MAINSTREAM RENEWABLE POWER LIMITED

COASTAL PROCESSES ASSESSMENT FOR NEART NA GAOITHE OFFSHORE WIND FARM

TECHNICAL REPORT

Report Reference. P1476_RN2709_Rev2

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SUMMARY

As part of the Crown Estate's Scottish Territorial Waters (STW) round of Offshore Wind Farm (OWF) licensing, two proposed developments that were granted a licence were named 'Inch Cape' and 'Neart na Gaoithe'. These are both located off the east coast of Scotland in the Forth and Tay area. The STW Forth and Tay OWF developers are Repsol Nuevas Energias UK Limited (RNEUK), which is developing the Inch Cape site, and Neart na Gaoithe Offshore Wind, a subsidiary company of Mainstream Renewable Power Limited (Mainstream), which is developing the Neart na Gaoithe site. These two developers have collected and shared information where appropriate, and have jointly commissioned the relevant studies, including this assessment. In addition to these two STW development areas, the Round 3 Firth of Forth OWF, which will be developed by Seagreen Wind Energy Limited, is within the area of interest, and has been included in this assessment.

Each developer is undertaking the required Environmental Impact Assessment (EIA) for its own site. In support of these EIAs, Intertek METOC has been commissioned to undertake assessments of meteorological/oceanographic (metocean) and coastal processes relating to each development, as well as the wider region as a whole. Intertek METOC has been supported in these assessments, in particular with the description of the baseline conditions and the sediment-related components, by Partrac Consulting Limited (Partrac). EMU Limited (EMU) is co-ordinating the EIA for the Neart na Gaoithe development.

These developments will potentially affect both the metocean and coastal processes regimes in and around the development areas. Effects may range from short to long term, and the assessment has considered the long-term timescales up to 50 years. The OWF developers require an understanding of the magnitude and significance of these effects, with a view to implementing, where necessary, appropriate mitigation measures in order to minimise impacts.

The study required the delivery of a calibrated and validated coastal hydrodynamic (HD) and spectral wave (SW) model of the area, and the delivery of a coastal processes assessment using the models and other available information. The modelling system and the associated assessments provide the developers and other stakeholders with the regional and site-specific characterisation of the metocean and physical geo-marine environment. This allowed the baseline environmental conditions to be determined, against which the effects of each individual development, and any in-combination and cumulative effects of all developments, have been assessed.

This document is the Technical Report for the Neart na Gaoithe site, and provides the results of the assessment with specific reference to the Neart na Gaoithe development. Site specific information for this development (provided to Intertek METOC by Mainstream) has been used, where possible. This report includes the effects of the development in both the near and far-field, and also any in-combination and cumulative effects of all developments, including the proposed Inch Cape and the Round 3 Firth of Forth OWFs.

The key conclusions from the study are as follows:

The presence of installation equipment, such as jack-up rigs and cable laying vessels, during the construction phase of the development may cause very small, localised and transient effects to the near-field hydrodynamics and wave climate, and to the seabed itself (through depressions and scour), but these will be negligible.

Construction processes, such as the preparation of foundations and the burial of export and inter-array cables, will result in the displacement of seabed sediment into the water column. The impacts from these activities will be relatively small and localised to the near-field, with peak elevated concentrations of suspended sediment between 30 and 300 mg/l (depending on the activity), and maximum deposition thickness between 0.03 and 0.3 m. No impacts are predicted beyond about 3 kilometres of the activity in all cases.

The presence of the wind turbines and their foundations in the Neart na Gaoithe development site will cause only small and localised modifications to the metocean and sediment regimes.

The predicted changes to water level due to the Neart na Gaoithe development are very small (<0.025% of water depth), and generally localised to the near-field, with the exception of a very small change (<0.02% of spring tidal range) in the upper reaches of the Firth of Forth. These predicted changes would not be measureable, and are considered to be negligible.

The predicted changes to tidal currents due to the Neart na Gaoithe development are quite small (between 3 and 6% of peak spring tidal velocities), and restricted to the immediate vicinity of the development site. These predicted changes are small compared with the natural variability of current flows in the area, and considered to be of low significance to the hydrodynamic regime.

The predicted changes to the wave climate due to the Neart na Gaoithe development are also small (<3% of average wave heights), and restricted to the immediate vicinity of the development site. These predicted changes are small compared with the natural variability of wave heights, and are considered to be of low significance to the wave climate.

The consequent changes to the sediment transport processes due to the Neart na Gaoithe development are considered to be small, with the frequency of the exceedance of the critical shear stress changing typically by 1-3% (with a maximum difference of 6%). These changes are also restricted to the immediate vicinity of the development site.

Localised changes to flow around the structures also have the potential to lead to scouring of material.

The risk of scour around gravity bases will require a full engineering assessment in order to design suitable scour protection, and therefore scour will be significantly mitigated if gravity bases are used.

The impacts from the scoured material around jacket structures are considered to be small and localised within the near-field, and scour pits around each leg of the jacket structure will not overlap, regardless of turbine size. Therefore, the scour will be local, rather than general. The resulting plume of suspended sediment concentrations due to the scoured material will be small in extent, with peak concentrations between 100 and 300 mg/l, and concentrations beyond about 250 m of the structures reducing to < 10 mg/l. The resulting deposition footprints will be very localised around the turbine base, with a maximum thickness of 0.1 m and the extent of the footprint with a thickness >1 mm reaching up to 500 m.

The predicted cumulative impacts to water level due to the Neart na Gaoithe development and other nearby OWF developments are fairly widespread, but very small in magnitude (<0.07% of spring tidal range). These are considered to be of negligible significance.

The predicted cumulative changes to tidal currents due to the Neart na Gaoithe development and other nearby OWF developments are quite small (between 3 and 6% of peak spring tidal velocities), and very localised to the near-field of each development. These are considered to be of low significance. No cumulative far-field impacts are predicted on the tidal current regime.

The predicted cumulative changes to the wave climate due to the Neart na Gaoithe development and other nearby OWF developments are considered to be small (<3% of average wave heights), although the affected areas are approximately 3 to 4 times larger than the impacts from the Neart na Gaoithe development on its own. These are considered to be of low significance.

The predicted cumulative changes to sediment transport processes due to the Neart na Gaoithe development and other nearby developments are considered to be small, with the predicted frequency of exceedance of the critical shear stress changing typically by 1-3% (with a maximum difference of 6%). These changes are restricted to the immediate vicinity of the development sites. These are considered to be of low significance.

The proposed Neart na Gaoithe OWF development will not cause net changes to the regional sediment transport regime or sediment dynamics along the nearby coastline, even when the cumulative impacts from the proposed Inch Cape and Firth of Forth developments are considered.

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GLOSSARY

AL1	Cefas Action Level benchmark 1 (AL1)
BGS	British Geological Survey
BODC	British Oceanographic Data Centre
CD	Chart Datum
Cefas	Centre for Environment, Fisheries, and Aquaculture Sciences
CFD	Computational Fluid Dynamics
COWRIE	Collaborative Offshore Wind Research Into the Environment
D	Jacket leg diameter
d_{50}	Median grain size
Db	Brace width
DEFRA	Department for Environment, Food and Rural Affairs
EIA	Environmental Impact Assessment
EMU	EMU Limited
eo	Distance to the bed
FF	Far-field
FTMS	Forth and Tay Modelling System
h	Water depth
HD	Hydrodynamic (module)
Hdir	Wave direction
Hs	Significant wave height
HW	High water
JNCC	Joint Nature Conservation Committee
LW	Low water
M	stress amplification factor
Mainstream	Mainstream Renewable Power Limited

Metocean	Meteorological/oceanographic
MSL	Mean Sea Level
MW	Mega-watts
NF	Near-field
OWF	Offshore Wind Farm
Partrac	Partrac Consulting Ltd.
POL	Proudman Oceanographic Laboratory
PSD	Particle Size Distribution
PT	Particle Tracking (module)
RNEUK	Repsol Nuevas Energias UK Limited
SEA	Strategic Environmental Assessment
SEPA	Scottish Environment Protection Agency
SMP	Shoreline Management Plan
SNH	Scottish Natural Heritage
STW	Scottish Territorial Waters
SW	Spectral wave (module)
Tp	Peak wave period
Tz	Mean zero-crossing wave period
TSS	Total suspended solids
u	Flow velocity
UKCIP	UK Climate Impacts Programme
UKHO	UK Hydrographic Office
UKMO	UK Meteorological Office
Wdir	Wind direction
Ws	Wind speed
τ_{0wave}	Drag force on sediments due to waves

τ_{0wc}	Drag force on sediments from non-tidal influences
$\tau_{0current}$	Drag force on sediments due to tidal currents
τ_{crit}[1]	Critical bed stress

1 INTRODUCTION

As part of the Crown Estate's Scottish Territorial Waters (STW) round of Offshore Wind Farm (OWF) licensing, two proposed developments that were granted a licence are the 'Inch Cape' and 'Neart na Gaoithe' OWFs. These are both located off the east coast of Scotland in the Forth and Tay area. The STW Forth and Tay OWF developers are Repsol Nuevas Energias UK Limited (RNEUK), which is developing the Inch Cape site, and Neart na Gaoithe Offshore Wind, a subsidiary company of Mainstream Renewable Power Limited (Mainstream), which is developing the Neart na Gaoithe site. The two developers have collected and shared information where appropriate, and have jointly commissioned the relevant studies, including this assessment.

Figure 1-1 provides a geographic overview of the region, including the two STW developments. It also shows another proposed development, further offshore than the Inch Cape and Neart na Gaoithe sites, which is the Crown Estate Round 3 Zone 2 (Firth of Forth) site, approved under the third round of OWF licensing. The developer for the Firth of Forth site is Seagreen Wind Energy Limited.

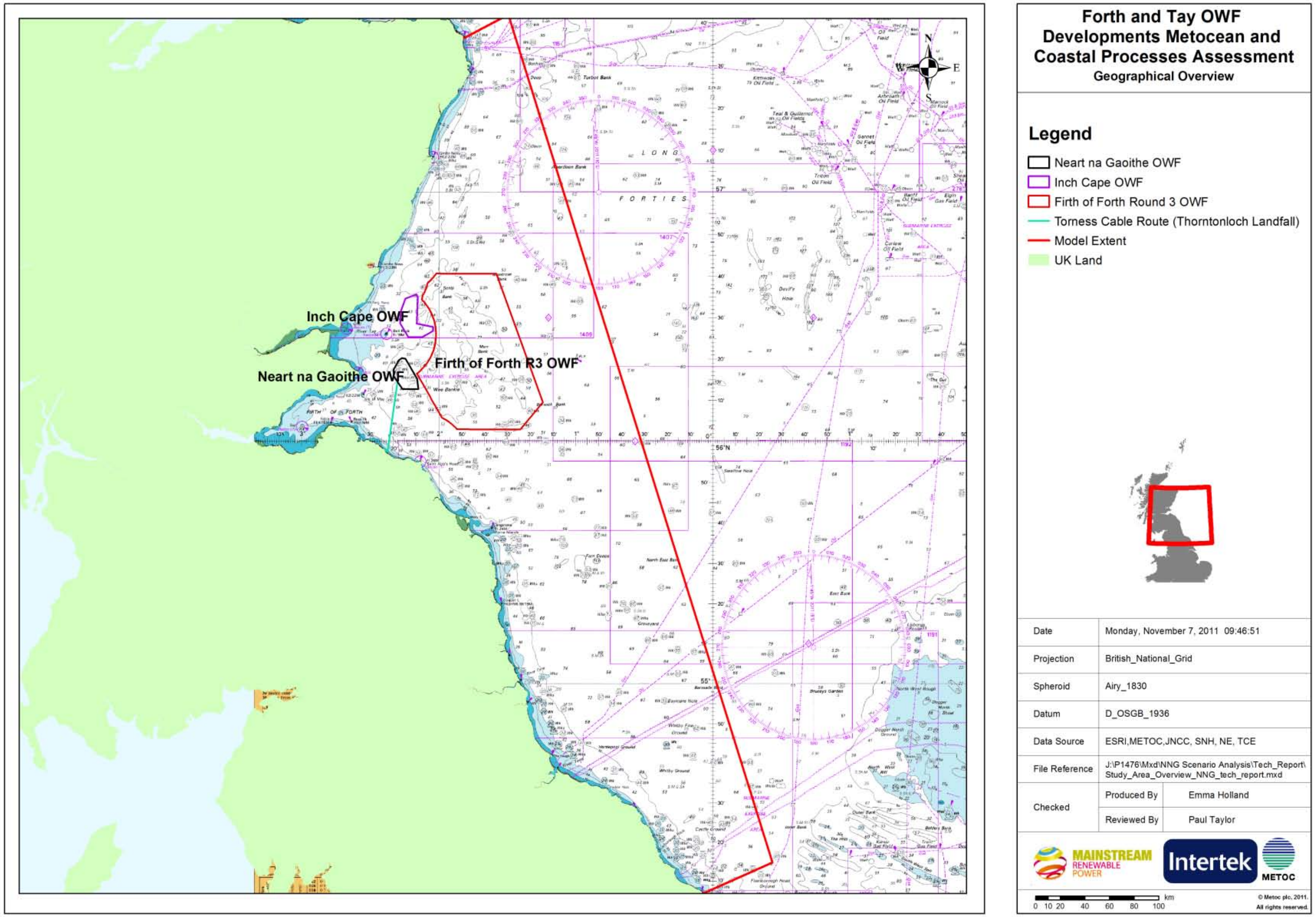
Each developer is undertaking the required Environmental Impact Assessment (EIA) for its own site. In support of these EIAs, Intertek METOC has been commissioned to undertake assessments of meteorological/oceanographic (metocean) and coastal processes relating to each development, as well as the wider region as a whole. Intertek METOC has been supported in these assessments, in particular with the description of the baseline conditions and the sediment-related components, by Partrac Consulting Limited (Partrac). EMU Limited (EMU) is co-ordinating the EIA for the Neart na Gaoithe development.

These developments will potentially affect both the metocean and coastal processes regimes in and around the development areas. Effects may range from short to long term, and the assessment has considered timescales up to 50 years. The OWF developers require an understanding of the magnitude and significance of these effects, with a view to implementing, where necessary, appropriate mitigation measures in order to minimise impacts.

The study required the delivery of a calibrated and validated coastal hydrodynamic (HD) and spectral wave (SW) model of the area, and the delivery of a coastal processes assessment using the models and other available information. The modelling system and the associated assessments provide the developers and other stakeholders with the regional and site-specific characterisation of the metocean and physical geo-marine environment. This allowed the baseline environmental conditions to be determined, against which the effects of each individual development, and any in-combination and cumulative effects of all developments, have been assessed.

This document is the Technical Report for the Neart na Gaoithe site, and provides the results of the assessment with specific reference to the Neart na Gaoithe development. Site specific information for this development (provided to Intertek METOC by Mainstream) has been used, where possible. This report includes the effects of the development in both the near and far-field, and also any in-combination and cumulative effects of all developments, including the proposed Inch Cape and the Round 3 Firth of Forth OWFs.

Figure 1-1: Geographic Overview



1.1 SCOPE OF WORK

- Prepare a **Methodology Statement**. This outlined the proposed methodology for the assessments, including the procedures for the baseline assessment, the model construction, and the analysis of impacts from the developments. This document was circulated to both clients, and all relevant stakeholders via Marine Scotland, for comment and approval.
- Undertake a **Data Review and Gap Analysis**. This included the collation and review of all relevant data (hydrodynamic, bathymetric, geological, bed morphology and sediment information) from existing sources, including specifically the data collected as part of the metocean, geotechnical, geophysical and benthic survey campaigns commissioned by the clients.
- Undertake a **Regional Baseline Assessment**. This was prepared in partnership with Partrac, and provides a detailed description of the existing metocean and sediment regime conditions on a region-wide basis. This includes an area from St Abbs Head (England) to Cairnbulg Point (NE Scotland) and extends eastwards to the eastern boundary of the proposed Round 3 Zone 2 area, thereby incorporating both of the STW sites, as well as the Round 3 site.
- Construct, calibrate and validate a suitable modelling system. The **Forth and Tay Modelling System (FTMS)** was built using an unstructured flexible mesh dynamic modelling system. This is a sophisticated two-dimensional modular based modelling system, and has the capacity to run both hydrodynamic and spectral wave models. It can be used to predict the physical properties of tidal currents and waves, and the interactions between these, for any specified area. It can also be configured with structures representing existing or proposed marine developments, such as OWFs, in order to quantify the effects such developments may have on the metocean regime.
- Undertake an **Impact Assessment** of the two proposed developments by considering the changes, or impacts to the metocean and sediment regimes, and thereby the coastal processes, due to each proposed development. Near and far-field, and short and long-term impacts have been considered, as well as any in-combination and cumulative effects from all developments. The potential effects of changing climatic conditions in the future (i.e. sea-level rise and increased ‘storminess’) have also been considered.
- Provide a **Technical Report** (this document) for each STW Forth and Tay developer, to provide a detailed description of the work undertaken.
- Prepare a relevant **Coastal Processes chapter,** summarising the work undertaken, for inclusion in the Environmental Statements being prepared by each client.

The key documents produced (to date) as part of this study are therefore:

- The Methodology Statement Report (Intertek METOC Report No: RN2550[i]);

- Comments on the Methodology Statement from Marine Scotland, and the formal response to these (included in Appendix A of this report);
- The Data Review and Gap Analysis Report (Intertek METOC Report No: RN2597[ii]);
- The FTMS Hydrodynamic and Spectral Wave Model Calibration and Validation Report (Intertek METOC Report No: RN2636[iii]); and
- The Regional Baseline Coastal Processes Description Report (Intertek METOC Report No: RN2728[iv]).

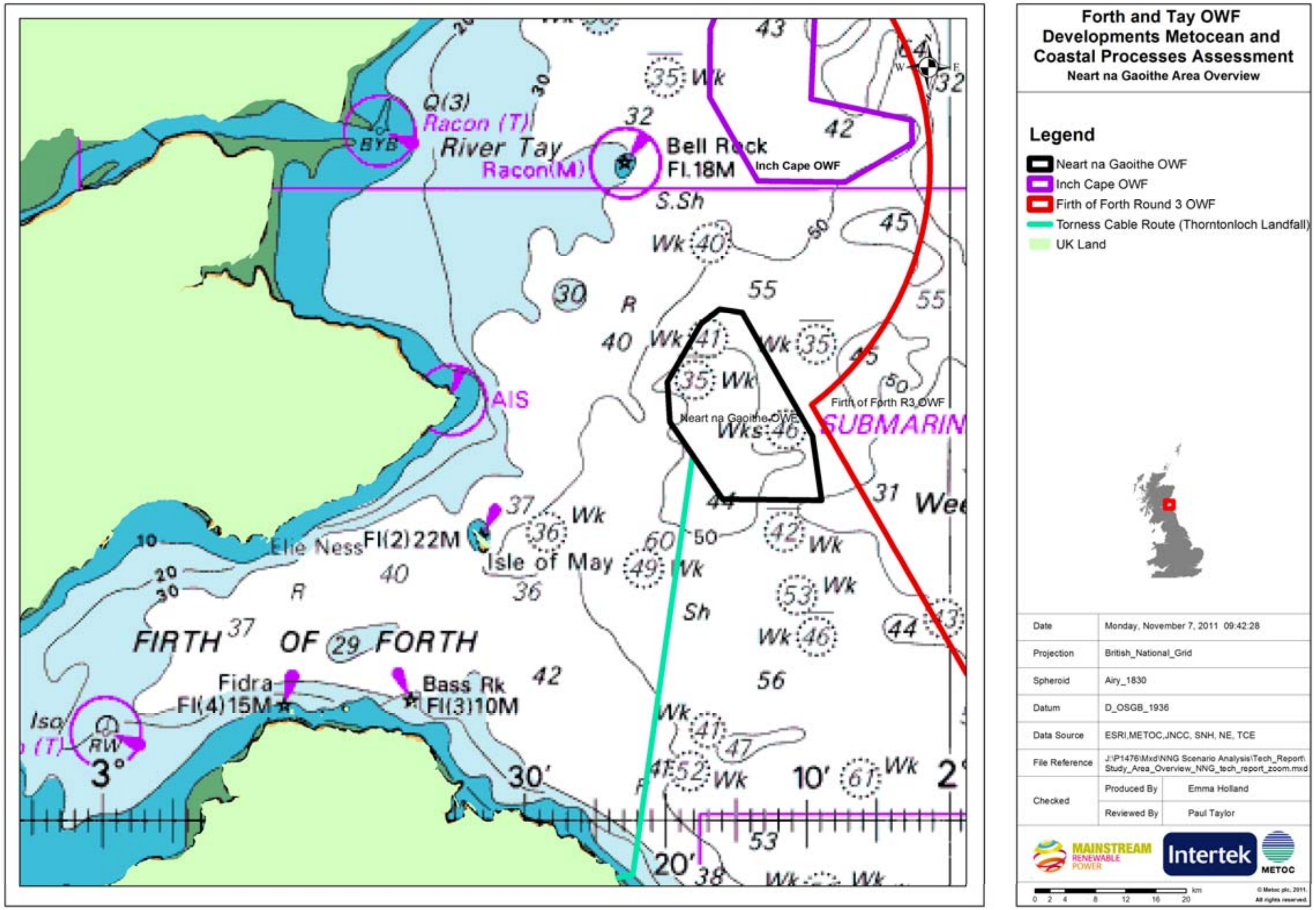
In addition, a more detailed description of the baseline conditions relevant to the Neart na Gaoithe site, prepared together with Partrac, is included in Appendix B of this report.

1.2 DEVELOPMENT OVERVIEW

The proposed Inch Cape and Neart na Gaoithe OWFs lie relatively close to each other within the Forth and Tay area of the STW. The Neart na Gaoithe site is located approximately 15 km off the Fife coast and covers an area of about 105 km^2. Water depths across the site range from 44-55 m. The project has the potential to generate a maximum capacity of 450 mega-watts (MW) of renewable energy.

Figure 1-2 provides an overview of the area together with details of the site.

Figure 1-2: Geographic overview of the Neart na Gaoithe OWF site and surrounding area



1.2.1 Turbine Arrays

At the time of this assessment, many details of the development were unknown. However, Mainstream provided Intertek METOC with preliminary design information[v] which has been used to make the necessary assumptions for this assessment. At the time of this assessment it was assumed that the wind farm would comprise turbines in the range of 3.6 to 6 MW, with the likely number of turbines ranging from 125 (3.5 MW) to 75 (6 MW). However, it should be noted that following completion of the modelling, the Rochdale Envelope has been decided, and the largest turbines potentially to be used will be 7 MW. The realistic worst case as modelled in this assessment is therefore not equivalent to the Rochdale Envelope.

It was also assumed that the turbines will be set out in a regular array, with lines running approximately northwest to southeast – aligned perpendicular to the predominant wind direction. Spacings between each turbine along the line will depend upon the turbine size selected, and might range from about 960 m (for the smaller 3.6 MW turbine) to about 1000 m (for the larger 6 MW machines). The spacing between lines will be between approximately 600 m and 630 m, again dependent on the size of the turbine used. These spacings are summarised in Table 1-1.

1.2.2 Foundation Types

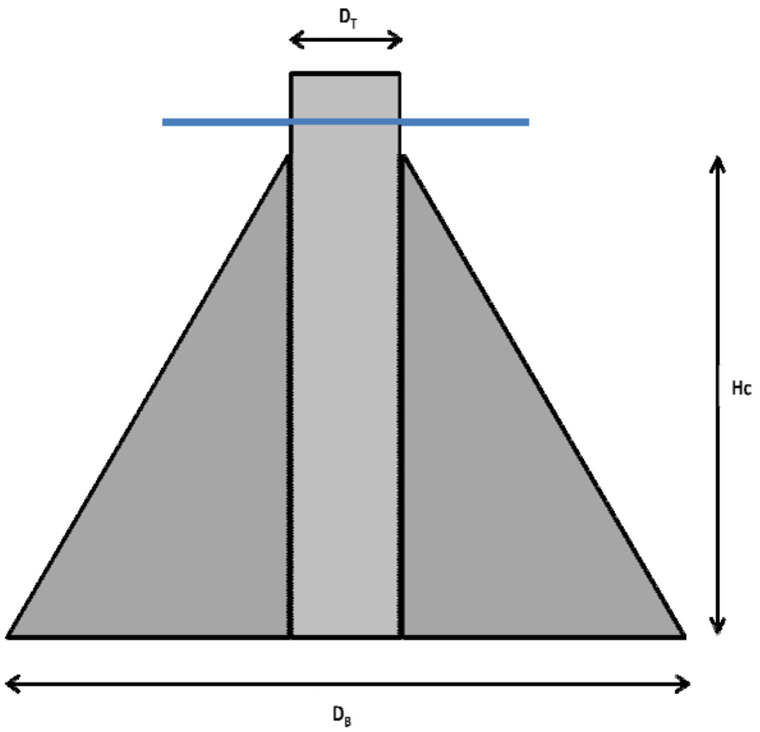
The foundation type for the turbines has not yet been decided, although it is unlikely that the monopile arrangement, used in many of the existing OWFs, will be used, due to the depth of water at the site and size of turbines that are anticipated. The foundation type is therefore likely to be either a gravity base or a jacket structure construction.

A gravity base foundation type would probably be made from concrete with a circular base plate, and a conical support structure around a central cylinder or tower. The central tower would rise to the sea surface, and would support the turbine itself. The actual dimensions of the gravity base will be dependent on the size of the turbine used, but the assumed design dimensions for the gravity bases, at the time of this assessment, are provided in Table 1-1, and in Diagram 1-1.

