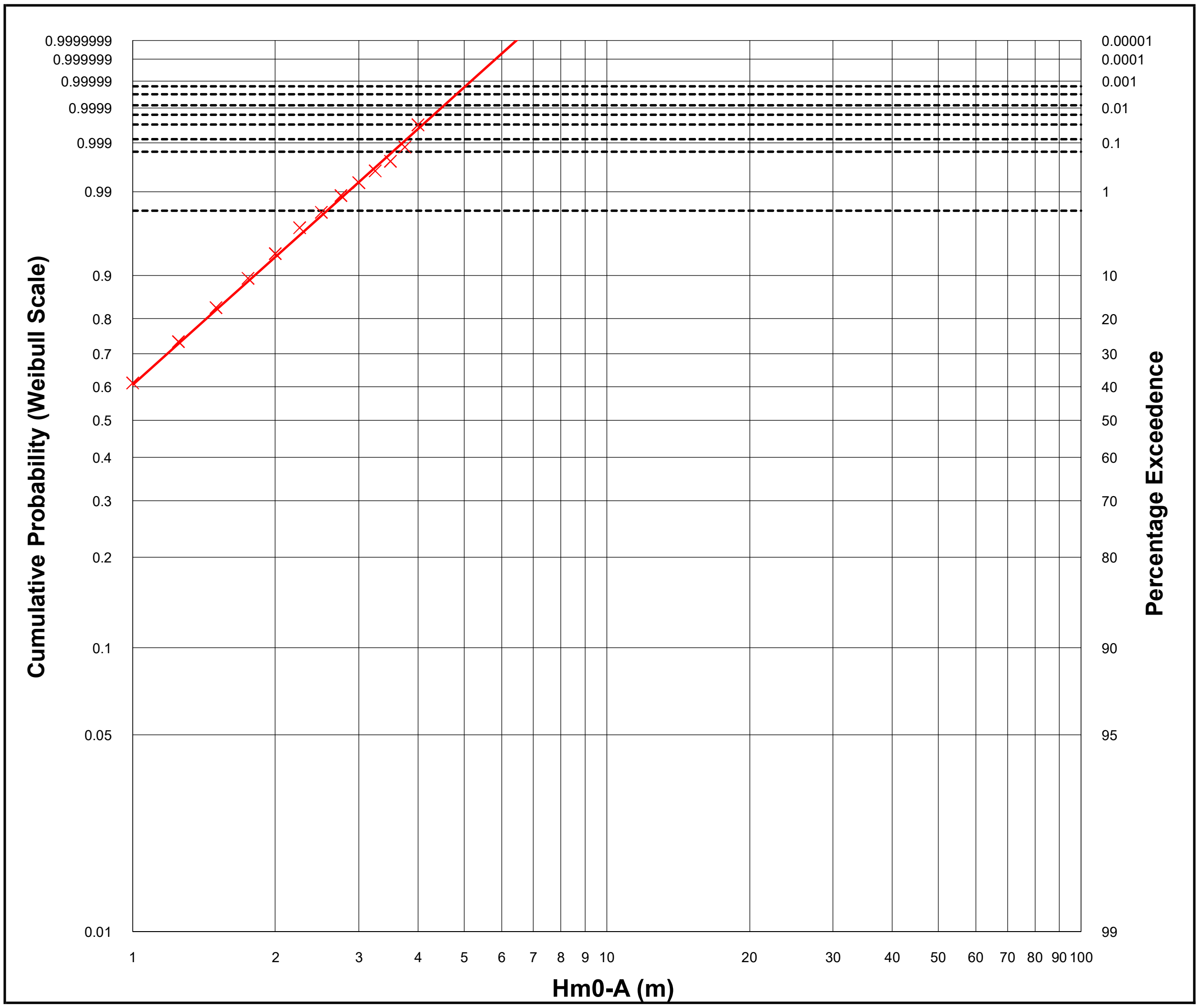
Return period	Cumulative Probability	Extreme value (m)
100 yr	0.99998914	4.48
50 yr	0.99997827	4.30
20 yr	0.99994568	4.06
10 yr	0.99989136	3.87
5 yr	0.99978271	3.68
2 yr	0.99945678	3.42
1 yr	0.99891355	3.21
0.0833 yr	0.98696262	2.40

Weibull parameters: A = 0.000 B = 0.928 C = 1.547
Regression line is fitted to the top 70% of the distribution. Fitting technique: least squares method
Data interval is 60.0 min

Notes:
1. Data source: Copernicus IBI Model
2. Location: 53.90°, 005.40° W
3. Period: 1 January 1992 to 30 December 2018
4. Based on 236,664 1-hourly data

Figure D.1 Weibull Extreme Value Analysis of Significant Wave Height for Copernicus IBI Model Grid Point North Boundary

Dublin Array Offshore Wind Farm



Extrapolations:
(Significant Wave Height, 60 min)

Return period	Cumulative Probability	Extreme value (m)
100 yr	0.99998370	5.03
50 yr	0.99996741	4.82
20 yr	0.99991852	4.54
10 yr	0.99983703	4.32
5 yr	0.99967407	4.09
2 yr	0.99918516	3.78
1 yr	0.99837033	3.53
0.0833 yr	0.98044392	2.57

Weibull parameters: A = 0.000 B = 1.048 C = 1.531

Regression line is fitted to the top 70% of the distribution. Fitting technique: least squares method

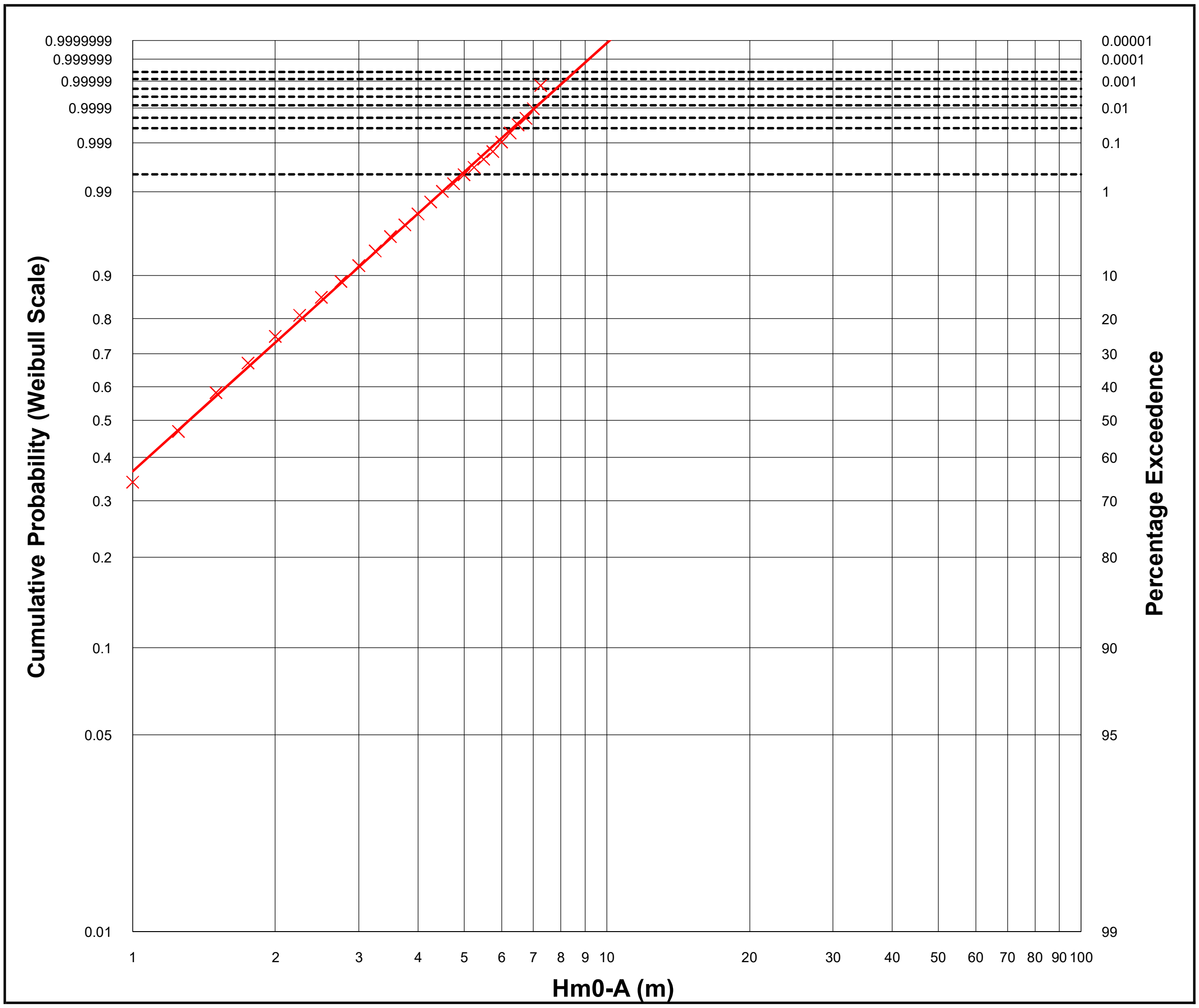
Data interval is 60.0 min

Notes:

1. Data source: Copernicus IBI Model
2. Location: 53.79°, 005.50° W
3. Period: 1 January 1992 to 30 December 2018
4. Based on 236,664 1-hourly data

Figure D.2 Weibull Extreme Value Analysis of Significant Wave Height for Copernicus IBI Model Grid Point East Boundary

Dublin Array Offshore Wind Farm



Extrapolations:
(Significant Wave Height, 60 min)

Return period	Cumulative Probability	Extreme value (m)
100 yr	0.99999593	8.55
50 yr	0.99999185	8.24
20 yr	0.99997963	7.82
10 yr	0.99995926	7.49
5 yr	0.99991852	7.15
2 yr	0.99979629	6.69
1 yr	0.99959258	6.33
0.0833 yr	0.99511098	4.94

Weibull parameters: A = 0.000 B = 1.668 C = 1.541

Regression line is fitted to the top 70% of the distribution. Fitting technique: least squares method

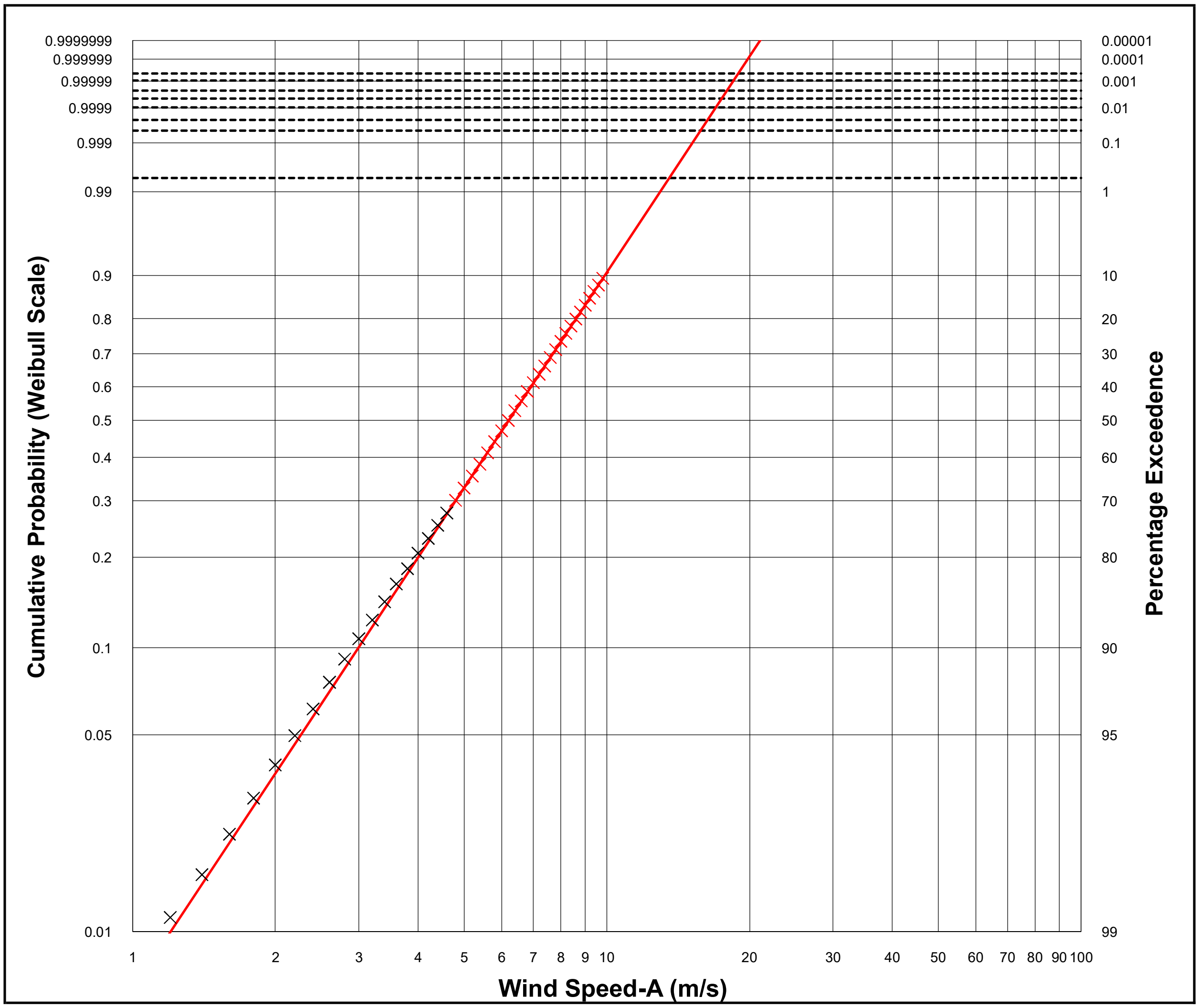
Data interval is 60.0 min

Notes:

1. Data source: Copernicus IBI Model
2. Location: 52.79°, 006.00° W
3. Period: 1 January 1992 to 30 December 2018
4. Based on 236,664 1-hourly data

Figure D.3 Weibull Extreme Value Analysis of Significant Wave Height for Copernicus IBI Model Grid Point South Boundary

Dublin Array Offshore Wind Farm



Extrapolations:
(Wind Speed, 60 min)

Return period	Cumulative Probability	Extreme value (m/s)
100 yr	0.99999525	18.92
50 yr	0.99999049	18.50
20 yr	0.99997623	17.92
10 yr	0.99995247	17.46
5 yr	0.99990494	16.97
2 yr	0.99976234	16.30
1 yr	0.99952468	15.76
0.0833 yr	0.99429614	13.54

Weibull parameters: A = 0.000 B = 7.160 C = 2.579
Regression line is fitted to the top 70% of the distribution. Fitting technique: least squares method
Data interval is 60.0 min

Notes:
1. Data source: European Centre for Medium-Range Weather Forecasts
2. Location: 53.59°, 005.09° W
3. Period: 1 January 1992 to 30 December 2018
4. Based on 236,664 1-hourly data

Figure D.4 Weibull Extreme Value Analysis of Wind Speed for Dublin Array

Appendix E

Determination of Realistic Worst Case Scenario

DUBLIN ARRAY - MARINE PROCESSES DETERMINATION OF REALISTIC WORST-CASE

Client: Intertek

Cooper Marine Advisors Ltd

June 2020

DUBLIN ARRAY - MARINE PROCESSES
DETERMINATION OF REALISTIC WORST-CASE

Document control

This document has been prepared by Cooper Marine Advisors Ltd for Intertek to report on the review of the realistic worst-case for the marine processes assessment of Dublin Array.

Title	Dublin Array - Marine Processes Determination of Realistic Worst-Case
Author(s)	Bill Cooper, Director, Cooper Marine Advisors Ltd (BCooper@CooperMarineAdvisors.co.uk)
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Summary of Changes	Updated to draw on additional sediment data
Circulation	Project team
Required Action	Review for comment
Filename	https://coopermarineadvisors-my.sharepoint.com/personal/bill_coopermarineadvisors_co_uk/Documents/Projects/Dublin Array Intertek/deliverables/RWC/Dublin Array - RWC Review - Cooper Marine Advisors - June 2020c.docx
Approval	Bill Cooper W. Cooper

Contents

Preface

This technical note responds to Service 2d - Modelling and Assessment of the Project's Realistic Worst Case Scenario (RWCS), including cumulative and in combination impacts (as required). At this stage, the intended circulation of this technical note is the Project Team only.

Acknowledgments

The authors of this technical note gratefully acknowledge the contributions provided by Innogy in helping to clarify issues related to the Project Description.

Abbreviations

D	Diameter of pile
EIA	Environmental Impact Assessment
MFE	Mass Flow Excavator
MW	Megawatt
OSP	Offshore Platform
RD	Rotor Diameter
RWCS	Realistic Worst-Case Scenario
SAC	Special Area of Conservation
TJB	Transition Joint Bay
TSHD	Trailer Suction Hopper Dredger
WID	Water Injection Dredging
WTG	Wind Turbine Generator
WWTP	Wastewater Treatment Plant

1. Introduction

An EIA based on assessing the realistic worst-case (also commonly referred to as the worst-case scenario or maximum design scenario) is a widely adopted approach to support the application of consent when flexibility needs to be retained in design options and when final design will only be confirmed at a later stage of project development after consent.

The realistic worst-case is established by screening the various installation and design options presented in the Project Description to conservatively and comparatively determine the largest source effects (at the array scale), and therefore develop the greatest potential impacts on marine receptors falling within the influence of a pathway from such sources (n.b. source effects established as the realistic worst-case are assessed in detail with marine process modelling tools, however, not all sources need to be modelled). The conservatism also provides a means to account for inherent uncertainties and assumptions in the Project Description at this point of project development.

Inherently, the adoption of the realistic worst-case for EIA assumes that all other options would have a lesser impact. The realistic worst-case therefore defines the full 'envelope' of effects of all options under consideration; an approach originally established as the Rochdale Envelope.

1.1. Document structure

Section 1 explains the scope and purpose of the technical note.

Section 2 identifies the best practice technical references underpinning the present review for the realistic worst-case and outlines the primary issues related to marine processes.

Section 3 provides a high-level overview of the Project Description.

Section 4 considers the realistic worst-case issue related to seabed disturbance.

Section 5 describes the realistic worst-case issue related to blockage across the offshore wind array.

Section 6 summaries key outcomes from the review of the Project Description for realistic worst-case scenarios.

Section 7 gives the list of references related to this technical note.

2. Realistic worst-case for marine processes

The realistic worst-case for marine processes has been determined using current best practice approach and advice:

COWRIE (2009). Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide. COWRIE Coast-07-08.

The Planning Inspectorate. (2018). Using the Rochdale Envelope. Advice Note Nine: Rochdale Envelope.

2.1. Generic considerations

The marine processes review of the Project Description for the realistic worst-case considers two primary themes which define ‘sources’ of effects:

a. **Seabed disturbance** is generally a response to a short-term activity which typically occurs during installation and decommissioning periods which may result in sediment plumes and subsequent deposition. In addition, some seabed disturbance activities may occur during the operational & maintenance period.

b. **Blockage** of waves and flows over the duration of the operational period (the longest period in the development cycle) due to structures placed on the seabed (across the array and along the cable routes) which result in modifications to wave energy transmission to the coast and development of local flow wakes which may induce local scour and interfere with general sediment transport processes.

Importantly, to establish the envelope of possible effects from multiple options the outcome of the review is not restricted to a single layout or foundation type or installation method.

3. Project Description

The review of the realistic worst case is based on technical details of design options outlined in the following spreadsheets:

Dublin Array Offshore Wind Farm. Consent Project Description Spreadsheet – Issue 1.2. (dated 6 April 2020)

DUB CPD Clarifications R01(dated 22 April 2020)

These spreadsheets include details of two different sizes of wind turbine generator (WTG) each with a different minimum spacing and indicative layout. The different turbine layouts require different inter-array connections, along with three different options for export cables and landfall locations (Shanganagh Park, Shanganagh Wastewater Treatment Plant (WWTP) or Poolbeg). Table 1 summarises key details for the two layout options.

Table 1. Summary information for layout options

Turbine Rating (MW)	Maximum number of turbines	Rotor Diameter, RD (m)	Indicative turbine spacing	Indicative turbine spacing (m)
12 to 15	61	220	4 RD within a row 4.8 RD between rows	880 1056
>15	45	285	4 RD within a row 4.8 RD between rows	1140 1368

By itself, this information does not define a realistic worst case, however, the 12 to 15 MW option does provide the greatest number of point sources across an array as well as the closest spacing between turbines to increase the chance of interactions between foundation type sources.

For the wind turbines there are also multiple (six) foundation options:

- monopile or suction bucket monopod;
- 3-legged multi-leg, pile or suction bucket; and
- 4-legged multi-leg, pile or suction bucket.

The dimensions of these foundations vary for the two turbine options.

In addition to WTG foundations there are also foundation options for two meteorological masts (monopile or multi-leg) and three offshore platforms (OSP) (monopile or 6-legged multi-leg). There is no gravity base option provided in the Project Description.

4. Seabed disturbance

The Consent Project Description spreadsheet includes the following activities which each may create seabed disturbance events;

- seabed preparation around foundations;
- drilling for piles;
- pre (installation) sweeping for sandwave removal;
- cable trenching;
- scour development; and
- decommissioning activities (reverse of installation).

The type of activity, the local environmental conditions where this occurs (e.g. water depths and flows), associated sediment types and volumes all contribute to the way sediment plumes and subsequent deposition may occur.

For the various sediment types involved, a key parameter is the settling velocity for any material displaced into the water column. Coarse grained sediments (e.g. gravels and coarse sands) will typically fall out of suspension relatively quickly without opportunity to be advected away from the source of disturbance. Conversely, fine grained sediments (e.g. fine sands to silts / clays) will typically take a long time to fall out of suspension with time to be subjected to tidal advection and dispersion. In some cases (for the finest sediments), the tendency to fall out of suspension (due to gravity) may be exceeded by lift forces (within the flow environment) which keeps material in suspension for longer.

Figure 1 presents a description of seabed sediment type across the project area based on the most up to date mapping combined with a collation of surface grab samples. Kish Bank is mainly a sandy environment with a small amount of gravel in places. In comparison, Bray Bank appears to have slightly coarser sediment. The export cable corridors for the two Shanganagh options cross into areas with coarser and mixed sediments which in the lee of Sorrento Point show higher amounts of silts and muds. In the very nearshore the seabed becomes rocky. For the Poolbeg export cable route the seabed initially shows a slightly higher gravel content than Kish Bank (sandy gravels and gravelly sands) which then demonstrates a slightly higher content of finer sediments (muddy sand and sandy mud) across the major part of Dublin Bay (Cooper Marine Advisors, 2020).

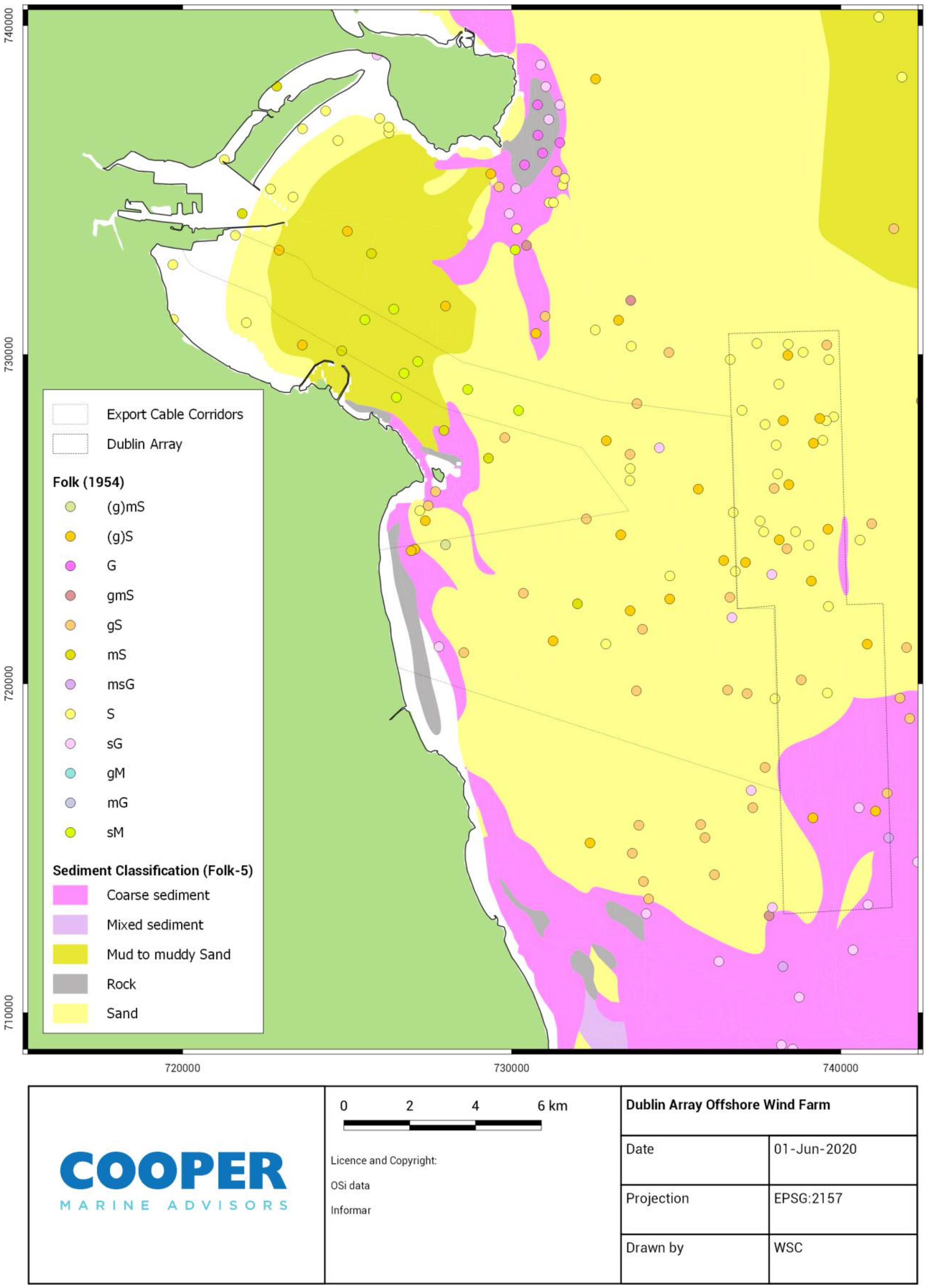

Figure 1: Sediment composition across the project area (Cooper Marine Advisors, 2020).

Table 2 provides a summary of representative sediment types expected to be present across the areas of seabed disturbance, the associated grain size, settling velocity and the theoretical time to fall out of suspension (for still water conditions) for an illustrative water depth of 20 m. The increment of grain size reflects the gradings analysis adopted by the most detailed survey information which is typically based on Buchanan (1984).

Table 2: Representative sediment types, settling velocities and theoretical time to fall out of suspension from 20 m

Sediment type / aggregate name	Size range (mm)	Representative size (mm)	Settling velocity (m/s)	Time to fall out of suspension (minutes)
Very fine gravel	2.000 to 4.000	3.000	0.216	1.5
Very coarse sand	1.000 to 2.000	1.500	0.147	2.3
Coarse sand	0.500 to 1.000	0.750	0.093	3.6
Medium sand	0.250 to 0.500	0.375	0.049	6.8
Fine sand	0.125 to 0.250	0.188	0.018	18.2
Very fine sand	0.063 to 0.125	0.094	0.005	66.5
Silt / Mud	0.004 to 0.063	0.033	0.001	516.6

For medium sands, the theoretical time to fall out of suspension over a water depth of 20 m is 6.8 minutes. If this was to take place at times of peak flows on spring tides (estimated to be around 1 m/s) then a maximum distance of tidal advection would be around 400 m, but considerably less for other periods of the tide when flow speeds are weaker. Accordingly, sediment sizes of medium sands and coarser can be considered to fall out of suspension quickly and will not form part of any lasting sediment plume and are therefore not represented in the particle tracking model. Their influence is considered separately in relation to areas of deposition and associated sedimentation depths.

Sediment sizes of fine sand, very fine sand and silts all have settling velocities which allow for the influence of tidal flows to advect and disperse the material over a wider area than for medium sands. Accordingly, these sediment sizes are all relevant to the formation of sediment plumes and are represented in the particle tracking model.

For the silt / clay grain size an estimated settling time of 516.6 minutes (equivalent to 8.6 hours) for 20 m water depths also means that the tide will have passed through at least one period of slack water and peak flows. When flow conditions are sufficient to develop lift forces that exceed the propensity for material to settle (under gravity) then this sized sediment is likely to remain in suspension for longer.

4.1. Seabed Preparation around foundations

Seabed preparation is required for foundations which require a flat seabed, typically suction bucket type or gravity base type foundations. Only suction bucket options apply in the case of Dublin Array.

The realistic worst-case is represented by the option of seabed preparation which is likely to place the greatest amount of fine sediment into the highest part of the water column (e.g. spoil disposal from Trailer Suction Hopper Dredger (TSHD)), the locations where this may occur and the volume of sediment involved for all foundations across the array.

Table 3 summarises the total volumes of excavation for seabed preparation around WTG foundations, noting the volume of excavation may not be directly equivalent to the volume of sediment removed since this requires knowledge of soil characteristics such as sediment type and porosity.

Table 3. Comparison of seabed preparation quantities for foundations

Turbine Rating (MW)	Maximum number of turbines	Total volume of excavation for all suction buckets (m^3)		
		Monopile	3-legged multi-leg	4-legged multi-leg
12 to 15	61	100,055	149,465	164,700
>15	45	91,125	154,001	**165,375**

The realistic worst-case scenario for seabed preparation is the removal of 165,375 m^3 of sediment from the 4-legged multi-leg WTG foundation option for the >15 MW turbine. This equates to 3,675 m^3 per location and an average excavation depth of 0.75 m.

In addition, there will be additional sources of sediment for seabed preparation required for the met mast (1,587 m^3 per foundation), as well as three sources for the OSP based on 6-legged multi-leg which each create an additional 2,700 m^3.

The total amount of sediment removed for seabed preparation of foundations across the array is therefore 175,062 m^3. This sediment is associated with seabed preparations around foundations for 45 WTG sites, a single met mast and three OSPs.

Dredging by hopper dredger (e.g. trailer suction hopper dredger – TSHD) is the stated method of seabed preparation under consideration. Dredging for seabed preparation can lead to various sources of sediment disturbance (Figure 2);

- Direct seabed disturbance by draghead during dredging (comparatively the smallest sediment volume);
- Overspill (of mainly fines) during filling of hopper leading to sediment plumes; and
- Spoil disposal (comparatively the highest sediment volume) from hopper doors into the marine environment initially forming an active phase of density flows followed by a passive phase of dispersion.

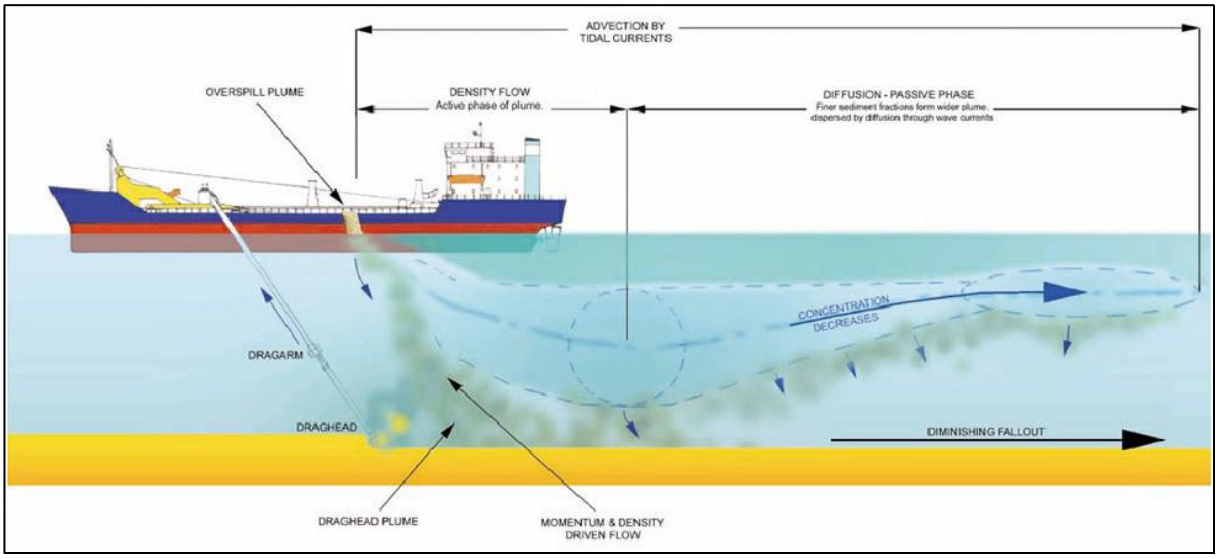

Figure 2: Schematic of sediment plume development during dredging activity (The Crown Estate and BMPA, 2009).

The largest volume of sediment will be disposed as spoil. The effect on the marine environment will depend on the location(s) where disposal of spoil may take place, the volume of disposal and the associated proportion of both coarse sediments (which may fall quickly onto the seabed and present a smothering risk to benthic receptors) and fine sediments (which may create temporary sediment plumes in the water column).

The Project Description suggests various options for disposal of spoil in the marine environment;

- Dredged material removed and disposed in a licenced area as close as possible to the array.
- Dredged material removed and disposed of within the array boundary.
- Dredged material being side cast of the foundation (at the seabed or sea surface).
- Dredged material held temporarily at on-site disposal areas before being used for backfill and ballast.
- Dredged material immediately re-used for backfill and ballast.

The realistic worst-case for marine processes is considered to be dredged material removed and disposed of within the array boundary using either of the two identified spoil locations. The option for disposal in a licenced area as close as possible to the array is likely to lead to very similar outcomes for plumes and spoil mounds since advection, dispersion and water depths are likely to be largely comparable.

4.1.1. Modelling scenarios

Modelling scenarios consider the potential for sediment plumes to develop as overspill events during dredging for seabed preparation. The worst-case scenario is based on the maximum potential excavated volume of 175,062 m^3. This quantity relates to the 4-legged multi-leg foundation for the 45 * >15 MW layout with each WTG location requiring 3,675 m^3 of excavation, along with associated foundations for (one) met mast and (three) OSPs.

Scenarios represent sequential dredging of two WTG sites for an equivalent excavation volume of 7,350 m^3. Importantly, the excavated volume does not represent the sediment volume in the hopper as this depends on both the *in situ* soil density and how the material will bulk out during the excavation process. For mixed grained sand which is "dense" (i.e. a stable unconsolidated deposit) an *in situ* dry bulk density value would be around 1.59 tonnes/m^3 (Terzaghi, Peck, & Mesri, 1996). The bulking factor varies according to soil type and dredging method with a value of 1.30 assumed for present purposes which is mid-range of 1.25 to 1.35 for sand, hardpacked (Bray, Bates, & Land, 1996).

As the sediment is pumped into the hopper the excess water is discharged as overspill back into the sea. The tendency is for some fine sediments to be washed out in the overspill which leads to the formation of sediment plumes from the point of discharge. A 5% loss of excavated volume is assumed for the overspill. This means the mass equivalent in the hopper would be around 11,102 tonnes, on average.

Dredgings from Kish Bank will be taken to the northern spoil site and for Bray Bank the southern spoil site will be used. As material is discharged through the hopper doors a second sediment plume of remaining fine sediment is likely to develop due to the passive phase of spoil disposal. The coarser sediment will fall to the seabed under the active phase of disposal and form a spoil mound.

Seabed preparation will consider the following scenarios to offer a representative set of upper and lower sediment plume concentrations and excursion distances;

- Overspill followed by spoil disposal from Kish and Bray sites for both spring and neap tides. The spring tide scenario will confirm the full extent of tidal excursion of a sediment plume whereas the neap tide will examine the reduced excursion which is also likely to contain comparatively higher concentrations of suspended sediments.

For reference, excavation of the total 175,062 m^3 for seabed preparation (with a bulking factor of 1.30 and a TSHD capacity of 11,000 m^3, accounting for overspill) would require an average of 20 full hopper loads (roughly spilt 50:50 across Kish and Bray), or more if partial loads are used.

The adoption of a single hopper load per scenario provides a means to scale-up for the effects of multiple excavation and disposal cycles.

Kish Bank (northern releases)

Table 5 identifies the sediment samples relevant to seabed preparation at foundation sites WTG-1 and WTG-3 across the northern extent of Kish Bank. The seabed sediments in this area have a high content of fine sands.

Table 4: Sediment gradings (percentage) for samples across northern part of the array area in the vicinity of foundation sites WTG-1 and WTG-3.

Sediment type / aggregate name	St 3	KB 2	KB 3	Generalised
Very fine gravel	12.8	3.44	0.0	5.42
Very coarse sand	3.1	5.02	0.13	2.75
Coarse sand	2.6	0.74	0.43	1.26
Medium sand	6.3	2.25	1.47	3.34
Fine sand	72.6	78.37	87.28	79.45
Very fine sand	2.0	10.08	10.41	7.50
Silt / Clay	0.5	0.09	0.28	0.29

The foundation sites considered for this scenario are;

WTG-3 – 706,384 E, 5,909,,859 N – 104 minutes on site to complete excavation

30 minutes transit to next site (including raising and deploying of drag-head)

WTG-1 – 704,885 E, 5,910,305 N – 104 minutes on site to complete excavation

When the dredger is at each location, and filling the hopper, the excess water is discharged via spillways. Some of the finer grained sediments (fine sands to silts) will be carried in this water as overspill to develop an initial sediment plume and preferentially leaving the coarser sediments in the hopper. The rate of overspill depends on many factors. If a representative loss of 5% of hopper load was assumed then this would equate to 368 m^3 of finer sediments within the overspill. The hopper would still have 6,044 m^3 of finer sediment taken to the spoil site. If the total time to fill the hopper was estimated as 4 hours then an equivalent sediment discharge rate would be around 49.17 kg/s (44.78 kg/s fine sediment, 4.23 kg/s very fine sediment and 0.16 kg/s silt) over this period. These discharges would occur at the sea surface from each of the locations identified above and for the nominated excavation periods.

Once the hopper is full the sediment would be taken to the northern spoil site within the array. The estimated transit time from the northern part of Kish Bank to the northern spoil site is 30 minutes. An indicative discharge location is given as; 704,578 E, 5,905,944 N.

During the initial phase of spoil disposal there will be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion for fine sand are 875.2 tonnes, very fine sand 82.6 tonnes and silt 3.2 tonnes.

Bray Bank (southern releases)

Table 5 identifies the sediment samples relevant to seabed preparation at foundation sites across Bray Bank. Since the majority of foundations are away from the bank the samples in Table 5 reflect the composition of the surrounding seabed which has a higher gravel content. This contrasts with sandwave clearance where the areas to be cleared are limited to mobile sandy seabeds on and around the bank (n.b seabed preparation dredging on the sandbank is likely to mimic the sandwave clearance scenario).

Table 5: Sediment gradings (percentage) for samples across southern part of the array area in the vicinity of foundation sites WTG-43 and WTG-44.

Sediment type / aggregate name	St 5	St 6	St 7	St 17	Generalised
Very fine gravel	18.4	35.1	76.3	3.7	33.39
Very coarse sand	9.7	12.0	5.0	1.0	6.93
Coarse sand	8.4	13.9	3.9	3.6	7.45
Medium sand	8.9	14.0	5.9	55.3	21.04
Fine sand	49.6	20.2	7.7	36.3	28.46
Very fine sand	4.2	3.6	0.8	0.1	2.18
Silt / Clay	0.8	1.2	0.2	0.0	0.55

The foundation sites considered for this scenario are;

WTG-43 – 708,161 E, 5,894,418 N – 104 minutes on site to complete excavation

30 minutes transit to next site (including raising and deploying of drag-head)

WTG-44 – 706,711 E, 5,893,724 N – 104 minutes on site

15 minutes transit to next site

Met mast (S) – 706,565 E, 5,893,517 N – 45 minutes on site

When the dredger is at each location, and filling the hopper, the excess water is discharged via spillways. Some of the finer grained sediments (fine sands to silts) will be carried in this water as overspill to develop an initial sediment plume and preferentially leaving the coarser sediments in the hopper. The rate of overspill depends on many factors. If a representative loss of 5% of hopper load was assumed then this would equate to 445 m^3 of finer sediments within the overspill. The hopper would still have 2,333 m^3 of finer sediment taken to the spoil site. If the total time to fill the hopper was estimated as 4 hours then an equivalent sediment discharge rate would be around 49.71 kg/s (44.88 kg/s fine sediment, 3.43 kg/s very fine sediment and 0.87 kg/s silt) over this period. These discharges would occur at the sea surface from each of the three locations identified above and for the nominated period.

Once the hopper is full the sediment would be taken to the southern spoil site within the array. The estimated transit time from the southern part of Bray Bank to the southern spoil site is 30 minutes. An indicative discharge location is given as; 705,667 E, 5,898,831 N.

During the initial phase of spoil disposal there will be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediments become susceptible to advection and dispersion and the formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop the passive phase of the plume (Becker, *et al.*, 2015). Accordingly, the amount of fine sediment available for advection is; fine sand 338.5 tonnes, very fine sand 25.9 tonnes and silt 6.5 tonnes.

4.2. Drilling of foundation piles

For drilling of foundation piles which produce drill cuttings, the realistic worst-case is represented by the largest volume of fine sediments released into the water column over the shortest interval which then has the potential to lead to the highest suspended sediment concentration within a plume that advects away from the point of discharge. In some cases, the production of chalk drill cuttings can raise a greater level of regulator concern which relates to the potential increased visibility of any sediment plume as well as a change of substrate type when a chalk deposit is formed on a non-chalk seabed. The presence of sub-surface chalk layers has not been identified for Dublin Array.

Table 6 summarises the total volume of drill cuttings for each WTG foundation type. These volumes represent a 5% chance of drilling being required for monopiles (up to 42 m pile depth) and a 20% chance for multi-leg foundations (up to 93.5 m pile depths). The higher chance for multi-leg piles relates to their longer pile depths increasing the potential need to drill into sub-surface rock.

Table 6. Comparison of drill cuttings quantities

Turbine Rating (MW)	Maximum number of turbines	Total volume of drill cuttings (m^3)		
		Monopile	3-legged multi-leg	4-legged multi-leg
12 to 15	61	13,798	**106,876**	49,059
>15	45	16,700	97,154	48,667

The realistic worst-case for the total volume of drill cuttings is 106,876 m^3 for the 3-legged multi-leg WTG foundation option for the 61* 12 to 15 MW turbine array. This equates to 8,760 m^3 across 12 WTG locations, with each foundation comprising a 3-legged multi-pile.

In addition, the met mast and 6-legged pile foundation for the three offshore platforms also have the potential to require drilling, however, the pile diameters and drilling depths are much less than the equivalent WTG multi-leg foundations and therefore the chance that these sites need to be drilled reduces as well as the volumes potentially involved.

The production rate is estimated to be between 1,000 to 4,000 m^3/day, however, the actual rate will depend on many factors, not least pile diameter, rock types and drill pressure. The realistic worst-case is achieved from the higher rate of production. To deliver 8,760 m^3 of cuttings with a production rate of 4,000 m^3/day would take at least 2.2 days, not accounting for any intervening period to relocate the drill rig for each leg.

In general, it can be expected that the particle size of the drill cuttings will be in a range from > 0.02 mm up to coarse grain size of less than 2 mm. The content of fine silty material (< 0.06 mm) can be estimated to be less than or equal to 20%. Since the absolute gradings of any drill cuttings will remain unknown at this time a spread of potential grain sizes has been considered with a 50% spilt between material likely to disperse more widely and material that is likely to fall to the seabed and form a cuttings pile. Table 1

Table 9 provides a summary of drill cuttings volumes and release rates for each WTG location for representative particle sizes. Release rates would persist for at least 2.2 days at each location.

Table 7: Estimated size distribution of drill cuttings.

Sediment type / aggregate name	Representative size (mm)	Percentage of drill cuttings (%)	Volume of drill cuttings (m^3)	Release rate (kg/s)
Very fine gravel	3.000	10	876	12
Very coarse sand	1.500	10	876	12
Coarse sand	0.750	15	1314	18
Medium sand	0.375	15	1314	18
Fine sand	0.188	15	1314	18
Very fine sand	0.094	15	1314	18
Silt / Clay	0.033	20	1752	25

All drill arisings will be released from the top of the drill rig (surface release).

The most likely sites where drilling might be necessary are off-bank locations in the deeper water area of the south-west part of the array. Present geophysical information shows an acoustic blanking directly below the surface layer leading to the higher risk of unexpected soil conditions (including rock) than other areas.

4.2.1. Modelling scenarios

Modelling scenarios will consider the fate of drill cuttings sequentially released from the sea surface from two representative WTG locations in the deeper water area of the south-west part of the wind park.

The modelling will consider the proportion of finer sediments represented in the drill cuttings which is most susceptible to wider dispersion (fine sands, very fine sands and silts). The coarser sediment fractions (medium sands, coarse sands, very coarse sands and very fine gravels) which are expected to quickly settle to the seabed within the first hour of disposal will not be modelled, rather they will be assessed separately based on sediment volumes, fall velocity, water depths and ambient flows.

For each release site, a period of 14 days will be simulated starting on a spring and a neap tide. The initial 5.2 days (two sites drilling for 2.2 days along with 0.8 days to relocate) will represent the continuous release of drill cuttings at the assumed production rate, followed by a further 8.8 days to help assess the time to return to ambient conditions. The spring tide scenario will confirm the full extent of tidal excursion of a sediment plume whereas the neap tide will examine the reduced excursion which is also likely to contain comparatively higher concentrations of suspended sediments.

The following sequence of release locations will be considered:

WTG-58 – 705,265 E, 5,893,561 N – 3154 minutes on site to complete drilling

1152 minutes transit to next site

WTG-57 – 705,227 E, 5,894,441 N – 3154 minutes on site to complete drilling

Results from the drill cuttings scenarios also provide a means of assessing equivalent sediment plumes that could occur due to overspill created by dredging for seabed preparation, noting also that these two activities would not occur at the same time.

4.3. Pre (installation) sweeping of cable routes

Sweeping is required to remove steep sandwaves which may restrict use of some cable laying equipment. By definition the material type involved in sweeping a sandwave is mainly sand-sized sediment.

The options for pre-sweeping include;

- Water injection dredging (WID) with an indicative width of 12 m;
- Boulder clearance tool with an indicative width of 24 m;
- Mass flow excavator (MFE) with an indicative width of 2.4 m; or
- Dredging using a TSHD with an indicative width of 50 to 80 m (20 m plus 1:5 side slopes).

All pre-sweeping options apart from dredging would locally displace the sandwave material at or close to the seabed. Given that sandwaves are composed of mainly sand-sized particles then there is limited opportunity for any sediment plume to develop from such activity. Only the dredging option removes the material from the seabed for disposal elsewhere in the marine environment. The dredging option can be considered the realistic worst-case on the following basis;

- width of influence is the greatest (which then leads to highest volume of sediment disturbance);
- (minor) disturbance at seabed from draghead;
- overspill during dredging from (near) sea surface, leading to sediment plumes; and
- seabed disposal of spoil in high volume release leading to sediment plumes and formation of spoil mounds, presenting the greatest risk of smothering.

a. Inter-array and inter-platform cables

For the inter-array and inter-platform cables there is 100 km and 24 km, respectively, of cabling across the array area. Pre-sweeping is anticipated along 70% of the length of inter-array cables (70 km) and 80% of the inter-platform cables (19.2 km).

Dredging of sandwaves will involve a 50 m disturbance width which creates an area of 3.5 km^2 for inter-array cables and 0.96 km^2 for inter-platform cables, a total area of 4.46 km^2 which represents around 7.6% of the array area of 59 km^2. Sandwaves in the array area are estimated to reach heights of up to 3 m. Assuming a maximum dredging depth of 3 m across the entire sweeping area (a conservatively gross assumption given that sandwave heights are interspersed with mainly troughs and not all sandwaves are as high as 3 m) then the maximum volume of sediment involved would be up to 7,350,000 m^3 for inter-array cables and 2,016,000 m^3 for inter-platform cables, a total volume of 9,366,000 m^3, but also probably much less given the imbedded conservatism in the estimate. The spoil is likely to be split between the north and south disposal areas and selected on the basis of the shortest transit from the dredging location.

b. Export cables

Depending on the export capacity of electricity generated a combination of landfalls may be considered; Shanganagh Park, Shanganagh WWTP or Poolbeg, and a combination of three OSPs; north, central and south (Figure 3). There is a maximum of two circuits to the Shanganagh Park and the WWTP landfalls (both options are for Carrickmines sub-station where capacity is limited to two circuits), however, a combination of the two Shanganagh landfalls is not an option. A maximum of three circuits is possible to Poolbeg or a combination of up to two circuits to one Shanganagh landfall and up to two to Poolbeg. Table 8 provides a summary of all potential export cable route options along with the associated length of export cable and amount of sandwave clearance required. The realistic worst-case option is informed by the longest and therefore greatest volume of sandwave clearance but also the proximity of activity to sensitive receptors and methods of removal.

Table 8. Landfall options and resulting cable lengths and requirements for sandwave clearance.

Landfall options	Total cable length (m)	Total sandwave clearance sweeping length (m)
Shanganagh Park (2 circuits)	29,664	7,455
Shanganagh WWTP (2 circuits)	30,470	7,083
Poolbeg (2 circuits)	50,097	5,431
Shanganagh Park (2 circuits) plus Poolbeg (1 circuit)	50,046	7,197
Shanganagh WWTP (2 circuits) plus Poolbeg (1 circuit)	50,851	**8,896**
Shanganagh Park (1 circuit) plus Poolbeg (2 circuits)	58,437	6,814
Shanganagh WWTP (1 circuit) plus Poolbeg (2 circuits)	**59,379**	5,627
Poolbeg (3 circuits)	70,478	7,267

The realistic worst-case option for sandwave clearance is taken as the longest total path through sandwave areas. This is the Shanganagh WWTP (2 circuits) plus Poolbeg (1 circuit) option which passes through 8,896 m of sandwaves. The realistic worst-case for sandwave clearance differs from the realistic worst-case for cable trenching which relates to Shanganagh WWTP (1 circuits) plus Poolbeg (2 circuit). This option has the longest overall trenching distance but also covers a wider set of environmental conditions than the three circuits to Poolbeg.

Based on a conservative maximum sandwave height of 6 m being present along all sections of the export cable requiring clearance provides a total sweeping volume of 3,202,553 m^3 of sandy material. The working assumption is that this material will be disposed of within the array boundary at the two nominated spoil sites. Logically, the material dredged will be taken to the closest disposal site. If a TSHD dredger with a capacity of 11,000 m^3 is used this would require 291 cargoes on average, assuming a bulking factor of 1.20 which is mid-range of 1.15 to 1.25 for sand, medium soft to hard (Bray, Bates, & Land, 1996). The *in situ* volume of excavated material in the hopper is therefore expected to be around 9,167 m^3.

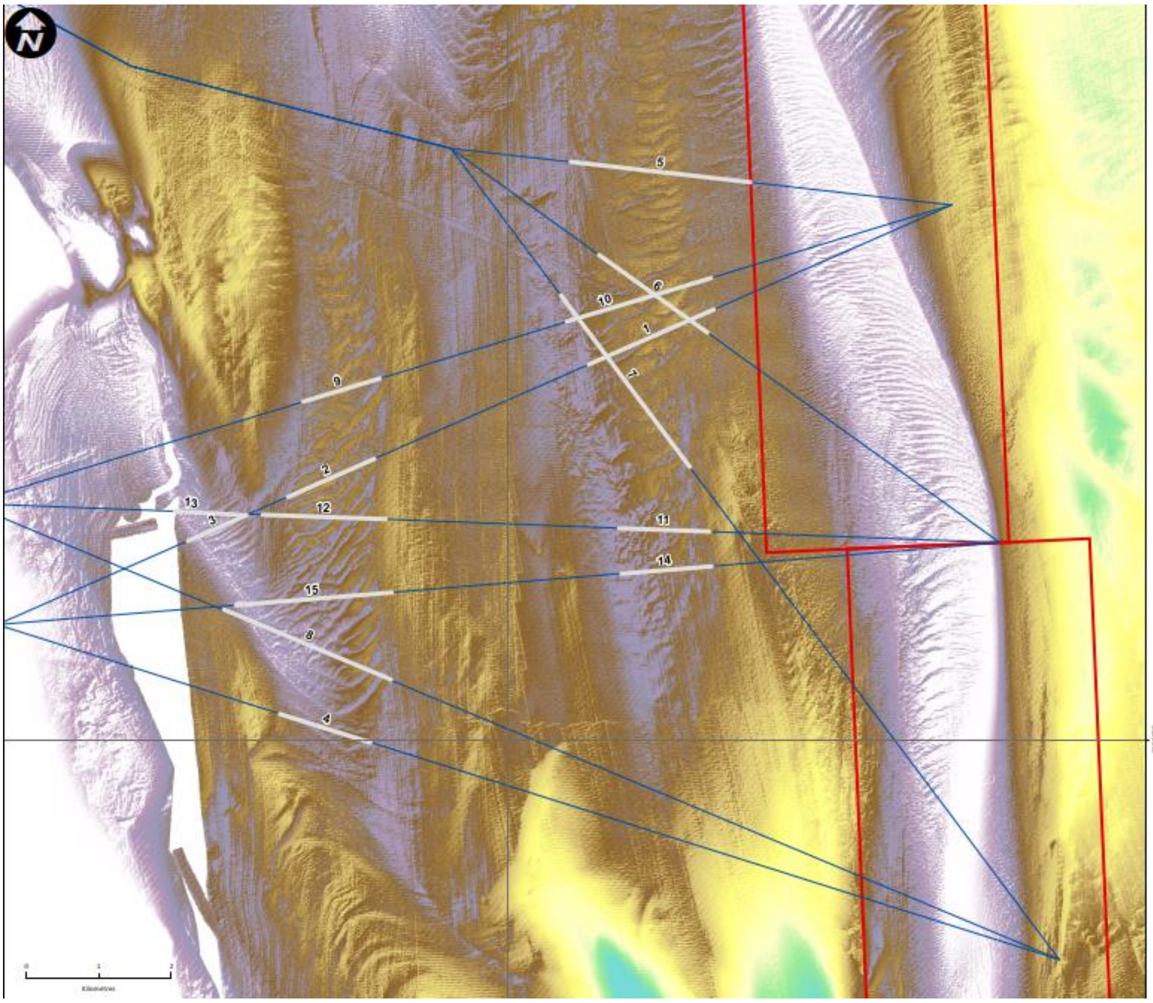

Figure 3: Sections of export cable routes with sandwaves requiring pre-sweeping

4.3.1. Modelling scenarios

a. Inter-array and inter-platform cables

Sandwave clearance for inter-array and inter-platform cables are considered together as this is essentially the same activity in the same area using the same method.