Table 1-1: Anticipated gravity base dimensions

Parameter	Small (3.6MW)	Large (6MW)
Base Diameter, D_B (m)	30	35
Tower Diameter, D_T (m)	6	8
Height of conical section	18	34
Cross Sectional Area Per Structure (m^2)	516	859
Rotor Diameter (m)	120	126
Spacing between turbines along row (aligned NW to SE) (m)	960	1008
Spacing between turbine rows (m)	600	630
Maximum number of turbines	125	75

Diagram 1-1: Schematic of proposed gravity base



A jacket foundation is a construction of tubular steel, typically 0.5 to 1.5 m in diameter, formed of four cylindrical legs and a lattice of cross-bracing. Again the actual size and design of the jacket will be dependent on the size of the turbine, but the anticipated dimensions of the jacket, if used, are provided in Table 1-2. Figure 1-3 provides an indication of the jacket structure that would be used (based on information provided at the time of assessment).

Table 1-2: Anticipated dimensions for proposed jacket foundation type

Parameter	Small (3.6 MW)	Demonstrator (5MW)	Large (6MW)
Length of Leg Chord (m)	55	55	55
Diameter of Leg Chord (m)	0.77	0.85	1.23
Length of Brace (m)	20	20	20
Diameter of Brace (m)	0.522	0.58	0.7
Cross sectional area of leg (m^2)	42.075	46.75	67.65

Figure 1-3: Photo of the jacket foundation used at the Beatrice OWF

Note: it is assumed that the proposed jacket construction for Neart na Gaoithe would be very similar to those employed at Beatrice OWF

1.2.3 Inter Array and Export Cables

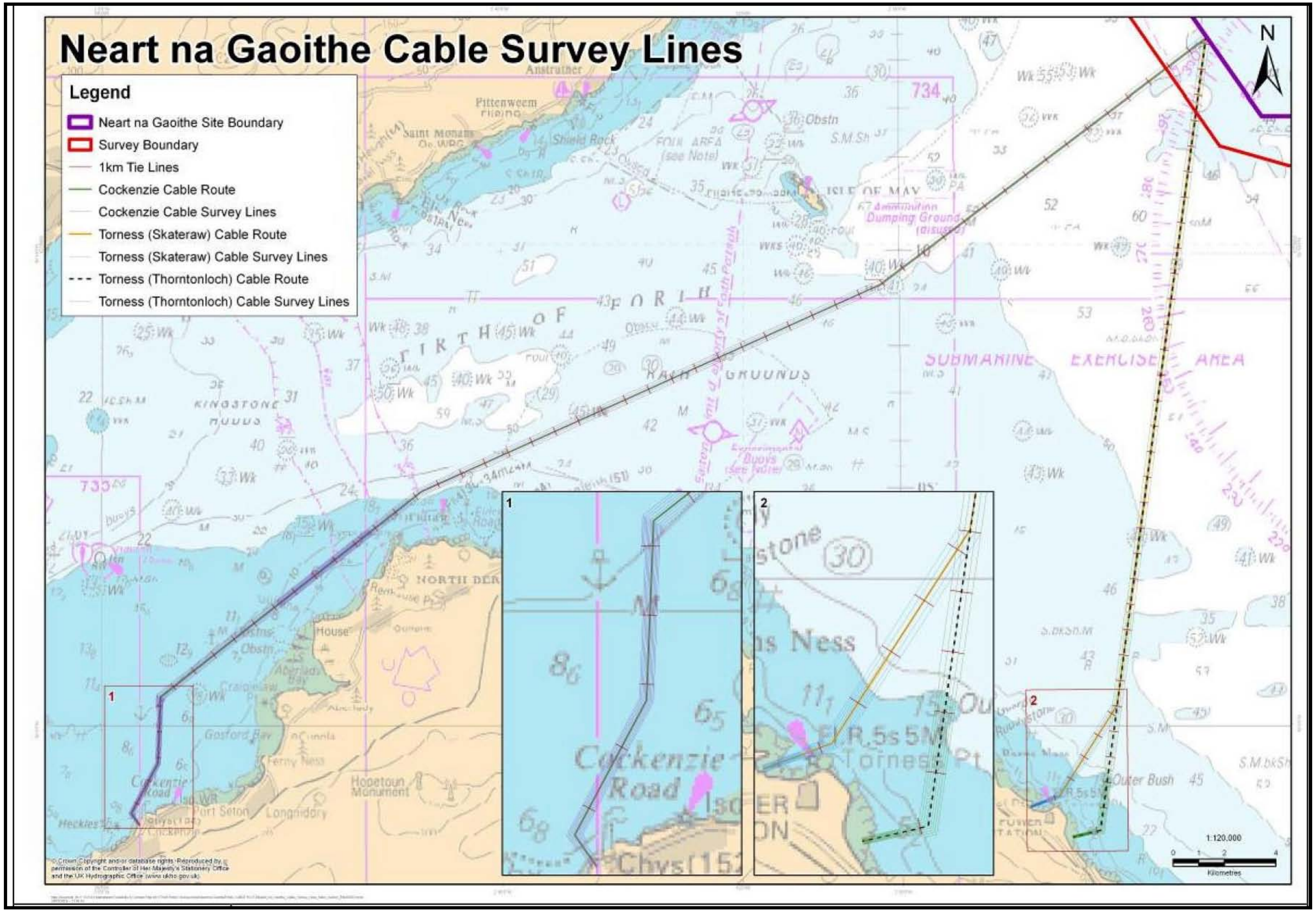
The turbines will be connected via inter-turbine cables, and the OWF will be connected to the national grid via an export cable. All cables will be buried to a depth of up to 2 m for protection wherever possible (the exceptions being at crossing points with other cables or pipelines, and possibly in any areas of outcropping bedrock). Cable burial will be by either jetting or trenching plough installation techniques, although directional drilling may be required under coastal defences at the landfall sites.

Initially, the developers identified two potential export cable routes and three possible landfall sites (as there were two potential landfall sites for one of the routes). These are shown in Figure 1-4.

Since these initial options were drawn up, a decision has been made to drop the more northern ‘Cockenzie’ route, and the Skateraw landfall on the southern ‘Torness’ route, from consideration.

The export cable route will therefore follow the Torness route, which exits the OWF development site at its southwestern boundary and follows an approximately southern bearing to landfall at Thortonloch, just south of the Torness headland (where there is a nuclear power station). The route is about 32 km long.

Figure 1-4: Originally proposed export cable routes from the Neart na Gaoithe OWF



1.2.4 Other Developments

The construction of Neart na Gaoithe OWF is due to commence by 2014, and completion of the development is anticipated by 2016. The OWF is being designed with an initial lifespan of 25 years, but it is likely to be re-powered to extend the life of the development for a further 25 years.

The proposed Inch Cape OWF site lies approximately 10 km north of the northern boundary of the Neart na Gaoithe site, and the proposed Firth of Forth Round 3 site lies immediately to the east of the site (encompassing a very large area that extends to the north and south of the Neart na Gaoithe site). The Inch Cape development is at a similar stage of planning as the Neart na Gaoithe development (although not quite as advanced), and the Firth of Forth site is at an earlier phase in its planning. Construction of the different phases of these developments is likely to occur between 2014 and 2018, and the OWFs are likely to have lifespans similar to that of Neart na Gaoithe. The Firth of Forth Round 3 site is likely to be developed in three different Phases.

Both of the other proposed developments are of potential concern for cumulative impact consideration, and they have been included in the long-term cumulative impact assessment. However, no other marine developments or industries have been identified as having the potential for in-combination effects.

1.2.5 Decommissioning

Currently there are no specific proposals outlined for the decommissioning of the development at the end of the design life of the OWF. It is quite possible that buried cables would be left in place, although it may be a requirement that all infrastructure, including buried cables and foundations, be removed.

1.3 METHODOLOGY

A Methodology Statement report was prepared by Intertek METOC and agreed with both Mainstream and RNEUK. The Intertek METOC report RN2550 describes in detail the proposed methodology for the coastal processes assessment. This was issued as a stand-alone report to the clients in February 2011, and was then forwarded to Marine Scotland (as representative of all stakeholders) for review.

The agreed methodology is fully aligned with the best practice guidance provided in the Collaborative Offshore Wind Research Into the Environment (COWRIE) report[vi].

The agreed approach is summarised as follows:

- Bespoke hydrodynamic, spectral wave and sediment models covering the two STW sites and the surrounding region would be developed, calibrated and validated. These models comprise the Forth and Tay Modelling System (FTMS). The FTMS would be constructed using industry standard software that uses a sophisticated, two-dimensional modular-based modelling system.
- Both the FTMS and the subsequent impact assessments would be developed and implemented according to industry best practice.

- The FTMS, together with the available field data, would be used to assess the following:
    - baseline conditions (an understanding of the metocean and sedimentological regimes as they are now);
    - post-construction impacts from each individual wind farm (focusing on how metocean and sedimentological conditions are modified relative to the baseline);
    - post-construction long-term (50 year) cumulative impacts from the two STW wind farms and the proposed Round 3 Zone 2 (Firth of Forth) wind farm;
    - post-construction long-term (50 year) in-combination impacts to include the three wind farms and any other industries or developments that may be identified in the area;
    - scour potential around individual structures and the need/justification for scour protection;
    - short-term impacts on suspended sediment concentrations during the construction phase (such as from laying foundations or dredging cables); and
    - the possible implications of climate change to the impacts predicted by the metocean and coastal processes assessment.

Following the submission of the Methodology Statement, and the subsequent response from Marine Scotland, the project team, which included Mainstream, RNEUK, EMU and Intertek METOC discussed and agreed in more detail the different scenarios to be included in the assessment. In particular, it was agreed to adopt a realistic 'worst case' scenario for the proposed developments, on the basis that the detailed design and layout of the developments were not yet known. This is in line with the 'Rochdale Envelope' approach as outlined by the Infrastructure Planning Commission, and led to the adoption of an 'assessment scheme' which is based on the type and number of foundations, the layout of turbines, and the construction techniques, that would all lead to the greatest impacts on coastal processes. In reality, the final development scheme is very likely to be different to the 'assessment scheme' used in this study, but as long as the final scheme is comparable with, or within the modelled (worst case) scheme, then predicted impacts as reported in this assessment will be indicative of the worst case actual impacts that might result.

In addition, it was agreed that cumulative impacts due to the three proposed OWFs in the region would be investigated, but that no additional in-combination effects needed to be considered. Cumulative impacts are defined as those resulting from other OWF developments and in-combination impacts are defined as those resulting from other industries in addition to any OWF developments. No other industries or developments were identified as having the potential to contribute to impacts to the coastal processes in the region.

Details of the assessment scheme, and the different scenarios assessed, are provided in more detail in Section 4.

1.4 CONSULTATION

The proposed approach, as detailed in the Methodology Statement report, was provided to Marine Scotland, the regulatory consultee and contact point for all interested stakeholders, for its review.

Marine Scotland collated comments from all relevant stakeholders, and provided a response to the proposed Methodology, in a letter to RNEUK[vii]. This letter is included in Appendix A. In general the stakeholders accepted the proposed methodology, and stated that:

"The proposed methodology is rigorous and well thought out. The proposed modelling methodology is particularly impressive."

However, a number of specific clarifications were requested, and these were addressed in a letter of response sent by RNEUK to Marine Scotland[viii]. This letter is also included in Appendix A.

The main comments on the methodology raised by Marine Scotland and the other stakeholders can be summarised as follows:

- Identification of sensitive receptors. Sensitive receptors within and around the development area, and the potential impacts on these due to changes in the metocean or coastal processes regimes, are considered as part of the broader EIA.
- Survey campaign. The targeted survey campaign obtained sufficient information to enable construction, calibration and validation of the Forth and Tay Modelling system, and parameterisation of the baseline and inputs for the coastal processes assessment. See, for example, Intertek METOC Report RN2636 (FTMS calibration and validation[iii]), and Appendix B Neart na Gaoithe Area Baseline Description.
- Sediment regime. The study has fully considered the potential impact of the development on different aspects of the sediment regime. This includes: sediment transport pathways, sources and sinks; bed forms and features (including sandbanks and sandbank stability); erosion; deposition; suspended load and suspended sediment concentrations; and bed load. See, for example, Appendix B Neart na Gaoithe Area Baseline Description, Section 5.3 Changes to the Sediment Regime, and Section 5.4.3 Changes to the Sediment Regime (Cumulative Impacts).
- Definition of "cumulative" and "in-combination". This is clarified in Section 1.3.

1.5 DATA SOURCES

Intertek METOC undertook an extensive review of all available data, including a gap analysis to identify any additional information that would be required. Full details of this data review and gap analysis are provided in the Intertek METOC report RN2597. The final version, which incorporated all client comments received, was submitted to Mainstream and RNEUK in May 2011.

The principal data sources used in the assessment were the field data collected during the dedicated geophysical and benthic surveys commissioned by Mainstream, together with the metocean survey campaigns commissioned by the both Mainstream and Repsol, and the model outputs derived from the FTMS developed specifically by Intertek METOC for the purpose of this assessment. These were supplemented by: other existing field data (held by third party organisations, such as the British Oceanographic Data Centre (BODC), the Proudman Oceanographic Laboratory (POL), the British Geological Survey (BGS) and the Centre for Environment, Fisheries, and Aquaculture Sciences (Cefas)); the existing scoping reports for the developments previously commissioned; and other third party information and reports, such as Shoreline Management Plans (SMP).

Table 1-3 provides a summary of the data and their sources used in the assessment.

Table 1-3: Summary of major data sources used

Data Source	Study/Data Name	Data Theme(s)	Data Location
Mainstream / RNEUK	Scoping Studies	Environmental baseline	At site
HR Wallingford reports	Firth of Forth Water Quality Model Assessment of Field Data Scoping Support (2009) Various background reports (engineering and survey design)	Water quality (turbidity) Baseline	East coast of Scotland/At site
Mainstream/RNEUK (collected by Partrac)	Metocean monitoring survey	Metocean monitoring data (waves, tides, wind)	At site
Mainstream (collected by EMU)	Hydrographic, geophysical and benthic surveys	Bathymetry, geophysical and particle size data	At site
Mainstream (collected by Gardline)	Geotechnical survey	Geotechnical data	At site
JNCC UK SeaMap	SeaMap 2010	Seabed habitats/landscapes	East coast of Scotland
Scottish Natural Heritage (SNH)	Coastal Cells in Scotland Cell 1 St Abb's Head to Fife Ness Cell 2 Fife Ness to Cairnbulg Point	Shoreline processes	East coast of Scotland
British Geological Survey (BGS)	1986. Tay Forth, Sheet 56°N-04°W, Seabed Sediments, 1:250,000 series 1987. Tay Forth, Sheet 56°N-04°W, Quaternary Geology, 1:250,000 series 1986. Tay Forth, Sheet 56°N-04°W, Solid Geology, 1:250,000 series General – geology and sediment maps: Holmes (1994); Holmes et al. (1999); Pantin (1991); Gatliff et al. (1994) Core archive Surface grab sample archive (www.bgs.ac.uk)	Geology, sedimentology, sediment features, sediment thickness and sediment transport	Tay and Forth
UK Hydrographic Office (UKHO)	Various contemporary charts (Admiralty Charts 175 and 190);	Bathymetry & tidal streams, water levels	East coast of Scotland

Data Source	Study/Data Name	Data Theme(s)	Data Location
	Tide Tables, Co-tidal Charts		
C-MAP (under licence held by Intertek METOC)	Electronic chart database	Bathymetry	East coast of Scotland
British Oceanographic Data Centre (BODC)	Data Inventory Deployments	Current measurements Wave measurements Surge data	Various port sites
Scottish Environment Protection Agency (SEPA)	River Inflows	Freshwater/sediment inputs	Major rivers
Cefas WaveNet	Data Inventory	Wave measurements	Directional waverider information from WaveNet from 19 August 2008 at 56^0 11.33'N. 2^0 30'W
UK Met Office (UKMO)	Data summary	Meteorological data	Eastern Scotland
Coastal Councils	Shoreline Management Plans (SMPs)	Shoreline processes, coastal processes	Tayside; Fife; East Lothian; Angus
Department of Trade and Industry (DTI) - Department for Business, Enterprise and Regulatory Reform (BERR)	SEA3, SEA 5; 2007/07 Atlas of Renewable Energy	Regional geomarine assessment; synoptic oceanographic parameters	Regional
UK Offshore Energy SEA (DECC 2009)		Regional geomarine assessment	Regional
Scottish Marine Renewables SEA (Faber Maunsell and Metoc 2007)		Regional geomarine assessment	Regional
The Tay Estuary Coastal References Database		Geology; sedimentology; fluvial flows	Tay and Forth
Intertek METOC	The Forth and Tay Modelling System developed specifically for this assessment	Metocean (hydrodynamic and spectral wave conditions)	Regional and site-specific

2 PHYSICAL ENVIRONMENT (BASELINE)

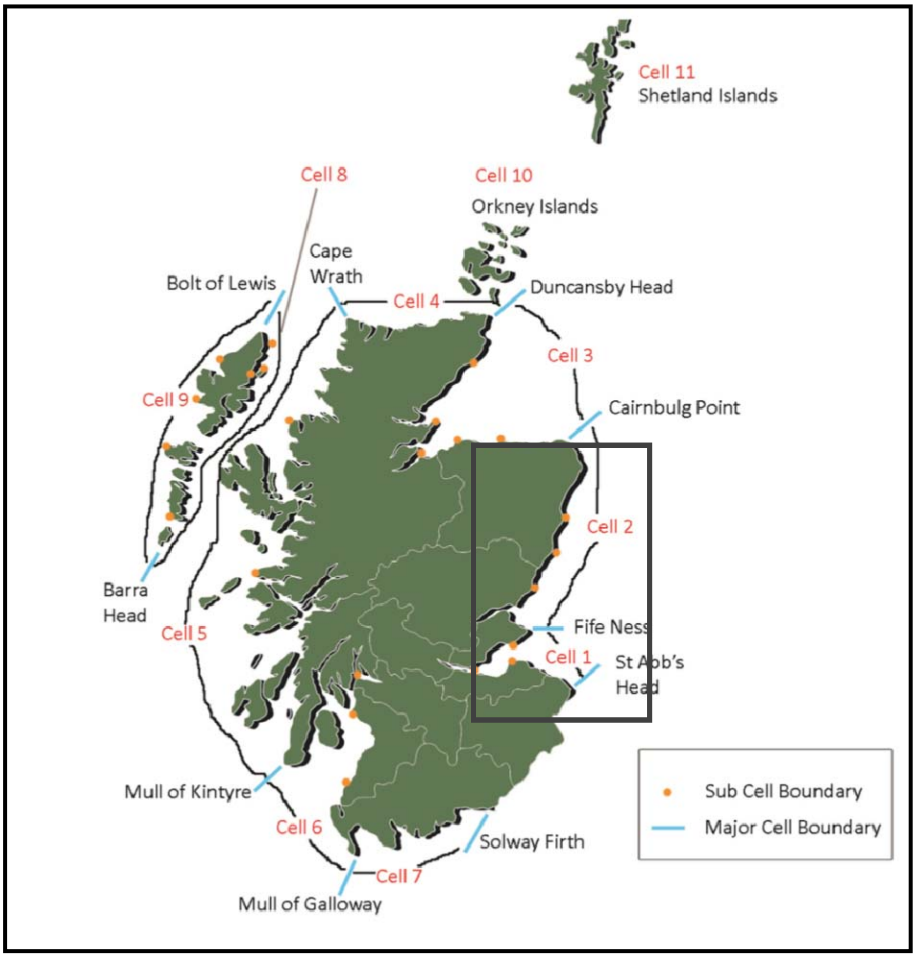
2.1 REGIONAL AREA

The existing physical environment, or baseline conditions, have been assessed by Intertek METOC in consultation with Partrac, based on a range of field data, existing literature and model outputs (as outlined in Table 1-3). The baseline metocean and sediment regimes on a regional basis are described in full in the Intertek METOC report RN2728, issued in September 2011.

The regional extent for the purposes of the assessment is defined as the marine offshore region extending from St Abb's Head (Berwickshire) to Cairnbulg Point (Aberdeenshire) and extending eastwards to the eastern boundary of the proposed Crown Estate Round 3 Zone 2. This area spatially embraces the two STW Forth and Tay OWF sites on a scale which encompasses the potential for cumulative effects of construction at the Zone 2 area, and is defined at the shoreline by coastal cell boundaries. On occasion in the Regional Baseline Report, the sub-cell boundary at Deil's Head (near Arbroath, Angus) has been used to delimit the description of shoreline processes. The western limit for consideration was the Forth Road Bridge.

Figure 2-1 shows the extent of the regional assessment in the context of the coastal cells, as defined by Ramsay and Brampton[ix].

Figure 2-1: Definition of the extent for the regional baseline description



2.2 NEART NA GAOITHE SITE

In addition to the regional scale assessment of baseline conditions, the study has included a more detailed analysis of the existing physical environment of the Neart na Gaoithe area, using site-specific data provided by Mainstream.

This analysis considered the bathymetry and sediment cover of the area, physical oceanographic processes (tides, waves and storm events), and the sediment transport regime, by both suspended sediment and bedload pathways. The full details of this analysis are provided in Appendix B.

The following provides a general summary of the coastal processes regime for the Neart Na Gaoithe site.

1) The seabed forms an expansive, largely level seabed plain with no dramatic changes in bathymetry or seabed slope. General water depths within the site boundary (encompassing about 105 km^2) range between 40 and 58 m Chart Datum (CD), with a mean of 50.6 m CD

2) Mean spring tide range is ~4.8 m.

3) The seabed is characterised by numerous low amplitude hummocks and mounds (over 25 mounds are present within the survey area). The mounds are commonly up to 4-6 m shallower than the surrounding seabed at depths of 40 to 48 m.

4) The sediments comprise gravelly muddy sand with boulders. Slightly gravelly muddy sand is most common across the western and southern parts of the development area where water depths are generally slightly greater. Towards the north of the wind farm site the thickness of these sediments decreases and bedrock is close to the surface, where the seabed type has been classified as muddy sand with occasional rock. From the centre and to east and southeast of the wind farm site the dominant sediment type is sand.

5) Across the site there is an almost complete absence of bedform features, except for scour features which are explicitly associated with localised flow accelerations. This suggests the site is largely a stable seabed.

6) The ambient tidal current regime is not sufficiently powerful to generate significant sediment transport on either the spring or neap tidal phases.

7) The site can be classified as 'slightly mobile' under the combined effects of waves and currents. Only storm conditions with waves in excess of 5.2-5.4 m significant wave height, and a mean wave period of >8-8.5 s are predicted to mobilise sediments across the site, and such conditions have a return period of > 1 in 10 years.

8) The site receives waves most frequently from a north-northeasterly direction (22.5 degrees); mean wave periods range between 2 and 9 seconds; and significant wave heights up to about 6 m. Waves also arrive from both the southeastern and southwestern quadrants but these form only a minor component of the wave direction spectrum.

9) Fair-weather suspended sediment concentrations are very low (< 10 mg/l) and comprise dominantly silts; concentrations are expected to rise generally only during storm conditions.

10) Large-scale (vertical) changes to general seabed level are not anticipated, except during severe storms.

11) A net directional (suspended) sediment transport in the direction of the flood tidal axis (S – SSW) exists, but residual tidal transport of suspended fine sediments is not judged to be significant on an annual basis.

12) Tidal bedload transport is not considered to occur, except in the vicinity of mound structures; wave-driven bedload transport may occur during storms but is not significant.

2.3 FUTURE CONDITIONS (CLIMATE CHANGE)

Over relatively short time periods (e.g. months) the mean sea level (MSL) can be regarded as being stationary (non-changing). However, over longer time periods (e.g. several years) MSL varies in response to sea level rise and long period tidal trends (e.g. the 18.6 year lunar nodal cycle). Hence, the baseline definition is non-stationary in situations when MSL also varies. The combination of an increasing mean sea level (as a function of sea level rise) and potentially increased storminess is an important issue for future coastal change within the outer Forth and Tay estuaries. Research for the Department for Environment, Food and Rural Affairs (DEFRA) by the UK Climate Impacts Programme (UKCIP) suggests increases of up to 10% in the speeds of extreme winds and heights of extreme waves on the coasts. The consequences in terms of coastal processes is likely to be most evident along the shorelines where much of the wave energy is finally dissipated leading to modified rates of littoral drift. The advancing position of mean high water on beaches will also lead to wave energy dissipation higher up on the foreshore with anticipated beach loss and scour in front of sea walls, or increased frequency of overtopping of coastal dunes or structures. Effects would also apply to offshore areas where the profile of sandbanks may reduce relative to local water depths introducing greater exposure to offshore waves (i.e. there is less wave shoaling and larger waves therefore can run up the shore). The impact of increased wave energy may have consequences for the sediment transport within the area.

Future sea level rise results from the net effect of global change in sea level and the local change in land levels due to post-glacial rebound and subsidence. Based on DEFRA guidance[x] the land in Scotland (which is rising) is assumed to have a rate of change of +0.8 mm per year. The recommended value of relative sea level rise for flood and coastal defence planning for Scotland is 2.5 mm per year in sea level rise to 2025, 7.0 mm per year from 2025 to 2055 and then 10 mm per year from 2055 to 2085.

3 BASELINE ASSESSMENT USING THE FORTH AND TAY MODELLING SYSTEM

A key requirement of the coastal processes assessment was the development of a dedicated hydrodynamic and spectral wave model. Intertek METOC has constructed, calibrated and validated the Forth and Tay Modelling System (FTMS) for the purpose of modelling the baseline metocean conditions, and the subsequent change or impact to the metocean and sediment regimes in both the near and far-field due to the proposed developments. Near-field studies consider the interaction between structures and the effect of the OWF within the site perimeter. Far-field studies consider the general effect of the OWF as a unit of the surrounding area[vi].

The FTMS has been constructed using an unstructured flexible mesh dynamic modelling system. This is a sophisticated two-dimensional modular based modelling system, and has the capacity to run both hydrodynamic and spectral wave models. It may be used to predict the physical properties of tidal currents and waves, and the interactions between these, for any specified area. The FTMS can also be configured to represent the effect of structures, such as wind farm turbines and their foundations, on the hydrodynamic conditions and wave climate.