The sediment types involved in sandwave clearance are mainly sands, by definition. Referring to existing baseline mapping of available sediment information enables areas of sandwaves across the array area to be identified and associated particle size information for those areas to be reviewed, where available.

Kish Bank (northern releases)

For a northern section of the array, sediment samples which coincide with areas with sandwaves are summarised in

Table 9 and presented in Figure 4. In all cases, sands are the dominant sediment type (95.9 to 99.8% of grab sample), with medium and fine sands the most common sand fraction particle size.

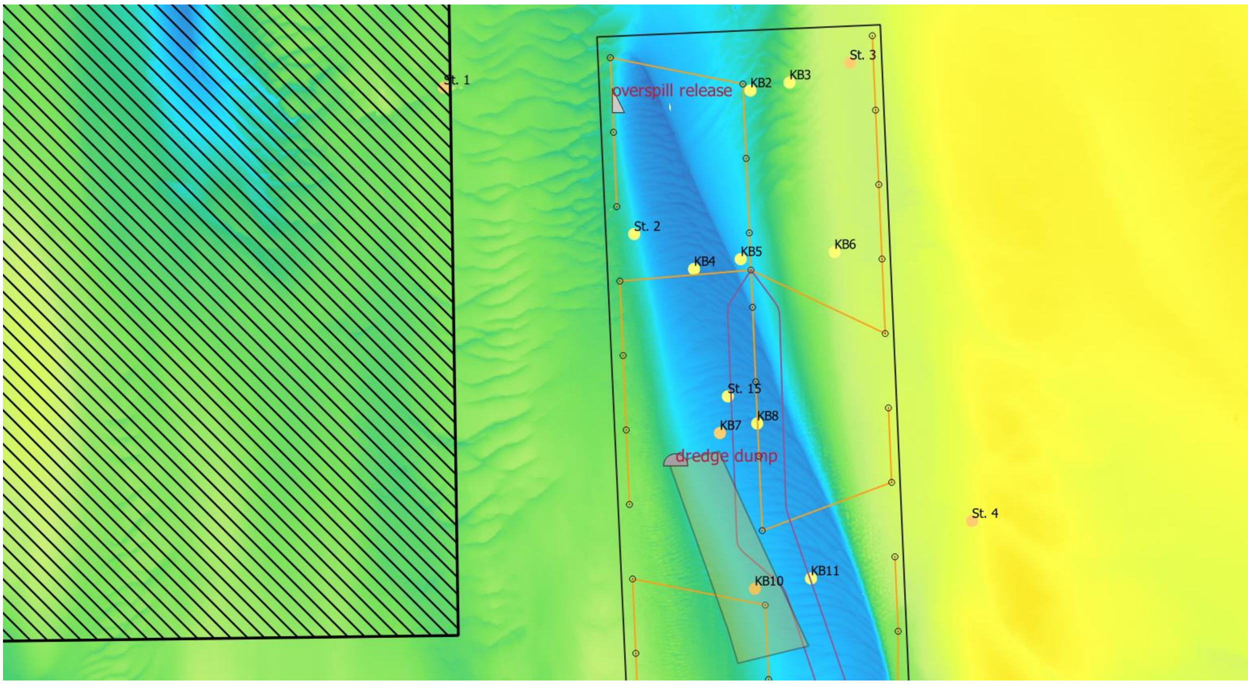

Figure 4: Grab sample sites across the northern section of array area (Kish Bank).

Table 9: Sediment gradings (percentage) for samples across northern part of the array area coinciding with sandwaves.

Sediment type / aggregate name	KB2	KB4	KB8	KB11	St. 2	St. 8	St. 15	Generalised
Very fine gravel	3.44	0.00	3.67	0.00	0.40	0.10	0.40	1.15
Very coarse sand	5.02	0.91	3.11	2.62	0.40	0.30	0.30	1.81
Coarse sand	0.74	0.95	4.10	6.65	2.40	0.90	1.40	2.45
Medium sand	2.25	55.34	26.03	47.17	52.10	21.40	62.20	38.10
Fine sand	78.37	41.59	57.15	40.85	44.30	76.90	35.40	53.55
Very fine sand	10.08	0.99	5.47	2.32	0.20	0.30	0.20	2.80
Silt / Clay	0.09	0.27	0.34	0.39	0.00	0.00	0.00	0.16

Modelling scenarios consider the fate of spoil disposal from a TSHD of an assumed capacity (nominally 11,000 m^3) at agreed spoil sites (two spoil sites within the development boundary of the offshore array, with the northern site selected for this scenario). NB the capacity of the dredger is not equivalent to the volume of sediment to be removed since many factors will bulk out the sediment being dredged. The bulking factor also varies according to soil type and dredging method. A bulking factor of 1.20 is assumed for present purposes which is mid-range of 1.15 to 1.25 for sand, medium soft to hard (Bray, Bates, & Land, 1996). The volume of excavated material in the hopper is therefore expected to be around 9,167 m^3.

For uniform sand which is "loose" (i.e. a relatively mobile unconsolidated deposit) an *in situ* dry bulk density value would be around 1.43 tonnes/m^3 (Terzaghi, Peck, & Mesri, 1996). This means the mass equivalent in the hopper would be 13,108 tonnes. [*in situ* sediment volume of 9,167 m^3 with bulk density of 1.43 tonnes/m^3 equating to 13,108 tonnes which bulks up in volume with water into the hopper at a ratio of 1.2 to fill 11,000m^3 of the hopper capacity].

When the dredger is filling excess water is discharged via spillways. Some of the finer grained sediments (fine sands to silts) will be carried in this water as overspill to develop an initial sediment plume and preferentially leaving the coarser sediments in the hopper. The rate of overspill depends on many factors. If a representative loss of 5% of hopper load was assumed then this would equate to 482 m^3 of finer sediments. The hopper would still have 4,965 m^3 of finer sediment taken to the spoil site. If the time to fill the hopper was estimated as 4 hours then an equivalent sediment discharge rate would be around 47.91 kg/s (45.41 kg/s fine sediment, 2.37 kg/s very fine sediment and 0.13 kg/s silt) over this period and along the area being cleared of sandwaves. These discharges would occur at the sea surface.

An example location for the overspill is given as 703,372 E, 5910163 N (UTM 29N).

Once the hopper is full the sediment would be taken to the northern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, *et al.*, 2015). Accordingly, the sediment plume quantities available for dispersion for fine sand are 672.9 tonnes, very fine sand 35.1 tonnes and silt 2.0 tonnes.

An example location for the spoil disposal is given as 704,100 E, 590,5848 N (UTM 29N).

Bray Bank (southern releases)

Sandwave clearance for the southern part of the array area will use the southern spoil site. Sediment samples which coincide with areas with sandwaves are summarised in

Table 10 and presented in Figure 5. In all cases, sands are the dominant sediment type (96.3 to 100% of grab sample), with fine sands the most common sand fraction particle size.

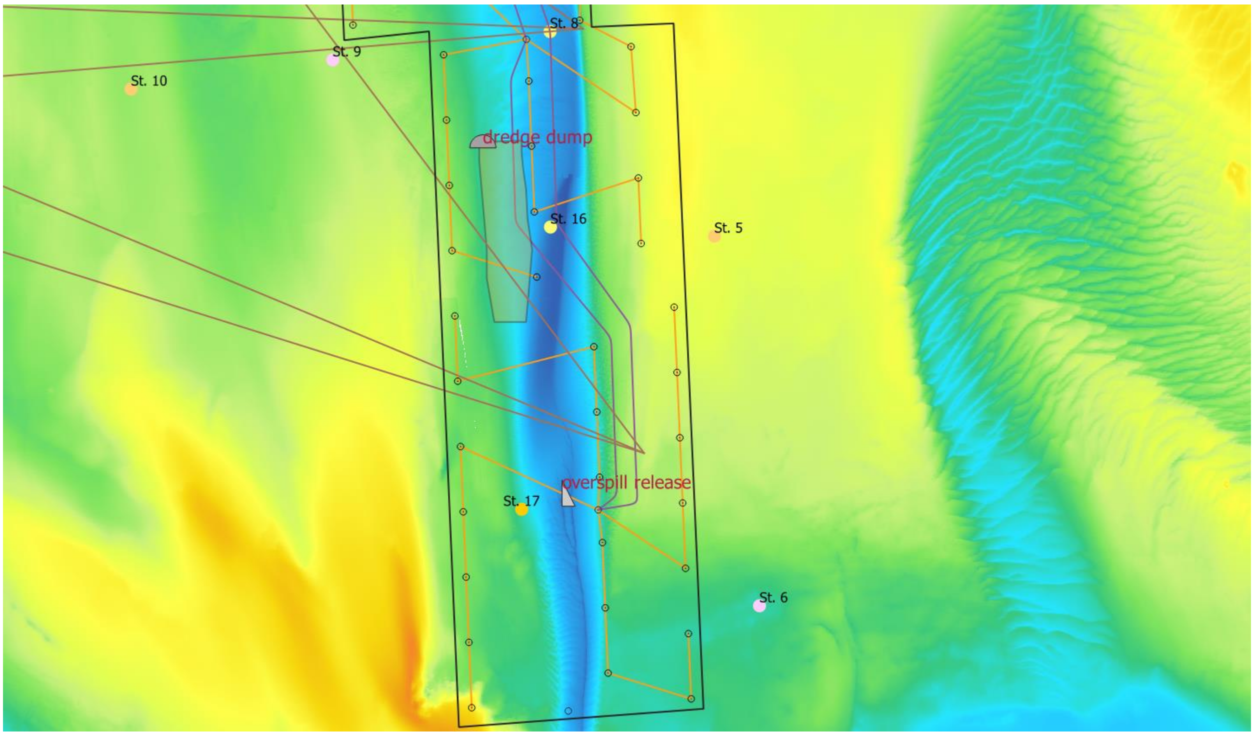

Figure 5: Grab sample sites across the southern section of array area (Bray Bank).

Table 10: Sediment gradings (percentage) for samples across southern part of the array area coinciding with sandwaves.

Sediment type / aggregate name	St 8	St 16	Generalised
Very fine gravel	0.1	0	0.05
Very coarse sand	0.3	0.1	0.20
Coarse sand	0.9	0.4	0.65
Medium sand	21.4	21.5	21.46
Fine sand	76.9	77.7	77.34
Very fine sand	0.3	0.3	0.30
Silt / Clay	0	0	0.00

Modelling scenarios consider the fate of spoil disposal from a TSHD of an assumed capacity (nominally 11,000 m^3) at the southern spoil site. NB the capacity of the dredger is not equivalent to the volume of sediment to be removed since many factors will bulk out the sediment being dredged. The bulking factor also varies according to soil type and dredging method. A bulking factor of 1.20 is assumed for present purposes which is mid-range of 1.15 to 1.25 for sand, medium soft to hard (Bray, Bates, & Land, 1996). The volume of excavated material in the hopper is therefore expected to be around 9,167 m^3.

For uniform sand which is “loose” (i.e. mobile unconsolidated deposit) an *in situ* dry bulk density value would be around 1.43 tonnes/m^3 (Terzaghi, Peck, & Mesri, 1996). This means the mass equivalent in the hopper would be 13,108 tonnes. [*in situ* sediment volume of 9,167 m^3 with bulk density of 1.43 tonnes/m^3 equating to 13,108 tonnes which bulks up in volume with water into the hopper at a ratio of 1.2 to fill 11,000m^3 of the hopper capacity].

When the dredger is filling excess water is discharged via spillways. Some of the finer grained sediments (fine sands to silts) will be carried in this water as overspill to develop an initial sediment plume and preferentially leaving the coarser sediments in the hopper. The rate of overspill depends on many factors. If a representative loss of 5% of hopper load was assumed then this would equate to 482 m^3 of finer sediments. The hopper would still have 7,005 m^3 of finer sediment taken to the spoil site. If the time to fill the hopper was estimated as 4 hours then an equivalent sediment discharge rate would be around 47.91 kg/s (47.73 kg/s fine sediment, 0.19 kg/s very fine sediment and 0.00 kg/s silt) over this period and along the area being cleared of sandwaves. These discharges would occur at the sea surface.

An example location for the overspill is given as 706,480 E, 5,896,450 N (UTM 29N).

Once the hopper is full the sediment would be taken to the southern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion for fine sand are 997.9 tonnes, very fine sand 3.9 tonnes and silt 0.0 tonnes.

An example location for the spoil disposal is given as 705,415 E, 5,901,100 (UTM 29N).

Disposal of spoil from a single hopper load will be demonstrated at each of the two (2) spoil sites (north and south) and for a release on both spring and neap tides. This provides for a total of four (4) overspill and four (4) disposal scenarios. The consequences of additional hopper loads to achieve the maximum sediment volume can then be considered based on scaling-up from the individual results.

For reference, extraction of 9,366,000 m^3 for sandwave clearance with a bulking factor of 1.20 and a TSHD capacity of 11,000 m^3, accounting for overspill, would require around 971 hopper loads. Disposal of the spoil would expect to be split across both spoil sites.

b. Export cable routes

Figure 6 presents the realistic worst-case sections of the export cable subject to sandwave clearance. These sections relate to export cable routes extending from north, central and south OSP and utilising two landfall locations; Poolbeg and Shanganagh WWTP.

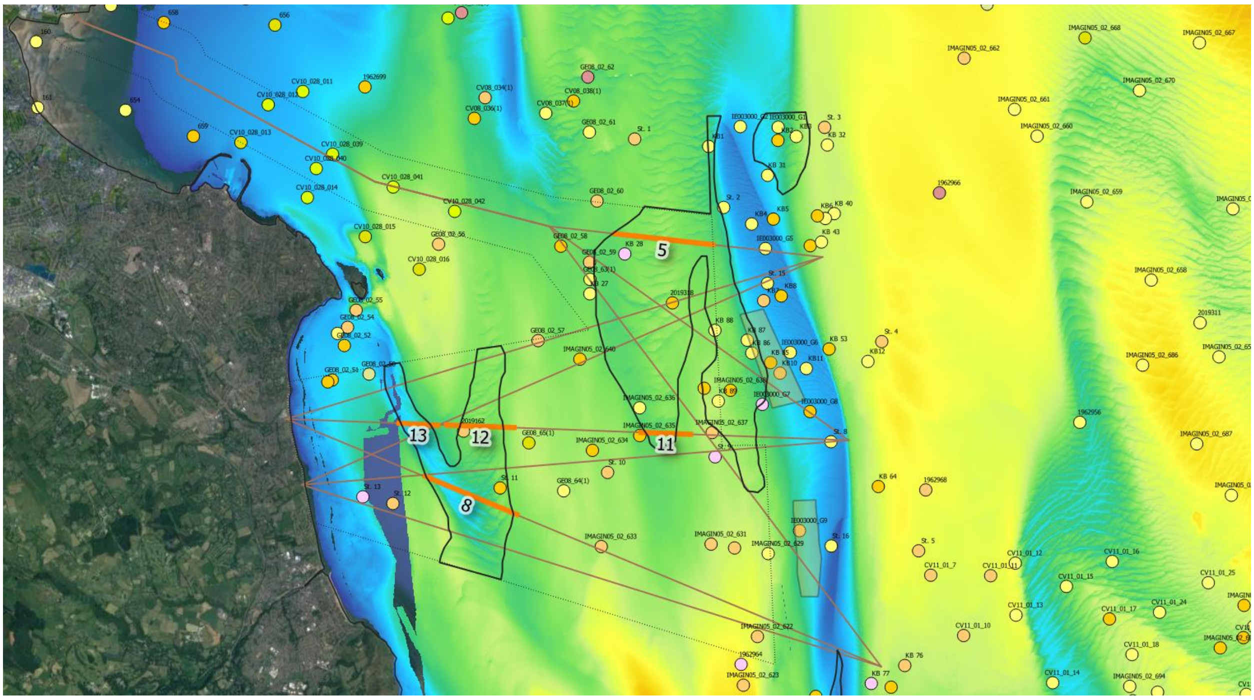

Figure 6. Realistic worst-case of sandwave clearance sections along the export cable options.

Based on a conservative maximum sandwave height of 6 m being present along all sections of the export cable requiring clearance provides a total sweeping volume of 2,668,794 m^3 of mainly sandy material. The present assumption is that this material will be disposed of within the array boundary utilising both of the nominated spoil sites. Logically, the material dredged will be taken to the closest site on each occasion. If a TSHD dredger with a capacity of 11,000 m^3 is used this would require 291 cargoes, assuming a bulking factor of 1.20 which is mid-range of 1.15 to 1.25 for sand, medium soft to hard (Bray, Bates, & Land, 1996). The *in situ* volume of excavated material in the hopper is therefore expected to be around 9,167 m^3 which is expected to be yielded from around 33 m along the path of sandwave clearance. For modelling purposes this can be assumed to be a stationary source.

Relevant details for each section of the export cable are provided for consideration as modelling scenarios:

a. Section 5 – North OSP to Poolbeg

Section length	= 2,489 m
Maximum volume of removal	= 746,694 m^3
Number of dredging loads	= 77

Sediments in this region are typically classified as slightly gravelly sand to sandy gravel with sample St. 1 (gravelly sand) being the closest sample within the sandwave field with a full gradings curve.

Overspill rates during the dredging activity are estimated as:

Fine sand	= 44.66 kg/s
Very fine sand	= 2.44 kg/s
Silt	= 0.81 kg/s

These rates would expected to occur for around 4 hours at the sea surface and for a representative location at:

701,909 E, 5,907,772 N (UTM 29N)

Once the hopper is full the sediment would be taken to the northern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion are;

Fine sand	= 11.6 tonnes
Very fine sand	= 0.6 tonnes
Silt	= 0.2 tonnes

An example location for the spoil disposal is given as:

704,125 E, 5,905,817 (UTM 29N)

b. Section 11- Central OSP to Shanganagh WWTP

Section length	= 1,245 m
Maximum volume of removal	= 373,500 m^3
Number of dredging loads	= 39

Sediments in this region are likely to be similar to Section 5 since this is the same area of sandwaves. St. 9 (sandy gravel) is the closest sample to the sandwave field with a full gradings curve.

Overspill rates during the dredging activity are estimated as:

Fine sand	= 47.18 kg/s
Very fine sand	= 0.59 kg/s
Silt	= 0.15 kg/s

These rates would expected to occur for around 4 hours at the sea surface and for a representative location at:

702,072 E, 5,902,859 N (UTM 29N)

Once the hopper is full the sediment would be taken to the northern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion are;

Fine sand	= 376.4 tonnes
Very fine sand	= 4.7 tonnes
Silt	= 1.2 tonnes

An example location for the spoil disposal is given as:

704,911 E, 5,903,595 (UTM 29N)

c. Section 12- Central OSP to Shanganagh WWTP

Section length	= 1,694 m
Maximum volume of removal	= 508,200 m^3
Number of dredging loads	= 53

St. 11 (slightly gravelly sand) is the closest sample to the sandwave field with a full gradings curve.

Overspill rates during the dredging activity are estimated as:

Fine sand	= 41.23 kg/s
Very fine sand	= 6.13 kg/s
Silt	= 0.56 kg/s

These rates would expected to occur for around 4 hours at the sea surface and for a representative location at:

697,745 E, 5,903,053 N (UTM 29N)

Once the hopper is full the sediment would be taken to the northern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion are;

Fine sand	= 42.7 tonnes
Very fine sand	= 6.4 tonnes
Silt	= 0.6 tonnes

An example location for the spoil disposal is given as:

704,911 E, 5,903,595 (UTM 29N)

d. Section 13 - Central OSP to Shanganagh WWTP

Section length	= 981 m

Maximum volume of removal	= 294,300 m^3
Number of dredging loads	= 31

St. 11 (slightly gravelly sand) is the closest sample to the sandwave field with a full gradings curve.

Overspill rates during the dredging activity are estimated as:

Fine sand	= 41.23 kg/s
Very fine sand	= 6.13 kg/s
Silt	= 0.56 kg/s

These rates would expected to occur for around 4 hours at the sea surface and for a representative location at:

695,893 E, 5,903,093 N (UTM 29N)

Once the hopper is full the sediment would be taken to the northern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion are;

Fine sand	= 42.7 tonnes
Very fine sand	= 6.4 tonnes
Silt	= 0.6 tonnes

An example location for the spoil disposal is given as:

704,911 E, 5,903,595 (UTM 29N)

e. Section 8 - South OSP to Shanganagh WWTP

Section length	= 2,489 m
Maximum volume of removal	= 746,700 m^3
Number of dredging loads	= 77

St. 11 (slightly gravelly sand) is the closest sample to the sandwave field with a full gradings curve.

Overspill rates during the dredging activity are estimated as:

Fine sand	= 41.23 kg/s
Very fine sand	= 6.13 kg/s
Silt	= 0.56 kg/s

These rates would expected to occur for around 4 hours at the sea surface and for a representative location at:

697,318 E, 5,901,261 N (UTM 29N)

Once the hopper is full the sediment would be taken to the northern spoil site within the array. At the time of disposal there will initially be a dynamic/active phase of discharge where the sediment falls to the seabed as a density flow to form a spoil mound. When the spoil impacts on the seabed there will be a subsequent passive phase where the finer sediment becomes susceptible to advection and dispersion and formation of a sediment plume, however, not all of the sediment volume will be available for advection with an estimate that 90% of the sediment remains in the mound and 10% is available to develop in the passive phase of the plume (Becker, et al., 2015). Accordingly, the sediment plume quantities available for dispersion are;

Fine sand	= 42.7 tonnes
Very fine sand	= 6.4 tonnes
Silt	= 0.6 tonnes

An example location for the spoil disposal is given as:

705,503 E, 5,901,016 (UTM 29N), southern spoil site.

Given sections 8, 12 and 13 are all based on the same sediment information and are discharging overspill from a similar area then a generalisation of effect can be assumed from a single section and scenario, such as for section 8. In this case, modelling section 8 also utilises the southern spoil disposal.

4.4. Cable trenching

The realistic worst-case for cable trenching is the method which has the fastest trenching rate in the largest trench which releases the most amount of fine sediments into the highest part of the water column. This source of sediment disturbance is different to pre (installation) sweeping as all of the cable routes are involved rather than just those parts where steep-sided sandwaves are present. In addition, the proportion of fine sediments is also expected to vary along the length of the cable routes, whereas pre-sweeping mainly deals with sand-sized material.

Various cable trenching options are considered in the Project Description to account for different seabed conditions with details summarised in Table 11.

Table 11: Trenching options

Trenching method	Indicative trench width (m)
Jet-trenching	0.7
Pre-cut-ploughing	5.71
Post-lay ploughing	0.3
Mechanical trenching	0.5
Mass flow excavator (MFE)	5.71

Of these options, MFE would appear to develop both a wide trench and also have the greatest potential to fluidise and raise fine sediments into suspension and is therefore considered as the realistic worst-case option. This consideration is in line with a comparative review of sediment disturbance from various burial tools provided in BERR (2008).

The MFE tool generally lays the cable at the same time with the coarser sediment fluidised from the seabed expected to rapidly fall out of suspension to bury the cable in the trench. MFE tools can operate at rates of 100 m/hr (for harder / more compact seabed) to 180 m/hr. Final rates depend on soil conditions and depth of burial requirements.

a. Inter-array cables

The trenching requirements across the offshore array area include both inter-array cables (100 km) and inter-platform cables (24 km), with a provision for 5% of the inter-array length to remain unburied. The total length for trenching to bury cables is therefore 119 km. At the fastest trenching rate of 180 m/hr this would take around 28 days of installation time to complete (not continuous).

Given a maximum depth of the trench of 7 m and a width of 5.71 m, the maximum volume of material to be excavated across the array would be 4,756,430 m^3. At a trenching rate of 180 m/hr, the equivalent disturbance for fluidised sediment is 7,194 m^3/hr or 2.0 m^3/s. An unconsolidated sandy seabed is likely to have a bulk density in the range 1,890 to 2,160 kg/m^3 whereas a muddy seabed will be between 1,770 to 2,320 kg/m^3 (Terzaghi, Peck, & Mesri, 1996). Depending on the local soil characteristics this variation in bulk density would also vary the total mass of fluidised sediment in the range 3,537.3 to 4,636.5 kg/s, however, only the proportion of fine sediment will remain in suspension for a sufficient period to be advected away from the trench by tidal flows to form a near-bed sediment plume. The coarser sediment will fall out of suspension and ideally into the trench to help bury the cable.

b. Export cable routes

The trenching requirements for export cables are based on the same assumptions of trenching method considered for inter-array cables, noting that the maximum trench depth increases to 10 m for 100% of the export cable.

Based on details presented in Table 8 the realistic worst-case route option covers a toral distance of 59,379 m for the Shanganagh WWTP (1 circuits) plus Poolbeg (2 circuit). This option has the longest overall trenching distance which also covers a wider set of environmental conditions than the three circuits to Poolbeg alone.

Given a maximum depth of the trench of 10 m and a width of 5.71 m, the maximum volume of material to be excavated would be 3,390,541 m^3. At a trenching rate of 180 m/hr, the equivalent disturbance for fluidised sediment is 10,278 m^3/hr or 2.9 m^3/s. An unconsolidated sandy seabed is likely to have a bulk density in the range 1,890 to 2,160 kg/m^3 whereas a muddy seabed will be between 1,770 to 2,320 kg/m^3 (Terzaghi, Peck, & Mesri, 1996). Depending on the local soil characteristics this variation in bulk density would also vary the total mass of fluidised sediment in the range 5,053 to 6,624 kg/s, however, only the proportion of fine sediment will remain in suspension for a sufficient period to be advected away from the trench by tidal flows to form a near-bed sediment plume. The coarser sediment will fall out of suspension and ideally into the trench to help bury the cable.

4.4.1. Modelling scenarios

a. Inter-array cables

The modelling will consider representative sections (up to 2 lines) of the inter-array cables where there is a high content of fine sediments (fine sands, very fine sands and silts) and in close proximity to sensitive environmental receptors. These sections will consider around 36-hours of a continuous moving source along a section of the inter-array cable (equivalent distance of around 4 km at a rate of 180 m/hr) with a subsequent 48-hours to identify the time taken for plumes to fully dissipate into background concentrations of suspended sediment. The fine sediment fraction (fine sands, very fine sands and silts) will be released in the model above the seabed to represent a fluidised volume, notionally at 2 m above the seabed. Each section will be simulated for a spring and neap tide (4 scenarios).

Line 1: WTG-1, WTG-2, WTG-6, WTG-7 to OSP-North

This line covers a distance of 5.7 km on the north-west part of the array with a seabed represented by sediment samples KB2, KB1, St. 2 and KB4, sites which provide full gradings information.