A flexible mesh model has the advantage of using a spatially varying resolution, so that the complex bathymetries and coastal topographic features can be sufficiently resolved by the model. It also allows fine resolution to be configured in the key areas of interest (for instance around the OWF sites), whilst a coarser resolution can be employed in areas that do not require or warrant such fine detail (such as in the deeper waters closer to the open water boundaries).

The FTMS was built with a spatial resolution varying from approximately 60 m in the area of interest to approximately 2500 m in the offshore part of the model domain. This allows adequate representation of the physical processes in both the near-field and the far-field. A total of 131,582 triangular elements are used in the model. The model covers an area of 33,462 km^2.

Figure 3-1 shows the model domain of the FTMS as a whole, and Figure 3-2 shows the model in more detail around the Neart na Gaoithe site. The depths shown are in metres relative to MSL (the vertical datum used in the FTMS).

Figure 3-1: Forth and Tay Modelling System (FTMS) model domain and mesh resolution

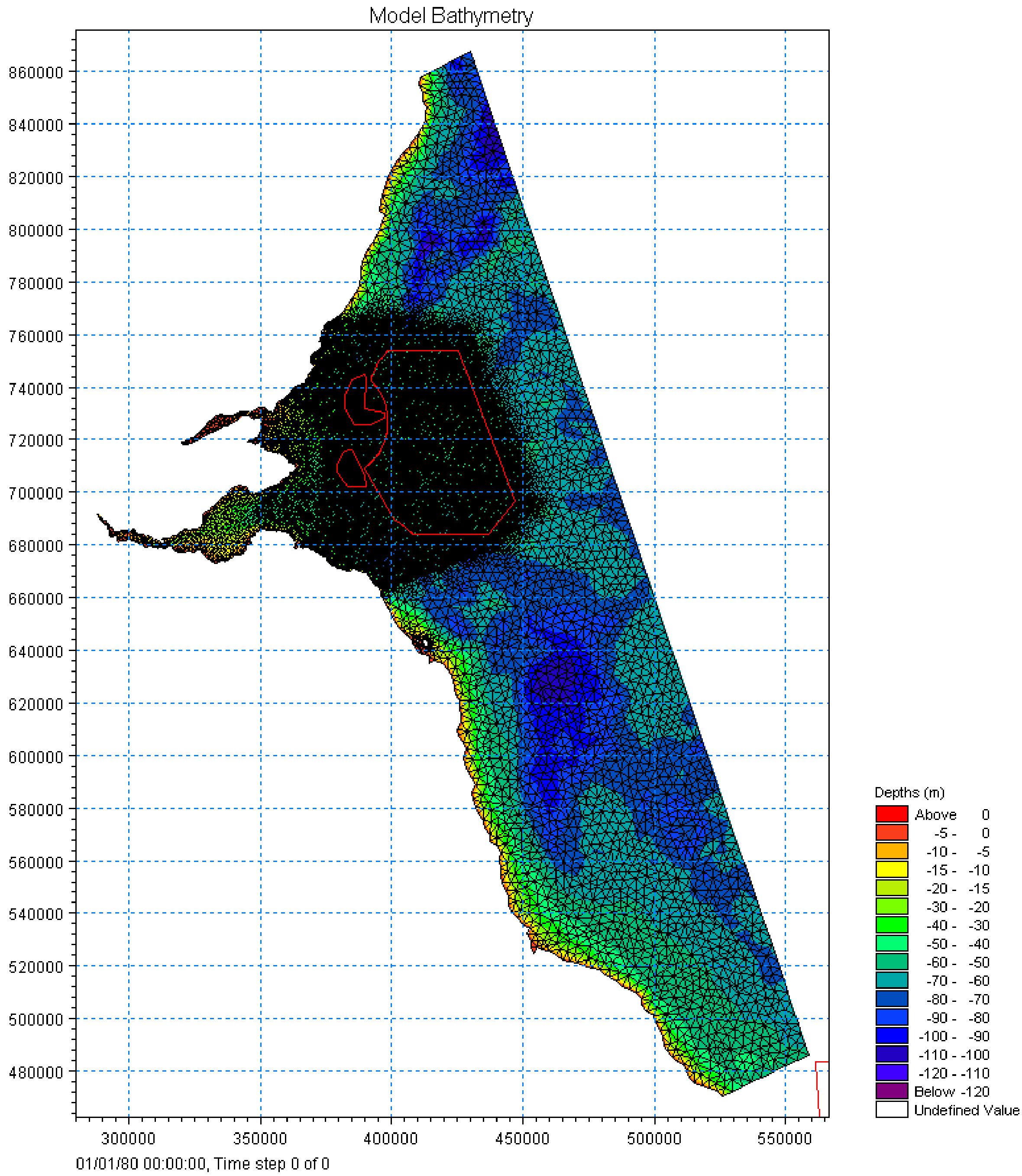
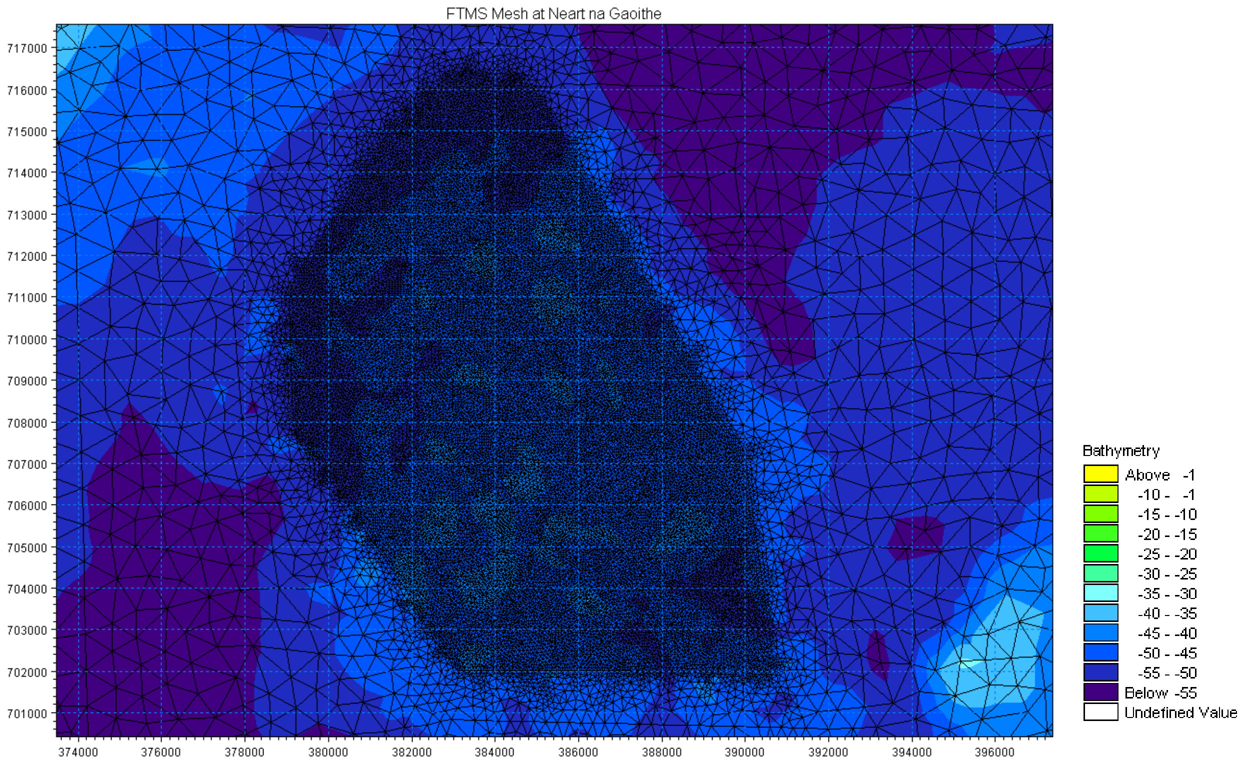


Figure 3-2: FTMS resolution around the Neart na Gaoithe site



A summary of the performance of the FTMS hydrodynamic and spectral wave models in the area of the Neart na Gaoithe development is provided in Appendix C (Section C4). Full details of the construction, calibration and validation of the FTMS are provided in the Intertek METOC report RN2636, issued in September 2011.

This report concluded that:

> The FTMS hydrodynamic and spectral wave models have been well calibrated and validated against appropriate field data, and have been demonstrated to be performing very well across the model domain. The FTMS is therefore fit for the purpose of undertaking the coastal processes assessment for the Inch Cape and Neart na Gaoithe OWFs.

The validated FTMS was used to determine the baseline metocean conditions (water levels, current flows and wave climate), and the resulting baseline sediment regime, against which any modelled changes due to the OWF developments were compared.

3.1 HYDRODYNAMIC REGIME

The hydrodynamic (HD) component of the validated FTMS was used to model the typical tidal conditions experienced across the Neart na Gaoithe site and the region as a whole. A long-term time series of water level was analysed in order to produce tidal harmonic constituents applicable to the general study area. These tidal constituents were used to re-predict a time series of tidal elevations for a full year. From this time series, and the tidal harmonic constituents, it was possible to determine representative mean spring and mean neap tidal conditions. The model was then run for a period during which these mean spring and mean neap conditions occurred. In this way, the FTMS was used to model typical conditions of water level and current velocity.

The typical hydrodynamic conditions across the region were extracted from the model outputs. Figures showing water levels and current speeds are shown in Appendix C – Section C1. High water (HW) and low water (LW) levels on both spring and neap tides, and peak speeds on the flooding and ebbing tides are shown. In addition, percentile (%ile) speeds (calculated over the modelled mean spring and neap tides which are representative of typical tidal conditions) are presented. The selected percentiles represent the percentage of current speeds (through the tidal cycle) that are less than the speed presented. For example, if the 90%ile current speed is 0.5 m/s, then currents will be less than this value (0.5 m/s) for 90% of the time (or conversely speeds only exceed 0.5 m/s for 10% of the time).

The 50, 90, 95 and 99%iles provide a sufficient set of results to represent the general hydrodynamic regime, with a focus on the more extreme (energetic) end of the distribution. The 50%ile represents the average conditions, and the 90, 95 and 99%iles capture the lower frequency but more extreme tidal conditions, which are those more likely to cause sediment mobilisation. The equally infrequent quiescent conditions (i.e. the 10, 5, and 1%ile conditions) are considered to be of lower relevance to the metocean and coastal process study.

Regional (far-field) scale plots are shown in Appendix C – Section C1.1, and more detailed plots around the proposed development (near-field) are shown in Section C1.2.

These plots show that hydrodynamic conditions do not vary much across the Neart na Gaoithe site and its surrounding environment, with water levels and current flows being spatially very uniform at each state of the tide. Water levels range between about 2 m (HW) to -2.6 m (LW) – relative to MSL – during spring tides, and between about 1 m (HW) to -1.2 m (LW) during neap tides. Current speeds reach up to about 0.6 m/s on both the flooding and ebbing spring tides, and up to about 0.4 m/s on both the flooding and ebbing neap tides.

The tidal cycle has a slight asymmetry, with the flood tide slightly dominating the ebb tide during both spring and neap tides (see Appendix B for more details). This will influence the net sediment transport pathways.

These modelled data are consistent with the observed data collected during the metocean campaign, and with other general information about the tidal regime within the area. Table 3-1 provides a summary of comparisons of modelled and measured tidal ranges and currents at the Neart na Gaoithe site.

The semi-diurnal tide is the dominant cause of current flow throughout the study area. Non-tidal components of the total current are of relatively smaller significance. This is because they are either low in magnitude (such as general circulation currents) or infrequent in nature (such as storm surge currents). For example, the 50-year return storm surge current, as determined through analysis undertaken by Partrac and PhysE (see Appendix B), is similar in magnitude to the peak current on a mean spring tide (about 0.6 m/s). More frequent storm surges will have correspondingly lower associated current speeds. Surface wind drift currents can reach speeds of a few tens of centimetres per second in any direction, but these will be confined to the upper layer (top few metres) of the water column and will therefore have no effect on seabed sediment mobility. However, it should be noted that non-tidal flows, such as storm surges and wind-driven currents, would be in addition to the tidal currents experienced at the time.

3.2 WAVE CLIMATE

The spectral wave (SW) component of the FTMS was used to model the baseline wave climate. Long duration time series of wave and wind data at two locations on the offshore (eastern) boundary of the FTMS were acquired from the UK Meteorological Office (UKMO). These data covered an 11-year period (2000 to 2011) and were derived from the UKMO UK Waters wave model. The data were analysed in order to determine the frequency of occurrence of waves with different heights, periods and directions. The analysed wave and wind data were then used to drive the SW model under a large number of different wave conditions (with different wave heights, periods and directions) in order to represent the long-term wave climate across the model domain. Both onshore waves propagating into the model domain from the North Sea, and offshore wind-generated wave conditions were included.

Appendix D provides details of the wave climate data analysis.

The frequency of occurrence of each of the different modelled wave conditions were used to undertake a statistical analysis of the modelled wave climate, from which different percentiles of the key wave parameters (significant wave height, mean and peak wave period) were derived. The selected percentiles represent the percentage of wave conditions which are less than the presented value. For example, the 90%ile significant wave height is the wave height that 90% of all waves are less than (or conversely, the wave height which only 10% of waves exceed).

Figures showing the modelled baseline wave climate are included in Appendix C – Section C.2. These include plots of significant wave height (H_s), mean zero-crossing (mean) wave period (T_z), and peak wave period (T_p), which are shown as 50, 90, 95 and 99%iles. Section C.2.1 includes the regional (far-field) scale plots, and Section C2.2 provides more detail around the Neart na Gaoithe development area (near-field).

These figures indicate that the wave climate across the proposed development area is very uniform, with little spatial variation in either significant wave height or mean/peak wave period. The significant wave height varies between 1.2-1.4 m (50%ile) to 5.2-5.4 m (99%ile), with mean wave period varying between 4.5-5.0 s (50%ile) to 8.5-9.0 s (99%ile), and peak wave period varying between 9.5-10.0 s (50%ile) to 14.0-15.0 s (99%ile). These modelled results are consistent with all other previous analyses of the wave climate in the area. Table 3-1 provides a summary of the modelled and measured wave conditions experienced at the Neart na Gaoithe site.

Table 3-1: Comparison of modelled and measured parameters at the Neart na Gaoithe site

Parameter	Measured / Observed*	Modelled
Spring tidal range (m)	4.5 m	4.6 m
Neap tidal range (m)	2.2 m	2.2 m
Mean peak spring tidal current (m/s)	0.5 to 0.6 m/s	0.6 m/s
Mean peak neap tidal current (m/s)	0.3 to 0.4 m/s	0.4 m/s
50%ile Significant wave height (m)	1.13 m (mean)	1.2 – 1.4 m
50%ile Mean wave period (s)	4.45 s (mean)	4.5 – 5.0 s
50%ile Peak wave period (s)	9.04 s (mean)	9.5 – 10 s

*Observed measurements taken from the Metocean campaign – see Appendix B

3.3 SEDIMENT REGIME

The sediment regime is fundamentally driven by the tidal currents and wave climate and is a function of the type and amount of sediment available for erosion, transport, and subsequent deposition (or accretion).

In order to assess any impact of the proposed development on the local and far-field sediment regime (and thereby the coastal processes), the existing (baseline) bed shear stress due to the tidal currents, the wave climate, and ultimately the combination of both tidal currents and wave processes, was determined.

The bed shear stress is the force exerted at the seabed due to the combination of currents and waves (wave-orbital velocity). The bed shear stress is also a function of the grain size of the seabed sediment. If the bed shear stress exceeds the critical shear stress required for entrainment, then mobilisation of the seabed material will occur, and this material will be transported either along the seabed (as bedload), or in the water column (as suspended load), depending on the material type and the magnitude of the bed shear stress. Both the bed shear stress and the critical entrainment stress are dependent on the median grain size (d_{50}). For this reason, a spatially varying seabed d_{50} map was developed, based on the site-specific sediment samples within and around the Neart na Gaoithe site (from the geophysical campaign), and supplemented with the data available from the British Geological Survey (BGS).

Figure 3-3 and 3-4 show contour plots of the critical shear stress for entrainment. The full description of the analysis of the bed shear stress and critical shear stress for entrainment is provided in Appendix E.

Figures showing the baseline sediment regime are shown in Appendix C – Section C.3. These include contours of the 50, 90, 95 and 99%ile bed shear stress due to currents, waves, and combined (currents and waves). Section C.3.1 includes the regional scale plots, and Section C.3.2 shows these in more detail around the proposed development area.

The baseline sediment regime has been summarised in four key plots (Figures 3-5 to 3-8). These show the spatial variation in the percentage of time that the critical shear stress for entrainment is exceeded due to the combined bed shear stress. Because bed shear stress varies continually due to the orbital wave motion, the mean and maximum bed shear stress throughout a wave cycle, and the percentage of time these exceed the critical shear stress, have been determined.

Figures 3-5 and 3-6 show contours on the regional (far-field) scale, for the mean and maximum combined bed shear stress respectively. Figures 3-7 and 3-8 show the same, but in more detail around the proposed development.

These are based on the combined effects of currents and waves, and indicate how often seabed sediment will be mobilised due to the baseline hydrodynamic regime and wave climate. These results are discussed in more detail in Appendix B.

These plots indicate that over the greater extent of the central and southern parts of the proposed site, the exceedance of critical shear stress is 5 - 10% (i.e. seabed sediment will be mobilised between 5 and 10% of the time). To the north of the site, down the eastern periphery, and at an area to the southwest of the site, sediments are mobilised for up to 10 – 15% of the time. Due to the depth of water at site, only the very largest (highest and longest period) waves cause small orbital motions at the bed. The dominant cause of critical entrainment stress exceedance is the tidal current.

Though there are spatial differences in the percentage exceedance of critical shear stress across the site, these are not large. Therefore, based upon this evidence the site can be classified as slightly mobile under waves and currents combined.

Figure 3-3: Critical shear stress (for entrainment) map – Regional area

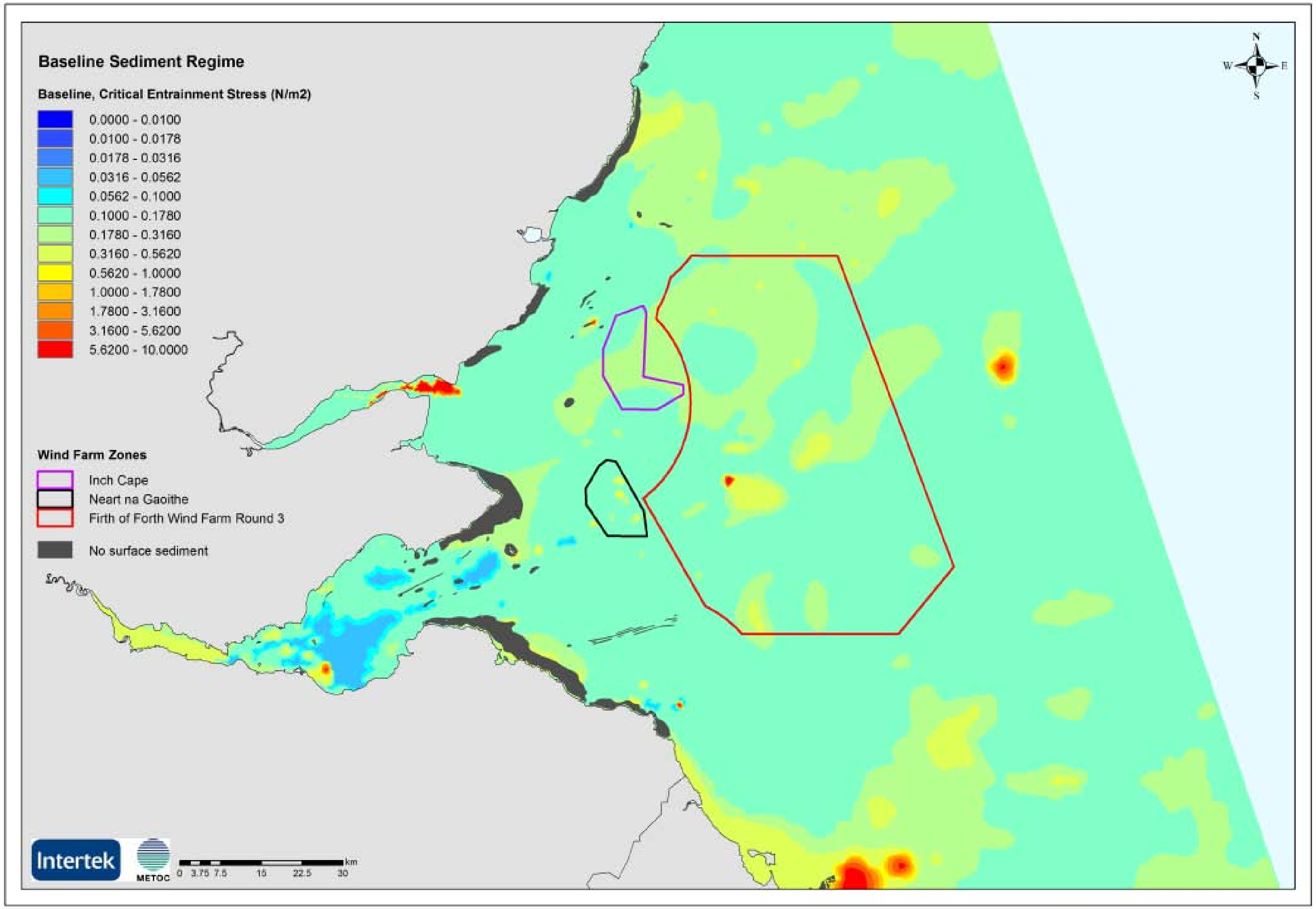


Figure 3-4: Critical shear stress (for entrainment) map – Neart na Gaoithe development area

Figure 3-5: Exceedance of critical shear stress (for entrainment) due to mean combined bed shear stress – Regional area

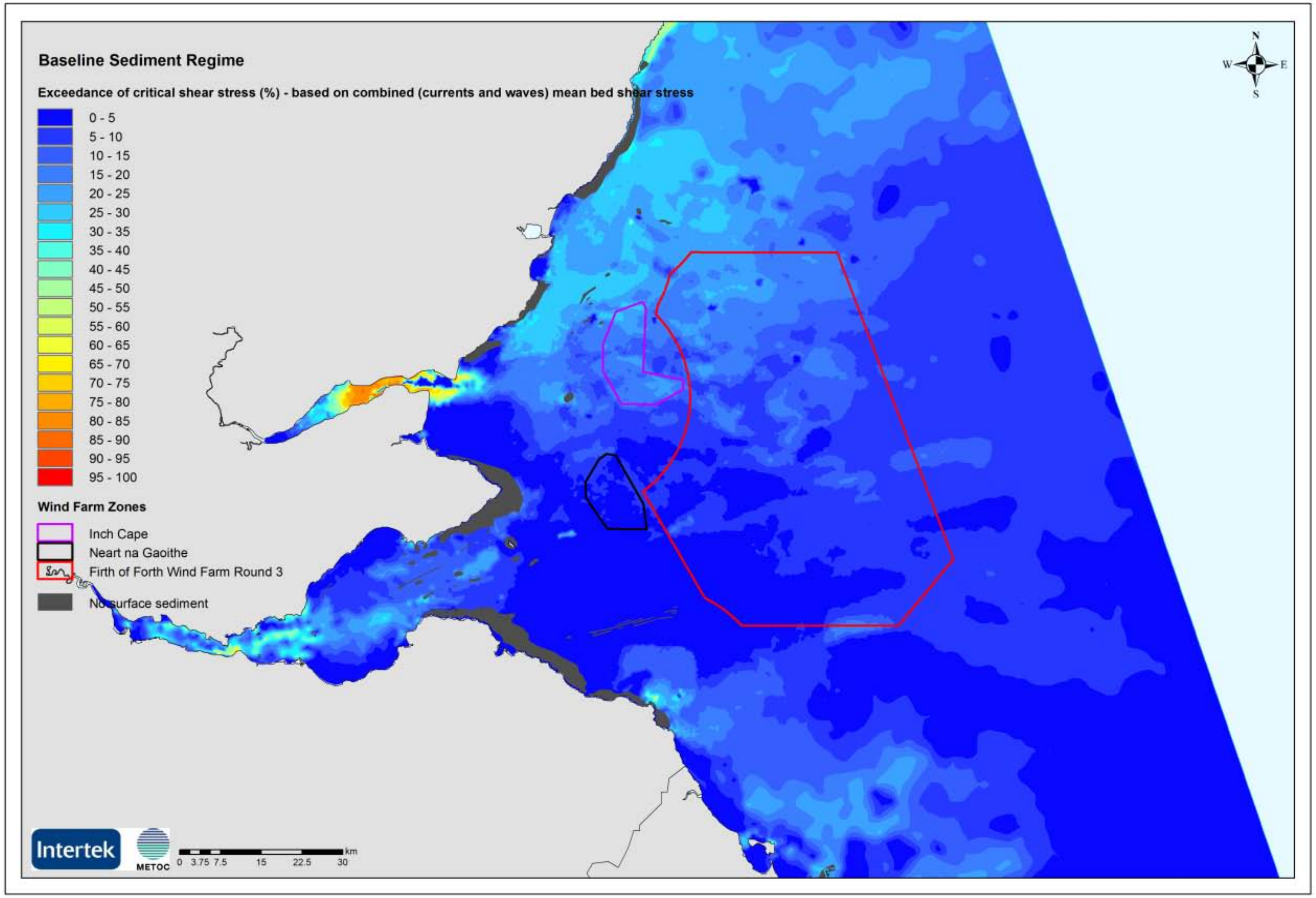


Figure 3-6: Exceedance of critical shear stress (for entrainment) due to maximum combined bed shear stress – Regional area