- WTG-1 704,885 E 5,910,305 N (UTM 29N) to WTG-2 703,386 E 5,910,750 N (UTM 29N), distance of 1,564 m in a duration of 8.7 hours at 180 m/hr
    - Sediments represented by KB2, slightly gravelly sand with release rates of;
        - 3,172 kg/s of fine sand
        - 408 kg/s very fine sand
        - 4 kg/s silt
- Reposition of cable vessel 1.5 hours
- WTG-2 703,386 E 5,910,750 N (UTM 29N) to WTG-6 703,435 E 5,909,611 N (UTM 29N), distance of 1,140 m in a duration of 6.3 hours at 180m/hr
    - Sediments represented by KB1, sand with release rates of;
        - 2,180 kg/s of fine sand
        - 216 kg/s very fine sand
        - 9 kg/s silt
- Reposition of cable vessel 1.5 hours

- WTG-6 703,435 E 5,909,611 (UTM 29N) to WTG-7 703,484 E 5,908,472 N (UTM 29N), distance of 1,140 m in a duration of 6.3 hours at 180m/hr
    - Sediments represented by St.2, sand with release rates of;
        - 1,793 kg/s of fine sand
        - 8 kg/s very fine sand
        - 0 kg/s silt
- Reposition of cable vessel 1.5 hours
- WTG-7 703,484 E 5,908,472 (UTM 29N) to OSP-North 705,007 E 5,907,457 N (UTM 29N), distance of 1,830 m in a duration of 10.2 hours at 180m/hr
    - Sediments represented by KB4, sand with release rates of;
        - 1,683 kg/s of fine sand
        - 40 kg/s very fine sand
        - 11 kg/s silt
- Total time = 36.0 hours

Line 2: WTG-44, WTG-40, WTG-39, WTG-37 to OSP-South

This line covers a distance of 5.3 km on the south-west part of the array with a seabed represented by sediment sample St. 17 which provide full gradings information.

- WTG-44 706,711 E 5,893,724 N (UTM 29N) to WTG-40 705,212 E 5,894,170 N (UTM 29N), distance of 1,564 m in a duration of 8.7 hours at 180 m/hr
    - Sediments represented by St. 17, slightly gravelly sand with release rates of;
        - 1,469 kg/s of fine sand
        - 4 kg/s very fine sand
        - 0 kg/s silt
- Reposition of cable vessel 1.5 hours
- WTG-40 705,212 E 5,894,170 N (UTM 29N) to WTG-39 705,163 E 5,895,309 N (UTM 29N), distance of 1,140 m in a duration of 6.3 hours at 180m/hr
    - Sediments represented by St. 17, slightly gravelly sand with release rates of;
        - 1,469 kg/s of fine sand
        - 4 kg/s very fine sand
        - 0 kg/s silt
- Reposition of cable vessel 1.5 hours
- WTG-39 705,163 E 5,895,309 N (UTM 29N) to WTG-37 705,114 E 5,896,448 N (UTM 29N), distance of 1,140 m in a duration of 6.3 hours at 180m/hr
    - Sediments represented by St. 17, slightly gravelly sand with release rates of;
        - 1,469 kg/s of fine sand
        - 4 kg/s very fine sand
        - 0 kg/s silt
- Reposition of cable vessel 1.5 hours
- WTG-37 705,114 E 5,896,448 N (UTM 29N) to OSP-South 706,588 E 5,896,751 N (UTM 29N), distance of 1,479 m in a duration of 8.2 hours at 180m/hr
    - Sediments represented by St. 17, slightly gravelly sand with release rates of;
        - 1,469 kg/s of fine sand
        - 4 kg/s very fine sand
        - 0 kg/s silt

- Total time = 34.1 hours

b. Export cables

The realistic worst-case option for export cables is considered to be Shanganagh WWTP (1 circuit) plus Poolbeg (2 circuits) (Table 8). This options covers a total distance of 59.4 km for two separate routes to landfall. The Poolbeg route is notable as this crosses Dublin Bay where there is an area with a high proportion of fine sediments; sandy mud to muddy sand. This route also crosses Rockabill to Dalkey Island SAC, South Dublin Bay and River Tolka Estuary SPA and the overlapping South Dublin Bay SAC.

Modelling considers three representative sections of the realistic worst case option. In a 24 hour period the distance covered by cable trenching activity achieving a rate of 180 m/hr would be around 4 km.

Section 1: Poolbeg landfall, midway through Rockabill to Dalkey Island SAC

Section 1 covers a distance of around 4 km along the export cable to Poolbeg that passes through Rockabill to Dalkey Island SAC. Seabed sediments are represented by sediment sample St. 1 (gravelly sand) which provide full gradings information (n.b. samples closer to the cable route but without full gradings demonstrate gravelly sand remains relevant across the general area).

- 698,717 E 5,908,248 N (UTM 29N) to 694,823 E 5,909,232 N (UTM 29N), distance of 4 km in a duration of 24 hours at 180 m/hr
    - Sediments represented by St. 1, gravelly sand with release rates of;
        - 223 kg/s of fine sand
        - 12 kg/s very fine sand
        - 4 kg/s silt

Section 2: Poolbeg export cable, Dublin Bay

Section 2 covers a distance of around 4 km along the export cable to Poolbeg that passes through Dublin Bay, including a portion of South Dublin Bay and River Tolka Estuary SPA.

- 691,456 E 5,911,081 N (UTM 29N) to 690,585 E 5,911,556 N (UTM 29N), distance of 992 m in a duration of 5.5 hours at 180 m/hr. Local sediment type is defined by samples #655, #656 and #659 which span this part of the export cable. All samples indicate that fine grained sands are dominant.
    - Sediment release rates of;
        - 2,460 kg/s of fine sand
        - 1,173 kg/s very fine sand
        - 284 kg/s silt

- 690,585 E 5,911,556 N (UTM 29N) to 689,845 E 5,911,952 N (UTM 29N), a section within the South Dublin Bay and River Tolka Estuary SPA covering a distance of 839 m in a duration of 4.7 hours at 180 m/hr. Local sediment type is defined by sample #659 which indicates fine grained sands are dominant.

    - Sediment release rates of;
        - 3,142 kg/s of fine sand
        - 543 kg/s very fine sand
        - 189 kg/s silt

- 689,845 E 5,911,952 N (UTM 29N) to 689,779 E 5,912,334 N (UTM 29N) to 689,145 E 5,912,614 N (UTM 29N), a section within the South Dublin Bay and River Tolka Estuary SPA covering a distance of 1,080 m in a duration of 6 hours at 180 m/hr. Local sediment type is defined by sample #658 which indicates fine grained sands are dominant.

    - Sediment release rates of;
        - 2,293 kg/s of fine sand
        - 1,405 kg/s very fine sand
        - 145 kg/s silt

- 689,145 E 5,912,614 N (UTM 29N) to 687,880 E 5,913,087 N (UTM 29N), a section crossing from the South Dublin Bay and River Tolka Estuary SPA into the South Dublin Bay SAC and covering a distance of 1,361 m in a duration of 7.6 hours at 180 m/hr. Local sediment type is defined by samples #162 and #654 which indicates fine grained sands are dominant.

    - Sediment release rates of;
        - 2,438 kg/s of fine sand
        - 1,477 kg/s very fine sand
        - 103 kg/s silt

Section 3: Shanganagh WWTP export cable, south of Rockabill to Dalkey Island SAC

Section 3 covers a distance of around 4 km along the export cable to Shanganagh WWTP that passes south of Rockabill to Dalkey Island SAC.

- 698,311 E 5,900,884 N (UTM 29N) to 694,283 E 5,902,544 N (UTM 29N), distance of 4.3 km in a duration of 24 hours at 180 m/hr. Local sediment type is defined by samples St.11 and St. 12 which span this part of the export cable and both indicating gravelly sand.

    - Sediment release rates of;
        - 1,491 kg/s of fine sand
        - 138 kg/s very fine sand

- 32 kg/s silt

Section 1, 2 and 3 each consider 24-hours of a continuous moving source along the export cable where the sediment conditions remain relatively similar for each section. These releases are followed by a subsequent 48-hours (or longer) to identify the time taken for plumes to fully dissipate into background concentrations of suspended sediment. Each section will be simulated for a spring and neap tide (6 scenarios).

4.5. Scour development

Overview

Local scouring is a near-field process when flows are blocked and need to accelerate past an object on or close to the seabed, such as a foundation or free-spanning cable. The intensified flow speeds passing around the object create vortices (turbulence) that increase bed shear stress acting on the seabed which then leads to local scouring when the seabed sediments are susceptible to these higher erosional forces.

The scale of local scouring is mainly related to the scale and shape of the structure as well as sediment properties (e.g. angle of repose). For slender cylindrical monopiles (i.e. when the ratio of pile diameter, D, to water depth, h is < 0.5), the scour depth is a function of the pile diameter, D, and a near-circular form of scour is created, although this can also be asymmetric in shape depending on the way ebb and flood flows affect the structure. This is referred to as “local scour”.

When piles are closely spaced (e.g. multi-legged jacket structures) then the extents of local scouring around each pile can overlap and create a wider area of “group scour”.

The scouring process continues (deepening and widening of the scour hole) until an equilibrium condition is reached which eventually accommodates and dissipates the faster flows and near-bed vortices. This situation is generally described as the equilibrium scour depth.

The rate of scouring can be fast when the seabed is already highly mobile, this is generally referred to as a “live-bed” regime. Where wave forces can also act on the seabed (shallow water situations) then the rate of scouring can increase. If the mobile layer of sediments is thin or absent and sub-soils are stiffer (more resistant to erosion) then the scouring process may be slowed or restricted.

Scouring around foundations can be mitigated by placing scour protection around the object to armour the seabed against the heightened erosional forces. Conventional scour protection materials are riprap rock armour. In addition, a filter layer can be installed prior to piling which would then mitigate for any post-installation scouring prior to the armour layer being added.

General changes in seabed levels, separate to any influence of structures, can also occur which may also present a risk to foundations and the long-term performance of scour protection. When the general seabed levels drop this is commonly referred to as “global scour” and could potentially destabilise scour protection.

Sandbank environments tend to be in dynamic equilibrium with their local tidal and wave environment and are prone to changes in seabed levels, especially in response to storm events.

Environmental issues

An unprotected foundation will lead to development of a scour hole which is likely to be a small-scale feature. There will be an associated small volume of sediment eroded from the scour hole which will generally move down-drift to become part of the wider sediment transport environment. This erosion process will be short-term. The separation distance between foundations is sufficient to remove the risk of interactions across the array which could lead to group scour and the potential to modify a large-scale morphological feature, such as a sandbank. In engineering terms, the absence of scour protection would be considered the realistic worst-case and typically require longer piles to compensate for increased over-turning moments.

A foundation with scour protection introduces an additional direct loss of seabed and a coarser substrate type to the ambient conditions which may lead to a local change in benthic community type. This effect would persist for the duration of the windfarm. In ecological terms, the use of scour-protection would be considered as the realistic worst-case in most situations.

Realistic worst-case

Table 12 provides a summary of the total areas where local scour is likely to occur around the base of each foundation option if no scour protection was provided. This estimate assumes the width of scour development (to the equilibrium scour depth) would be proportional to 4D, where D is the diameter of the pile. These areas have the potential to be developed during the period prior to scour protection being installed, however, the present option allows for a filter layer to be pre-installed to help mitigate scouring in this period.

Table 12. Initial estimate of area susceptible to local scour

Turbine Rating (MW)	Maximum number of turbines	Total area of scour around pile base (m^2)		
		Monopile	3-legged multi-leg	4-legged multi-leg
12 to 15	61	103,484	91,088	45,993
>15	45	**119,282**	77,931	42,942

When full scour protection is installed the height of rock armour above the seabed is up to 2 m with a 1:2 slope at the edge. This increases the diameter of direct loss to become slightly larger than 4D. The total areas for scour protection (excluding the area of any piles) are given in Table 13.

Table 13. Scour protection areas

Turbine Rating (MW)	Maximum number of turbines	Total area of scour around pile base (m^2)		
		Monopile	3-legged multi-leg	4-legged multi-leg
12 to 15	61	143,345	**160,076**	107,317
>15	45	155,473	132,217	92,704

Based on the details offered in

Table 12, the realistic worst-case option for the direct loss of seabed due to scour protection relates to the 3-legged multi-leg for the 12 to 15 MW WTG option.

For multi-pile foundations the suction bucket option includes stiffeners which are considered to mitigate turbulent effects around the base of the foundation, as well as the top of the bucket acting as a non-erodible surface. This assumes the top of the bucket always remains at or below the level of the seabed. If the seabed level dropped to reveal the sides of the foundation then flows may become blocked and local scouring may occur.

Related evidence

The 25.2 MW Arklow Bank Wind Park Phase I is an operational offshore wind farm commissioned in 2004 and comprises seven monopile foundations each with a diameter of 5 m. These foundations are located in shallow water at the top of Arklow Bank in water depths of around 5 m below LAT. This site is around 30 km south of Dublin Array in a comparable sandbank setting. There was a short delay between installation of the monopiles on Arklow and the installation of scour protection. This interval was sufficient for scour holes to develop around the base of the monopiles. Subsequently, scour protection (rip-rap rock armour with a median diameter of 0.42 m (Esteban, López-Gutiérrez, Negro, & Sanz, 2019)) was installed into the naturally-occurring scour holes using a back-hoe on the side of a jack-up barge. Post-installation monitoring and diver observations indicated that in some cases the scour hole was not completely in-filled by rock armour and the performance of scour protection was also acting like a loose falling-apron of rock in response to the dynamic profile of the sandbank (Department of Energy and Climate Change, 2008).

Other evidence from recent offshore wind farms has also shown increased turbulence in the seabed boundary layer can elevate near-bed mobile layers of fine sediment (undeposited material of likely estuarine source), if present, into the water column and form a visible sediment plume. This is not directly a scour process and persisted irrespective of the installed scour protection.

4.6. Decommissioning activities

Specific decommissioning activities are generally unspecified at the time of consent. The default EIA assumption is that decommission activities will create similar levels (and not greater) of sediment disturbance to those that are expected to occur during installation.

5. Blockage

The Project Description includes details of structures which may create blockage effects on flows and waves; met mast, WTG and offshore platform foundations as well as cable protection measures for crossings and hard sea beds.

5.1. Foundations

All structures fixed to the seabed with a vertical profile in the water column have the potential to interfere and locally ‘block’ incident waves and flows, which in turn may also influence the development of local scour. The realistic worst-case is the net effect of all structures planned for across the offshore array (wind turbines, met masts and offshore sub-stations) with consideration of the vertical cross-section of each foundation, their solidity ratio[1] and the spacing between structures. In the present case a conservative solidity factor of 0.4 is estimated.

A lower number of large foundations may not necessarily translate to the realistic worst-case if a greater number of moderately sized structures placed closer together (smaller separation) accumulates to a larger net effect for the whole array.

Table 14 provides a summary of blockage factors for pile based foundations and Table 15 for bucket based foundations. The bucket base includes a consideration of the influence of stiffeners at the base of the foundation.

Table 14. Relative comparison of blockage factors for pile based foundations

Turbine Rating (MW)	Maximum number of turbines	Vertical cross-section of structures (m^2)		
		Monopile	3-legged multi-leg	4-legged multi-leg
12 to 15	61	14,640	23,790	21,981
>15	45	13,500	18,900	18,243

Table 15. Relative comparison of blockage factors for bucket based foundations

Turbine Rating (MW)	Maximum number of turbines	Vertical cross-section of structures (m^2)		
		Monopile	3-legged multi-leg	4-legged multi-leg
12 to 15	61	17,629	**25,635**	24,177
>15	45	15,705	24,851	20,608

Based on this comparative assessment, the realistic worst-case for foundation blockage is a 3-legged bucket foundation (with stiffeners) for the array of 61 WTG based on 12 to 15 MW ratings.

Of the two array layout options (minimum spacing and indicative layout), the minimum spacing layout has the higher potential capacity for interaction of wake type effects between adjacent foundations in

[1] **Solidity ratio** is defined as the ratio of effective area (projected area of all the individual elements of a structure) of a frame normal to the wave, tidal flow or sediment transport direction divided by the area enclosed by the boundary of the frame. A solid structure will have a solidity ratio of 1, whereas an open frame lattice structure (e.g. jacket type) will generally have a much lower solidity ratio (typical values are expected to be between 0.3 to 0.4).

comparison to the indicative layout. On this basis the realistic worst case for modelling is the array layout of 61 WTG based on minimum spacing (Figure 7), unless this introduces a known constraint which would make this option unrealistic. Accordingly, the foundation sites and locations for inter-array cables requiring dredging will also be developed from this layout option.

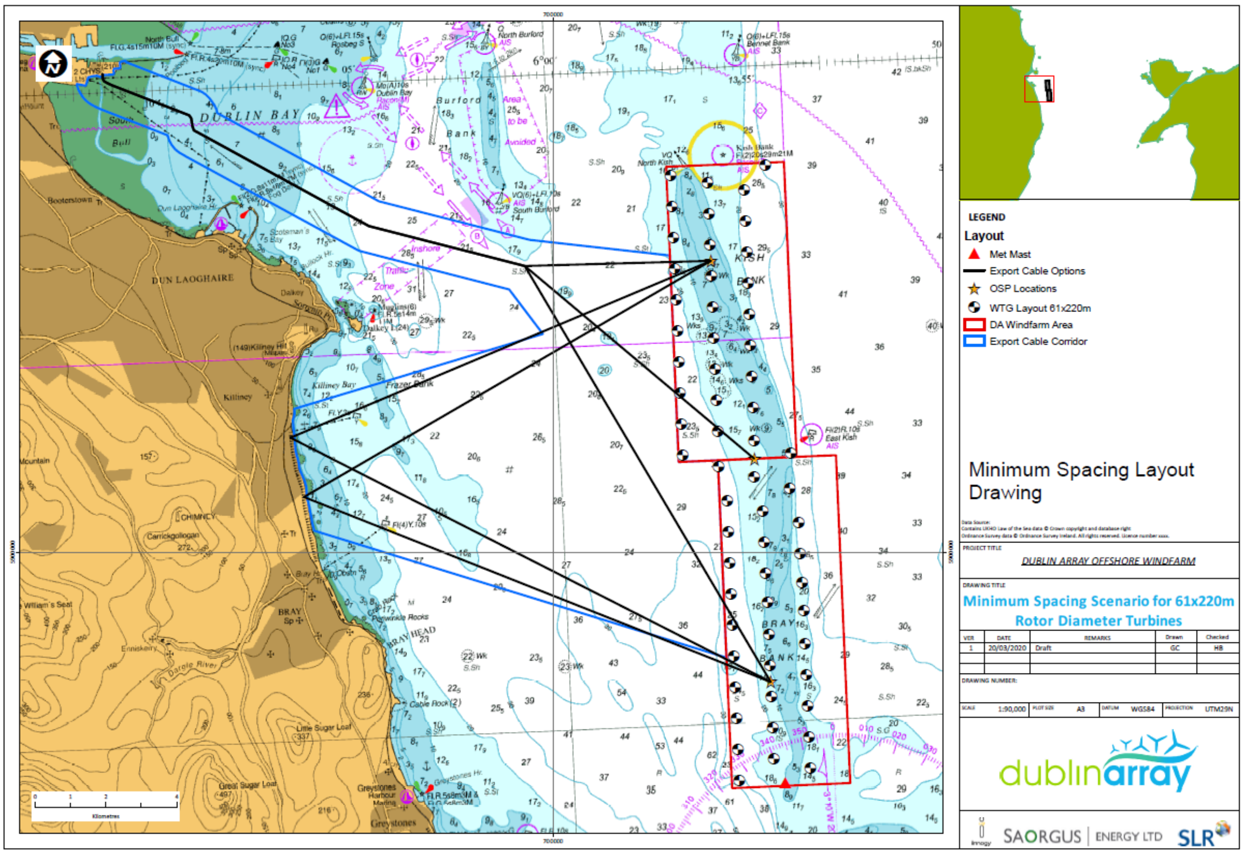

Figure 7: Realistic worst-case layout based on minimum spacing for 61 WTG

5.1.1. Modelling scenarios

Blockage effects across the array will be evaluated for effects on tides and waves and the consequence of these effects on sediment transport pathways.

Blockage will be represented as sub-grid parameterisation of the “effects” of multiple foundation structures across the array. For the RWC, this will be represented by 61 WTG foundations based on a 3-legged multi-leg bucket (including stiffeners), along with one met mast and three offshore sub-stations. Each foundation provides added friction effects at the grid scale which is determined by the MIKE-FM structures module. The structures module assumes a basic shape of a monopile. For the 3-legged multi-leg bucket the “effective” diameter would reduce to an equivalent monopile diameter of 21 m.

The modelling scenarios will consider the range of conditions anticipated during the operational period, this includes changes to tidal conditions over spring and neap periods and changes to waves under typical conditions as well as more extreme conditions, such as return periods up to 1 in 10 years.

The evaluation of potential impacts will include consideration of changes around the sandbank as well as along the adjacent coastline.

5.2. Cable protection

The Project Description includes a provision for up to 10% of the cable length (5% for the inter-array cables) to have cable protection measures.

Only Poolbeg has a requirement for cable crossings of existing assets (one cable and one pipeline) whereas all export cables have provisions for one inter-array and one inter-platform crossing. Each cable crossing is estimated to be up to 400 m in length. Cable crossing will comprise rock berms 400 m in length and 1 m high.

Additional cable protection is required for a 100 m section of unburied cable at offshore platforms.

Finally, a provision is made for up to 10% of the length of all export cables (5% for inter-array cables) to require remedial burial using cable protection should this be required during the operational and maintenance period.

Cable protection measures include one or a combination of the following options:

- Rock or gravel burial
- Concrete mattresses
- Flow energy dissipation devices (used to describe various solutions that dissipate flow energy and entrap sediment, and including options such as frond mats, and mats of large linked hoops)
- Dredged sandy material
- Protective aprons or coverings (solid structures of varying shapes, typically prefabricated in concrete or high-density plastics)
- Bagged solutions, (including geotextile sand containers, rock-filled gabion bags or nets, and grout bags, filled with material sourced from the site or elsewhere).

The option with the highest profile above the seabed will be the realistic worst-case which is likely to be conventional rock dumping.

5.2.1. Modelling scenarios

Cable protection measures are generally small-scale features creating localised effects and cannot be fully represented in numerical models.

The EIA approach will be to provide a discussion of the conceptual effects of cable protection measures.

6. Summary

A review of the latest version of the Project Description (version 1.2) has been made to determine the realistic worst-case on marine processes for issues related to sediment disturbance and array-scale blockage effects.

The present review has considered the larger turbine options of 12 to 15 MW and > 15 MW, six variants of foundation type and three alternative export cable routes to establish the realistic worst-case.

For blockage, the larger number of more closely spaced 3-legged multi-leg suction bucket foundations for 12 to 15 MW turbines presents the realistic worst-case.

For sediment disturbance, there are multiple installation events which may create a source of material that leads to material in suspension and deposition. Cable trenching by MFE is an activity which creates a large source of material that can potentially be put in suspension to form a sediment plume and is an activity that covers the offshore array as well as the export cable corridors. Sandwave clearance by dredging has the potential to create the largest volume of spoil from discrete parts of the array and the largest risk of smothering by deposition.

7. References

Becker, J., van Eekelen, E., van Wiechen, J., de Lange, W., Damsma, T., Smolders, T., & van Koningsveld, M. (2015). Estimating source terms for far field dredge plume modelling. *Journal of Environmental Management, 149*, 282 to 293.

Bray, R. N., Bates, A. D., & Land, J. M. (1996). *Dredging: A Handbook for Engineers 2nd Edition.*

Buchanan, J. B. (1984). *Sediment analysis In: (eds.) Holme N. A. and A.D. McIntyre. Methods for the study of marine benthos 2nd ed. pp. 41-65.* Blackwell, Oxford.

Cooper Marine Advisors. (2020). *Dublin Array - Marine Processes. Collation of baseline sediment data.*

Department of Energy and Climate Change. (2008). *Dynamics of scour pits and scour protection – Synthesis report and recommendations (Milestones 2 and 3). A report for the Research Advisroy Group. Final Report.*

Esteban, M. D., López-Gutiérrez, J., Negro, V., & Sanz, L. (2019). Riprap Scour Protection for Monopiles in Offshore Wind Farms. *Journal of Marine Science and Engineering, 7*(440). doi:doi:10.3390/jmse7120440

Innogy. (2018). *Horizontal Directional Drilling. Environmental Information Report. Document in reference to the Triton Knoll Electrical System Order (2016). Document No: 2505-TKN-CON-K-RA-0030. Rev: 02. CONFIDENTIAL.*

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil Mechanics in Engineering Practice. Third Edition.* John Wiley & Sons, Inc.

The Crown Estate and BMPA. (2009). *Marine aggregate terminology. A Glossary.*

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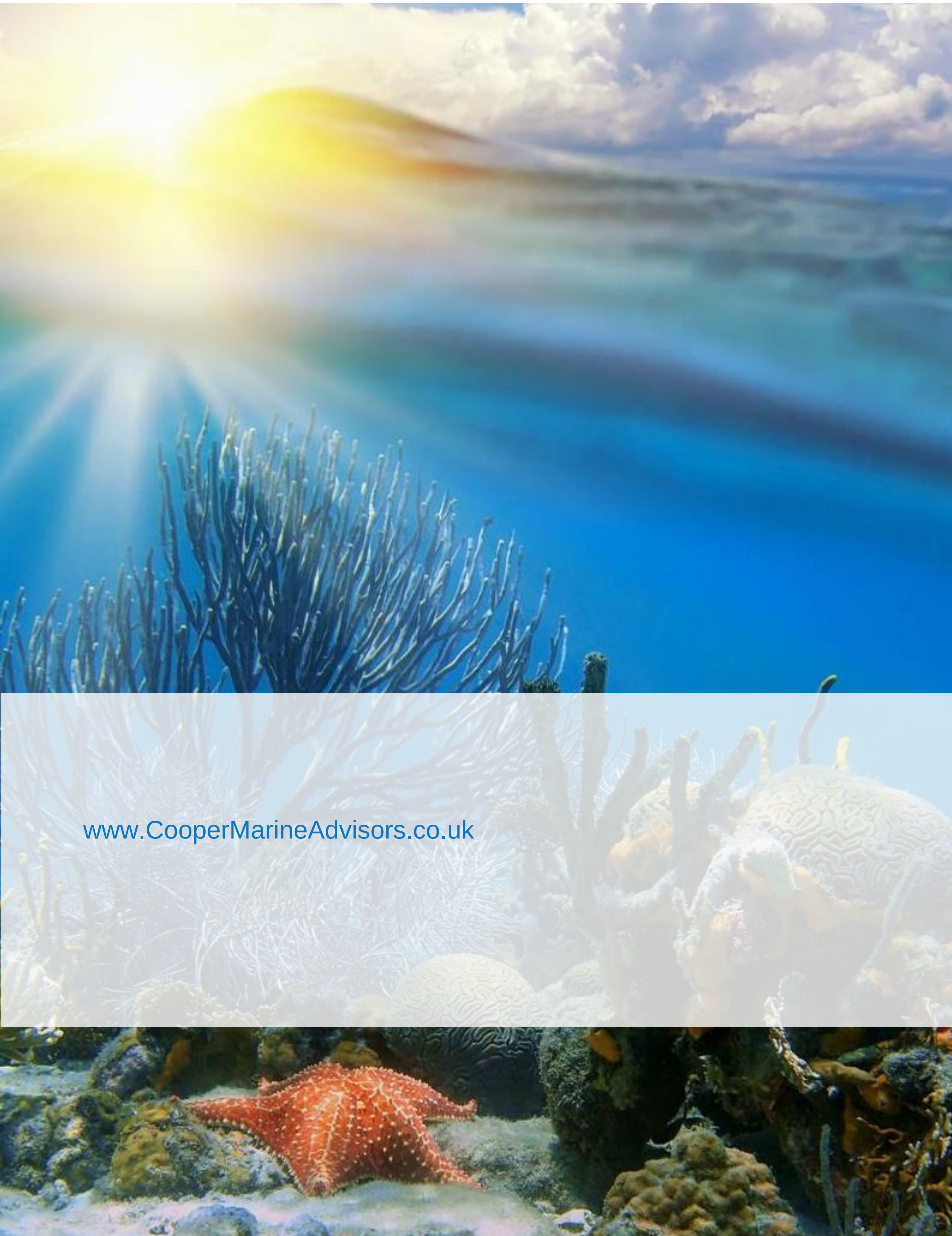

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Appendix F

Collation of Sediment Data

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DUBLIN ARRAY - MARINE PROCESSES
COLLATION OF BASELINE SEDIMENT DATA

Client: Intertek

Cooper Marine Advisors Ltd

August 2020

COOPER MARINE ADVISORS

DUBLIN ARRAY - MARINE PROCESSES

COLLATION OF BASELINE SEDIMENT DATA

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Approval	Bill Cooper W. Cooper

Contents

Preface

This technical note extends the data collation of baseline sediment data to address data gaps and to inform modelling requirements of sediment plume related issues. At this stage, the intended circulation of this technical note is the Project Team only.

Acknowledgments

The authors of this technical note gratefully acknowledge the contributions provided by Innogy in in sourcing further sediment data sets.

Abbreviations

BGS	British Geological Survey
EIA	Environmental Impact Assessment
EUNIS	The European Nature Information System
GSI	Geological Survey Ireland
PSD	Particle Size Distribution

1. Introduction

Sediment information is required to inform different aspects of project development including baseline characterisation for environmental impact assessment (EIA) and also project design. When modelling tools are applied to investigate sediment disturbance events the preferred data type is a sufficiently resolved particle size distribution (PSD) which is typically developed from a set of grab samples spread across the areas of interest, however, this data may not always be available so equivalent details may have to be inferred from alternative data sources.

This note describes collation of baseline sediment data undertaken to support the Dublin Array offshore wind farm.

1.1. Document structure

Section 2 explains the scope and purpose of the technical note.

Section 3 outlines the sediment classification schemes applied across the various identified datasets.

Section 4 establishes a quality scoring system to help identify the usefulness of each dataset.

Section 5 identifies the various datasets informing the updated description of seabed sediments.

Section 6 provides a brief overview of the sediment variations across key areas of proposed development.

Section 7 lists the references related to this technical note.

2. Aims of the collation of baseline sediment data

2.1. Previous studies

Gavin and Doherty GeoSsolutions Ltd. (GDGeo) has previously reported on a desk study to collate existing geophysical and geotechnical data clipped across Dublin Array and cable corridors. Amongst other data types, the information includes a collation of sediment grab samples and a map of seabed classification based on an interpretation of MBES backscatter (GDGeo, 2019). Some of the collated sediment samples provide the local ground-truthing to the interpreted backscatter data for sediment lithology but their coverage is relatively sparse in several key locations and most notably across Dublin Bay which is the route for the Poolbeg export cable option (Figure 1).

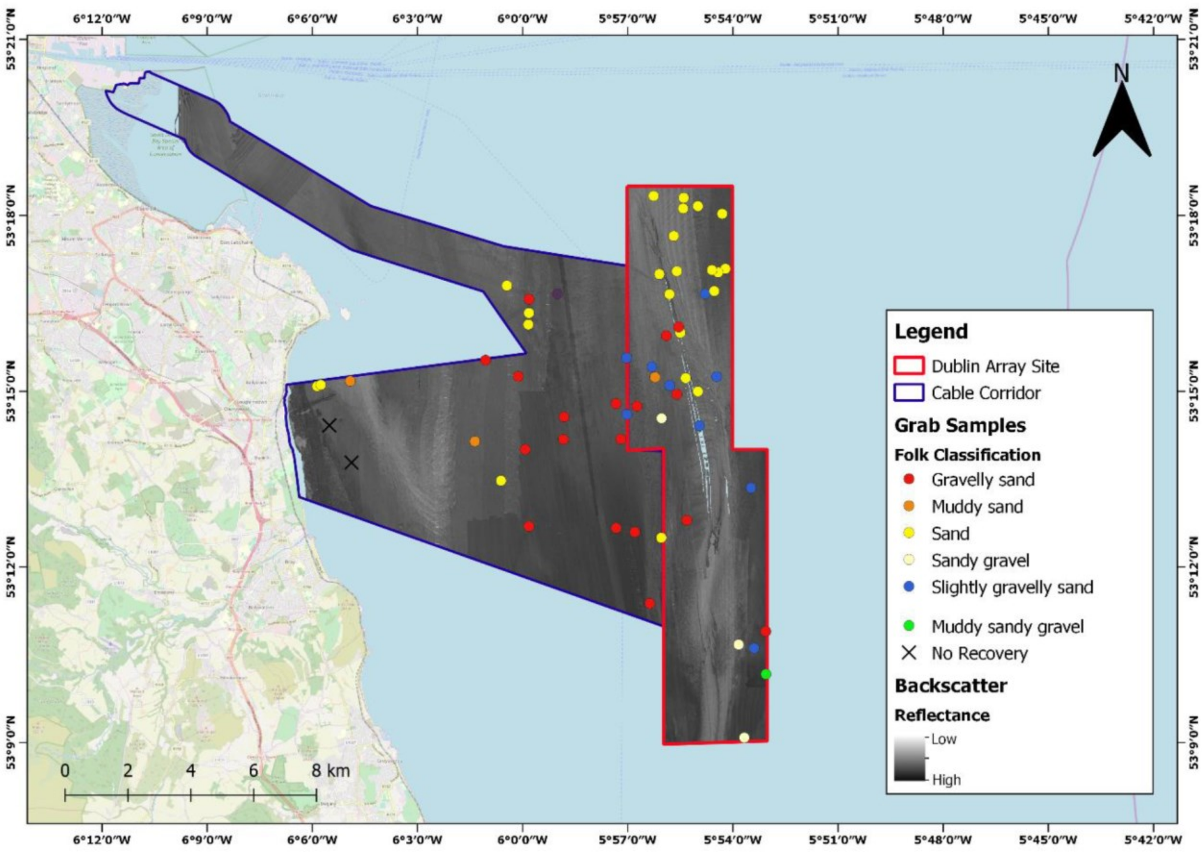


Figure 1: Initial data collation of sediment samples (GDGeo, 2019).

2.2. Aims

The purpose of the present work is to build on the earlier efforts from GDGeo, address key data gaps and develop data requirements to help characterise the inputs for sediment plume modelling. The main activities include;

- Collate the baseline information to cover areas of interest;
- Provide hierarchy of relevance to application of data based on quality score;

- Deconflict data and harmonise to common classification, etc; and
- Develop map-based outputs.

2.3. Areas of interest

The immediate areas of interest are the locations where sediment disturbance is expected to occur during the construction phase of the project and the areas where sediment deposition may occur. This includes the offshore lease area extending across Kish and Bray sandbanks and the export cable corridors which extend to three landfall options. The adjacent areas are also included where these help inform and explain the pattern of sediment distributions and also support the impact assessment of potential deposition events.

3. Sediment classification schemes

A notable feature of the available data is the diversity of sediment classification schemes. For modelling purposes a sufficient quantification of the PSD is preferred to help resolve the relative contributions of different sediment grades where each sediment grade demonstrates a distinctive behaviour, such as settling velocity. The Buchanan scale (Table 1) (an adaptation of the Wentworth scale (Wentworth, 1922)) provides a suitable scale for discriminating sediment grades by particle size.

Table 1: Classification of sediment particle size based on Buchanan (1984)

Range of Particle Size	Classification	Phi Unit
<63µm	Silt/Clay	>4 Ø
63-125 µm	Very Fine Sand	4 Ø, 3.5 Ø
125-250 µm	Fine Sand	3 Ø, 2.5 Ø
250-500 µm	Medium Sand	2 Ø, 1.5 Ø
500-1000 µm	Coarse Sand	1 Ø, 1.5 Ø
1000-2000 µm (1 – 2mm)	Very Coarse Sand	0 Ø, -0.5 Ø
2000 – 4000 µm (2 – 4mm)	Very Fine Gravel	-1 Ø, -1.5 Ø
4000 -8000 µm (4 – 8mm)	Fine Gravel	-2 Ø, -2.5 Ø
8 -64 mm	Medium, Coarse & Very Coarse Gravel	-3 Ø to -5.5 Ø
64 – 256 mm	Cobble	-6 Ø to -7.5 Ø
>256 mm	Boulder	< -8 Ø

Since not all data is reported with a detailed PSD requires alternative sediment classification schemes to be considered. The Folk scheme offers a (semi-qualitative) description of sediment composition which is developed from the percentage contribution of muds, sands and gravels (Folk, 1954). To note, a particle size distribution adopting the Wentworth scale can be developed to a description of sediment composition based on Folk.

The Folk scheme is commonly used in regional interpretations of seabed sediments such as BGS 1:250,000 surficial sediment maps which adds a standard colour scheme (Long, 2006). Figure 2 presents the modified Folk classification scheme used by BGS based on 15 divisions. N.B. A further class 'rock & boulders' provides a total of 16 divisions.

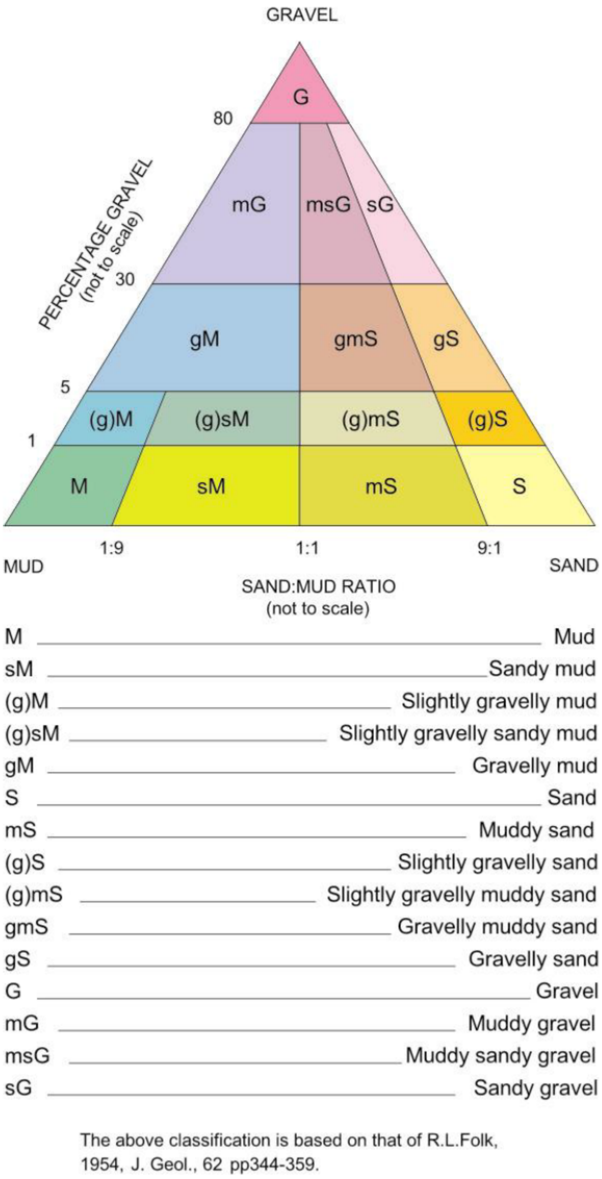
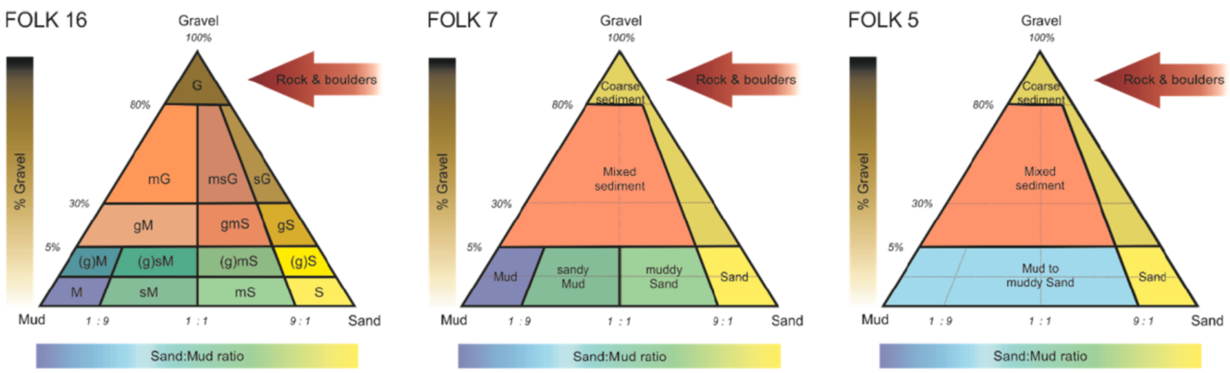


Figure 2: Folk (15 division) classification used on BGS 1:250,000 seabed sediment maps (Long, 2006).

Some datasets apply a reduced number of divisions and are referred to as Folk-7 or Folk-5 (Figure 3), or Folk-11. Whilst the downscaling step to lower divisions is straightforward the upscaling process introduces various assumptions which can be managed by referring to other available information and/or introducing appropriate conservatism.



FOLK, 16 classes	FOLK, 7 classes	FOLK, 5 classes
Rock & Boulders	Rock & Boulders	Rock & Boulders
Gravel - G sandy Gravel - sG) gravelly Sand - gS	Coarse sediment	Coarse sediment *(Gravel >= 80% or (Gravel >= 5% and Sand >=90%)*
muddy Gravel - mG muddy sandy Gravel - msG gravelly Mud - gM gravelly muddy Sand - gmS	Mixed sediment	Mixed sediment *(Mud 95-10%; Sand < 90%; Gravel >= 5%)*
(gravelly) Mud - (g)M Mud - M	Mud *(Mud >= 90%; Sand < 10%; Gravel < 5%)*	Mud to muddy Sand *(Mud 100-10%; Sand < 90%; Gravel < 5%)*
(gravelly) sandy Mud – (g)sM sandy Mud - sM	sandy Mud *(Mud 50-90%; Sand 10-50%; Gravel < 5%)*	
(gravelly) muddy Sand – (g)mS muddy Sand - mS	muddy Sand *(Mud 10-50%; Sand 50-90%; Gravel <5%)*	
(gravelly) Sand – (g)S Sand	Sand *(Mud < 10%; Sand >= 90%; Gravel < 5%)*	Sand

Figure 3: Relationship between Folk level 16, 7 and 5 (Kaskela, et al., 2019)

Other sediment classification schemes exist to inform seabed habitats, such as The European Nature Information System (EUNIS). This scheme describes seabed sediment as either rock, mud, sand and muddy sand, sand, mixed and coarse sediments according to different zones such as littoral, infralittoral, circalittoral and sublittoral. The EUNIS classification scheme can be associated with the Folk scheme (11 divisions) (Figure 4) but key differences also exist in the definition between muddy sand and sandy muds.

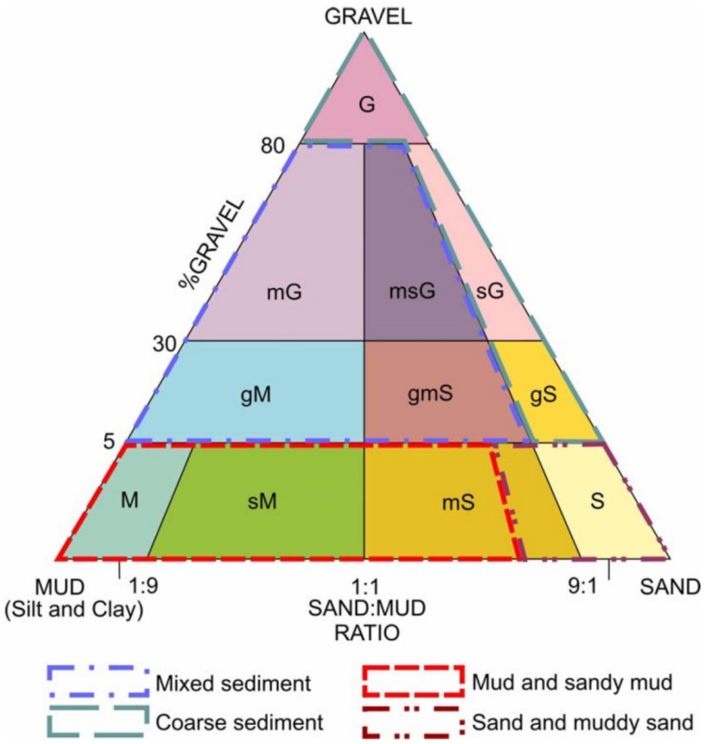


Figure 4: Association between Folk-11 and EUNIS (Long, 2006).

4. Quality score

The collated information to describe seabed sediments comes from a variety of sources, represents a variety of time periods and is presented in a variety of different classifications schemes. Inherently, the usability of information to establish modelling requirements is tied with these issues. A quality score is assigned to each dataset to recognise this usability which is summarised in Table 2.

Table 2: Quality score system

High	Medium	Low
Details can be applied directly	Details may require interpretation	Details may be unsuitable
Fully documented survey report	Partial documentation	No documentation
Fully resolved particle size distribution (resolved to Wentworth classes)	Limited particle size distribution (includes % mud, sand and gravel)	No particle size distribution (limited to a Folk classification)
Data less than 10 years old	Data older than 10 years	Data older than 20 years
Multiple samples across area of interest	Sparse distribution of samples, some beyond area of interest	Majority of samples outside area of interest
	Interpreted information (e.g. acoustic determination backed by ground truthing)	Interpreted information (acoustic determination without sufficient ground truthing)

The application of seabed sediment information follows this hierarchy with preference given to data with a quality score of high.

Importantly, when the datasets are considered as a whole this has the potential to elevate the value of a lower quality dataset when this data can be associated to the higher value information by spatial correlation. For example, a low scoring datasets adjacent to a high scoring dataset which has a full PSD with an equivalent sediment type implies the low scoring dataset is likely to have a comparable PSD.

5. Collation of baseline information

The seabed sediment data initially collated by GDGeo has been extended, updated and verified using additional information from the following sources;

a. Mapped interpretation of sediment type

Name: IE_GSI_MCU_SedimentClassification_WGS84

File: SedimentClassification_UpdatedApr2020.shp

Source: INFOMAR

URL: sediment classification

Classification schemes: Folk (5 parameter), EUNIS

Scale: Various (low to medium)

Date: 11 February 2020

Quality score: Medium

Description: This sediment classification map is a composite of various information taken at source scale, including INSS and INFOMAR. The data offers complete coverage over the project area and up to low water.

b. Grab samples - 1

Name: IE_GSI_MCU_GroundTruthing_WGS84

File: GroundTruthing_UpdatedApr2020.shp

Source: INFOMAR

URL:
https://secure.dccae.gov.ie/arcgis/rest/services/INFOMAR/IE_GSI_MCU_GroundTruthing_WGS84/MapServer

Classification schemes: Folk (16 parameter)

Scale: individual sites

Date (survey): 2nd to 7th June 2010

Quality score: Medium

Description: This dataset provides the basis of ground-truthing of the generalised sediment map (IE_GSI_MCU_SedimentClassification_WGS84). The original dataset includes a number of sites from Dublin City University (DCU) across Dublin Bay but they are not reported with a full set of attributes. This has been partly addressed here by drawing out applicable details from the associated cruise report (O'Reilly, Szpak, Monteys, & Kelleher, 2010) which are based on a qualitative description rather than a full particle size analysis.

c. Grab samples - 2

Name: n/a

File: Non-INFOMAR Samples_clipped.shp

Source: GSI

URL: n/a

Classification schemes: Folk (16 parameter)

Scale: individual sites

Date: 14th February 2012

Quality score: Low

Description:	This dataset was developed by GDGeo to complement the sediment grab samples from INFORMAR. Nine samples across the array area which apply the 16 parameter Folk scheme. There is no supporting documentation.

d. Grab samples - 3

Name:	n/a
File:	MV Kilquade1998.shp
Source:	Marine Institute
URL (report):	https://oar.marine.ie/handle/10793/212
Classification schemes:	Folk (16 parameter), % mud, sand and gravel
Scale:	individual sites
Date (survey):	3 to 10 November 1998
Quality score:	Medium
Description:	This clipped dataset provides 16 samples covering the array area and the offshore part of the export cable route to Poolbeg. The origins of this data are contained in Appendix II of Wheeler *et al*. (2000) which provides a total of 89 samples. The georeferencing of this data is unknown. The data has been reclassified for Dublin Array as there were errors in some of the original Folk codes.

e. Grab samples - 4

Name:	n/a
File:	Irish Sea Sandbanks.shp
Source:	National Parks & Wildlife Service
URL (report):	www.npws.ie/sites/default/files/publications/pdf/IWM29.pdf
Classification schemes:	Buchanan, Folk (16 parameter), % mud, sand and gravel
Scale:	individual sites
Date (survey):	31 May 2005
Quality score:	Medium
Description:	This dataset provides 11 samples covering Kish Bank and surrounding area. This is an updated version of 'Benthic 2005.shp' previously developed by GDGeo and with an revised definition to the Folk (16 parameter) classification.

f. Grab samples - 5

Name:	GeoIndex
File:	Geoindex.shp
Source:	BGS
URL (data):	http://mapapps2.bgs.ac.uk/geoindex_offshore/home.html

Classification schemes:	1.0 phi increments compatible with Buchanan, Folk (16 parameter), % mud, sand and gravel
Scale:	individual sites
Date (survey):	1980
Quality score:	Medium
Description:	This dataset is clipped for the area around Dublin Array and provides 7 samples surround Kish and Bray Bank from Cruise 1980/8. Two sites fall with the export cable corridors.

g. Grab samples - 6

Name:	Marine Ecological Assessment – Dublin Array Wind Farm
File:	aquafact sediment samples.shp
Source:	Aquafact
URL:	n/a
Classification schemes:	Buchanan, Folk (16 parameter)
Scale:	individual sites
Date (survey):	2008 (D1 to D12) and 2017 (D13 to D17)
Quality score:	High
Description:	Project survey of Dublin Array for Sarogus Ltd (Aquafact, 2018). This dataset provides 16 samples for the area around Dublin Array and for the export cable route (not Poolbeg option). D14 (close to landfall) returned cobbles and pebbles limiting a full particle size analysis.

h. Grab samples - 7

Name:	MMAH
File:	sediment samples psa.shp
Source:	National Parks & Wildlife Service / MERC Consultants
URL:	n/a
Classification schemes:	Buchanan, Folk (16 parameter) and %mud, sand and gravel.
Scale:	individual sites
Date (survey):	2016
Quality score:	Medium
Description:	Assembled from an MS-Access database and related Shapefiles to produce a dataset of 20 samples across Dublin Bay. The data was originally collected to help describe seabed substrate types for designated sites (North Dublin Bay and South Dublin Bay SAC).

5.1. Summary of data search

The result of the additional data collation is presented in Figure 6 which provides 15 samples across the Poolbeg export cable corridor, 25 for the two Shanganagh export cable corridors, 32 for Kish Bank and 11 for Bray Bank; a total of 83 grab samples (excluding sites outside of these areas). A single merged dataset is provided based on common attributes between the individual datasets. These data are illustrated using the Folk-16 sediment classification against the 2020 updated sediment map based on a Folk-5 parameter scheme (Figure 5).

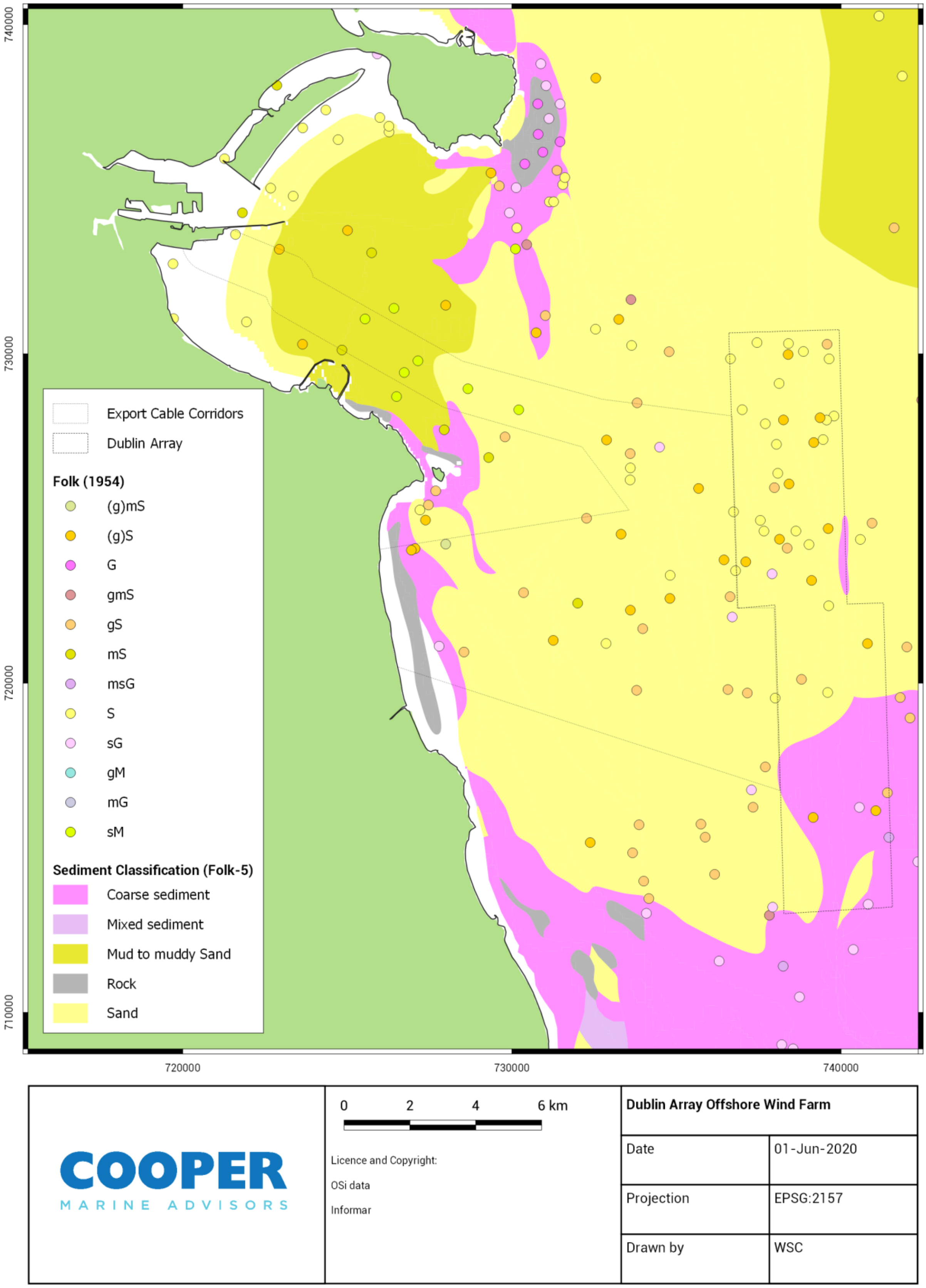


Figure 5: Seabed substrate mapping for Dublin Array.