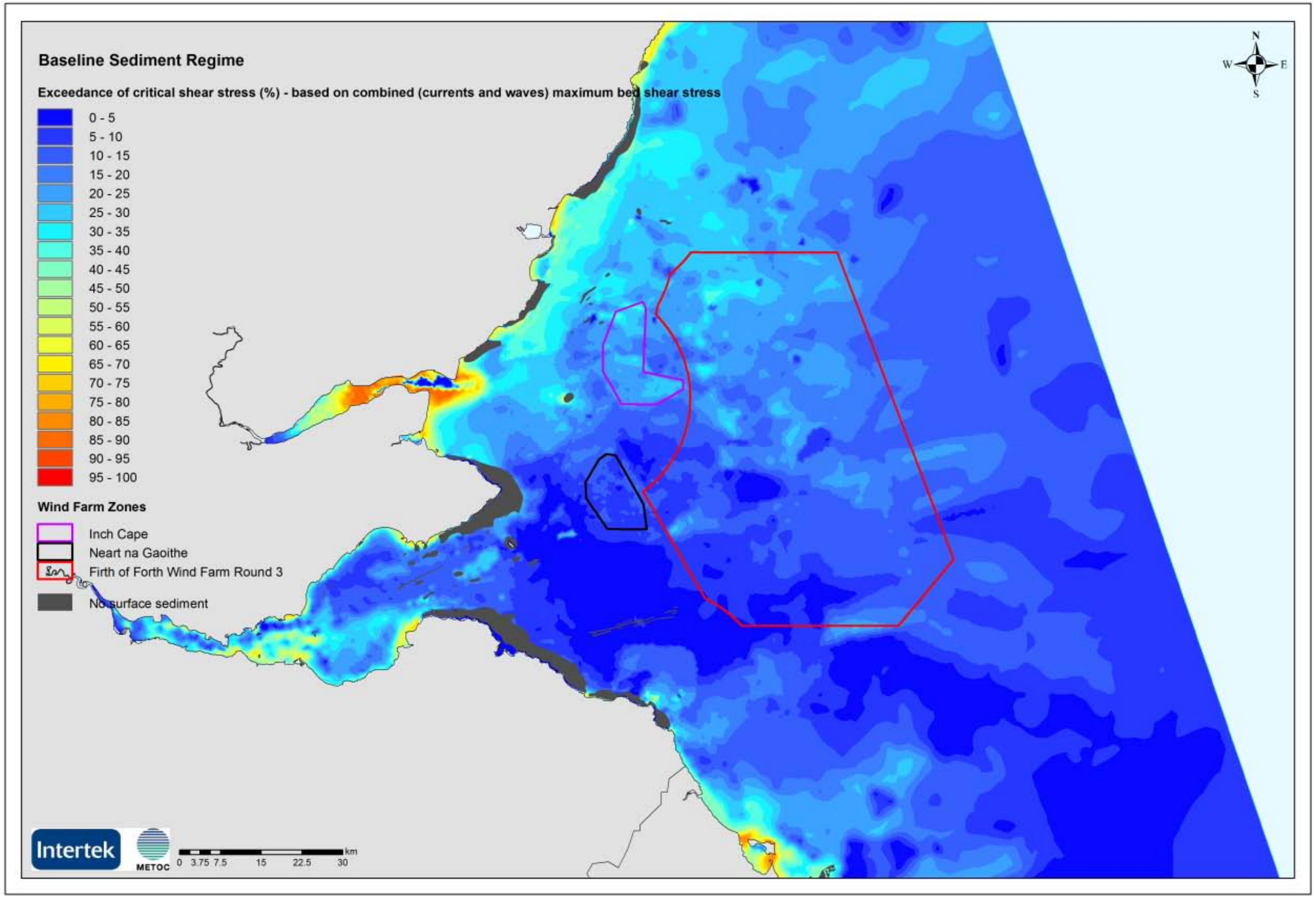


Figure 3-7: Exceedance of critical shear stress (for entrainment) due to mean combined bed shear stress – Neart na Gaoithe development area

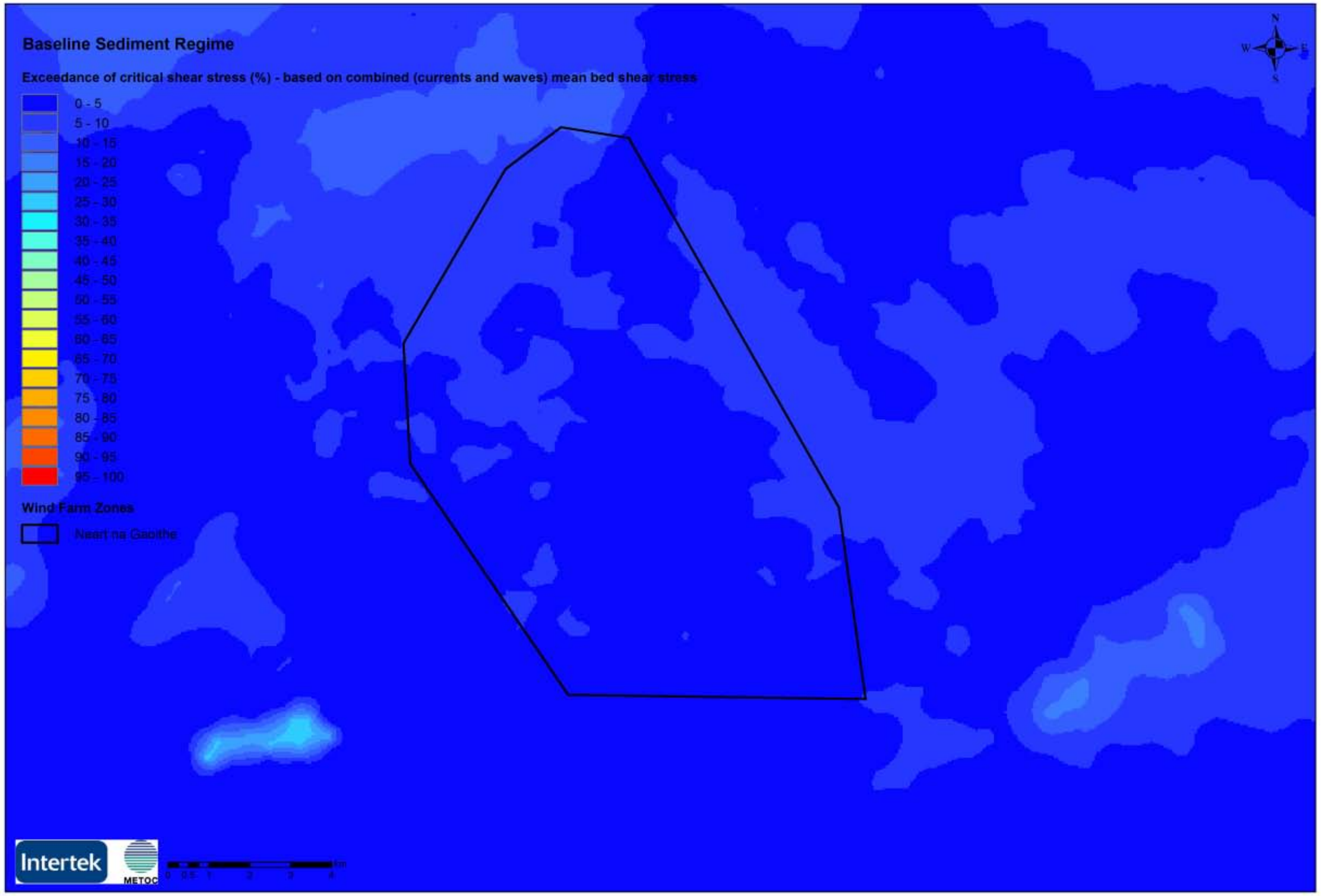
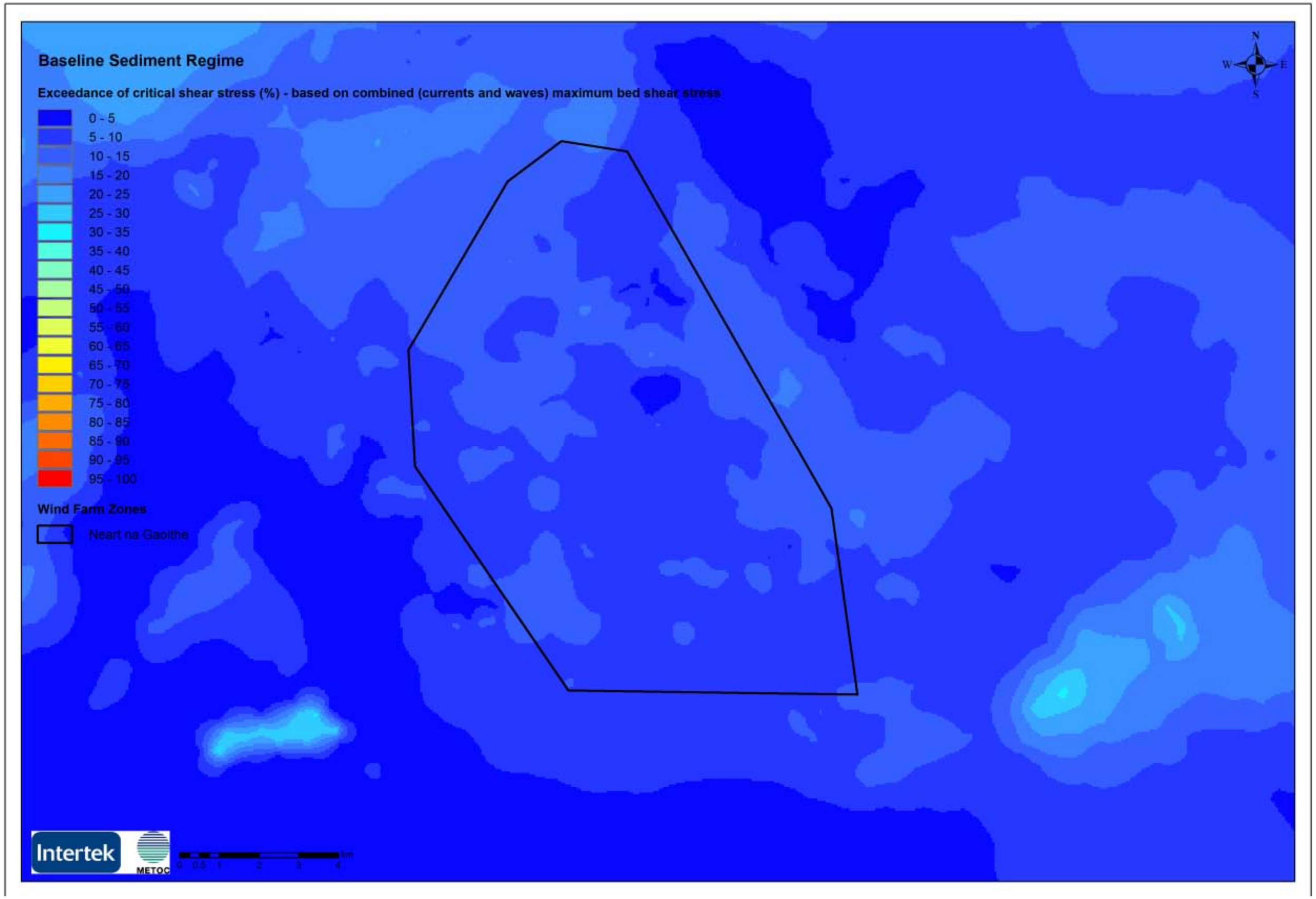


Figure 3-8: Exceedance of critical shear stress (for entrainment) due to maximum combined bed shear stress – Neart na Gaoithe development area

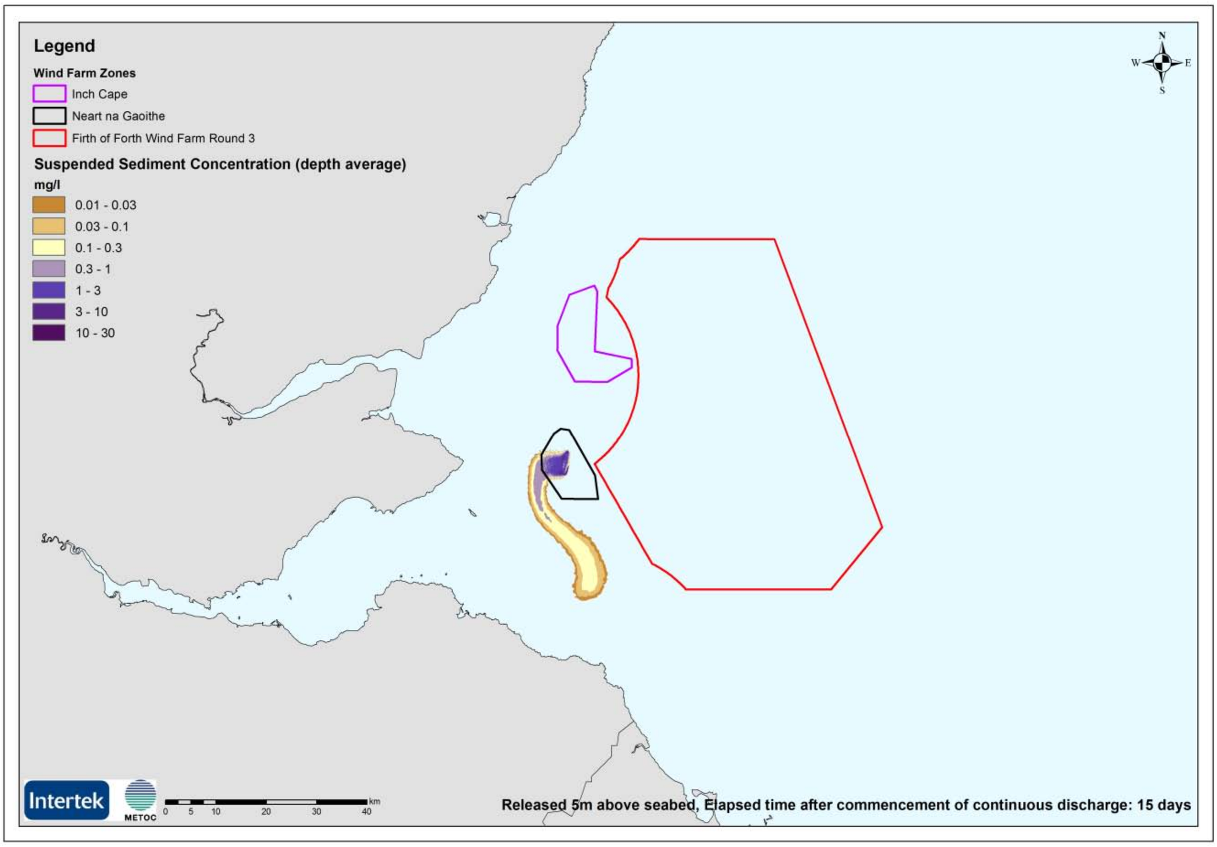


3.3.1 Far-field Suspended Sediment Transport

The typical far-field net transport of suspended sediment from the development site was modelled using the FTMS particle tracking module. A dummy continuous discharge of a neutrally-buoyant plume over a spring-neap cycle was modelled using the FTMS, driven by the baseline (pre-development) HD model. The dummy discharge was released at the centre of the Neart na Gaoithe site, in order to represent the net movement of suspended sediment from the development site. A similar run was undertaken with the developments in place, in order to identify any change in the net movement due to the developments (see Section 5). However, the modelled plume does not represent any specific discharge due to the development.

Figure 3-9 shows the results of this run, which indicates the net transport to the south of the site. This is caused by the flood-dominated tidal regime experienced in the area.

Figure 3-9: Far-field suspended sediment transport pathway



4 ASSESSMENT OF IMPACTS

In order to assess and quantify the potential impacts on coastal processes due to the proposed development, changes to the baseline (existing) metocean and sediment regimes have been determined using the FTMS. Any changes to these existing regimes might result in a change to the coastal processes in the area, and a consequential impact on the geo-marine environment.

The methodology applied has been outlined in Section 1.4, and is provided in more detail in the Intertek METOC report RN2550 (Methodology Statement). This approach has been agreed with the clients, and with Marine Scotland (and all other relevant stakeholders), and is also in line with the best practice guidance provided in the COWRIE report[vi].

The applied approach can be summarised as follows:

1) The baseline (existing) conditions were determined based on the best available information, including field data collected specifically by the developers, and supported by output from the FTMS. This is reported in the Intertek METOC report RN2728 (Regional Baseline Description), and in Appendix B of this report.

2) The FTMS numerical modelling system was developed, calibrated and validated. This has been configured so that it is suitable for modelling the metocean and sediment regimes in both the near and far-field, and is capable of incorporating the effects of the proposed development on these regimes. The FTMS is described in full in the Intertek METOC report RN2636 (Model Calibration and Validation).

3) The FTMS was used to model a range of metocean (tide and wave) conditions under the baseline scenario (no OWF developments). These model outputs were used to determine the baseline sediment regime (in terms of bed shear stress and exceedance of critical shear stress for entrainment). This is described in Section 3 and Appendix C.

4) The FTMS was then used to model the same range of conditions under the 'with-development' scenarios, (including the cumulative and future climate scenarios) and to compare the resulting metocean and sediment regimes with the baseline regimes.

5) The magnitude of the changes to these regimes, and the resultant changes to the coastal processes were determined, for inclusion in the assessment of the significance of the effects within the EIA by EMU.

A range of temporal and spatial scales, as well as a number of different scenarios, were incorporated in the assessment, which are detailed in this section.

4.1 TEMPORAL SCALES OF ASSESSMENT

As agreed with the clients and stakeholders, the potential changes to the coastal processes have been assessed over the following temporal scales:

- Construction phase;
- Operational phase, including:

  - Short-term post-construction impacts;
  - Long-term post-construction impacts; and
- Decommissioning phase[vi]

4.1.1 Construction Phase

This included the analysis of any impact to the metocean and sediment regimes due to the construction processes (rather than from the development itself). The presence of large installation equipment, such as jack-up rigs, and the process of laying foundations and burying cables, all have the potential to have an effect on the environment, and these were considered as part of the assessment.

4.1.2 Short-term Post-Construction Phase

This included the assessment of any short-term impacts from the development following completion (over timescales of days to weeks). The presence of the turbine structures and their associated foundations will cause a change to both the flow of water and the characteristics of waves as they pass through the development site and are modified by the structures. Current speeds will increase locally as the flow accelerates around the structures, and waves may be partially blocked or otherwise modified by the structures. Such changes will also lead to an increase in the potential for sediment entrainment and erosion around the structures, resulting in scour around the turbine foundations and exposed cables.

Therefore, as well as the short-term changes to the baseline regimes, an estimate of the potential scour around the foundations and cables, and the subsequent fate of scoured material was included in the assessment.

4.1.3 Long-term Post-Construction Phase

This included the assessment of the long-term impacts over the lifetime of the development (25 to 50 years), and included the cumulative impacts from the other proposed OWFs in the area. It also included an assessment of the effects of a changing climate, and the resulting changes to the metocean and sediment regime due to sea-level rise and increased 'storminess'. These potential changes were compared with the predicted changes (to the present baseline) due to the development.

4.1.4 Decommissioning Phase

This included the assessment of the impacts due to the decommissioning processes, including the removal of foundations and buried cables.

4.2 Spatial Scales of Assessment

In accordance with best practice[vi], and as agreed with the clients and stakeholders, the potential changes to the coastal processes have been assessed over the following spatial scales:

- Near-field; and

- Far-field[vi]

Owing to the unstructured and flexible resolution of the modelling system developed, it was possible to analyse both the near-field and far-field impacts using the FTMS. In addition, the near-field assessment was supported by the empirically-based analysis of the potential scour around individual structures

4.2.1 Near-field Scale

The near-field study included the assessment of impacts from the proposed development on a local scale. This included the effect on the local environment from individual turbines, and a determination of any localised cumulative or overlapping impacts between adjacent turbines. The near-field scale study included the assessment of effects from the entire development on environmental processes in the immediate vicinity of the development.

The spatial resolution of the FTMS throughout the proposed development site and immediately surrounding it was approximately 60 m. The model therefore incorporated at least ten model elements (cells) between turbine structures, and this resolution was considered appropriate for the near-field assessment of the Neart na Gaoithe site.

It should be noted that the near-field processes and effects (such as small scale turbulence around structures) are not resolved explicitly in the FTMS, and such processes are parameterised in the model to account for the overall effect. Very fine resolution Computational Fluid Dynamics (CFD) modelling would be required to fully resolve such processes, and it is generally considered that such costly analysis is not appropriate for an EIA.

The parameterisation of the relevant processes was undertaken using the specific mechanisms as provided and recommended by the developers of the industry-standard modelling software. These included determining the current-induced drag force and a decay term around each individual structure, so that the currents, water levels and wave energy are appropriately modified. The parameterisations applied, and the subsequent representation of the individual structures within the model, is explained in more detail in Appendix F.

In addition, the assessment of the potential for scour around the individual structures has not been undertaken directly using the FTMS, which is not suitable for such small scale analysis. An empirically-based assessment, using well-known engineering equations, has been undertaken. This assessment used the modelled currents and waves from the FTMS as inputs to the equations. The fate of the estimated volume of scoured material was then modelled using the FTMS to determine the excursion of any resulting plume of suspended sediment, in-water suspended sediment concentrations, and the resulting footprint and thickness of the deposited material.

It should be noted that although the two STW OWF developments were resolved in the FTMS in sufficient detail to assess the near-field scale effects (i.e. those from individual turbines), the spatial resolution around the Round 3 Firth of Forth development site was coarser, and therefore not sufficient to assess the near-field scale impacts within that site. However, the model is sufficiently resolved to assess any impact from the development as a unit, and therefore cumulative impacts from this site have been accounted for.

4.2.2 Far-field Scale

The far-field study included the assessment of the impacts from the proposed development on a regional scale. This included the effect from the entire development on coastal processes beyond the development site, and in particular extending to the shoreline. The far-field assessment also included the cumulative impacts from the other proposed OWFs. Fundamentally the model accounts for overall acceleration and deflection of current flows, and the loss of wave energy due to the developments as a whole, and models the gradual return to ambient metocean conditions with increasing distance from the development.

The resolution of the FTMS in the far-field varied from about 150 m close to the proposed development sites, to 2500 m in the offshore areas. Within the Round 3 Firth of Forth development site the model resolution was approximately 500 m, and within the coastal areas, including the Forth and Tay estuaries, the model resolution was about 800-1200 m. The FTMS was therefore considered to be suitable for assessing the processes in the far-field. This is in line with the COWRIE best practice guidelines[vi]. The far-field tidal fluctuations (in current speeds and water levels) and the general wave climate, as well as the overall effect on these from the wind farm developments as a whole, are considered to be adequately represented in the FTMS.

4.3 Assessing the Effects of Structures

Any structures placed within the marine environment, such as the foundations for the turbines, may lead to changes to the metocean regime. Near-field effects on currents will include the bifurcation and deflection of flow, and the resulting acceleration and deceleration of current speeds, and small scale turbulence around structures. Structures will interact with the wave field potentially causing scattering/diffraction, reflection and shoaling of waves.

As discussed previously, such processes were not explicitly resolved in the FTMS, but were parameterised in order to model the overall effect of such processes, in both the near and far-field. The FTMS provides different options for the parameterisation of structures, and these were investigated to determine the most appropriate method.

The details of how the proposed development was incorporated in the FTMS are provided in Appendix F.

4.4 Summary of Assessment Scenarios

The study therefore used different assessment techniques and tools in order to account for all of the various temporal and spatial scales, and the different types of effect that needed to be investigated. These are summarised in Table 4-1 below.

Table 4-1: Summary of assessment topics and modelling tools/methods applied

Potential Effect	Near-field (NF) Modelling Tools	Far-field (FF) Modelling Tools	Processes included / Outputs
Changes to hydrodynamics (water levels and current flows)	FTMS Hydrodynamic (HD) module (utilising the fine model resolution around the development site).	FTMS HD module (utilising the variable resolution of the model mesh).	Bifurcation of flow around structures (NF) Localised acceleration of currents (NF) Change in general circulation (FF) Change in tidal symmetry, orientation (FF) General change in energy of hydrodynamic regime (NF/FF)
Changes to the wave climate	FTMS Spectral Wave (SW) module (utilising the fine model resolution around the development site).	FTMS SW module (utilising the variable resolution of the model mesh).	Refraction Shoaling Bottom dissipation Wave breaking White capping Wind-wave generation Directional spreading Frequency spreading Wave-current interaction General change in energy of the wave regime
Changes to sediment regime	FTMS HD and SW modules FTMS Particle Tracking (PT) module Site-specific (and regional) sediment grain size data Standard equations to determine the locations and frequency of occurrence of sediment mobilisation (based on bed shear stress).		Near bed tidal currents Near bed wave orbital velocities Seabed sediment size distributions Bed shear stress Critical shear stress for entrainment
Fate of scoured material around foundations	Empirical scour equations	FTMS PT module	Equilibrium scour depth and scour pit dimensions Suspended sediment concentrations Deposited sediment thickness and extent
Fate of dredged material from gravity base preparations	FTMS PT module	FTMS PT module	Estimate of dredged material Suspended sediment concentrations Deposited sediment thickness and extent
Fate of disturbed material during cable burying	FTMS PT module	FTMS PT module	Estimate of disturbed material Suspended sediment concentrations Deposited sediment thickness and extent

4.5 Determination of Significance of Effects

To determine the magnitude of an effect, the physical change in the environment from baseline (background) conditions as a result of the development needs to be quantified.

The magnitude of effect is a function of the following four parameters: spatial extent, duration, frequency, and severity. The exact definition and application of these parameters will vary according to each topic and receptor group.

It is the purpose of this assessment to quantify the physical changes to the metocean and sediment regimes, so that the significance of the effects can be assessed as part of the EIA.

4.6 Realistic 'Worst Case' Scenario

As discussed in Section 1.3, the final design of the Neart na Gaoithe OWF is currently not yet known. Therefore, in order to ensure a conservative approach to the assessment, a realistic 'worst case' scenario was applied. This is in line with the 'Rochdale Envelope' approach as advised by the Infrastructure Planning Commission, and is consistent with similar previous studies. The realistic worst case scenario for the assessments was agreed with the clients.

It should be noted that the realistic worst case scenario in terms of impacts to the coastal processes (which is therefore the realistic worst case used in this assessment) is not necessarily the same as the worst case in terms of other issues (such as noise impacts), and that different worst case scenarios may well be used for different aspects of the EIA. Furthermore, and for the same reason, a different scenario was used for the scour assessment than that used for the rest of this assessment. The realistic worst case scenario applied therefore differs between the different topics of assessment. The concept is that the assessed scenario leads to the likely worst case impacts, and is not necessarily meant to represent an actual development design.

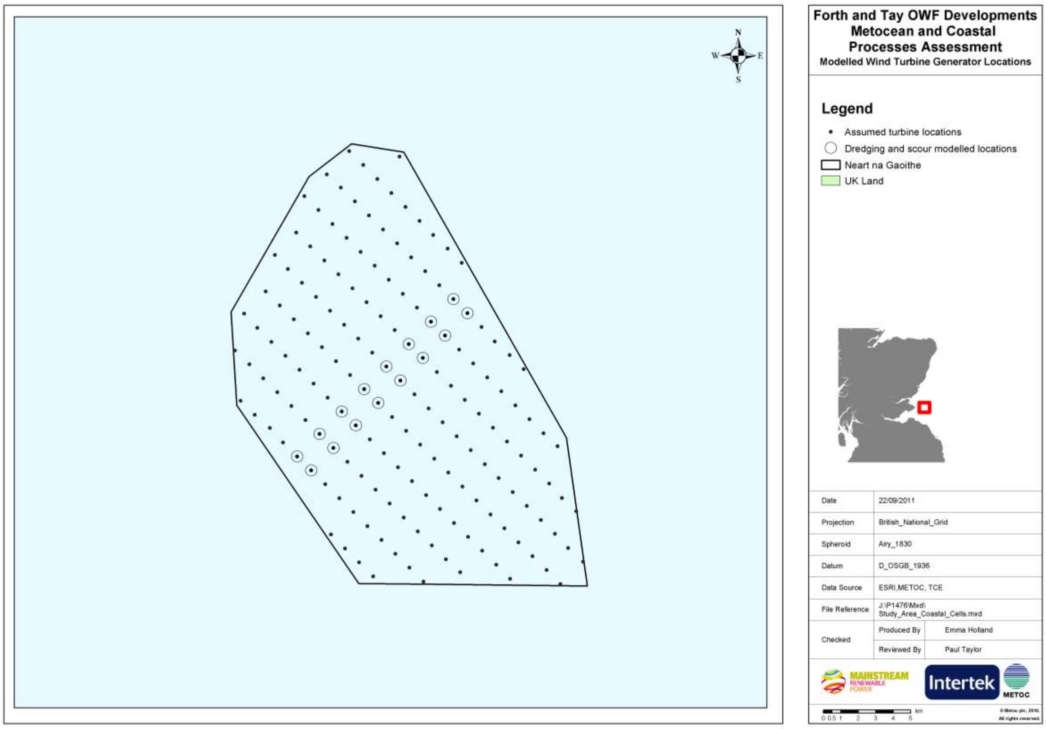
4.6.1 Metocean Impacts Scenario

Following discussion with the client's development project team, and based on the experience of Intertek METOC and Partrac, it was determined that a gravity base foundation type, rather than a jacket structure, would lead to the greatest change to the metocean regime, due to the greater cross-sectional area which would lead to the impedance of currents and waves within the water column. Through calculation and discussion with the client, it was also agreed that the larger foundation (for the 6 MW turbine – as expected at the time) would lead to greater overall impact than the smaller foundation base required for the 3.6 MW turbine. Although the spacing between turbines would be slightly greater for the 6 MW turbines (1000 m compared with 960 m – see section 1.3), the significantly greater cross-sectional area of each of the larger bases would lead to greater impacts overall.

In addition, owing to the fact that it is not yet known which area of the proposed site will be developed, and to ensure the assessment was conservative, the layout used in the assessment assumed complete coverage of 6 MW turbines over the entire site. Using the assumed turbine spacing (1000 m along the line and 630 m between lines), the number of modelled turbines was 126. This exceeds the maximum number of 6 MW turbines (75) based on the consented capacity of the proposed development, and is therefore a conservative development layout. Figure 4-1 shows the layout of the modelled Neart na Gaoithe development.

It should be noted that for the near-field and far-field impacts of the development on the metocean regime and coastal processes, all 126 assumed turbines were included in the modelling. However, for the impacts from the construction phase activities, and for the scour assessment, two representative rows of turbines were modelled, and the resulting impacts were extrapolated to assess the overall impacts, as necessary. This is discussed in more detail in the relevant sections below.

Figure 4-1: Location of modelled turbines within the Neart na Gaoithe Development



4.6.2 Construction Phase Disturbed Sediment Scenarios

There are a number of construction phase activities which may lead to impacts on the environment, and which were therefore considered in the assessment. These were as follows:

- Dredging of seabed to prepare/level bed for gravity base foundation;
- Burial of export and inter-array cables; and
- Anchoring of jack-up rig for installation of foundations/turbine.

The main effect from any sediment disturbed during the construction phase will be an increase in suspended sediment concentrations, and to a lesser degree potentially a smothering of benthic communities on the seabed. The magnitude of these impacts will be dependent on the volume, particle size and type of disturbed sediment, the local hydrodynamic regime, and the water depth.

4.6.2.1 Gravity base foundation preparation

In preparation for gravity base foundations, the seabed would be levelled and the removed seabed sediment will be discharged back into the water column. The technique applied, the volume of material removed, and the depth and rate of discharge will be dependent on the type and size of foundations, the seabed sediment composition, and the water depth. For the realistic worst case scenario, a number of assumptions were made, as the necessary details regarding the foundation type and seabed preparations were not known at the time of the assessment. These assumptions are as follows:

- It was assumed that a square area, 50 m x 50 m, around each 35 m diameter gravity base will be dredged to a depth of 2 m. This equates to an assumed dredged volume of 5000 m3 per turbine location.

This assumed dredged area was estimated by including a conservative 'tolerance' of at least 7.5 m around the area required for the larger 6 MW gravity base. The assumed dredged depth of 2 m was provided by Mainstream.

- It was assumed that the dredging process will be on a continual basis, with the dredging of each foundation base taking 24 hours to complete, and the commencement of each new base starting immediately after the previous base.
- It should be noted that in the plots that show the impacts (Appendix H), a daily 'snapshot' of the evolving plume has been extracted from the model – the time selected each day is just as the discharge from one turbine has ceased, and the discharge from the next turbine has just commenced. The plots therefore show the plume from the previous day's discharge, and a very small amount of discharged sediment from the next turbine.
- It was assumed that the discharge rate for the dredged material will be on a continual basis. In reality, it is likely to take several days to complete the preparation of each base, and there will be periods between the discharge of dredged material.
- It was assumed that the dredged material from each turbine base will be discharged at that turbine location.
- It was assumed that the dredged material might be discharged at any depth within the water column. Therefore two different scenarios were modelled, one with the discharge close to the sea surface, the other close to the seabed.
- It was assumed that the spatial variation in conditions across the site, in terms of the hydrodynamic regime, and the sediment type and particle size distribution, are very small, and would not lead to any noticeable variation in the resulting impacts of suspended sediment concentration or deposition footprint.

It should be noted that the scale of the other assumptions that would affect the resulting impacts, such as the volume, rate and discharge depth of the discharged material, far exceeds the very small potential variation that might result if a different turbine location within the development site were to be modelled.

Therefore, in order to determine the indicative worst case impacts that might occur at the site due to gravity base foundation preparation, two neighbouring lines of turbines (each with eight turbines) through the middle of the proposed development site were selected for the modelling. These are shown on Figure 4-1.

A representative particle size distribution for the dredged sediment was also applied. This was based on the sediment samples taken throughout the proposed development site. The modelled particle size distribution is shown in Table 4-2, and a summary of the modelling inputs is shown in Table 4-3.

Table 4-2: Representative particle size distribution applied

Sediment Category	Mean Grain Size (mm)*	Settling Velocity (m/s)	%
Very Coarse Gravel	47.75	1.4171	0.00
Coarse Gravel	24.00	1.0560	0.00
Medium Gravel	11.94	0.7968	0.08
Fine Gravel	5.93	0.5548	0.22
Very Coarse Gravel	3.00	0.3494	0.35
Very Coarse Sand	1.50	0.2030	0.54
Coarse Sand	0.75	0.1031	1.97
Medium Sand	0.38	0.0471	8.49
Fine Sand	0.19	0.0179	48.76
Very Fine Sand	0.09	0.0054	29.50
Mud	0.03	0.0007	10.09

*mean grain size has been estimated based on the range of grain sizes for each sediment category, as per the Wentworth scale

Table 4-3: Summary of inputs for the gravity base preparation impact assessment

Location	Discharge volume (per gravity base) m^3	Discharge rate (kg/s)	Discharge duration (per gravity base)	Start of dredging/release	
				Tide	Tidal Phase (approx)
Turbine 1 (row 1)	5000	153.35*	24 hours	Spring	HW
Turbine 2 (row 1)	5000	153.35*	24 hours	Spring	HW-50mins
Turbine 3 (row 1)	5000	153.35*	24 hours	Spring	HW-1h40mins
Turbine 4 (row 1)	5000	153.35*	24 hours	Intermediate	HW-2h30mins
Turbine 5 (row 1)	5000	153.35*	24 hours	Intermediate	HW+3h20mins
Turbine 6 (row 1)	5000	153.35*	24 hours	Neap	LW+2h
Turbine 7 (row 1)	5000	153.35*	24 hours	Neap	LW+1h15mins
Turbine 8 (row 1)	5000	153.35*	24 hours	Neap	LW+20mins
Turbine 1 (row 2)	5000	153.35*	24 hours	Intermediate	LW-30mins
Turbine 2 (row 2)	5000	153.35*	24 hours	Intermediate	LW-1h15mins
Turbine 3 (row 2)	5000	153.35*	24 hours	Spring	LW-2h
Turbine 4 (row 2)	5000	153.35*	24 hours	Spring	LW-3h
Turbine 5 (row 2)	5000	153.35*	24 hours	Spring	HW+2h25mins
Turbine 6 (row 2)	5000	153.35*	24 hours	Intermediate	HW+1h35mins
Turbine 7 (row 2)	5000	153.35*	24 hours	Intermediate	HW+45mins
Turbine 8 (row 2)	5000	153.35*	24 hours	Neap	HW

*based on area of 50m x 50m, depth of 2m and density of sand of 2650 kg/m^3

The fate of the dredged material was modelled using the FTMS Particle Tracking module.

The dredging (and discharging of material) from the first turbine began at HW on a spring tide and therefore the modelling covered a period of sixteen days, which incorporated a spring-neap tidal cycle. The modelling is considered to be representative of the likely impacts, regardless of when in the tidal cycle the operation actually takes place, or where within the site the material is discharged.

In terms of worst case impacts from this discharged material, a release at the sea surface would result in a larger plume of suspended sediment, and a larger, yet thinner deposition footprint. However, a release near the seabed would lead to a smaller plume, and a smaller, but thicker deposition footprint.

Since the discharge depth is not yet known, and it is quite feasible that the release could be at any depth within the water column, the fate of the gravity base dredged material was modelled at two different release depths: 2 m below the sea surface; and 5 m above the seabed, at each of the sixteen turbine locations selected for modelling.

4.6.2.2 Cable Burial

The export and inter-array cables are likely to be buried wherever possible.

Cable burial may be achieved using a variety of mechanical approaches, including jetting, mechanical trenching and ploughing. Modern technologies are now developed to the point where loss of sediment is substantially minimised; however, some material is unavoidably and permanently disturbed both through sediment removal and direct trenching vehicle impact. For the purposes of the realistic worst case scenario, a burial depth of 2 m, as requested by Mainstream for both the export and inter-array cables, was assumed. In addition, a conservative trench width of 1 m was assumed.

As described in Appendix G, and also as concluded in previous studies, the trenching technique is likely to lead to the greatest volume of disturbed seabed sediment. The rate of trenching depends on a number of factors, such as the vessel used, the water depth and the sediment type. However, a typical rate for trenching is 400 m per hour. For a conservative trench depth of 2 m and width of 1 m (as assumed for this assessment), this equates to a maximum volume of displaced material of 800 m^3 per hour (conservatively assuming 100% liberated sediment during trenching).

Therefore to assess the potential impacts from the cable burial activities, the FTMS Particle Tracking module was used to model a moving discharge (a rate of 400 m per hour) along the export cable route. Three representative locations along the proposed Torness export cable route were modelled: one close to the development site; one approximately mid-way along the route; and one close to landfall. These locations were selected based on the particle size distribution data from the site-specific surveys. Since finer sediment will remain in suspension longer, it was assumed that areas with the greatest proportion of finer sediment would lead to larger plumes of suspended sediment and therefore greater impacts. The specific Particle Size Distribution (PSD) data collected during the benthic survey along the proposed cable route at the selected modelling locations were applied in the modelling. These are shown in

Table 4-4. A summary of the modelling inputs for the cable burial assessment is shown in Table 4-5, and the results are presented in Appendix H.

Table 4-4: Particle size distribution data applied in the cable burial assessment

Sediment Category	Mean Grain Size (mm)	Sample ID 99 (Inshore) %	Sample ID 93 (Midpoint) %	Sample ID 43 (Offshore) %
Very Coarse Gravel	47.75	0.00	0.00	0.00
Coarse Gravel	24.00	0.00	0.00	0.00
Medium Gravel	11.94	0.19	0.00	0.00
Fine Gravel	5.93	0.10	0.00	0.00
Very Fine Gravel	3.00	0.20	0.00	0.10
Very Coarse Sand	1.50	0.28	0.01	0.07
Coarse Sand	0.75	1.77	0.02	0.70
Medium Sand	0.38	14.20	0.15	3.23
Fine Sand	0.19	47.02	0.64	43.69
Very Fine Sand	0.09	22.46	53.21	39.10
Mud	0.03	13.79	45.97	13.11

Table 4-5: Summary of cable burial modelling inputs

Release location	Discharge Volume per hour (m^3)	Discharge rate (kg/s)	Discharge duration	PSD sample ID
Inshore	480*	353**	12.5 hours (mean spring tide)	99
Midpoint	480*	353**	12.5 hours (mean spring tide)	93
Offshore	480*	353**	12.5 hours (mean spring tide)	43

* based on depth of 2m, width of 1m, trenching rate of 400 m per hour, and a porosity of 60% (as determined from the sediment material collected at the site and provided by Partrac)

**this equates to a mass of 1,272,000 kg per hour based on a volume of disturbed sediment of 480 m^3 per hour and a density for sand of 2,650 kg/m^3

4.45.1.1 Jack-up Rig Anchoring

Although there may be some sediment disturbed during the installation by jack-up rigs (through anchoring and spud cans), it was considered that any impacts would be small, transient and localised. The potential volume of disturbed material will be very small in comparison with the dredged material likely to be removed and discharged during the gravity base preparations. Any impacts due to the use of jack-up rigs during installation will therefore be much smaller than those estimated from the gravity base preparation modelling.

4.45.2 Scour Assessment Scenario

For the purposes of the scour assessment, it was agreed that if gravity bases were employed as the foundation type, scour protection would definitely be required, and that adequate scour protection and mitigation options would be included in the engineering design of the bases. Any impact due to scour around gravity bases would therefore be minimised as a matter of course.

It was therefore agreed that the worst case scenario in terms of impacts on the environment due to potential scour would be from jacket structures, and the scour assessment therefore assumed jacket structures would form the foundation type. The empirical assessment of scour around the jacket structures is detailed in full in Appendix G.

This assessment determined that the maximum volume of scoured material from a single jacket structure (for the larger 6 MW turbine) would be 1100 m^3, and that it would take approximately 86 days (several spring-neap tidal cycles) for the equilibrium depth scour pits to develop. The fate of the potential scoured material was modelled using the FTMS Particle Tracking module, driven by the modelled hydrodynamic regime. In order to be conservative, the maximum volume of scoured material (1100 m^3) was released at a number of turbines in the middle of the proposed site over a 16-day period (i.e. roughly one spring-neap cycle). The same sixteen turbine locations, and the same representative PSD, were used as in the gravity base foundation preparation scenario, and the material was discharged close to the seabed.

4.45.3 Cumulative Impacts Scenario

For the cumulative impact scenario, the proposed Inch Cape STW OWF and the Firth of Forth Round 3 OWF were also included in the model. The same realistic ‘worst case’ scenario approach was used for the layout of the Inch Cape OWF as for the Neart na Gaoithe OWF, with the modelled turbine array having complete coverage over the entire development site. This led to 328 turbines being included in the assessment, which is many more than the actual maximum number possible (167), based on the licence. For the Firth of Forth OWF, the larger gravity base (for the 6 MW turbine) was used, but the number of turbines was limited to the anticipated maximum number of 1000 (based on 725 turbines for phases 2 and 3), as outlined in the Firth of Forth OWF Scoping Report[xi]. Modelling complete coverage of the entire Firth of Forth zone at maximum capacity would have resulted in the inclusion of more than 3000 turbines, which was considered too extreme and unrepresentative of worst case conditions.

It should be noted that as no other information regarding the Round 3 site was available, other than the scoping report, the 1000 modelled turbines were positioned as close to the Neart na Gaoithe and Inch Cape OWFs as possible, in order that the worst case cumulative impacts would were assessed. The final array layout for the Firth of Forth OWF will not be as modelled, and the turbines are likely to be more evenly spread between the three phases, and further from the STW OWFs. Actual cumulative impacts due to this development are therefore very likely to be less than those reported here.

Table 4-6 summarises the realistic worst case scenario details for the three OWFs. Figure 4-2 shows the layout of the three modelled OWFs for the cumulative scenario.

Table 4-6: Realistic worst case scenario details

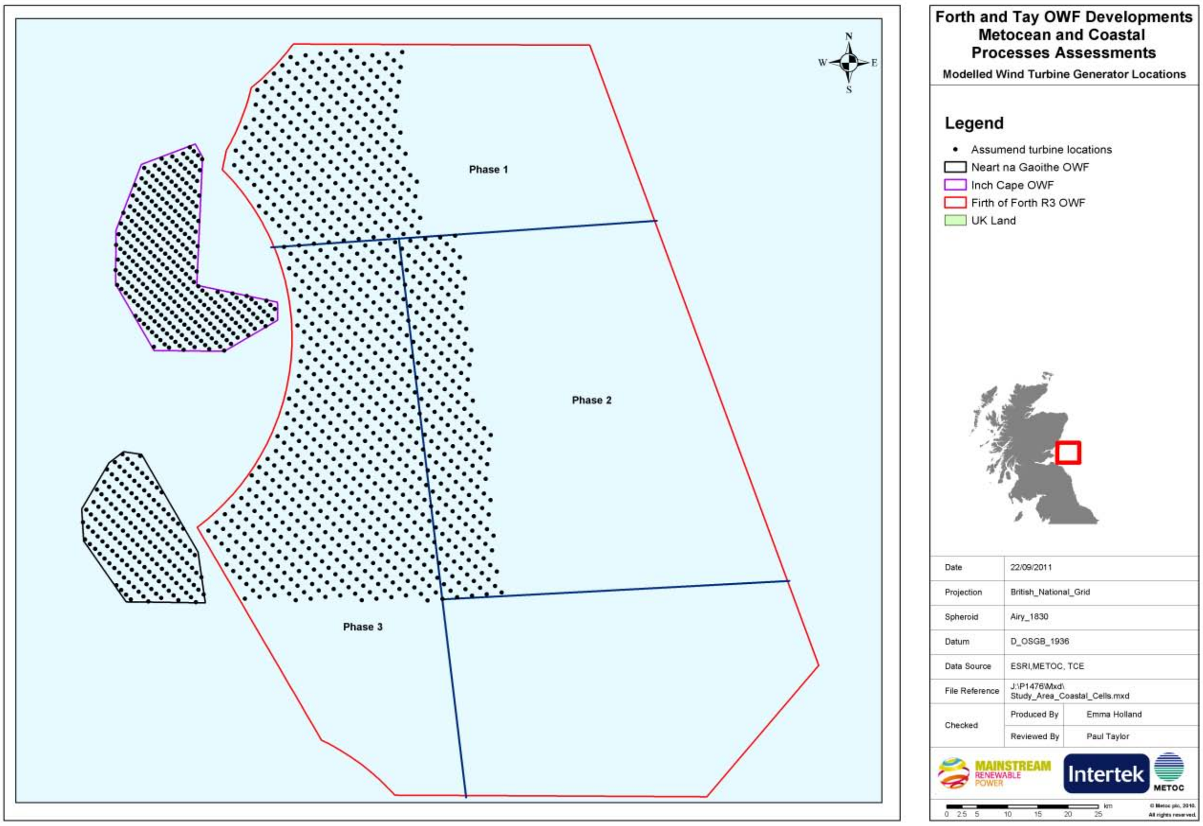
Parameter	Neart na Gaoithe	Inch Cape	Firth of Forth
Turbine capacity (MW)	6	7-10	6
Base diameter, D_B (m)	35	50	50
Tower diameter, D_T (m)	8	8	8
Height of conical section	34	45	45
Cross sectional area per structure (m^2)	859	1345	1345
Rotor diameter (m)	126	107‡	107‡
Spacing between turbines (along line) (m)	1008	856‡	856‡
Spacing between turbine lines (m)	630	535‡	535‡
Maximum number of turbines*	75*	167*	1000*
Modelled number of turbines**	126†	328†	1000*
Gravity base dredged material per turbine (m^3)	5000	n.a	n.a
Cable burial depth (m)	2	n.a	n.a

*Based on awarded capacity of proposed development

†Based on the complete coverage of the entire site

‡Rotor diameter and spacings based on the smaller turbine, but note that gravity base dimensions are based on the larger turbine. This leads to greater overall impact.

Figure 4-2: Outline of modelled realistic worst case layouts for the three proposed OWFs for the cumulative impact scenario



4.45.4 Changes to Far-field Suspended Sediment Transport

In order to assess any changes to the general hydrodynamic regime, and consequently the net movement of suspended sediment from the development site, a continuous discharge of a neutrally-buoyant plume over a spring-neap cycle was modelled using the FTMS particle tracking module, driven by the baseline HD model (see Section 3.3.1). The same dummy discharge was then modelled using the HD model configured with the three proposed developments in place. The outputs were visually compared with those from the baseline run in order to identify any significant changes.

It should be noted that this scenario is not meant to represent a particular discharge of sediment from the site due to the development, but is meant to a identify any changes to the far-field transport of suspended sediment from the development site.

4.45.5 Future (Changing) Climate Scenario

For the assessment of changes to coastal processes under a different climate in the future, the UKCIP projections of sea-level rise and increased storminess, as outlined in Section 2.3, were applied to the Baseline scenario. A time horizon of 50 years from 2016 was used in order to determine the level of increases to sea level, extreme wave heights and wind speeds. This was requested by the client and is based on the expected time of completion of the development, and the initial design life of the project (25 years), plus the expected extension of the life of the development through re-powering of the development (a further 25 years). The climate changes applied are summarised in Table 4-7.

Table 4-7: Future (changing) climate projections used

Parameter	UKCIP projection	Baseline Condition (2016)	Future Condition (2066)
Sea-Level Rise (m)*	2.5mm/yr (to 2025) 7mm/yr (2025 – 2055) 10mm/yr (2055 – 2085)	0	0.355 m
Wind Speed (m/s)	+5% (to 2055) +10% (2055 – 2115)	*x*	1.1*x*
Wave Height (m)	+5% (to 2055) +10% (2055 – 2115)	*x*	1.1*x*

5 RESULTS OF IMPACT ASSESSMENT

This section provides details of the assessment of the proposed development on metocean and coastal processes. The discussion is divided into changes to the hydrodynamic regime, changes to the wave climate, and then the resulting changes to the sediment regime. In addition, the cumulative impacts are summarised, and finally the assessment of potential changes due to the future (or changing) climate are discussed.

The FTMS HD and SW models were configured with the gravity base foundations and turbine structures at the assumed turbine locations for the Neart na Gaoithe OWF (for the Neart na Gaoithe only impacts – see Figure 4.1), and for all three OWF developments (for the cumulative impacts – see Figure 4.2). The same scenarios as were used for the baseline assessment (Section 3) were modelled under the 'with development' configurations, and the results compared with the baseline to identify any differences to baseline conditions. The baseline results were subtracted from the 'with-development' results, so that positive changes indicate an increase (say in current speed) due to the development, and negative changes show a decrease.

Appendix H provides all of the impact assessment plots.

It should be noted that the absolute accuracy of the FTMS in predicting water levels, tidal currents and wave parameters is limited, due to a number of sources of error and uncertainty, including in the field data itself, and in the inherent limitations of the numerical approximations to real world physical processes. The model has been demonstrated to perform well when compared to field data, based on the coastal model guidelines from the Foundation for Water Research[xii] which were applied in the model calibration and validation process[iii]. An indication of the level of accuracy of the model is provided by the FWR guidelines, which aim for modelled levels to be within 0.1 m, and for modelled speeds to be within 0.1 m/s of measured values for 90% of time and space combinations

However, for the impact assessment undertaken here, the difference or change due to the development has been determined by modelling two different scenarios using the same fundamental model. The accuracy of the relative differences predicted is much greater than the accuracy of the absolute predictions, and very small predicted changes would be considered to accurate.

5.1 CHANGES TO THE HYDRODYNAMIC REGIME

5.1.1 Construction Phase

The effects on the hydrodynamic regime due to the construction phase will be caused by the presence of the engineering and installation equipment, 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. The effect of the construction phase has not been modelled.

The 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 installation operations (i.e. cable burial and foundation preparation) were to occur simultaneously.

5.1.2 Operational Phase

The effects on the hydrodynamic regime due to the operational phase of the development have been modelled using the FTMS HD model (as discussed in Section 4). The results of the modelling are shown in Appendix H Sections H.1.1 and H.1.2. These plots show the predicted changes to water level and current speed on both the local scale (near-field) and regional scale (far-field).