6. Baseline description of the seabed

The baseline description of the seabed substrate can be interpreted from the collated information by considering the generalised mapping and adding a higher level of detail of local variability based on local sediment grab samples.

Kish Bank is mainly a sandy environment with a small amount of gravel in places. In comparison, Bray Bank appears to have slightly coarser sediment.

The export cable corridors for the two Shanganagh options cross into areas with coarser and mixed sediments, which in the lee of Sorrento Point shows higher amounts of silts and muds. In the very nearshore the seabed becomes rocky.

For the Poolbeg export cable route, the seabed initially shows a slightly higher gravel content than Kish Bank (sandy gravels and gravelly sands) which then demonstrates a slightly higher content of finer sediments (muddy sand and sandy mud) for the section across the major part of Dublin Bay.

7. References

Aquafact. (2018). *Marine Ecological Assessment. Dublin Array Wind Farm. JN1445.*

Buchanan, J. B. (1984). *Sediment analysis In: (eds.) Holme N. A. and A.D. McIntyre. Methods for the study of marine benthos 2nd ed. pp. 41-65.* Blackwell, Oxford.

Folk, R. L. (1954). The distinction between grain size and mineral composition in sedimentary-rock nomenclature. *Journal of Sedimentary Petrology, 62*, 344-359.

GDGeo. (2019). *Geophysical and Geotechnical Desk Study for Dublin Array Wind Farm. 18207. for Innogy Renewables Ireland Ltd.*

Kaskela, A. M., Kotilainen, A. T., Alanen, U., Cooper, R., Green, S., Guinan, J., . . . Stevenson, A. (2019). Picking Up the Pieces—Harmonising and Collating Seabed Substrate Data for European Maritime Areas. *Geosciences, 9*(84). doi:doi:10.3390/geosciences9020084

Long, D. (2006). *BGS detailed explanation of seabed sediment modified folk classification.*

O'Reilly, S. S., Szpak, M., Monteys, X., & Kelleher, B. P. (2010). *CV10_28 Cruise Report. 2nd June - 7th June 2010.*

Wentworth, C. K. (1922). A Scale of Grade and Class Terms for Clastic Sediments. *The Journal of Geology, 30*, 377-392.

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Appendix G

Spoil mound Analysis

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DUBLIN ARRAY - MARINE PROCESSES

ASSESSMENT OF SPOIL MOUNDS

Client: Intertek

Cooper Marine Advisors Ltd

August 2020

DUBLIN ARRAY - MARINE PROCESSES

ASSESSMENT OF SPOIL MOUNDS

Document control grid

This document has been prepared by Cooper Marine Advisors Ltd for Intertek to report on the review of baseline sediment data to support the marine processes assessment of Dublin Array.

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Approval	Bill Cooper W. Cooper

Contents

Preface

This technical note provides an assessment of near-field spoil mounds which are expected to develop when a trailer suction-hopper dredging discharges sediment across the two nominated spoil sites within the Dublin Array lease area. At this stage, the intended circulation of this technical note is the Project Team only.

Abbreviations

EMODnet	European Marine Observation and Data Network
LAT	Lowest Astronomical Tide
MSL	Mean Sea Level
OSP	Offshore Substation Platform
RWC	Realistic Worst-Case
STFATE	Short-Term FATE
TSHD	Trailer Suction Hopper Dredger
USACE	US Army Corp of Engineers
UTM	Universal Transverse Mercator
WTG	Wind Turbine Generator
WWTP	Waste Water Treatment Plant

1. Introduction

The marine processes realistic worst-case (RWC) assessment of Dublin Array has identified the use of a trailer suction hopper dredger (TSHD) for seabed preparation activities (sandwave clearance for inter-array and export cables, and seabed levelling at foundations) to lead to the highest risk of smothering of benthic receptors as a consequence of spoil disposal within nominated locations within the array lease area (Cooper Marine Advisors, 2020).

This report presents the assessment of near-field spoil disposal mounds for Dublin Array based on the realistic worst-case assumptions. This work partners with the modelling of sediment plumes related to the dredging activity.

1.1. Document structure

Section 2 describes the method of assessment for spoil mounds.

Section 3 provides details of each spoil disposal scenario and presents the results.

Section 4 provides an overview of the spoil mound assessment.

Section 5 lists the references related to this technical note.

2. Assessment of spoil mounds

2.1. Overview

Spoil mounds can form when a TSHD rapidly discharges a hopper load of coarse sediments which fall to quickly to the seabed in the active phase of disposal due to a negatively buoyant density flow. The coarser sediment may have limited capacity to be moved on by the ambient flows and the mound remains as a semi-permanent feature subject to a slow rate of re-mobilisation. In some situations, multiple phases of spoil disposal across a defined area may overlap and gradually redefine the profile of the seabed over such an area unless onward sediment transport can move the material away.

2.2. Approach

The STFATE (Short-Term FATE) model for split barge and hopper dredge disposal operations of dredged material disposal in open water (USACE, 1995) is applied to assess individual discharges from a TSHD at two locations within the Dublin Array.

The primary inputs to the model are the water depth and flow conditions at the location of the spoil sites along with the volume and type of sediment being disposed of. STFATE also allows for the spoil to be described with up to four different particle sizes with associated values for specific gravity, fall velocity and deposition voids ratio. A specific gravity of 2.65 is applied for all fractions in this case. The model also accounts for the basic dimensions of the TSHD.

The definition of particle sizes are aligned to the sediment gradings information used to establish the realistic worst-case for sediment disturbance issues (i.e. sandwave clearance and seabed levelling). Table 1 summarises the properties of the various particle sizes applied in STFATE which focuses on sediment fractions that fall rapidly to the seabed with limited opportunity for wider dispersion at the time of release. Fine sand, very fine sand and silt fractions are represented separately in the sediment plume dispersion model since these sediment sizes have slower settling velocities and remain subject to advection and dispersion from the point of release with tidal flows.

Table 1. Representative sediment types, settling velocities and deposition voids ratio

Sediment type / aggregate name	Size range (mm)	Representative size (mm)	Settling velocity (m/s)	Deposition void ratio
Very fine gravel	2.000 to 4.000	3.000	0.216	0.5
Very coarse sand	1.000 to 2.000	1.500	0.147	0.5
Coarse sand	0.500 to 1.000	0.750	0.093	0.55
Medium sand	0.250 to 0.500	0.375	0.049	0.6

2.3. Indicative spoil disposal sites

There are two indicative locations being considered for spoil disposal within the lease area of Dublin Array. The northern site is located on the western flank of Kish Bank and the southern site on the western flank of Bray Bank.

2.3.1. Northern disposal site

The northern disposal site covers an area of approximately 1.79 km² with water depths varying from around 11 to 19 m below LAT (Figure 1). Sections of inter-array, OSP and export cables pass through the site as well as the indicative location of WTG-20 (45 WTG option).

The mapped sediment type across the site is sand (Source: EMODnet Geology) with grab samples KB85 and KB10 indicating slightly gravelly sand and gravelly sand, respectively. Medium sands appear to be the dominant particle size.

An indicative location central to the disposal site is used to help characterise the fate of spoil disposal; 704,800 N 5,904,800 N (UTM 29N). Depths at this location are around 14.5 m below LAT (Figure 1). Whilst the flanks of the sandbank appear relatively featureless there is evidence of sandwaves on the top of the bank as well as at the base of the bank.

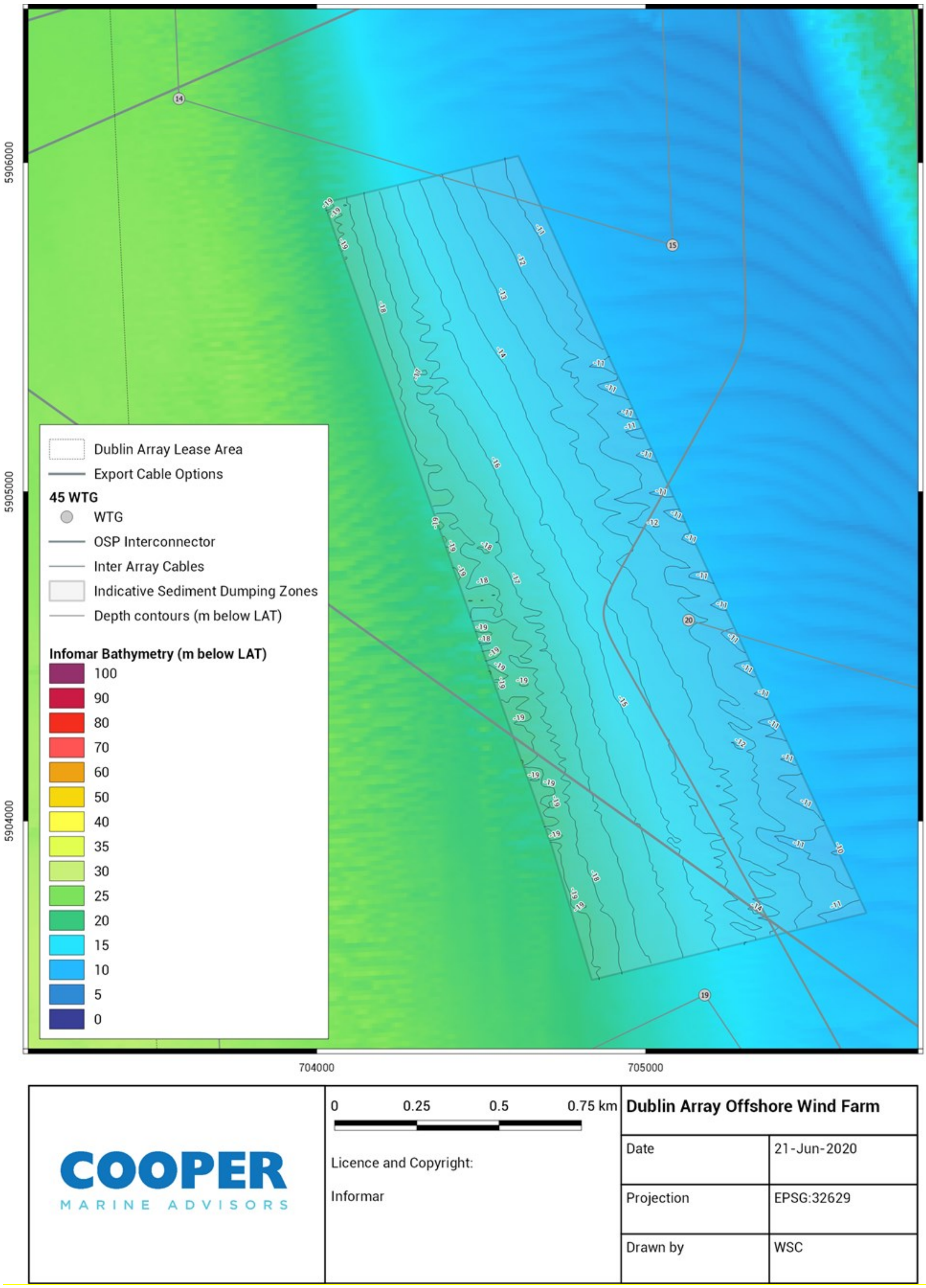

Figure 1. Water depth across northern disposal site.

A typical seven day spring to neap tidal variation (predicted by the hydrodynamic model) is shown for this location (Figure 2). For this period, the spring tidal range is around 3.84 m and for the neap period this reduces to around 1.85 m. Peak flows occur on the flood tide and vary from around 0.96 m/s on springs to 0.58 m/s on neaps. Corresponding peak ebb flows are 0.71 m/s and 0.47 m/s, respectively. The asymmetry between flood and ebb peak flows is an important process for driving net sediment transport pathways in a clockwise direction around the bank for those sediments which can be mobilised by these flow speeds. These conditions are expected to be similar across the disposal site with some variation due to water depth.

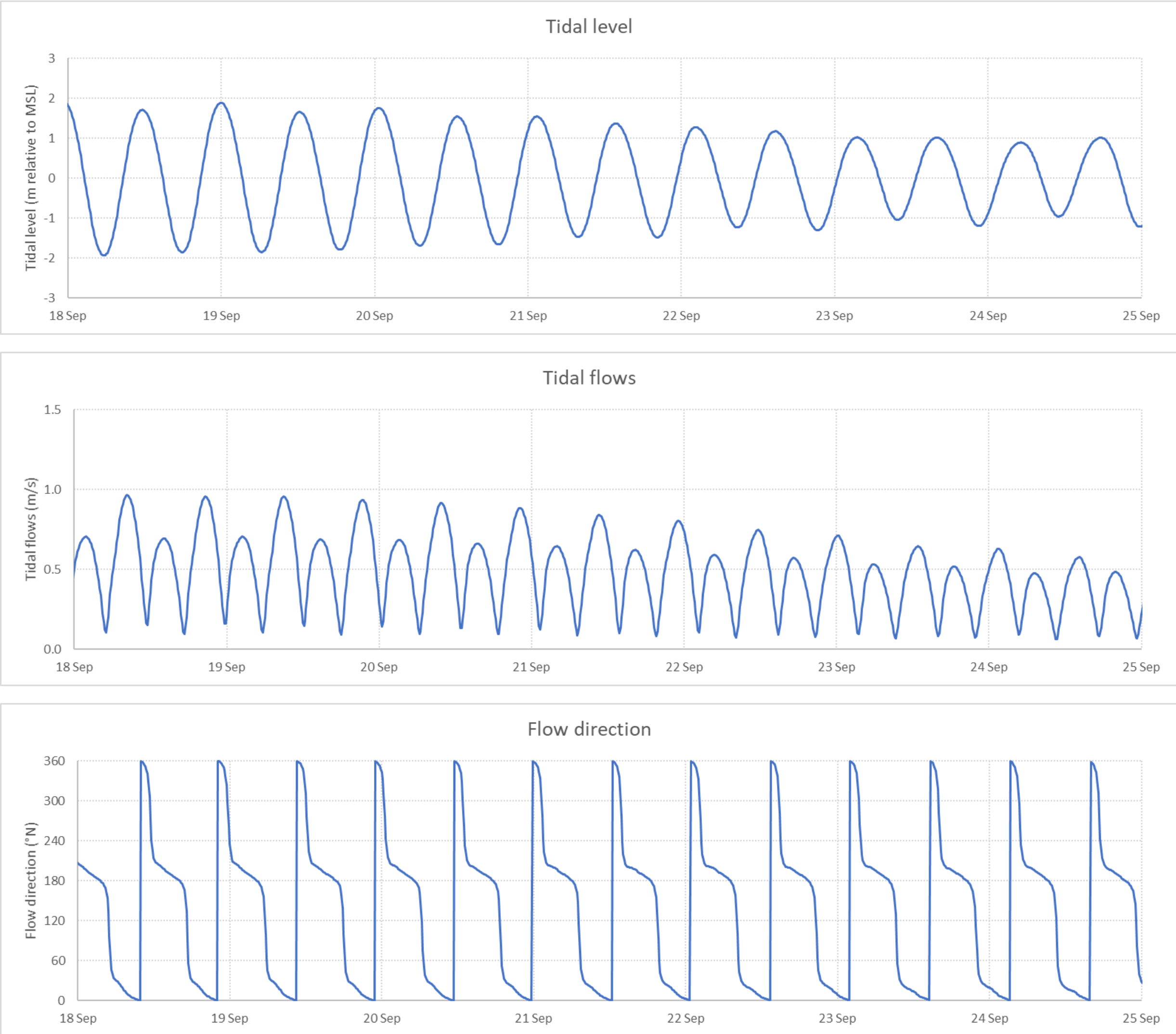

Figure 2. Predicted tidal conditions at the northern spoil site.

A preliminary assessment of sediment mobility is provided for the representative coarse grained sediments which is based on predicted water depths and peak flow speeds at the northern disposal site. Table 2 summarises when sediment transport is predicted for each grain size and differentiated between peak flood and peak ebb for spring and neap tides. Mobility is assessed for all sediment transport formulae provided in the 1-D model Sedtrans05 (Neumeier, Ferrarin, Amos, Umgiesser, & Li, 2008).

Table 2. Review of sediment mobility at northern spoil site.

Sediment type	Representative grain size (mm)	Spring		Neap	
		Peak Flood	Peak Ebb	Peak Flood	Peak Ebb
Fine gravel	3.00	No	No	No	No
Very coarse sand	1.50	Yes	No	No	No
Coarse sand	0.75	Yes	Yes	No	No
Medium sand	0.375	Yes	Yes	Yes	No

Based on this preliminary assessment then sediments represented by fine gravel (or greater) are not likely to be mobilised by tidal flows at any time. In contrast, peak flood flows on the spring tide present the highest transport rate for medium sands and are the only tidal condition with the capacity to also form current induced bedforms up to the size of sandwaves when this sized sediment is the dominant sediment type (Li & Amos, 1998).

2.3.2. Southern disposal site

The southern disposal site covers an area of approximately 1.38 km² with water depths also varying from around 11 to 19 m below LAT (Figure 3). Sections of inter-array and export cables pass through the site but without any WTG (45 WTG option).

The mapped sediment type across the site is sand (Source: EMODnet Geology) with grab sample IE003000_G9 indicating gravelly sand.

An indicative location central to the disposal site is used to help characterise the fate of spoil disposal; 705,750 N 5,900,050 N (UTM 29N). Depths at this location are around 13.7 m below LAT (Figure 3). In comparison to the northern disposal site, this location appears relatively featureless with no distinctive sandwaves.

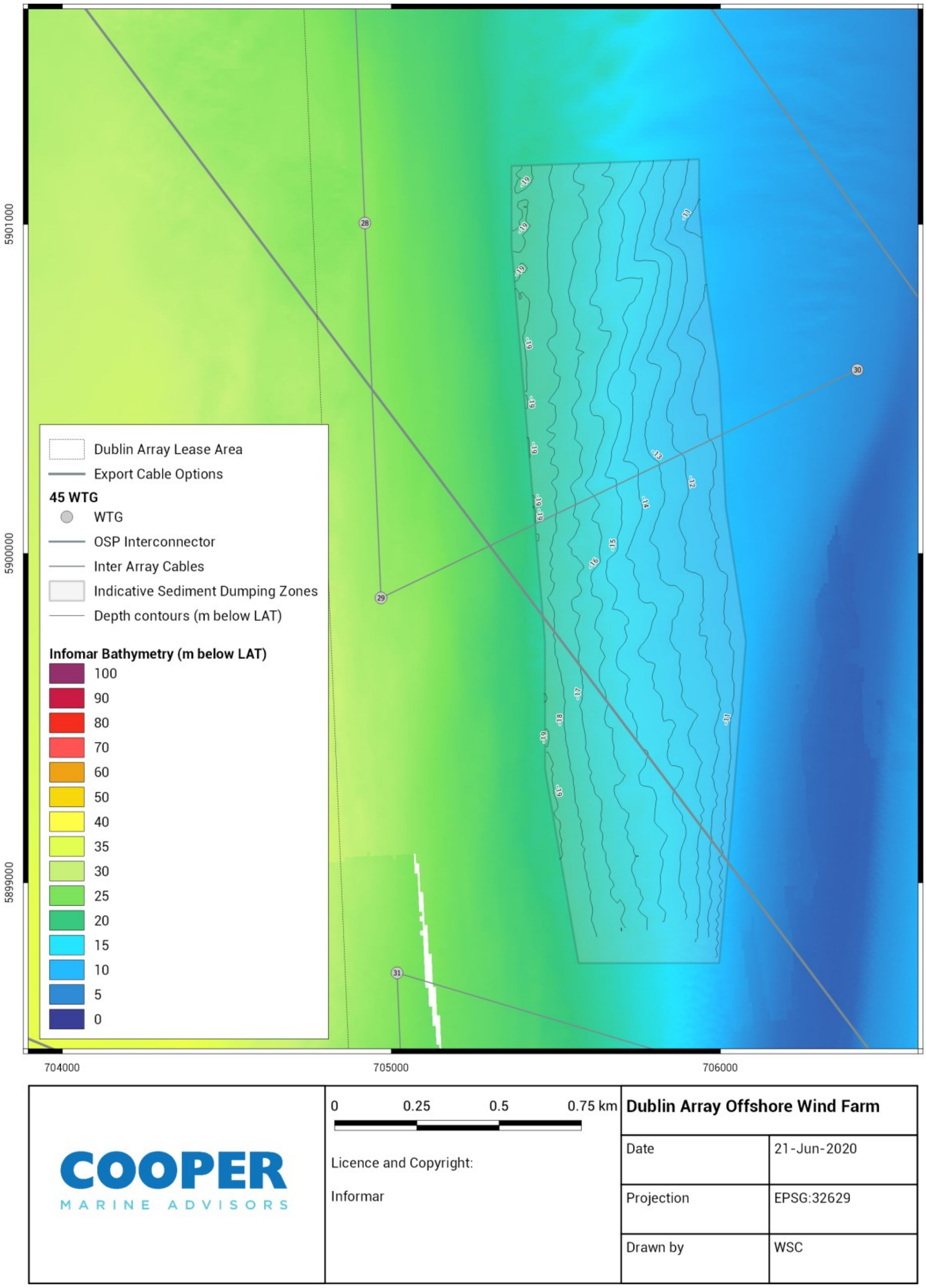

Figure 3. Water depth across southern disposal site.

A typical seven day spring to neap tidal variation (predicted by the hydrodynamic model) is shown for this location (Figure 4). For this period, the spring tidal range is around 3.69 m and for the neap period this reduces to around 1.77 m. The tidal range across Bray Bank is slightly less than for Kish Bank due to the relatively shorter distance from the degenerate amphidrome to the south. The slightly lower tidal range has an associated affect on peak tidal flows which are around 0.88 m/s on springs to 0.57 m/s on neaps. The northerly flood tide again appears to be dominant over the southerly ebb which is an important process for driving net sediment transport pathways in a clockwise direction around the bank for those sediments which can be mobilised by these flow speeds. These conditions are expected to be similar across the disposal site with some variation due to water depth.

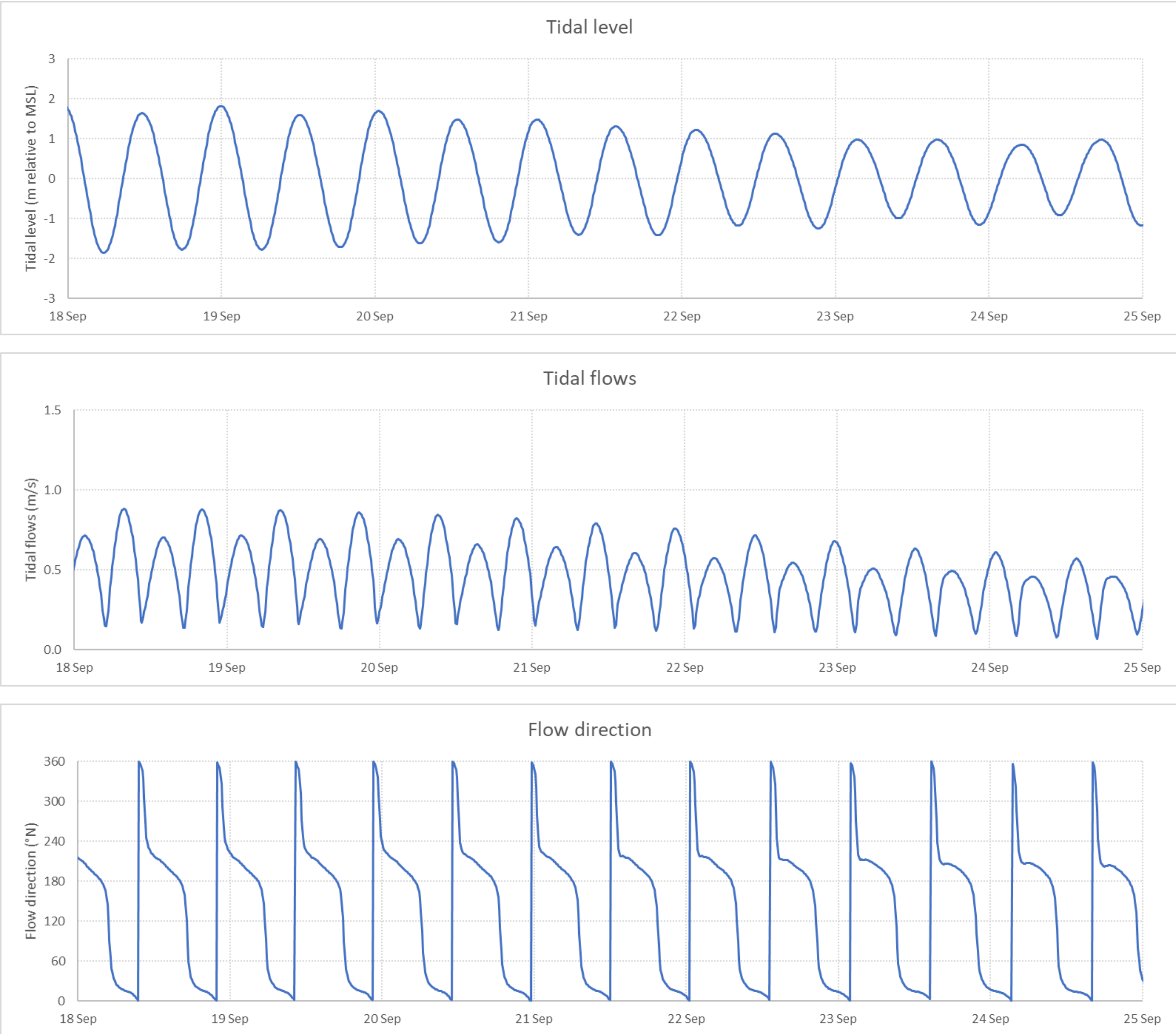

Figure 4. Predicted tidal conditions at the southern spoil site.

A preliminary assessment of sediment mobility is provided for the representative coarse grained sediments which is based on predicted water depths and peak flow speeds at the southern disposal site. Table 3 summarises when sediment transport is predicted for each grain size and differentiated between peak flood and peak ebb for spring and neap tides. Mobility is assessed for all sediment transport formulae provided in the 1-D model Sedtrans05 (Neumeier, Ferrarin, Amos, Umgiesser, & Li, 2008).

Table 3. Review of sediment mobility at southern spoil site.

Sediment type	Representative grain size (mm)	Spring		Neap	
		Peak Flood	Peak Ebb	Peak Flood	Peak Ebb
Fine gravel	3.00	No	No	No	No
Very coarse sand	1.50	No	No	No	No
Coarse sand	0.75	Yes	Yes	No	No
Medium sand	0.375	Yes	Yes	Yes	No

Based on this preliminary assessment then sediments represented by very coarse sand (or greater) are unlikely to be mobilised by tidal flows at any time. In contrast, peak flood flows on the spring tide present the highest transport rate for medium sands and are the only tidal condition with the capacity to also form current induced bedforms up to the size of sandwaves when this sized sediment is the dominant sediment type (Li & Amos, 1998).

3. Scenarios and results

3.1. Seabed preparation around foundations

Spoil disposal from seabed preparation (levelling around foundations) will most likely utilise the northern disposal site for seabed preparations for foundations located close to Kish Bank and the southern site for foundations associated with Bray Bank.

3.1.1. Northern disposal site

A generalised description of the sediment grain size distribution involved in seabed preparation is developed for the RWC (Cooper Marine Advisors, 2020) which indicates fine sands as the dominant sediment type for sites on Kish Bank. This sediment fraction (and finer fractions) is likely to advect and disperse away from the release location as a sediment plume with the coarser fractions (medium sands and larger) falling quickly to the seabed.

Based on a TSHD capacity of 11,000 m^3, a loading cycle for clearing up to two foundation sites at a time each requiring an *in situ* removal of up to 3,675 m^3 and assuming a bulking factor of 1.3 when the sediment fills the hopper, with an overspill loss of 5% of finer sized sediments, means that the total bulked up volume of sediment (and water) per cargo would be estimated as 9,077 m^3 (82.5% full hopper). N.B. the equivalent un-bulked volume would be 6,983 m^3. This volume can be apportioned to the corresponding sediment gradings distribution related to the locations of seabed levelling, Table 4.

Table 4. Representative sediment volumes by grain size for seabed levelling across Kish Bank.

Sediment type / aggregate name	**Hopper load (m^3)**	**Fate**
Very fine gravel	398	Seabed mound
Very coarse sand	202	Seabed mound
Coarse sand	92	Seabed mound
Medium sand	246	Seabed mound
Fine sand	5,505	Sediment plume
Very fine sand	520	Sediment plume
Silt / Clay	20	Sediment plume
Total volume	**6,893**	

Given there are 21 WTG foundations on Kish Bank, plus smaller volumes required for seabed levelling at up to two OSP, leads to an estimate for 12 dredging and disposal cycles. These disposals have an equal probability to occur on any phase of tide and tidal range.

The expected realistic worst-case result for a maximum depth of deposition is when the release occurs towards low water slack tide on spring tides which provides the shortest distance to the seabed and the least chance for any (partial) advection of disposal during descent to the seabed from the hopper.

The expected realistic worst-case for areas covered by the spoil is during the peak flood tide on spring tides when some of the material (medium sands) may have the chance to advect during descent to the seabed from the hopper, with the coarsest material (very fine gravels and larger) largely falling direct to the seabed.

Table 5 provides summary details for spoil mounds based on the greatest depth and largest area covered by a single spoil mound depending on the state of tide at the time of disposal. The areas covered are defined above a threshold of 0.05 and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels (Tyler-Walter, Tillin, d'Avack, Perry, & Stamp, 2018).

Table 5. Summary of spoil mound dimension for the northern disposal area from seabed levelling (single disposal) on Kish Bank.

Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
Slack tide, low water	1.77	1,045	581
Peak flood	0.84	2,032	639

Figure 5 and Figure 6 present a 3D view of the spoil mound relative for the slack water and peak flood cases, repsectively, using a fixed horizontal and vertical scale to provide a basis of comparsion (all dimensions are in feet). The spoil mound for the peak flood case shows some separation between a small gravel and coarse sand mound and larger mound of medium sands.

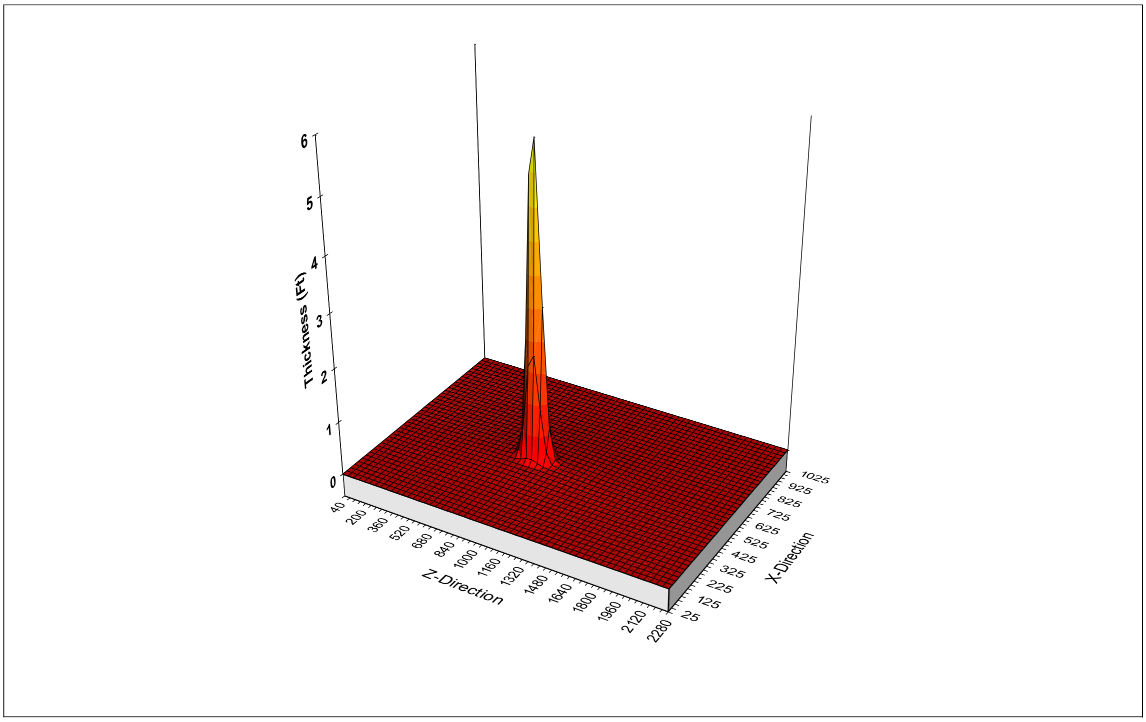

Figure 5. Slack tide low water, spring tide, northern disposal site, seabed levelling across Kish Bank.

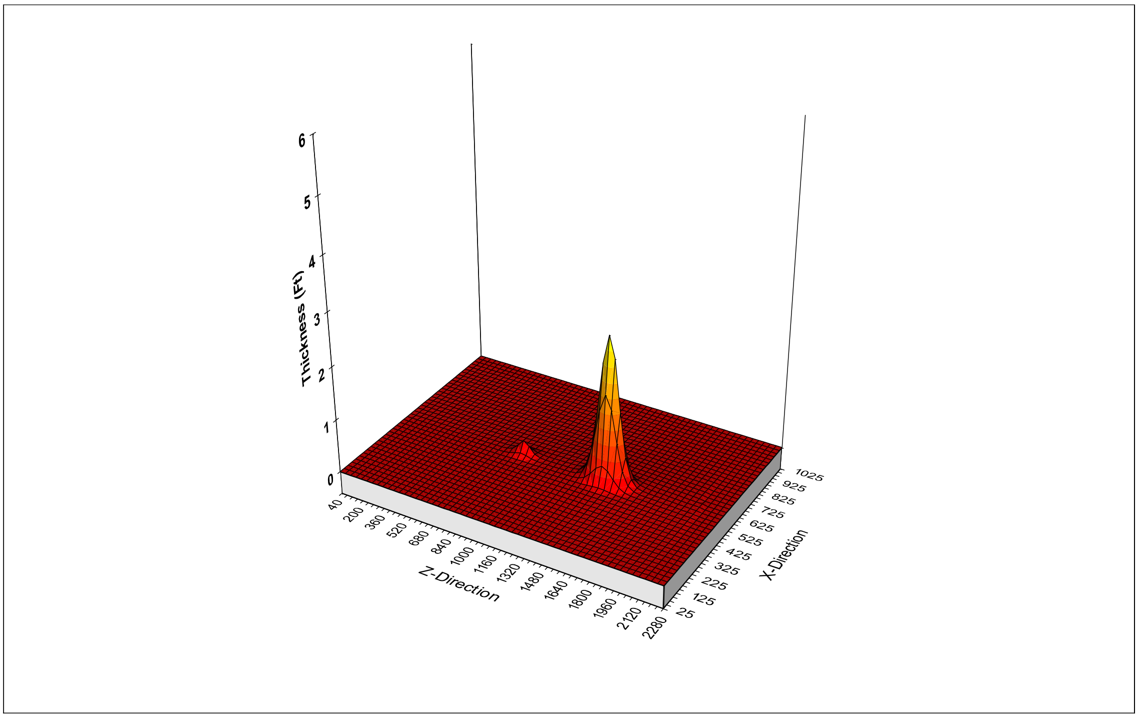

Figure 6. Peak flood, spring tide, northern disposal site, seabed levelling across Kish Bank.

3.1.2. Southern disposal site

A generalised description of the sediment grain size distribution involved in seabed preparation is developed for the RWC (Cooper Marine Advisors, 2020) which indicates very fine gravel as the dominant sediment type for sites on Bray Bank. The finer sediment fractions are likely to advect and disperse away from the release location as a sediment plume with the coarser fractions (medium sands and larger) falling quickly to the seabed.

Based on a TSHD capacity of 11,000 m^3, a loading cycle for clearing up to two foundation sites at a time each requiring an *in situ* removal of up to 3,675 m^3 and assuming a bulking factor of 1.3 when the sediment fills the hopper, with an overspill loss of 5% of finer sized sediments, means that the total bulked up volume of sediment (and water) per cargo would be estimated as 9,077 m^3 (82.5% full hopper). N.B. the equivalent un-bulked volume would be 6,983 m^3. This volume can be apportioned to the corresponding sediment gradings distribution related to the locations of seabed levelling, Table 6.

Table 6. Representative sediment volumes for seabed levelling across Bray Bank.

Sediment type / aggregate name	**Hopper load (m^3)**	**Fate**
Very fine gravel	2,454	Seabed mound
Very coarse sand	509	Seabed mound
Coarse sand	548	Seabed mound
Medium sand	1,546	Seabed mound
Fine sand	1,757	Sediment plume
Very fine sand	134	Sediment plume
Silt / Clay	34	Sediment plume
Total volume	**6,893**	

Given there are 20 WTG foundations on Bay Bank, plus smaller volumes required for seabed levelling at a met mast and OSP, leads to an estimate for 11 dredging and disposal cycles. These disposals have an equal probability to occur on any phase of tide and tidal range.

The expected realistic worst-case result for a maximum depth of deposition is when the release occurs towards low water slack tide on spring tides which provides the shortest distance to the seabed and the least chance for any (partial) advection of disposal during descent to the seabed from the hopper.

The expected realistic worst-case for areas covered by the spoil is during the peak flood tide on spring tides when some of the material (medium sands) may have the chance to advect during descent to the seabed from the hopper, with the coarsest material (very fine gravels and larger) largely falling direct to the seabed.

Table 7 provides summary details for spoil mounds based on the greatest depth and largest area covered by a single spoil mound depending on the state of tide at the time of disposal. The areas covered are defined above a threshold of 0.05 and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels (Tyler-Walter, Tillin, d'Avack, Perry, & Stamp, 2018).

Table 7. Summary of spoil mound dimension for southern disposal area from seabed levelling (single disposal) on Bray Bank

Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
Slack tide, low water	0.70	20,148	4,355
Peak flood	0.52	23,690	3,252

Figure 7 and Figure 8 present a 3D view of the spoil mound relative for the slack water and peak flood cases, repsectively, using a fixed horizontal and vertical scale to provide a basis of comparsion (all dimensions are in feet). The spoil mound for the peak flood case shows some separation between a small gravel and coarse sand mound and larger mound of medium sands.

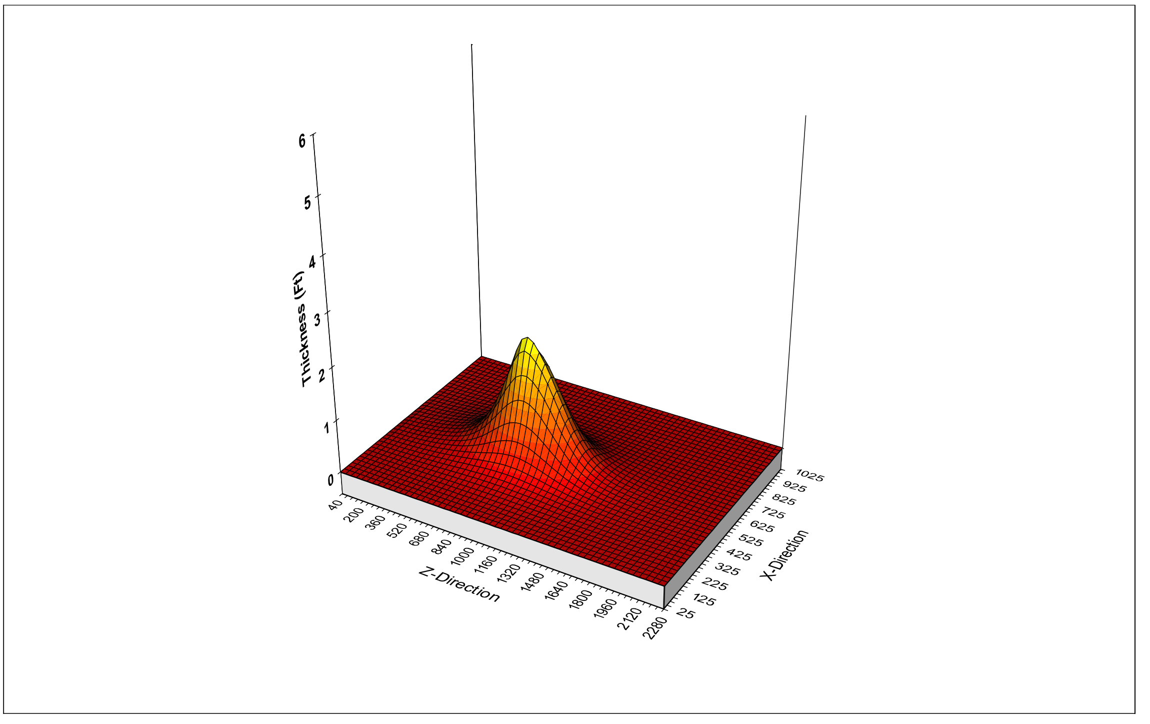

Figure 7. Slack tide low water, spring tide, southern disposal site, seabed levelling across Bray Bank.

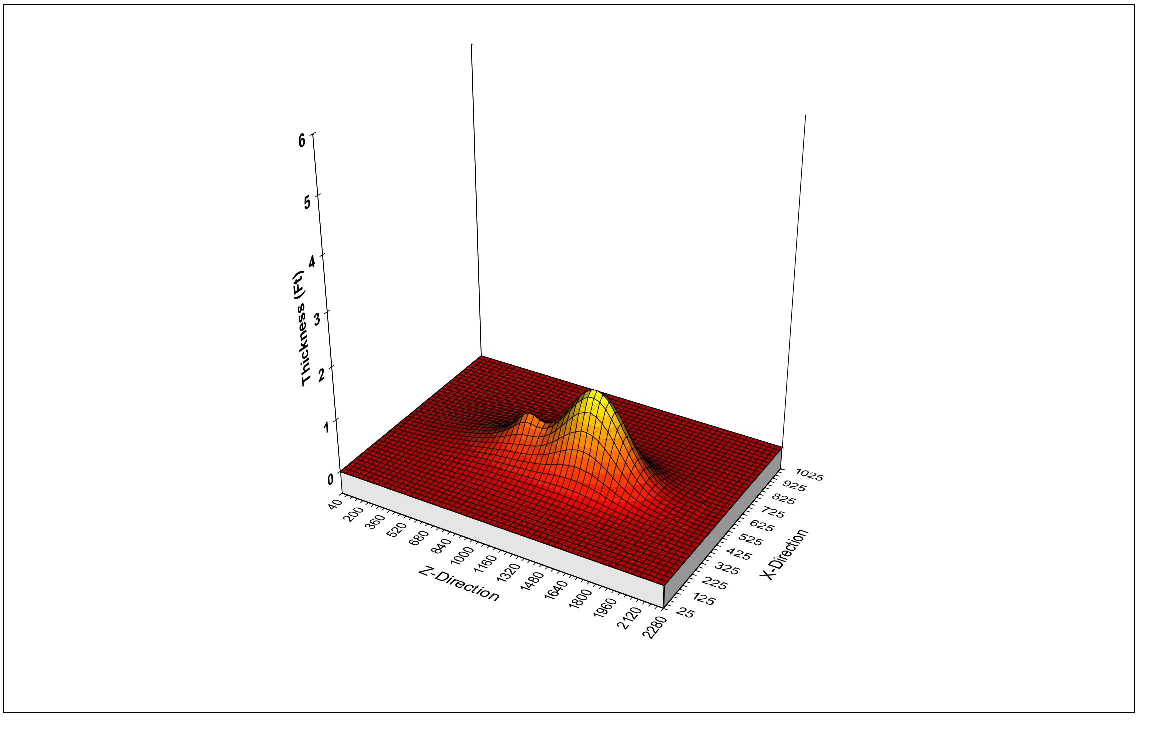

Figure 8. Peak flood, spring tide, southern disposal site, seabed levelling across Bray Bank.

The larger areas covered by spoil mounds for the southern disposal site are due to the higher proportion of coarser sediments represented in the spoil which falls to the bed to form a larger mound when compared to equivalent disposals at the northern site.

Table 2 and Table 3 indicate that the gravels in the spoil mounds are unlikely to be mobilised by peak flows and this sized sediment, when present, will most likely remain in place.

3.2. Pre (installation) of cable routes

Sweeping is required to remove steep sandwaves which may restrict use of some cable laying equipment. By definition the material type involved in sweeping a sandwave is mainly sand-sized (medium and fine) sediment. Sandwave clearance is planned for sections of the inter-array, inter-platform and export cables with sea disposal from TSHD planned for northern and southern disposal sites which are likely to be selected according to the closest transit times from areas being dredged.

3.2.1. Northern disposal site

A generalised description of the sediment grain size distribution involved in sweeping of sandwaves is developed for the RWC (Cooper Marine Advisors, 2020) which indicates fine and medium sands are the dominant sediment type for sites on Kish Bank. This sediment fraction (and finer fractions) is likely to advect and disperse away from the release location as a sediment plume with the coarser fractions (medium sands and larger) falling quickly to the seabed.

Based filling a TSHD with a capacity of 11,000 m^3, assuming a bulking factor of 1.2 when the sediment fills the hopper, and with an allowance for 5% overspill loss of finer sized sediments, means that the total volume of *in situ* sediment per cargo would be estimated as 9,160 m^3. This volume can be apportioned to the corresponding sediment gradings distribution related to the locations of seabed levelling, Table 8.

Table 8. Representative sediment volumes for sandwave clearance across Kish Bank.

Sediment type / aggregate name	Hopper load (m^3)	Fate
Very fine gravel	110	Seabed mound
Very coarse sand	175	Seabed mound
Coarse sand	236	Seabed mound
Medium sand	3,673	Seabed mound
Fine sand	4,706	Sediment plume
Very fine sand	246	Sediment plume
Silt / Clay	14	Sediment plume
Total volume	**9,160**	

The maximum volume for sandwave clearance of 9,366,000 m^3 across the array would require around 971 hopper loads for disposal with these being shared between the northern and southern disposal sites. These disposals have an equal probability to occur on any phase of tide and tidal range.

The expected realistic worst-case result for a maximum depth of deposition is when the release occurs towards low water slack tide on spring tides which provides the shortest distance to the seabed and the least chance for any (partial) advection of disposal during descent to the seabed from the hopper.

The expected realistic worst-case for areas covered by the spoil is during the peak flood tide on spring tides when some of the material (medium sands) may have the chance to advect during descent to the seabed from the hopper, with the coarsest material (very fine gravels and larger) largely falling direct to the seabed.

Table 9 provides summary details for spoil mounds based on the greatest depth and largest area covered by a single spoil mound depending on the state of tide at the time of disposal. The areas covered are defined above a threshold of 0.05 and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels (Tyler-Walter, Tillin, d'Avack, Perry, & Stamp, 2018).

Table 9. Summary of spoil mound dimension for the northern disposal area from sandwave clearance (single disposal) on Kish Bank.

Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
Slack tide, low water	0.98	14,864	7,084
Peak flood	0.91	15,039	6,445

Figure 9 and Figure 10 present a 3D view of the spoil mound relative for the slack water and peak flood cases, repsectively, using a fixed horizontal and vertical scale to provide a basis of comparsion (all dimensions are in feet). The spoil mound for the peak flood case shows some separation between a small gravel and coarse sand mound and larger mound of medium sands.

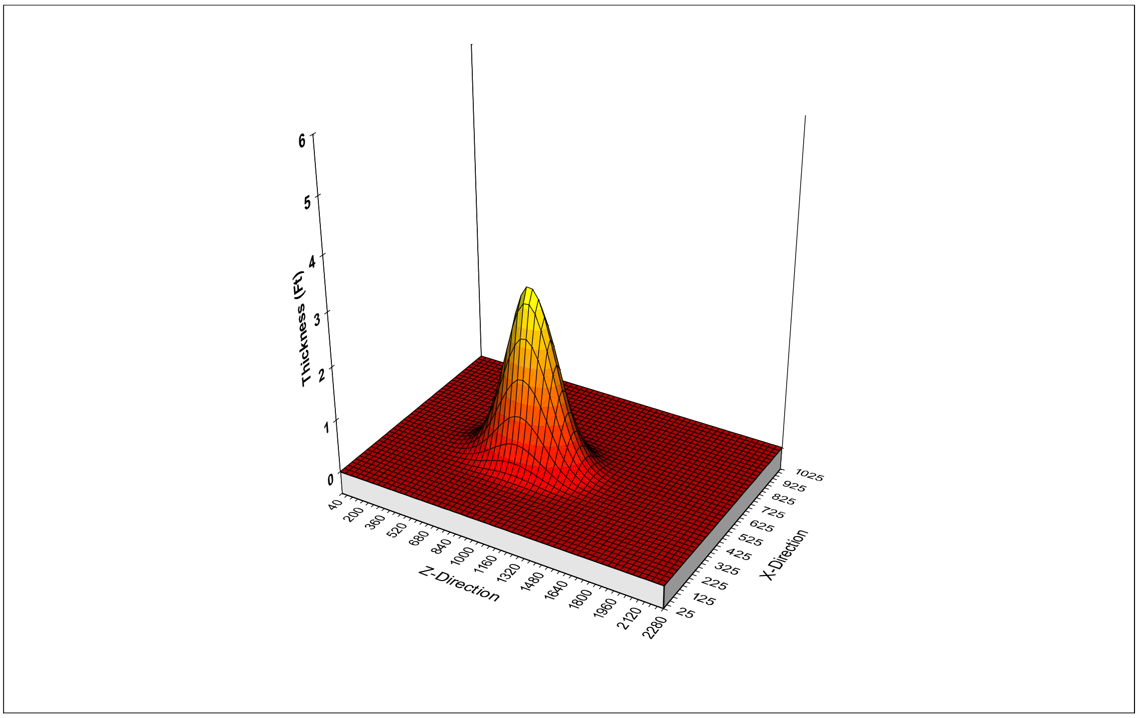

Figure 9. Slack tide low water, spring tide, northern disposal site, sandwave clearance across Kish Bank.

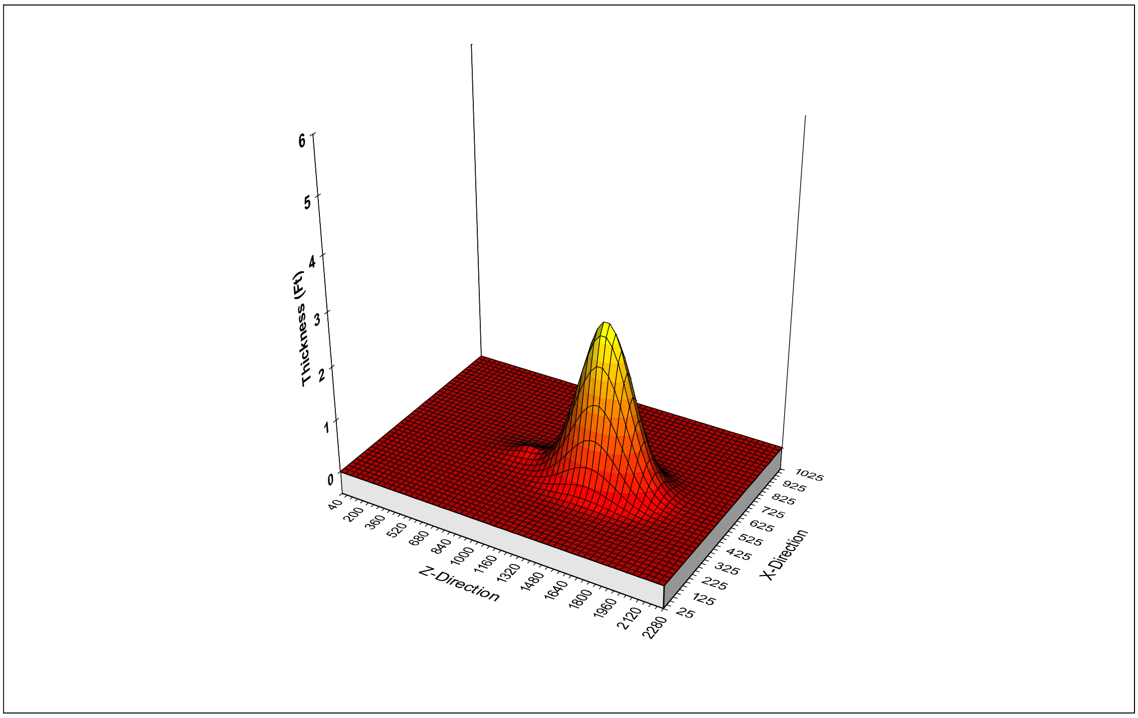

Figure 10. Peak flood, spring tide, northern disposal site, sandwave clearance across Kish Bank.

3.2.2. Southern disposal site

A generalised description of the sediment grain size distribution involved in sweeping of sandwaves is developed for the RWC (Cooper Marine Advisors, 2020) which indicates fine sands are the dominant sediment type for sites on Bray Bank. This sediment fraction (and finer fractions) is likely to advect and disperse away from the release location as a sediment plume with the coarser fractions (medium sands and larger) falling quickly to the seabed.

Based filling a TSHD with a capacity of 11,000 m^3, assuming a bulking factor of 1.2 when the sediment fills the hopper, and with an allowance for 5% overspill loss of finer sized sediments, means that the total volume of *in situ* sediment per cargo would be estimated as 9,162 m^3. This volume can be apportioned to the corresponding sediment gradings distribution related to the locations of seabed levelling,

Table 10.

Table 10. Representative sediment volumes for sandwave clearance across Bray Bank.