Analysis of these plots indicates that the effects on the hydrodynamic regime due to the proposed Neart na Gaoithe development are small and generally localised to the proposed site.

5.1.2.1 Changes to Water Levels

Near-field

There is an area (approximately 4 km x 8 km) around the southwest boundary of the proposed development site where the mean spring HW level is predicted to be between 0.5 and 1 mm (<0.1%) lower than the baseline, and a slightly smaller sized area around the northeast boundary where the mean spring LW level is predicted to be up to 1 mm higher than the baseline.

There are also a number of much smaller areas, localised around individual turbines, where water levels are predicted to increase, again by up to 1 mm. These are located on the opposite side of the site to the areas of reduced water level (i.e. on the northeast side at spring HW and on the southwest side at spring LW).

These areas of changes are aligned with the general orientation of the tidal ellipse in the area of the site, as would be expected. Therefore, on the flooding tide the turbines on the northeast of the development cause a very localised build up or increase in water level, with a corresponding reduction in water level 'downstream' of the flooding tide. The opposite happens on the ebbing tide.

No noticeable changes (i.e. > 0.5 mm) to water level during mean neap tides are predicted.

The predicted near-field changes of (up to) ±1 mm are approximately 0.002% of the total water depth, and about 0.025% of the mean spring tidal range at the site. The predicted changes are well within natural variability and would not be measurable in the field.

Far-field

Far-field changes to water level are predicted to be unnoticeable over most of the assessment area. However, there is an area within the upper reaches of the Firth of Forth where the spring HW level is predicted to be between 0.5 and 1 mm lower than the baseline.

This change to water level in the Firth of Forth is not necessarily unexpected, since the Firth shows resonant tidal characteristics. One of the consequences of this is that the tidal range increases with distance up the Firth. For example, the range at Alloa (far western end) is about 25% greater than at the entrance to the Firth (near Dunbar), and nearly 35% greater than at Neart na Gaoithe.

So a (for example) 1% change in range will show up as a bigger absolute difference at the western end of the Firth.

In addition, a small change in the tidal phase (e.g. if it travels slower through the OWF area) could be amplified as the wave propagates up the Firth, which could affect the timing of high and low water. There is also a pronounced funnelling effect towards the west.

However, the magnitude of the change in water level in the Firth is less than 0.02% of the mean spring tidal range, which is 5 m in this part of the Firth, and this change would therefore not be measurable.

No noticeable changes to water levels at mean spring LW or during mean neap tides are predicted.

The predicted changes to water level due to the Neart na Gaoithe development are therefore very small (<0.025%), and generally localised to the near-field, with the exception of a small change (<0.02%) in the upper reaches of the Firth of Forth. The significance of the impact on water level in both the near and far-field is considered to be negligible.

5.1.2.2 Changes to Tidal Currents

Near-field

In the near-field, localised changes to current speeds due to the development are predicted. The northwest area of the site experiences larger areas of change, with speeds increasing by up to 0.02 m/s (3% of baseline) and decreasing by up to 0.04 m/s (6% of baseline) on the mean spring peak ebb and mean spring peak flood tide respectively. The affected areas are aligned with the general tidal orientation, as is expected, with areas of change centred around individual turbines. Generally current flow will be reduced 'upstream' and 'downstream' of the structure, and increased around the sides, as the flow is first retarded in front of the gravity base, then bifurcates and accelerates around the structure, and then slows and rejoins the ambient flow behind.

Differences during neap tides are much less marked, and most of the site does not experience any noticeable change (i.e. there is < 0.01 m/s change).

Analysis of the differences seen in the percentile speeds shows that only very small and localised changes to the average (50%ile) conditions are seen, but for the higher percentile conditions (90, 95 and 99%ile), there is a general pattern of increased flow around the northwestern boundary of the site (up to 0.016 m/s or ~2% of baseline), with a corresponding reduction in flows in the southeastern and more central areas of the site (up to 0.024 m/s or ~3% of baseline). It should be noted that the mean peak ebb/flood spring tide will occur for approximately 4% of the time, and so is approximately equal to the 95%ile speed.

The maximum predicted changes (+0.02 m/s and -0.04 m/s) are between 3% and 6% of the peak spring tidal currents (0.6 m/s). These changes are relatively small, and localised, and are comparable with the natural variability in currents likely to be experienced at the site. The significance of the impact on the general current regime is therefore considered to be low.

However, it should be noted that the predicted change in current speeds do have the potential to lead to scour around the foundation bases if scour protection is not employed. The potential for scour has been assessed separately, and is summarised in Section 5.3.2.2, and reported in full in Appendix G.

Far-field

No noticeable changes to tidal currents are seen in the far-field, beyond the immediate vicinity of the proposed development site.

> The predicted changes to tidal currents due to the Neart na Gaoithe development are quite small (up to a maximum of 6%), and restricted to the immediate vicinity of the development site. The significance of the impact on the general current regime is considered to be low.

5.1.3 Decommissioning Phase

As yet it is not known what decommissioning process will be employed at the end of the lifetime of the development. It is possible that all buried equipment (cables and foundations) would be left *in situ*. However, it is also possible that all equipment associated with the development might need to be removed, including the buried cables. The decommissioning activities, if required, will be of a similar nature to the construction activities, but in reverse, although there will be no need for any dredging or gravity base foundation preparation. For this reason, the likely impacts on the hydrodynamic regime during the decommissioning phase will be similar to those predicted during the construction phase, and will be small, localised and temporary.

It is therefore considered that effects on the hydrodynamic regime due to the decommissioning phase will be similar to the construction phase, and the significance of any impacts on the general hydrodynamics will be negligible.

5.2 Changes to the Wave Climate

5.2.1 Construction Phase

As with the effect on the hydrodynamic regime, the impact of the construction phase on the wave climate will be due to the presence of the associated engineering and installation equipment, such as jack-up rigs and cable laying vessels. This equipment will be located for short periods of time at one location at a time, and therefore any impacts on the wave climate will be small, localised and transient. In addition, it is very likely that the installation of the wind farm will need to take place during more quiescent wave conditions, as operations will not be possible when more extreme waves are present. Effects on the wave climate due to the presence of installation equipment are lower for smaller waves.

It is therefore considered that the effects of the construction phase on the wave climate will be negligible.

5.2.2 Operational Phase

The effect of the operational phase of the OWF on the wave climate will be primarily associated with the blocking of the passage of waves through the development site by the turbines and their gravity base foundations.

The effects on the wave climate due to the operational phase of the development have been modelled using the FTMS SW model (as discussed in Section 4). The results of the modelling are shown in Appendix H Sections H.1.2 and H.1.3. These plots show the predicted changes to significant wave height due to the development on both the local scale (near-field) and regional scale (far-field).

Analysis of these plots indicates that the effects on the wave climate due to the Neart na Gaoithe development are relatively small and generally localised to the proposed site and the immediate vicinity.

5.2.2.1 Changes to Significant Wave Height

Near-field

In the near-field, changes to significant wave height due to the development are seen across the majority of the proposed site, and in the immediate vicinity (up to 10 km) surrounding the site boundary. Significant wave heights are reduced compared with baseline conditions, typically by between 0.01 and 0.03 m, although the maximum differences seen are 0.04 m (2.8% of 50%ile baseline). Regardless of the percentile wave height, the predicted effect of the development is a general reduction in wave height, with the greatest differences seen for the 90%ile wave conditions, with almost the entire development site experiencing a reduced wave height, and some small areas outwith the site also experiencing slightly lower (between 0.01 and 0.02 m) wave heights.

These predicted changes (up to 0.04 m) are between 2.8% and 0.8% of the 50%ile and 99%ile wave heights (respectively) experienced at the site.

This general reduction in wave heights is expected since the wind farm development will remove some wave energy as waves pass through the site. There are no increased wave heights predicted.

It is noted that the percentage change to the 50%ile condition is greater than the percentage change to the less frequent (90 - 99%ile) conditions. This is expected given that wave energy removed by the structures will be proportionally less for more extreme conditions of higher wave energy.

Far-field

The proposed development is seen to affect the wave climate (by reducing significant wave heights by up to 0.02 m) in the immediate area surrounding the proposed site, up to a maximum distance of 10 km. Beyond this localised impact, there are no noticeable changes (i.e. > 0.01 m) predicted in the far-field. These predicted changes are well within the natural variability of wave conditions experienced throughout the area of interest.

The predicted changes to the wave climate due to the Neart na Gaoithe development are considered to be small (<3% of average waves), and restricted to the immediate vicinity of the development site. The significance of the impact on the general wave climate is considered to be low.

5.2.3 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.

It is therefore considered that effects on the wave climate due to the decommissioning phase will be negligible.

5.3 Changes to the Sediment Regime

5.3.1 Construction Phase

The impact of the construction phase on the sediment regime will primarily be due to the release of disturbed seabed sediment into the water column through the various installation processes. In particular the impacts from the preparation of the bed for the gravity base foundations (if used) and from the process of cable burial have been modelled using the particle tracking module within the FTMS.

The results of the modelling are shown in Appendix H Section H.1.7. These plots show the predicted extent and concentrations of suspended sediment plumes (above background levels), and the resulting deposition footprint due to the disturbed sediment. It should be noted that although only the middle two turbine lines have been modelled, since conditions across the site are relatively uniform, and no cumulative impacts beyond the neighbouring row of turbines is predicted, the results are indicative of impacts that would result from any turbine location within the development site. There will be small variations, due to small differences in the PSD, water depth and current flows across the site, but these will be negligible.

5.3.1.1 Impacts due to preparation of gravity base foundations

Analysis of the results shows that impacts are localised around the area of the operation, and relatively small. The greatest impacts are seen to result from the discharging of the dredged material from the gravity base preparations at the sea surface. In this scenario it is assumed that all of the dredged material is released just below the sea surface at the turbine location, and that the preparation for each new gravity base begins immediately after completion of the previous base. Elevated depth-averaged concentrations of suspended sediment due to this activity have a peak of up to 300 mg/l very close to the release location. Within approximately 1 km of the release location, concentrations are predicted to be less than 10 mg/l during most states of the tide, which is comparable with the background concentrations. The farthest extent of the suspended sediment plume (with a concentration of >1 mg/l) is up to approximately 4 km from the release location. Analysis of the model outputs indicates that all suspended sediment will settle out of the water column within 1 day of release near the surface.

Typical background (fair-weather) concentrations of suspended sediment, based on the limited sampling undertaken during the metocean campaign, range between 3 and 8 mg/l across the development site.

The resulting suspended sediment plume therefore is relatively high compared with the background concentrations (peak of 300 mg/l), although this peak is localised, and short-lived. The significance of this impact on the general sediment regime is considered to be negligible, given its very transient nature. However, the significance of this impact to any other receptors is dependent on the vulnerability of the receptor in question.

The resulting deposition footprint around each turbine location will be up to 0.03 m (3 cm) thick. These will be elliptical and aligned with the tidal ellipse, extending up to about 1 km away from the turbine location to a thickness of 1 mm or more. The deposition footprints around each gravity base will therefore just about join with the neighbouring footprints, to form a more or less continuous layer of deposited dredged material of varying thickness across the development site. The deposited material will be of very similar nature to the ambient seabed material, and subject to the same processes of erosion and accretion due to tidal and wave processes. There will be no material change to any seabed features or bedforms such as sandbanks. The significance of the impact to the general seabed features is therefore considered to be negligible.

If the dredged material were to be released close to the seabed (rather than at the sea surface), the impacts on suspended sediment concentrations are predicted to be less, as would be expected. The depth-averaged concentrations in the resulting plume are similar in magnitude, but the size of the plume is much smaller. This is because the material settles out much more quickly, leading to a smaller but thicker deposition footprint, with a thickness of up to 0.3 m. The farthest extent of the deposition footprint for this scenario (to a thickness of 1 mm or more) is up to 0.5 km from the release location. Sediment may be deposited further than this (up to 1 km) but at a thickness between 0.3 and 1 mm. The development area will generally have deposited dredged material across it of varying thickness, although there might be some small areas that do not experience any noticeable deposition.

It should be noted that suspended sediment concentrations at different depths in the water column are likely to be greater than the depth-averaged concentrations shown in the plots. Mid-depth and near-bed modelled concentrations (not shown) indicate that the peak concentrations could be between 2 and 20 times greater than the depth-averaged concentrations shown in the plots. By extension, near-surface concentrations will have a tendency to be lower than the depth-average.

The discharge of dredged sediments during the preparation of gravity base foundations will lead to elevated concentrations of suspended sediment (with very localised peaks up to 300 mg/l (depth-averaged)), but the resulting plumes will not be advected beyond the immediate vicinity of the development site, and they will settle out within 1 day of discharge. The resulting deposition footprint is likely to cover the development area with varying thickness, generally between 1 and 10 mm, and with peaks between 3 and 30 cm. The significance to the general seabed features and the sediment regime is considered to be negligible, although impacts on other receptors is dependent on their vulnerability and has not been assessed here.

5.3.1.2 Impacts due to the Cable Burial Process

Analysis of the FTMS Particle Tracking model predictions indicates that impacts due to the export cable burial process will be significantly less than those predicted from the gravity base preparations. This is as expected given the lower quantities of disturbed sediment. Regardless of the location along the cable route, the elevated suspended sediment concentrations are typically between 3 and 10 mg/l, with some very localised peaks in some small areas reaching 30 mg/l. The associated suspended sediment plumes are generally less than 5 km in extent, and settle out within a maximum of 4 hours. The resulting deposition footprints are equally localised. Maximum predicted deposition thickness is 3 mm. The extent of the deposition footprint (with thickness > 0.1 mm) is up to about 2 km either side of the cable trench. The deposition footprint is smaller than the extents of the suspended sediment plume due to the fact that very fine material will effectively remain in suspension indefinitely, or will slowly settle out beyond 2 km from the release location but will not form a noticeable deposited layer.

These predicted impacts conservatively assume that the entire volume of the trench will be suspended into the water column.

If other cable burial techniques (not trenching) are employed, then the resulting impacts will be smaller than those reported here, which are from the realistic worst case scenario.

Impacts from the burial of inter-array cables have not been explicitly modelled, since the volumes disturbed and the PSD of sediment will be similar to those assessed for the export route. The impacts presented for the realistic worst case export cable burial are therefore considered to be representative of potential impacts that might occur from the inter-array cable burial.

The process of cable burial might lead to very localised impacts (elevated concentrations) of suspended sediment (with peaks up to 30 mg/l), but the resulting plumes will not be advected beyond the near-field vicinity of the cable, and will settle out within a few hours of disturbance. The resulting deposition footprint is likely to be very thin (typically <0.1 mm) with peaks up to 3 mm. The significance to the general seabed features and the sediment regime is considered to be negligible, although impacts on other receptors is dependent on their vulnerability and has not been assessed here.

5.3.2 Operational Phase

The impact of the operational phase of the OWF on the sediment regime will be primarily associated to changes to sediment entrainment, by reducing or increasing the amount of bed shear stress (by altering the wave and/or current regime). If bed shear stress is increased, for example due to the acceleration of currents around the structures, then more sediment could become entrained and transported, either as bedload or suspended sediment. Conversely, a reduction in bed shear stress (e.g. due to reduced wave heights) might lead to greater rates of deposition.

In particular, the effects of the OWF on the sediment regime might be associated with scouring of sediment around the foundations of the turbines, with the scoured material being transported elsewhere.

The effects on sediment transport processes have been modelled using the HD and SW modules of the FTMS, in combination with analysis of the seabed sediment characteristics. An estimate of the volume of scoured material was made using empirical equations (see Appendix G), and the fate of the scoured material was modelled using the FTMS Particle Tracking module.

The results of the analysis are shown in Figures 5-1 to 5-4 (and also for completeness in Appendix H Sections H.1.5 and H.1.6). These plots show the predicted changes to exceedance of the critical shear stress (both the maximum and mean bed shear stress across a wave cycle due to combined currents and waves are depicted). Section H.1.8 shows the results of the modelling of the scoured material.

5.3.2.1 Changes to the sediment transport processes

In this Section, we report changes in the percentage of time for which the critical entrainment stress is exceeded. In all cases, the predicted changes are reported as an absolute percentage, not a relative percentage. So, for example, if a particular location experiences exceedance of the critical entrainment stress for 5% of the time at present, and this is predicted to increase to 6% of the time once the proposed development is fully installed, this will be reported as a 1% increase in critical entrainment stress exceedance, not 20%.

Analysis of Figures 5-1 and 5-2 (near-field) shows that the overall effect of the proposed wind farm on sediment transport processes is relatively small in magnitude, and limited to the local near-field area. There is a small area (approximately 6 km x 2 km) along the northwestern boundary of the site where the critical shear stress is predicted to be exceeded more frequently (typically for 1-3% of the time, with some very small peaks of up to 6% increase in the frequency of exceedance). Conversely, there is a slightly larger, but patchier, area along the eastern boundary and also in the central area of site, where the critical shear stress is predicted to be exceeded less often (typically for 1-3% of the time, with a maximum reduction in frequency of exceedance of 6%). The majority of the near-field area is not predicted to change by more than +/- 1%. This is considered to be well within the natural variability that would be experienced within the area (i.e. due to spatial and temporal changes in currents, waves and sediments).

The differences in the exceedance due to maximum bed shear stress (the peak stress that occurs during a wave cycle) are not as marked as for mean bed shear stress (the average across a wave cycle).

The areas of increased and decreased frequency of exceedance of the critical shear stress coincide with the areas of increased and decreased current speeds (due to the development) as would be expected. Owing to the nature of the tidal conditions, as described in Appendix B, currents are generally increased by the OWF in one area, and decreased in another during the flood tide, and *vice-versa*.

The bed shear stress is related to both the current speed and wave conditions (height and period). Generally the wave climate in the near-field has slightly less energy (lower wave heights) due to the presence of the wind farm, which would result in a lower bed shear stress. However, where current speeds are generally increased due to the wind farm, the combined bed shear stress (due to currents and waves) is predicted to increase. This is because, under normal conditions, currents cause significantly greater bed shear stress than waves at the Neart na Gaoithe development site.

Relatively small changes to the amounts of erosion and deposition would occur in these areas of increased/decreased exceedance of the critical shear stress (respectively). However, the areas and the magnitude of change are both considered to be relatively small, and the significance of the impact on the general sediment regime and seabed features is considered to be low.

Analysis of Figures 5-3 and 5-4 shows that no noticeable change to the percentage exceedance of the critical shear stress (i.e. ±1%) is predicted in the far-field.

The predicted changes to sediment transport processes due to the Neart na Gaoithe development are considered to be small, with the predicted frequency of exceedance of the critical shear stress changing typically by 1-3% (with a maximum difference of 6%). These changes are restricted to the immediate vicinity of the development site, and the significance of the impact on the near-field sediment regime is considered to be low. No significant impacts are predicted in the far-field, including the coastal zone, and the significance is therefore negligible.

Figure 5-1: Difference in the exceedance of critical shear stress (N/m²) – based on the combined (currents plus waves) maximum bed shear stress – near-field

Figure 5-2: Difference in the exceedance of critical shear stress (N/m²) – based on the combined (currents plus waves) mean bed shear stress – near-field

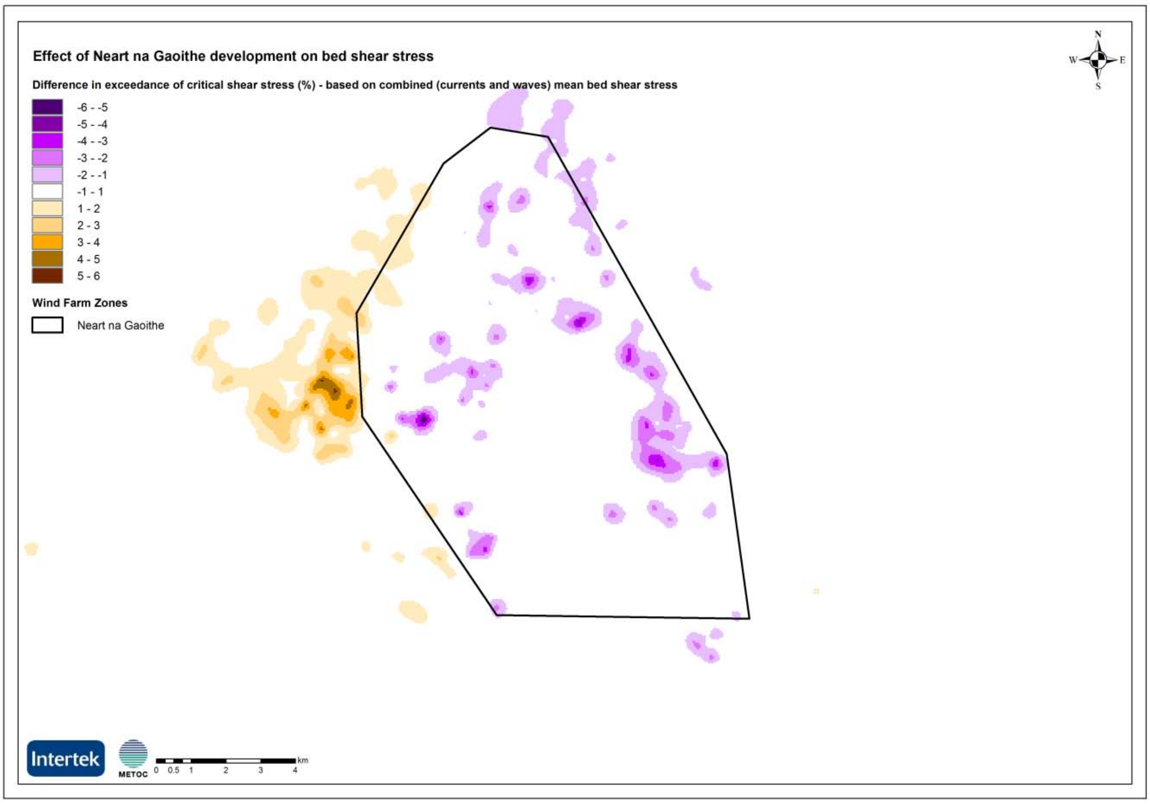


Figure 5-3: Difference in the exceedance of critical shear stress (N/m^2) – based on the combined (currents plus waves) maximum bed shear stress – far-field

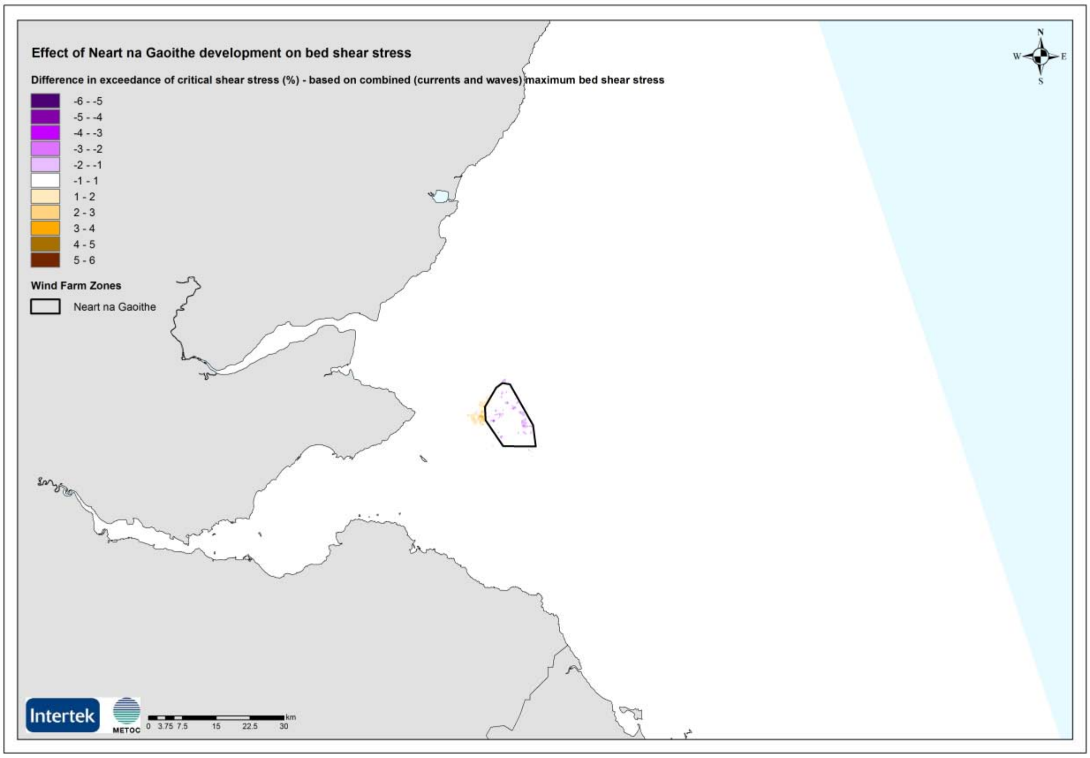
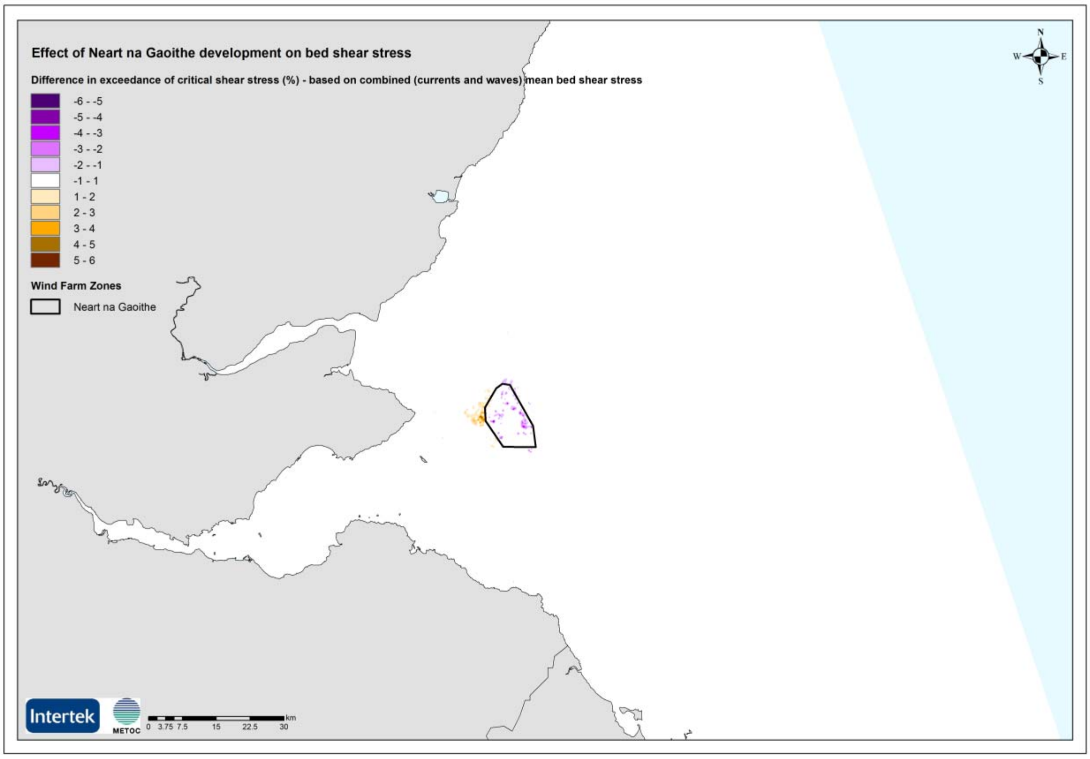


Figure 5-4: Difference in the exceedance of critical shear stress (N/m^2) – based on the combined (currents plus waves) mean bed shear stress – far-field



5.3.2.2 Impacts due to scour

The assessment of the potential for scour is provided in full in Appendix G, but the results are summarised in Table 5-1. For conservatism, the scour assessment considered jacket structures since these represent a worse case than gravity bases (which would be scour-protected).

Table 5-1: Summary of predicted equilibrium scour depth, lateral extent, volume of sediment per leg and per foundation, and the total scour footprint

Forcing	Scour Depth S_e (m)			Lateral extent X_s (m)			Volume of Scoured Sediment Per Leg, V_s (m^3)			Volume of Scoured Sediment Per Foundation, V_{TOT} (m^3)			Total Scour Footprint, α (m^2)		
	Leg Diameter (m)														
	1.7	1.9	2.5	1.7	1.9	2.5	1.7	1.9	2.5	1.7	1.9	2.5	1.7	1.9	2.5
Peak Spring Tide	2.22	2.48	3.26	3.98	4.45	7.99	49	69	275	196	276	1100	284	357	1063
Peak Neap Tide	No scour														
Return Period Currents (Yrs)															
1:1	3.47	3.88	5.11	6.23	6.97	12.51	169	244	987	676	976	3948	621	779	2369
1:10	6.48	7.25	9.53	11.64	13.01	23.36	1043	1458	5994	4172	5832	23976	1950	2439	7598
1:25	7.25	8.11	10.67	13.02	14.56	26.13	1443	2019	8319	5772	8076	33276	2407	3012	9407

The estimated scour pits around each leg of the jacket structure, and therefore scour pits from neighbouring turbines are not predicted to interact, and the likely scour would therefore be considered as local rather than global scour.

The fate of the scoured material has been modelled using the FTMS Particle Tracking module, and a worst case volume per turbine of 1100 m^3 was applied. This was released into the water column close to the bed continuously over a spring-neap cycle.

Two rows of turbines in the middle of the site were modelled. The results from this modelling are indicative of the potential impacts from scour around a turbine located anywhere within the development site. This is due to the fact that currents and sediment type and size are more or less uniform across the site. The small variations that would result due to any small differences in currents or PSD are well within the conservatisms and assumptions inherent in the assessment. The resulting deposition footprint from the scour around all turbines has therefore been determined by extrapolating the modelled deposition across the whole site, and accumulating any overlapping footprints.

The results of the modelling are shown in Appendix H Section H.1.8. Analysis of these results shows that the elevated suspended sediment concentrations would be relatively small and localised. Peak concentrations very close to the scour pit are predicted to between 100 and 300 mg/l, but beyond about 250 m of the structures, concentrations will be less than 10 mg/l, and will reduce to <1 mg/l within 1 km. These impacts will be transient and the suspended sediment will settle out relatively soon after release (on a timescale of hours).

The resulting deposition footprints will be very localised around the turbine base with a maximum thickness of 0.1 m, and the extent of the footprint with a thickness >1 mm will reach up to 500 m

The impacts from the scoured material around the structures is therefore considered to be small and localised within the near-field.

5.3.3 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.

5.4 CUMULATIVE IMPACTS

5.4.1 Changes to the Hydrodynamic Regime

The effect on the hydrodynamic regime due to the cumulative impacts from the three proposed OWF developments has been modelled using the FTMS HD model (as discussed in Section 4). The results of the modelling are shown in Appendix H Section H2.1. These plots show the predicted changes to water level and current speeds on the regional scale (far-field).

Analysis of these plots indicates that the effects on the hydrodynamic regime due to the proposed Neart na Gaoithe, Inch Cape and Firth of Forth developments are relatively small and generally localised to the proposed sites, although small changes to water levels are seen across a wider area.

5.4.1.1 Changes to Water Levels

There is an area (approximately 4 km x 8 km) around the southwest boundary of the proposed Neart na Gaoithe development site where the mean spring HW level is predicted to be up to 2.5 mm lower than the baseline. Surrounding this, covering a much larger area (from the development sites to the coast), the mean spring HW level is predicted to be up to 1.5 mm lower than the baseline.

Mean spring HW level is predicted to be further reduced within the Firth of Forth, reaching a peak change at the upper end of the estuary of 3.5 mm (lower than baseline).

There is also an area further offshore, within the Firth of Forth Round 3 zone, but east of the modelled turbine locations, where the mean spring HW level is up to 1.5 mm higher than the baseline.

These changes are due to the retardation of the flooding tide by the OWF developments which causes a build up or increase in water level, with a corresponding reduction in water level ‘downstream’ of the developments on a flooding tide. The opposite happens on the ebbing tide, with a large area showing a slight increase in water level at mean spring LW (up to 1.5 mm), and a smaller area, further offshore (i.e. ‘downstream’ of the developments on the ebbing tidal wave) experiencing a reduction in water level at mean spring LW (up to 1.5 mm).

Similar, but smaller changes are predicted at mean neap HW, although no noticeable change (i.e. > 0.5 mm change) to water level at mean neap LW is predicted.

The predicted general far-field changes of (up to) 2.5 mm are approximately 0.05% of the mean spring tidal range, and the maximum change (3.5 mm) in the Firth of Forth is about 0.07% of the mean spring tidal range in that area. These predicted changes are very small in comparison to natural variability, and would not be measurable. The significance of the impact is therefore considered to be negligible.

The predicted cumulative impacts to water level due to the Neart na Gaoithe and other OWF developments are fairly widespread, but very small in magnitude (<0.07% of mean spring tidal range). The significance of the impact on considered to be negligible.

5.4.1.2 Changes to Tidal Currents

The cumulative impacts on current speeds are very localised to the proposed OWF development sites. Similar sized areas and magnitudes of change are predicted as for the scenario with Neart na Gaoithe alone, with no noticeable cumulative effect from one OWF on another.

Current speeds are predicted to increase by up to 0.02 m/s, and decrease by up to 0.04 m/s on the mean spring peak ebb and mean spring peak flood tide respectively. The affected areas are aligned with the general tidal orientation, as is expected, with areas of change being very localised and centred around individual turbines. No noticeable changes are seen in the Forth of Firth Round 3 zone. This is due to the resolution of the model in this area, which is too coarse to show the localised (near-field) effects of the individual turbines. However, the general, far-field effect of the Round 3 development as a unit is fully accounted for in the modelling, and if these were to overlap with any effects from the Neart na Gaoithe or Inch Cape developments, then the cumulative impact would be demonstrated.

Differences during mean neap tides are much less marked, and most of the OWF sites do not show any noticeable change (i.e. > 0.01 m/s change).

As with the effect of the Neart na Gaoithe development on its own, there are no noticeable predicted changes to the tidal current regime in the far-field.

The predicted cumulative changes to tidal currents due to the Neart na Gaoithe and other nearby OWF developments are quite small (up to a maximum of 6%), and very localised to the near-field. No cumulative far-field impacts are predicted on the tidal current regime. The significance of the cumulative impact on the general current regime is considered to be low.

5.4.2 Changes to the Wave Climate

The cumulative effects on the wave climate due to the Neart na Gaoithe, Inch Cape and Firth of Forth Round 3 OWF developments have been modelled using the FTMS SW model (as discussed in Section 4). The results of the modelling are shown in Appendix H Section H2.2. These plots show the predicted changes to significant wave height due to the developments on the regional scale (far-field).

5.4.2.1 Changes to Significant Wave Height

Changes to significant wave height due to the developments are seen across the majority of the proposed sites, with wave heights typically reduced by between 0.01 and 0.03 m, with maximum differences of up to 0.04 m predicted. The cumulative effect of the three developments is to increase the size of the area affected, but not to increase the magnitude of the change. The proposed developments take energy out of the passing wave climate, and therefore the resulting wave heights are always reduced (waves are never bigger as a result of the developments).

The predicted changes to waves (up to 0.04 m) are between 2.8% and 0.8% of the 50%ile and 99%ile wave heights (respectively) experienced throughout the region.

> The predicted cumulative changes to the wave climate due to the Neart na Gaoithe and other OWF developments are considered to be small (<3% of average waves), although the affected areas are considerably larger than the impacts from the Neart na Gaoithe development on its own. The significance of the impact on the general wave climate is considered to be low.

5.4.3 Changes to the Sediment Regime

The cumulative effects of the proposed Neart na Gaoithe, Inch Cape and Firth of Forth Round 3 OWFs on the sediment regime have been modelled using the HD and SW modules of the FTMS, in combination with analysis of the seabed sediment characteristics.

The results of the analysis are shown in Figures 5-5 to 5-6 (and also for completeness in Appendix H Section H.2.3). These show the predicted changes to exceedance of the critical shear stress. As discussed in Section 5.3.2, the exceedance of the critical shear stress is a function of the combined currents and waves experienced at the site, and changes to the percentage of time this is exceeded indicates a change to the sediment regime. In the plots shown, the predicted changes are reported as an absolute percentage, not a relative percentage. So, for example, if a particular location experiences exceedance of the critical entrainment stress for 5% of the time at present, and this is predicted to increase to 6% of the time once due to cumulative impacts from the proposed developments, this will be reported as a 1% increase in critical entrainment stress exceedance, not 20%.

5.4.3.1 Changes to the sediment transport processes

Analysis of Figures 5-5 and 5-6 shows that the overall cumulative effect of the proposed wind farms on sediment transport processes is very similar to the effect from just the Neart na Gaoithe development. The cumulative differences in the exceedance of the critical shear stress are relatively small in magnitude, and limited to the local areas of the development sites.

This is as expected given that the combined bed shear stress is dominated by tidal currents, rather than waves, and the cumulative differences to currents are very similar to those predicted when considering the Neart na Gaoithe development on its own.

The cumulative impact from the other developments (as with that from the Neart na Gaoithe development on its own) is therefore considered to be negligible, and there is no change >1% to the percentage exceedance of the critical shear stress in the far-field. The predicted changes are within the natural variability expected at the site, and the significance of impacts to the sediment regime is therefore considered to be low.

The predicted cumulative changes to sediment transport processes due to the Neart na Gaoithe and other surrounding developments are considered to be small, with the predicted frequency of exceedance of the critical shear stress changing typically by 1-3% (with a maximum difference of 6%). These changes are restricted to the immediate vicinity of the development sites. The significance of impacts to the sediment regime is therefore considered to be low.

Figure 5-5: Cumulative difference in the exceedance of critical shear stress (%) – based on the combined (currents plus waves) maximum bed shear stress – far-field

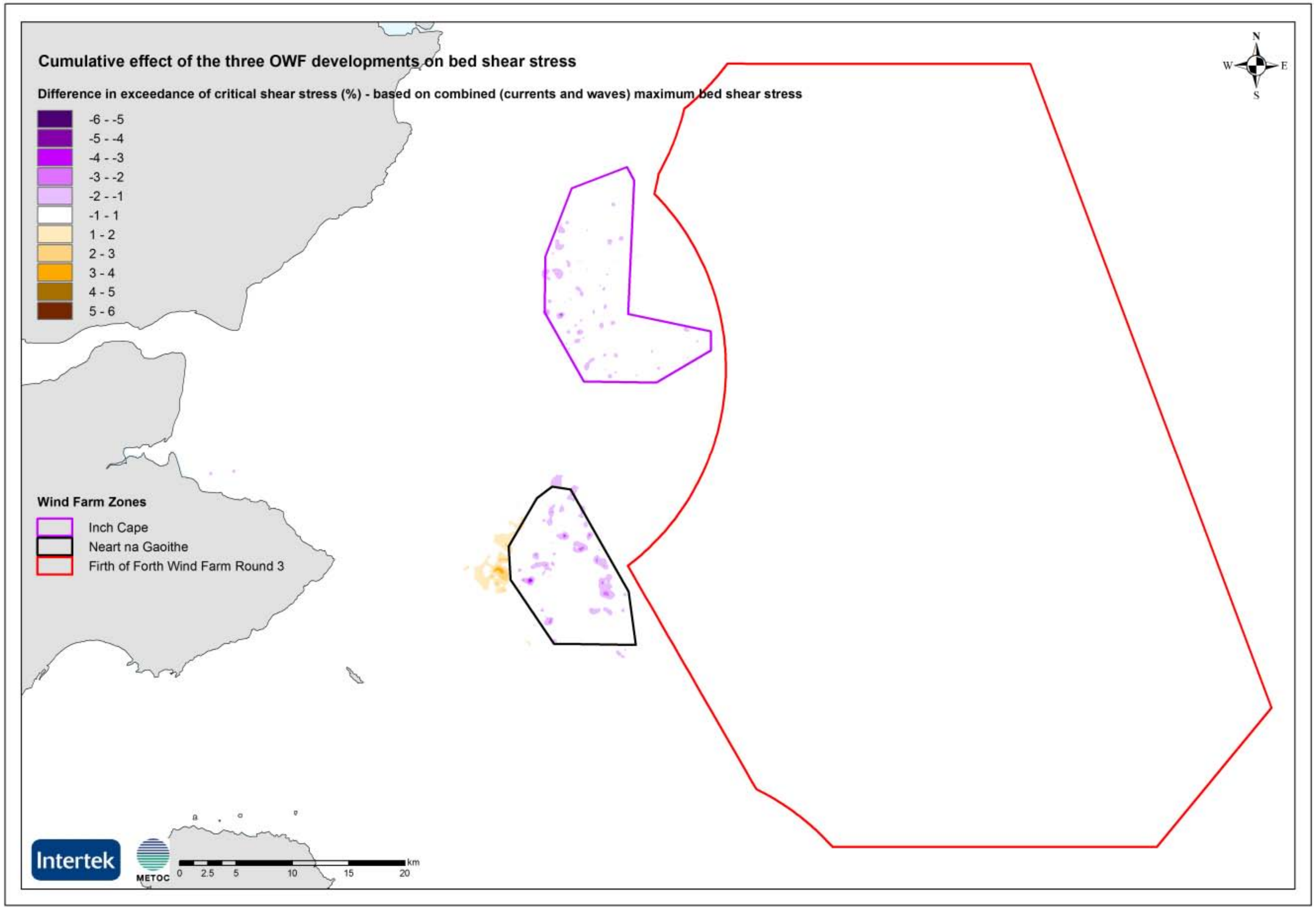
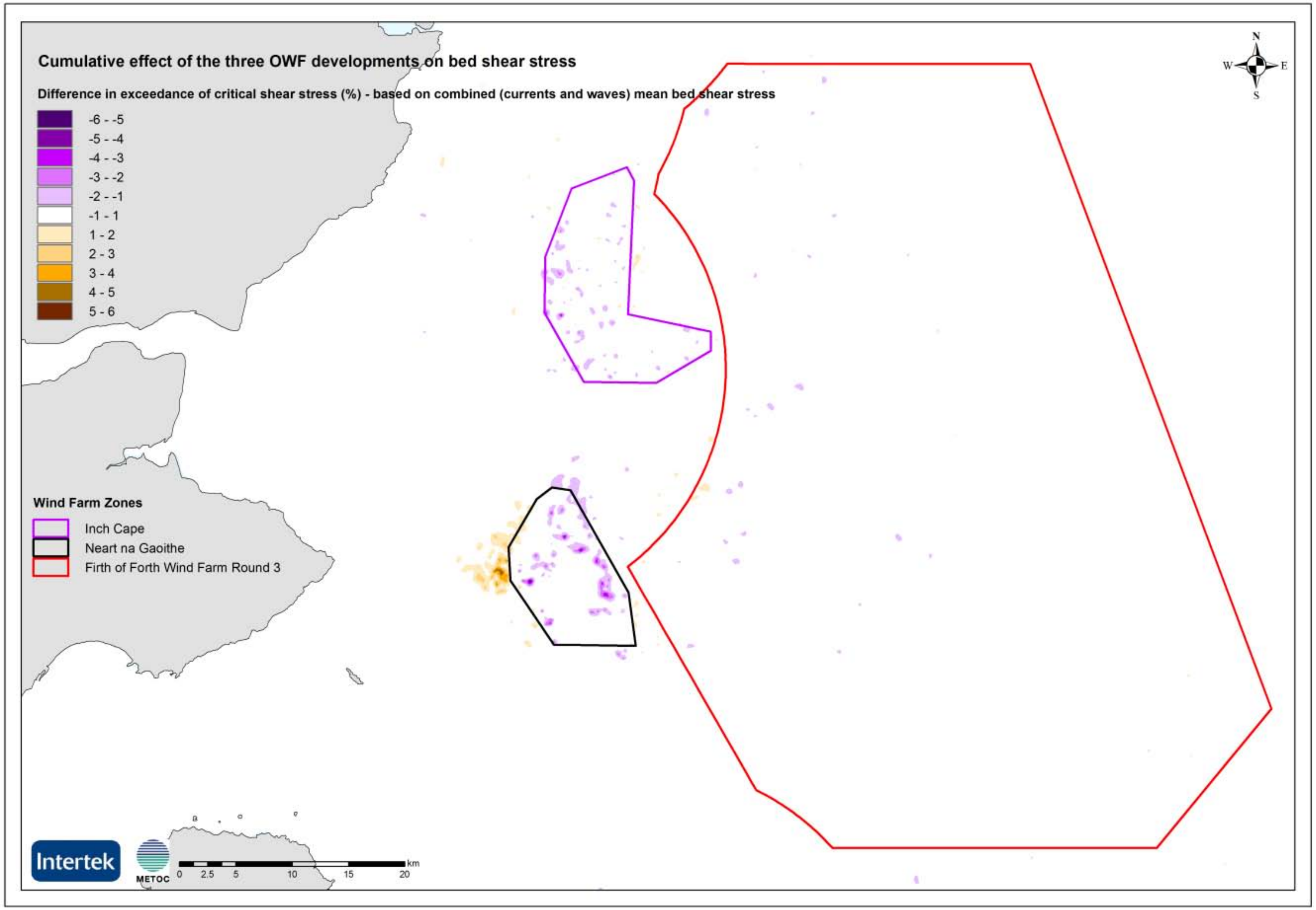


Figure 5-6: Cumulative difference in the exceedance of critical shear stress (%) – based on the combined (currents plus waves) mean bed shear stress – far-field



5.4.3.2 Far-field suspended sediment transport

An indication of any cumulative changes to the far-field suspended sediment transport due to the three proposed OWF developments was investigated using the FTMS Particle Tracking module. A continuous dummy release of a neutrally-buoyant plume over a spring-neap cycle was modelled using the 'with all developments' scenario HD model. The results were then compared with the same results generated using the baseline HD model. It should be noted that this modelled scenario is not representative of any discharge or release of sediment due to the development, but simply indicates the net movement of suspended sediment from the development area.

Figure 5-7 shows the baseline far-field suspended sediment plume (from the model run with no developments in place), and Figure 5-8 shows the same based on the model configured with all three developments. A visual comparison of these two plots shows that no significant differences are apparent. These plots indicate that the proposed OWF developments will not cause net changes to the regional sediment transport regime, even when the three sites are considered cumulatively.

Figure 5-7: Far-field suspended sediment pathway – baseline

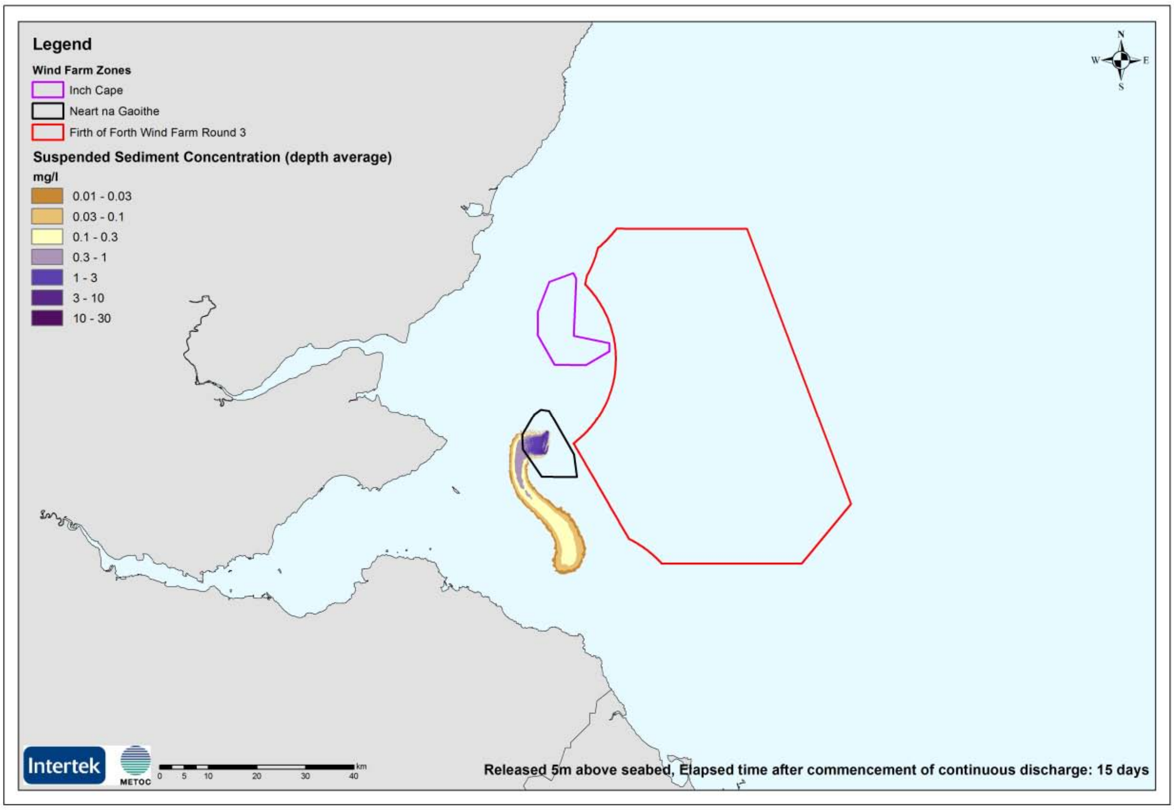
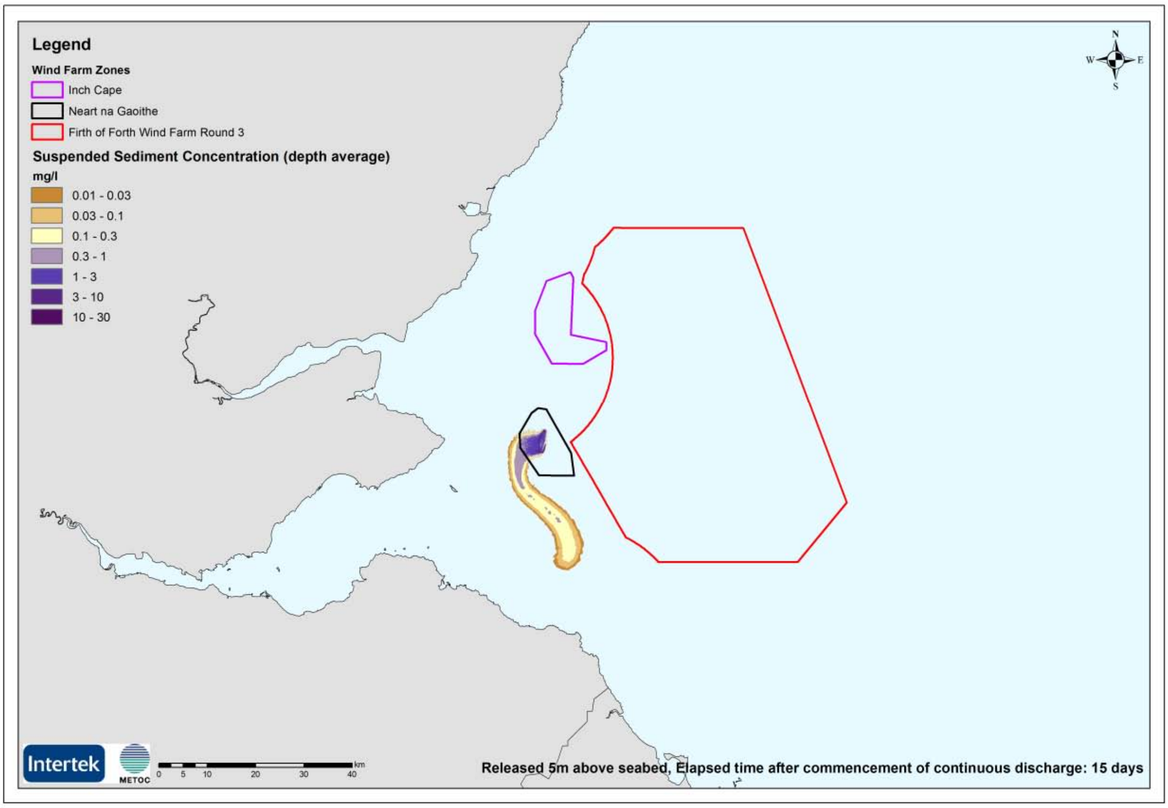


Figure 5-8: Far-field suspended sediment pathway – cumulative developments



5.4.4 In-combination Impacts

As outlined in Section 1.4, following initial consultation and review of the regional area, it was agreed with the clients that no other industries or activities had been identified within the area, and therefore no in-combination impacts needed to be considered.