Sediment type / aggregate name	Hopper load (m^3)	Fate
Very fine gravel	5	Seabed mound
Very coarse sand	19	Seabed mound
Coarse sand	63	Seabed mound
Medium sand	2,070	Seabed mound
Fine sand	6,978	Sediment plume
Very fine sand	27	Sediment plume
Silt / Clay	0	Sediment plume
Total volume	**9,162**	

Table 11 provides summary details for spoil mounds based on the greatest depth and largest area covered by a single spoil mound depending on the state of tide at the time of disposal. The areas covered are defined above a threshold of 0.05 and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels (Tyler-Walter, Tillin, d'Avack, Perry, & Stamp, 2018).

Table 11. Summary of spoil mound dimension for southern disposal area from sandwave clearance (single disposal) on Bray Bank

Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
Slack tide, low water	0.77	9,232	4,123
Peak flood	0.75	9,232	4,123

Figure 11 and Figure 12 present a 3D view of the spoil mound relative for the slack water and peak flood cases, repsectively, using a fixed horizontal and vertical scale to provide a basis of comparsion (all dimensions are in feet). The spoil mound for the peak flood case shows some separation between a small gravel and coarse sand mound and larger mound of medium sands.

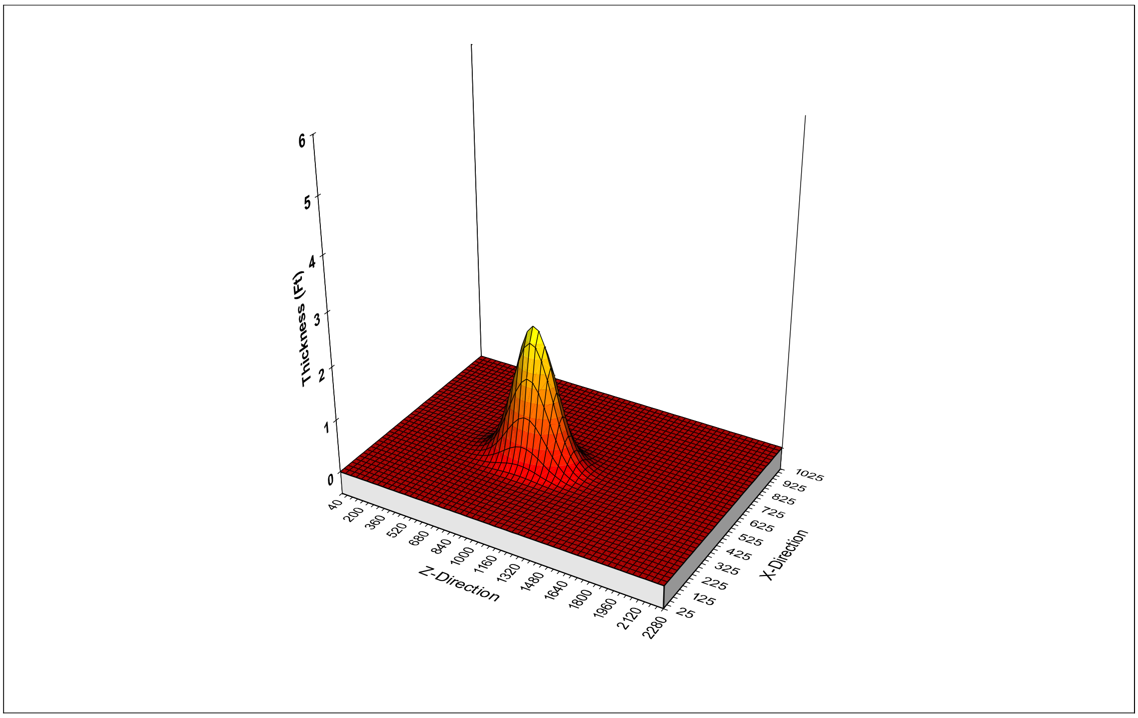

Figure 11. Slack tide low water, spring tide, southern disposal site, sandwave clearance across Bray Bank.

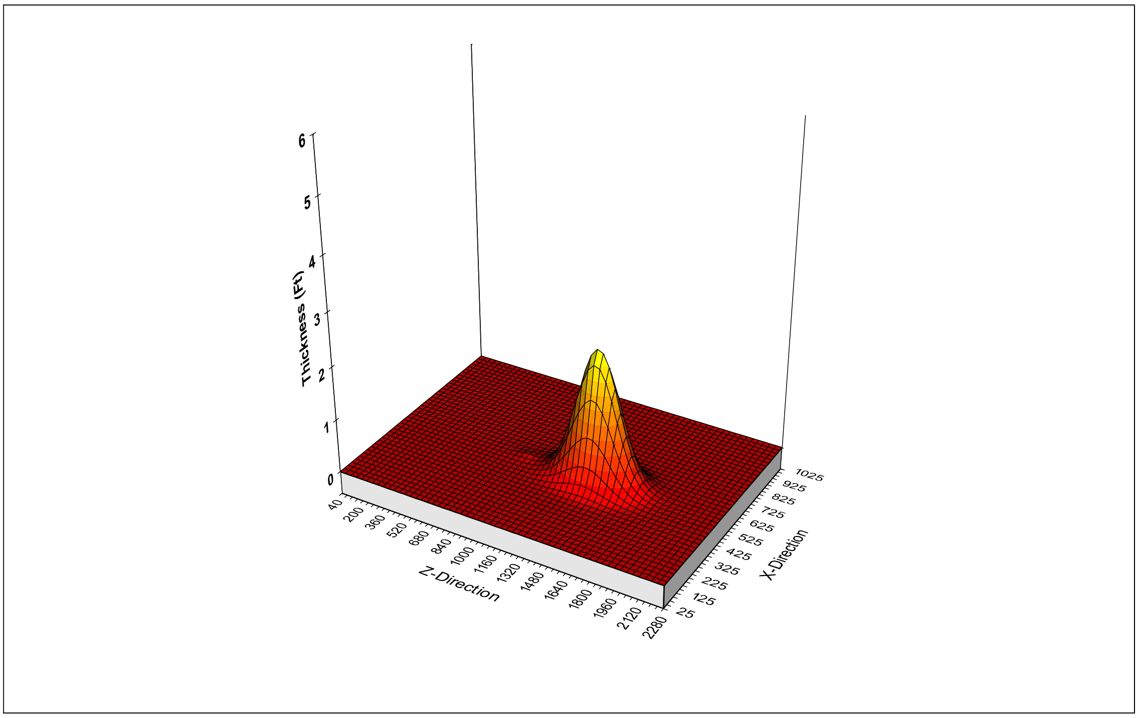

Figure 12. Peak flood, spring tide, southern disposal site, sandwave clearance across Bray Bank.

Although the areas covered by spoil mounds for slack water and peak flood appear identical there is a displacement of the centre of the mound for the peak flood scenario to the north by around 90 m.

Table 2 and Table 3 indicate that the medium sands in the spoil mounds are mobile during times of peak flows on spring tides as well as the peak flood tide during neaps which suggests these mounds would winnow away as part of the general sediment transport regime.

3.2.3. Export cable sandwave clearance

The RWC for sandwave clearance for the export cable route is assessed in Cooper Marine Advisors (2020) as sections extending from north, central and south OSP which utilise two landfall locations; Poolbeg and Shanganagh WWTP (Figure 13). This scenario involves sandwave clearance along Sections 5, 8, 11, 12 and 13. Only material from Section 8 is likely to be taken to the southern disposal site since all other sections are closer to the northern disposal site. A total sweeping volume of 3,202,553 m^3 is estimated which would equate to around 291 cargoes for an 11,000 m^3 TSHD and a bulking factor of 1.2.

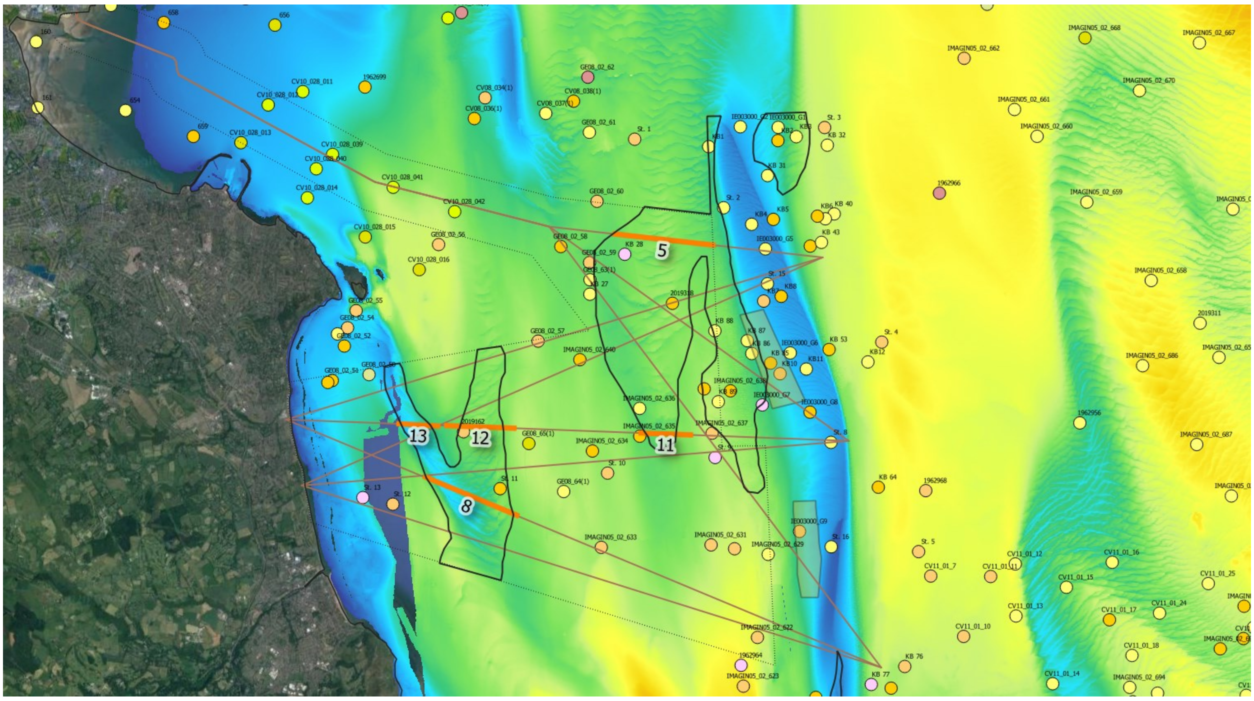

Figure 13. RWC option for sandwave clearance along the export cable routes (Cooper Marine Advisors, 2020).

Section 5 is expected to encounter relatively high proportions of coarse sediments (medium sized sand and larger represented by grab sample St 1) with this material being taken to the northern disposal site. Section 8 is also likely to encounter a high proportion of coarser sediment with this material likely to be taken to the southern disposal site. These two scenarios are considered further for potential spoil mounds.

a. Section 5 / northern disposal site.

Table 12 summarises the expected volumes of sediment grades for sandwave clearance along Section 5. Approximately 94% of the sediment volume is coarser sediment (medium sands and larger) which is expected to be involved in forming the spoil mound with the remainder (of finer grained sediments) being dispersed as a sediment plume.

Table 12. Representative sediment volumes for sandwave clearance across Section 5.

Sediment type / aggregate name	Hopper load (m^3)	Fate
Very fine gravel	772	Seabed mound
Very coarse sand	1,312	Seabed mound
Coarse sand	3,937	Seabed mound
Medium sand	3,068	Seabed mound
Fine sand	81	Sediment plume
Very fine sand	4	Sediment plume
Silt / Clay	1	Sediment plume
Total volume	**9,167**	

Table 14 provides summary details for spoil mounds based on the greatest depth and largest area covered by a single spoil mound depending on the state of tide at the time of disposal. The areas covered are defined above a threshold of 0.05 and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels (Tyler-Walter, Tillin, d'Avack, Perry, & Stamp, 2018).

Table 13. Summary of spoil mound dimension for northern disposal area from sandwave clearance (single disposal) from Section 5 of export cable.

Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
Slack tide, low water	1.20	20,381	9,232
Peak flood	0.75	23,226	9,058

Figure 14 and Figure 15 present a 3D view of the spoil mound relative for the slack water and peak flood cases, repsectively, using a fixed horizontal and vertical scale to provide a basis of comparsion (all dimensions are in feet). The spoil mound for the peak flood case shows some separation between a small gravel and coarse sand mound and larger mound of medium sands.

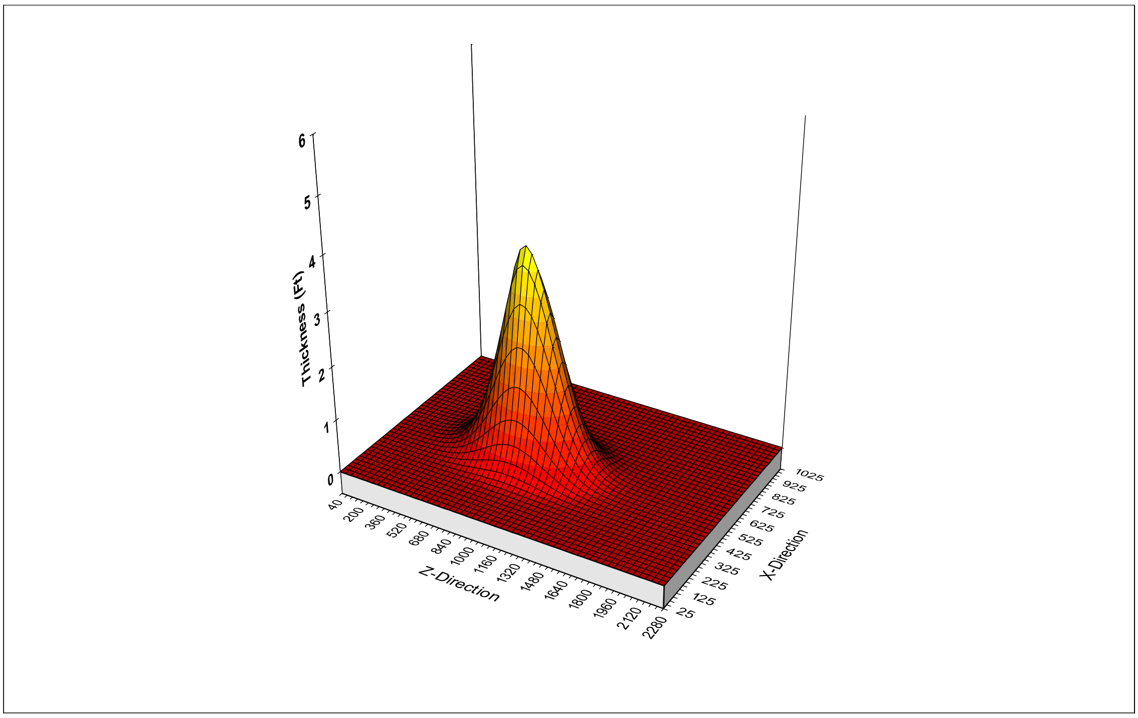

Figure 14. Slack tide low water, spring tide, northern disposal site, sandwave clearance across Section 5.

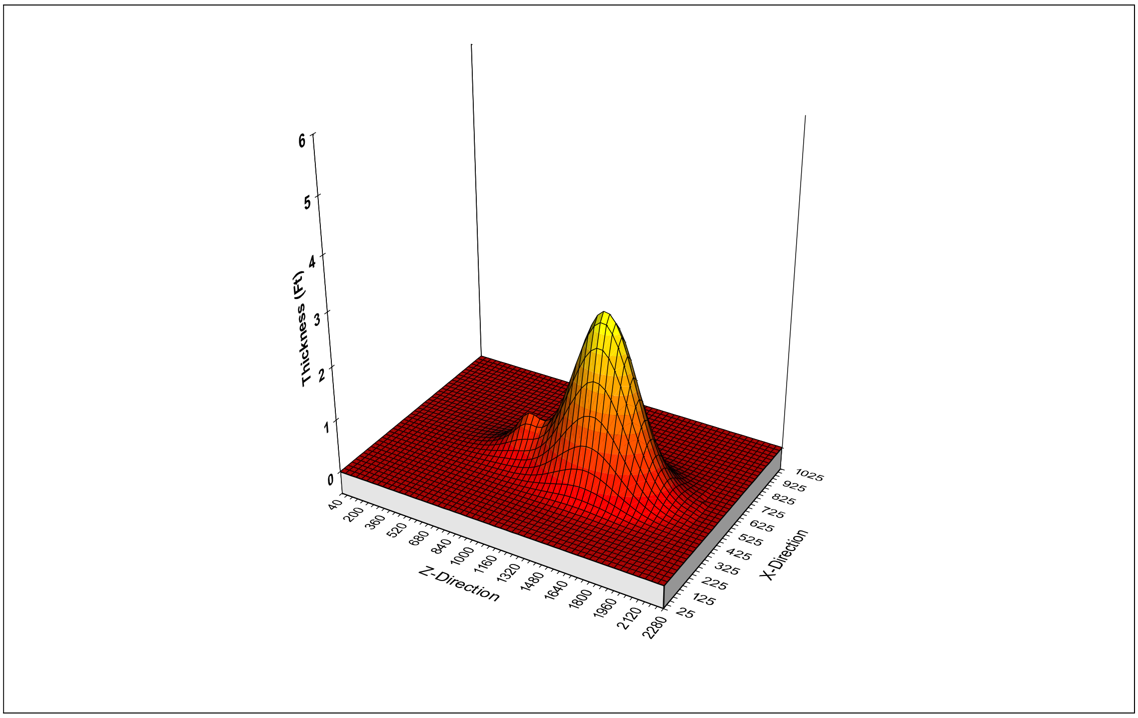

Figure 15. Peak flood, spring tide, northern disposal site, sandwave clearance across Section 5.

b. Section 8 / southern disposal site.

Table 14 summarises the expected volumes of sediment grades for sandwave clearance along Section 8. Approximately 91% of the sediment volume is coarser sediment (medium sands and larger) which is expected to be involved in forming the spoil mound with the remainder (of finer grained sediments) being dispersed as a sediment plume.

Table 14. Representative sediment volumes for sandwave clearance across Section 8.

Sediment type / aggregate name	Hopper load (m^3)	Fate
Very fine gravel	203	Seabed mound
Very coarse sand	241	Seabed mound
Coarse sand	482	Seabed mound
Medium sand	7,893	Seabed mound
Fine sand	299	Sediment plume
Very fine sand	4	Sediment plume
Silt / Clay	4	Sediment plume
Total volume	**9,167**	

Table 15 provides summary details for spoil mounds based on the greatest depth and largest area covered by a single spoil mound depending on the state of tide at the time of disposal. The areas covered are defined above a threshold of 0.05 and 0.30 m which is regarded as a condition which would risk the smothering of benthic receptors at light and heavy levels (Tyler-Walter, Tillin, d'Avack, Perry, & Stamp, 2018).

Table 15. Summary of spoil mound dimension for southern disposal area from sandwave clearance (single disposal) from Section 8 of export cable.

Scenario	Maximum depth of deposition (m)	Area covered (m^2) at depths > 0.05 m (light)	Area covered (m^2) at depths > 0.30 m (heavy)
Slack tide, low water	1.19	19,277	9,290
Peak flood	1.13	20,206	9,523

Figure 16 and Figure 17 present a 3D view of the spoil mound relative for the slack water and peak flood cases, repsectively, using a fixed horizontal and vertical scale to provide a basis of comparsion (all dimensions are in feet).

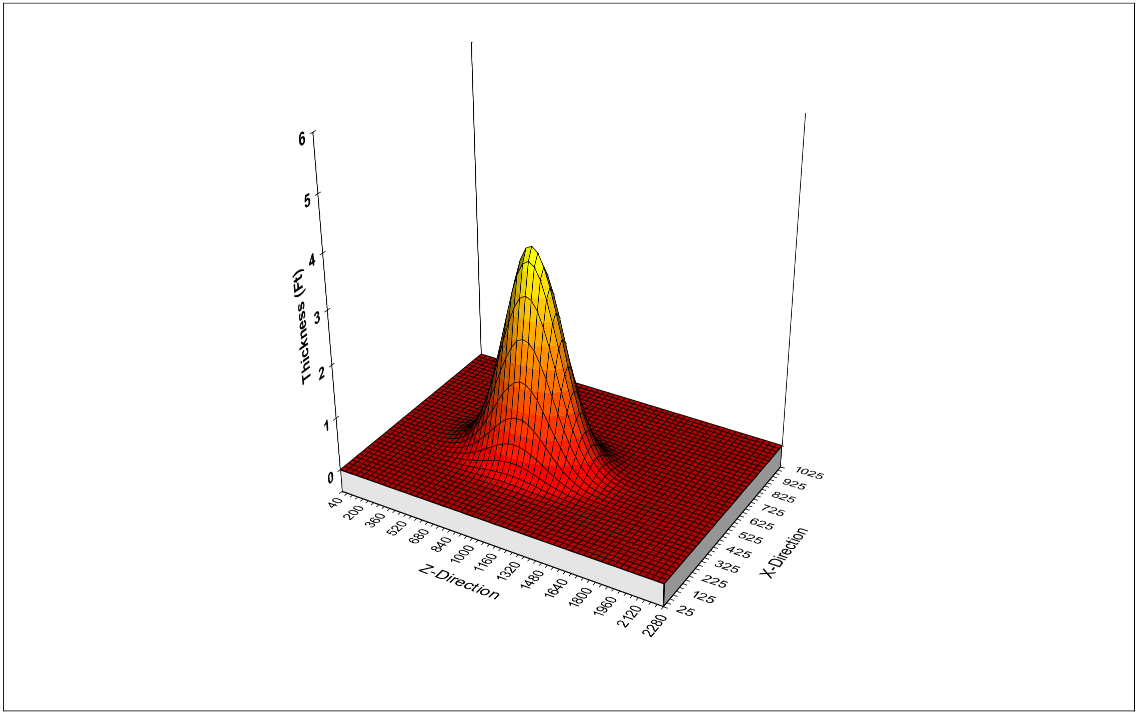

Figure 16. Slack tide low water, spring tide, southern disposal site, sandwave clearance across Section 8.

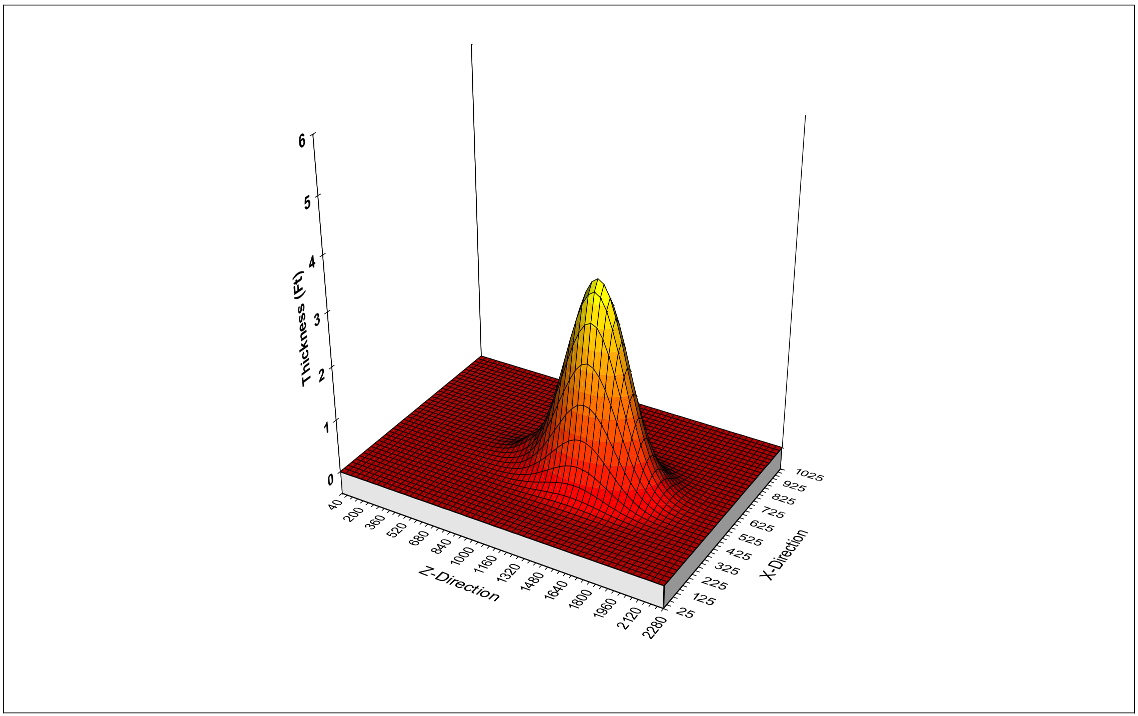

Figure 17. Peak flood, spring tide, southern disposal site, sandwave clearance across Section 8.

4. Summary

An assessment of near-field spoil mounds at northern and southern disposal sites has been provided to indicate the scale of individual features likely to be formed from a release from a 11,000 m^3 TSHD.

The assessment is provided for both seabed levelling and sandwave clearance activities and considers sediment types likely to be involved for the areas being dredged.

In most situations the material being dredged from the seabed is expected to have a relatively high content of coarser grained sediments (medium sized sands and greater) that will be involved in the formation of the spoil mound. The finer grained sediments (fine sand and smaller) are considered to be prone to slower settling and higher rates of tidal advection and dispersion which is likely to lead to the formation of sediment plumes (assessed separately).

The initial spoil mound is expressed as a maximum height and areas where the level of deposition may lead to a light or heavy impact on benthic communities, where present, which is susceptible to smothering.

The initial height and area of any individual spoil mound varies depending on the sediment volume, type of sediments and the period of the tide at the time of disposal (water depth and flow). Spoil mounds are likely to be highest for releases at slack tide / low water on spring tides with heights ranging from 0.7 to 1.77 m. Spoil mounds are expected to be slightly lower during peak flood on spring tides with heights ranging from 0.52 to 1.13 m. The areas covered by a spoil mound are also slightly larger at these times.

An assessment of sediment mobility at the disposal sites provides an indication to whether the material will remain in the form of a mound or may be prone to sediment transport over time with the material largely re-joining the same sediment system from where the removal occurred. Medium sands are expected to be mobile during peak flows on spring tides (ebb and flood) and also peak flood flows on neap tides. Coarse sand would only be expected to be mobilised during spring tides, and very coarse sand only during the peak of flood spring tides and the northern site only.

5. References

Cooper Marine Advisors. (2020). *Dublin Array - Marine Processes. Determination of realistic worst-case.*

Li, M. Z., & Amos, C. L. (1998). Predicting ripple geometry and bed roughness under combined waves and currents in a continental shelf environment. *Continental Shelf Research, 18*, 941-970.

Neumeier, U., Ferrarin, C., Amos, C. L., Umgiesser, G., & Li, M. Z. (2008). An improved sediment-transport model for continental shelves and coastal waters with a new algorithm for cohesive sediments. *Computer & Geosciences*. doi:doi:10.1016/j.cageo.2008.02.007

Tyler-Walter, H., Tillin, H. M., d'Avack, E. A., Perry, F., & Stamp, T. (2018). *Marine Evidence-based Sensitivity Assessment (MarESA) – A Guide. Marine Life Information Network (MarLIN). Marine Biological Association of the UK, Plymouth, pp. 91.*

USACE. (1995). *Development and verification of numerical models for predicting the initial fate of dredged material disposed in open water. Report 2. Theoretical developments and verification results. Final Report. Dredging Research Program. Technical Report DRP-93-1.*

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