5.5 CHANGES DUE TO THE FUTURE (CHANGING) CLIMATE

5.5.1 Changes to the Hydrodynamic Regime

The effect on the hydrodynamic regime due to potential climate change has been modelled using the FTMS HD model (as discussed in Section 4). The results of the modelling are shown in Appendix H Section H3.1. These plots show the predicted changes to water level and current speeds on the regional scale (far-field).

5.5.1.1 Changes to Water Levels

As expected, the change to water level due to climate change is seen more or less uniformly across the model domain, and throughout the tidal cycle. There is a predicted increase in high and low water levels during both the spring and neap tide equivalent to the projected sea-level rise of 0.355 m as would be expected. Slightly higher or lower changes are predicted near the head of the Firths of Forth and Tay, which is presumably due to amplification of the tidal wave in these locations coupled with a more general modification to the hydrodynamic regime caused by the increased water depths associated with climate change.

The predicted change in water level due to potential climate change is significantly greater, in both magnitude and extent, than the predicted change due to the proposed OWF developments.

5.5.1.2 Changes to Tidal Currents

The predicted change to tidal currents due to potential climate change is very varied, with both positive and negative changes to current speeds predicted in different locations. There is no clear pattern to the predicted changes, but typically current speeds are seen to vary by no more than 0.01 m/s across the model domain, with a decrease in speed generally more likely than an increase. Peak changes of up to +0.1 m/s and -0.3 m/s are seen in some isolated locations within the Firths of Forth and Tay, where the increase in water depth due to climate change is proportionately greater compared to the total water depth.

The predicted changes indicate that generally the effect of sea-level rise on tidal currents will be minimal, with tidal currents typically being very similar in most areas to the baseline conditions, but with possibly a bias towards a small reduction in current speeds. Greater differences are likely in isolated shallower areas close to the coast, and in particular within the Firths of Forth and Tay.

The predicted change in tidal currents due to potential climate change is generally quite small, but spatially varied. The predicted change is similar in magnitude to, but considerably more widespread than, the maximum predicted change due to the proposed OWF developments.

5.5.2 Changes to the Wave Climate

The effect on the wave climate due to potential climate change has been modelled using the FTMS SW model (as discussed in Section 4). The results of the modelling are shown in Appendix H Section H3.2. These plots show the predicted changes to significant wave height on the regional scale (far-field).

5.5.2.1 Changes to Significant Wave Height

The potential increase in storminess in the future gives predicted wave heights that are all greater than the baseline conditions. Modelled wave heights and wind speeds at the boundaries were increased by 10% to represent future climate change, resulting in an increase in significant wave height of between about 0.2-0.4 m (50%ile), to more than 1 m (99%ile).

The predicted change in significant wave height due to potential climate change is significantly greater than the predicted change due to the proposed OWF developments.

5.5.3 Changes to the Sediment Regime

The effects of potential climate change on the sediment regime have been modelled using the HD and SW modules of the FTMS, in combination with analysis of the seabed sediment characteristics.

The results of the analysis are shown in Figures 5-9 to 5-10 (and also for completeness in Appendix H Section H.3.3). These show the predicted changes to exceedance of the critical shear stress (both the maximum and mean bed shear stress across a wave cycle due to combined currents and waves are depicted).

These Figures indicate that exceedance of the critical shear stress under conditions of maximum bed shear stress is predicted to increase, typically by between 2 and 4%. Peak changes are predicted to be between 6 and 12%, and these are located close to the coast. These values refer to the increased percentage of the total time for which the critical shear stress is exceeded, rather than a relative change compared to the baseline.

Under the climate change scenario, exceedance of the critical shear stress under conditions of mean bed shear stress is predicted to result in a much less marked difference compared to the baseline. A much smaller portion of the model domain shows changes of >1% in the exceedance time. Generally, where changes are predicted, these indicate a reduction in the exceedance of critical shear stress, with a maximum reduction of between 5 and 10% in the upper Firth of Forth. As before, these values refer to the increased percentage of the total time for which the critical shear stress is exceeded, rather than a relative change compared to the baseline.

The predicted changes are consistent with the predicted changes to the hydrodynamic and wave climates. The general increase in wave heights results in a widespread general increase in the maximum bed shear stress (which is dominated by the peak orbital wave velocity under the more extreme wave conditions). However, although the mean bed shear stress is influenced by the mean wave energy, it is not dominated as much by waves, and therefore the influence of the currents (which do not generally increase) is greater. These competing factors result in the much smaller changes in exceedance of critical shear stress under conditions of mean bed shear stress than is seen for the maximum bed shear stress.

The predicted change in the maximum bed shear stress (and therefore in the exceedance of the critical shear stress) due to potential climate change is significantly greater, in both magnitude and extent, than the predicted change due to the proposed OWF developments.

Figure 5-9: Difference due to potential climate change in the exceedance of critical shear stress (% of time) – based on the combined (currents plus waves) maximum bed shear stress – far-field

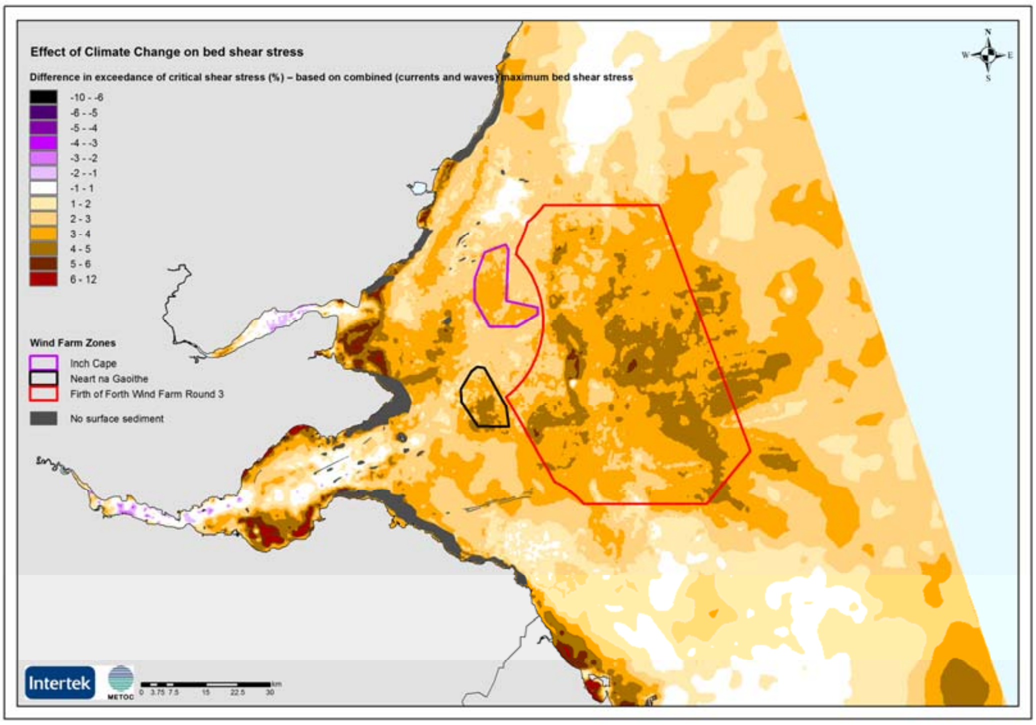
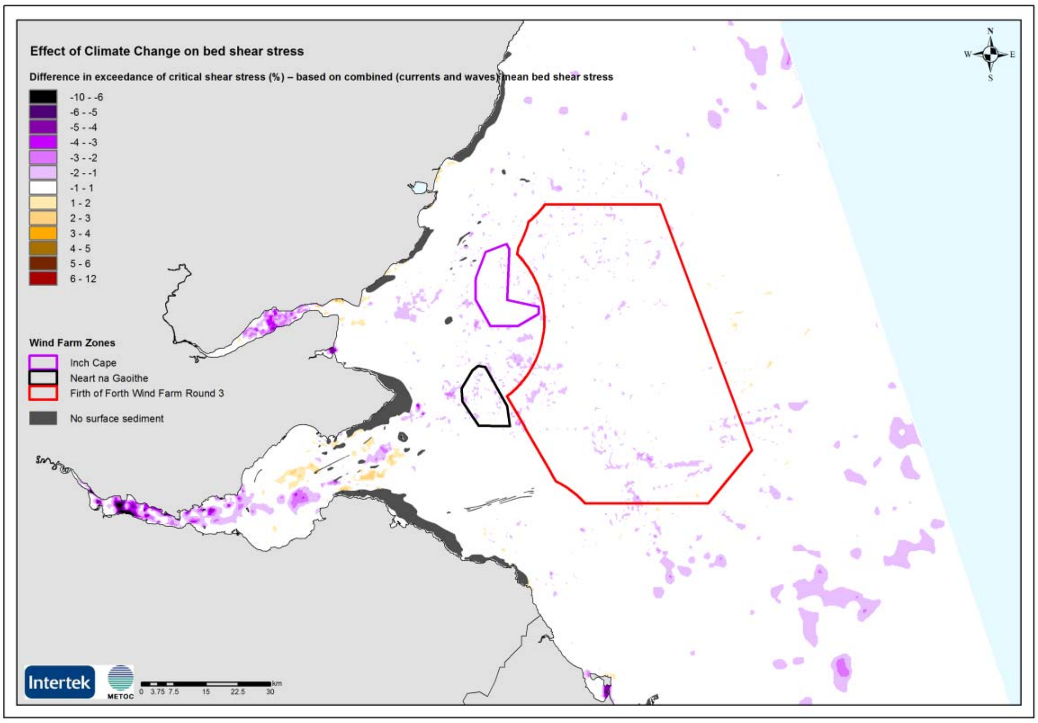


Figure 5-10: Difference due to potential climate change in the exceedance of critical shear stress (% of time) – based on the combined (currents plus waves) mean bed shear stress – far-field



6 CONCLUSIONS

6.1 CONCLUSIONS

This assessment has considered the impacts on the metocean and sediment regimes, and consequently the effect on coastal processes, due to the proposed Neart na Gaoithe Offshore Wind Farm (OWF) development. This is a Scottish Territorial Waters (STW) licensed OWF development, which lies approximately 15 km off the Fife coast and covers an area of about 105 km^2.

Both near-field and far-field impacts due to the development have been assessed. In addition, cumulative impacts from two other nearby proposed OWF developments (the STW Inch Cape site and the Round 3 Firth of Forth zone) have also been accounted for. Finally, the effects on the metocean and coastal processes that might result due to the potential changes to the climate in the future have also been considered.

The key conclusions from this assessment are presented below.

6.1.1 Construction Phase

The presence of installation equipment, such as jack-up rigs and cable laying vessels, during the construction phase of the development may cause very small, localised and transient effects to the near-field hydrodynamics and wave climate, but these will be negligible.

Construction processes, such as the preparation of foundations and the burial of export and inter-array cables, will result in the displacement of seabed sediment into the water column, and in the elevation of concentrations of suspended sediment.

The worst case increase in suspended sediment concentrations (SSC) due to foundation preparations might be up to 300 mg/l (due to the bed-levelling for gravity bases), but these peaks will be very localised around the discharge location. The resulting plumes may be advected by up to 4 km from the release location, and sediment will settle out within 1 day of discharge. The resulting deposition footprint is likely to cover the development area with varying thickness, generally between 1 and 10 mm, and with peaks between 3 and 30 cm.

The worst case increase in SSC impacts from the cable burial process (i.e. from trenching) will be up to 30 mg/l, but these will be very localised. The resulting plumes will not be advected beyond the near-field vicinity of the cable route and sediment will settle out within a few hours of disturbance. The resulting deposition footprint is likely to be very thin (typically <0.1 mm) with peaks up to 3 mm.

6.1.2 Operational Phase

The presence of the wind turbines and their foundations in the Neart na Gaoithe development site will modify the metocean and sediment regimes. Localised changes to flow around the structures also has the potential to lead to scouring of material.

The predicted changes to water level due to the Neart na Gaoithe development are very small (<0.025% of water depth), and generally localised to the near-field, with the exception of a small change (<0.02% of spring tidal range) in the upper reaches of the Firth of Forth.

The predicted changes to tidal currents due to the Neart na Gaoithe development are quite small (between 3 and 6% of peak spring tidal velocities), and restricted to the immediate vicinity of the development site.

The predicted changes to the wave climate due to the Neart na Gaoithe development are considered to be small (<3% of average wave heights), and restricted to the immediate vicinity of the development site.

The predicted changes to the sediment transport processes due to the Neart na Gaoithe development are considered to be very small, with the frequency of the exceedance of the critical shear stress changing typically by 1-3% (with a maximum difference of 6%). These changes are also restricted to the immediate vicinity of the development site.

6.1.2.1 Impacts of scouring

The risk of scour around gravity bases will require a full engineering assessment in order to design suitable scour protection, and therefore scour will be significantly mitigated if gravity bases are used.

If jacket structures are employed, the estimated equilibrium scour depth will be between 2.2 and 3.26 m; the lateral extent of the scour pit will be between 3.98 and 7.99 m; and the scoured area will between 284 and 1063 m^2. The actual dimensions of the scour pits around each leg of the structure will depend on the size of turbine installed. However, scour pits will not overlap regardless of turbine size, and therefore the scour will be local, rather than general.

The volume of scoured material will be between 196 and 1100 m^3, again depending on the size of the turbines. The resulting elevated SSC would be small and localised, with peak concentrations between 100 and 300 mg/l, and concentrations beyond about 250 m of the structures reducing to < 10 mg/l.

The resulting deposition footprints will be very localised around the turbine base, with a maximum thickness of 0.1 m and the extent of the footprint with a thickness >1 mm reaching up to 500 m.

The impacts from the scoured material around the structures is therefore considered to be small and localised within the near-field

6.1.3 Decommissioning Phase

As yet it is not known what decommissioning process will be employed at the end of the lifetime of the development. It is possible that all buried equipment (cables and foundations) would be left *in situ*. However, it is also possible that all equipment associated with the development might need to be removed, including the buried cables. In either case, the likely impacts on the hydrodynamic regime, wave climate and consequently the sediment transport processes will be small, localised and temporary.

The impacts due to disturbed sediments during the process of decommissioning will be similar to those predicted due to the installation processes during the construction phase, although it is noted that impacts are likely to be less, due to the fact that no bed-levelling through dredging would be required.

It is therefore considered that effects on hydrodynamic regime, wave climate and consequently the sediment transport processes due to the decommissioning phase will be negligible.

6.1.4 Cumulative Impacts

The predicted cumulative impacts to water level due to the Neart na Gaoithe development and other nearby OWF developments are fairly widespread, but very small in magnitude (<0.07% of spring tidal range).

The predicted cumulative changes to tidal currents due to the Neart na Gaoithe development and other nearby OWF developments are quite small (between 3 and 6% of peak spring tidal velocities), and very localised to the near-field of each development. No cumulative far-field impacts are predicted on the tidal current regime.

The predicted cumulative changes to the wave climate due to the Neart na Gaoithe development and other nearby OWF developments are considered to be small (<3% of average wave heights), although the affected areas are considerably larger than the impacts from the Neart na Gaoithe development on its own.

The predicted cumulative changes to sediment transport processes due to the Neart na Gaoithe development and other nearby developments are considered to be small, with the predicted frequency of exceedance of the critical shear stress changing typically by 1-3% (with a maximum difference of 6%). These changes are restricted to the immediate vicinity of the development sites.

The proposed OWF developments will not cause net changes to the regional sediment transport regime or sediment dynamics along the nearby coastline, even when the three sites are considered cumulatively.

6.1.5 Climate Change Impacts

The predicted change in water level due to potential climate change is significantly greater, in both magnitude and extent, than the predicted change due to the proposed OWF developments.

The predicted change in tidal currents due to potential climate change is generally quite small, but spatially varied. The predicted change is similar in magnitude to, but considerably more widespread than, the maximum predicted change due to the proposed OWF developments. However, the predicted change in significant wave height due to potential climate change is predicted to be significantly greater than the expected change due to the proposed OWF developments.

The predicted change in the maximum bed shear stress (and therefore in the exceedance of the critical shear stress) due to potential climate change is significantly greater, in both magnitude and extent, than the predicted change due to the proposed OWF developments.

It is therefore considered that the effects on water levels, wave climate and consequently the sediment transport processes due to the changing climate in the future are likely to be generally greater in both magnitude and extent than the predicted changes due to the proposed OWF developments.

6.2 LIMITATIONS

The work undertaken within this study has assessed the impacts of the development on the metocean regime and coastal processes. For any other elements of the EIA, this assessment should be considered together with the results of other environmental studies from the wind farm project team. This will allow a full analysis of engineering and environmental implications to ensure that all impacts are assessed in terms of their significance. As an example, the significance of the predicted deposition due to construction activities has been assessed in this study in relation to seabed features, but not on the potential impact the deposition may have on other receptors such as the benthic community.

This assessment has made use of numerical modelling techniques, using a calibrated and validated hydrodynamic and spectral wave models, in combination with relevant field data and empirical equations. As such, there are a number of sources of error and uncertainty, including in the field data itself and in the inherent limitations of the numerical approximations to real world physical processes.

The assessment of the baseline conditions are from validated models and are consistent with the field data and other relevant sources, such as previous studies, but will obviously include some inaccuracies. However, the numerical models used are very good at identifying relative differences between scenarios. The results and conclusions presented here are therefore valid and fit for the purpose of assessing the potential effects on the metocean and coastal processes. They also form a good basis for further analysis, but should not be used in isolation for any detailed engineering design.

In addition to the limitations in the numerical analyses, there are also a number of unknowns about the development itself (such as the number and size of turbines, or what foundation types will be used). Therefore the assessment has applied assumptions that result in the 'realistic' worst case for the assessment of each topic or issue. The final design of the scheme should be within the worst case scenario modelled, and actual impacts are therefore likely to be less than those presented here.

6.3 Summary Table of Predicted Impacts and Significance

Phase	Source	Receptor	Near-Field		Far-field		Cumulative		Notes on significance
			Magnitude of Change	Duration of Change	Magnitude of Change	Duration of Change	Magnitude of Change	Duration of Change	
Construction	Installation Equipment	Water Level	Negligible	Transient	No impact	No impact	No impact	No impact	Only negligible changes over a transient nature predicted in near-field. Scour rates around legs of installation vessels are negligible and transient. No far-field or cumulative impacts predicted
		Tidal Currents	Negligible	Transient	No impact	No impact	No impact	No impact	
		Wave Heights	Negligible	Transient	No impact	No impact	No impact	No impact	
		Suspended Sediment Concentrations	Negligible	Transient	No impact	No impact	No impact	No impact	
		Seabed features (bed-forms)	Negligible	Transient	No impact	No impact	No impact	No impact	
		Sediment Regime	Negligible	Transient	No impact	No impact	No impact	No impact	
		Coastal Processes	Negligible	Transient	No impact	No impact	No impact	No impact	
	Bed preparation for gravity bases (dredging)	Water Level	No impact	No impact	No impact	No impact	No impact	No impact	No impact predicted
		Tidal Currents	No impact	No impact	No impact	No impact	No impact	No impact	
		Wave Heights	No impact	No impact	No impact	No impact	No impact	No impact	
		Suspended Sediment Concentrations	Up to 300 mg/l above background	During dredging period only	No impact	No impact	No impact	No impact	Although impacts on SSC are relatively high compared with background levels, this will be for short period during construction. Significance of this impact will be dependent on the vulnerability of the relevant receptors.
		Seabed features (bed-forms)	Deposition up to 30 cm (typically < 10 mm)	Effectively permanent, but dependent on tidal conditions	No impact	No impact	No impact	No impact	Resulting deposition will occur over the whole development area. Settled material will be the same as the ambient conditions, and will be subject to the natural processes of erosion/deposition

									experienced at the site. No material change to seabed features or bed forms are predicted.
		Sediment Regime	No impact	No impact	No impact	No impact	No impact	No impact	No impact
		Coastal Processes	No impact	No impact	No impact	No impact	No impact	No impact	
	Cable Burial	Water Level	No impact	No impact	No impact	No impact	No impact	No impact	No impact
		Tidal Currents	No impact	No impact	No impact	No impact	No impact	No impact	
		Wave Heights	No impact	No impact	No impact	No impact	No impact	No impact	
		Suspended Sediment Concentrations	Up to 30 mg/l (very localised)	Transient – during cable-burial period only	No impact	No impact	No impact	No impact	Concentrations are relatively high compared with background levels,. But will be very localised and transient. Significance of impacts will be dependent on the vulnerability of the relevant receptors
		Seabed features (bed-forms)	Deposition up to 3 mm (typically <0.1 mm)	Effectively permanent, but dependent on tidal conditions	No impact	No impact	No impact	No impact	Resulting deposition will be very thin and very localised. Settled material will be the same as ambient, and no material change to seabed features will result.
		Sediment Regime	No impact	No impact	No impact	No impact	No impact	No impact	No Impact
		Coastal Processes	No impact	No impact	No impact	No impact	No impact	No impact	
Operational and Maintenance	Presence of gravity base and turbines	Water Level	Up to 0.025% of water depth	Effectively permanent, but dependent on tidal conditions	Up to 0.02% of spring tidal range	Effectively permanent, but dependent on tidal conditions	Up to 0.07% of spring tidal range.	Effectively permanent, but dependent on tidal conditions	Predicted impacts are very small compared with natural variability, and would not be measureable. Significance of impacts is therefore negligible in both near and far-field
		Tidal Currents	Up to 6% of spring velocities (typically < 3%)	Effectively permanent, but dependent on tidal	Negligible	Negligible	Negligible	Negligible	Near-field impacts are small and within the range expected due to natural variability. Far-field

				conditions					impacts will be negligible. Significance of impact to tidal regime is therefore low
		Wave Heights	Reduced by up to 2.8% (dependent on wave conditions)	Effectively permanent, but dependent on wave conditions	Negligible	Negligible	Reduced by up to 3% (dependent on wave conditions)	Effectively permanent, but dependent on wave conditions	Near-field and cumulative far-field impacts small compared with natural variability. Significance of impact to wave climate is therefore low
		Suspended Sediment Concentrations	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
		Seabed features (bed-forms)	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	
		Sediment Regime	Up to 6% absolute increase in exceedance of critical shear stress (typically ± 1%)	Effectively permanent, but dependent on tidal and wave conditions	Negligible	Negligible	Negligible	Negligible	Near-field impacts are comparable with natural variability. No material change to seabed features is predicted. No far-field or cumulative impacts are predicted. Significance of impacts to sediment regime is therefore low.
		Coastal Processes	Not Applicable as site is more than 15 km offshore	Not Applicable as site is more than 15 km offshore	Negligible	Negligible	Negligible	Negligible	No impact to coastal processes
	Scour around jacket structures	Water Level	No impact	No impact	No impact	No impact	No impact	No impact	No impact
		Tidal Currents	No impact	No impact	No impact	No impact	No impact	No impact	
		Wave Heights	No impact	No impact	No impact	No impact	No impact	No impact	
		Suspended Sediment Concentrations	Up to 300 mg/l locally (typically < 10 mg/l)	During formation of equilibrium scour pits –dependent on tidal but typically up to 3 months	No impact	No impact	No impact	No impact	Scour occurs on Spring tides only therefore excess sediments are introduced gradually and periodically
		Seabed features (bed-forms)	Scour pits formed around structures up to 3.26 m deep, with	Effectively permanent, but dependent on tidal	No impact	No impact	No impact	No impact	Scour pits expected to remain as stable, permanent features around structures (highly limited

			scoured area up to 1063 m2. Scoured material re-distributed within development area up to maximum of 0.1 m	and wave conditions					infilling)
		Sediment Regime	Negligible	Negligible	No impact	No impact	No impact	No impact	No impact
		Coastal Processes	Negligible	Negligible	No impact	No impact	No impact	No impact	
Decommissioning		Water Level	Negligible	Transient	No impact	No impact	No impact	No impact	Negligible and transient impacts – significance negligible
		Tidal Currents	Negligible	Transient	No impact	No impact	No impact	No impact	
		Wave Heights	Negligible	Transient	No impact	No impact	No impact	No impact	
		Suspended Sediment Concentrations	Up to 30 mg/l (very localised)	Transient – during cable-removal period only	No impact	No impact	No impact	No impact	
		Seabed features (bed-forms)	Deposition up to 3 mm (typically <0.1 mm)	Settled material subject to the natural process of erosion/deposition experienced at site	No impact	No impact	No impact	No impact	
		Sediment Regime	Negligible	Transient	No impact	No impact	No impact	No impact	
		Coastal Processes	Negligible	Transient	No impact	No impact	No impact	No impact	

7 REFERENCES

i Intertek METOC "Inch Cape and Neart na Gaoithe Offshore Wind Farms – Proposed Methodology for Metocean and Coastal Processes Assessments". Report No: P1476_RN2550_Rev1. February 2011

ii Intertek METOC "Inch Cape and Neart na Gaoithe Offshore Wind Farms – Data Gap Analysis and Data Review". Report No: P1476_RN2597_Rev2. May 2011

iii Intertek METOC "Inch Cape and Neart na Gaoithe Offshore Wind Farms Coastal Processes Assessment – Hydrodynamic and Spectral Wave Model Calibration and Validation". Report No: P1476_RN2636_Rev0. September 2011

iv Intertek METOC "Regional Coastal Processes Baseline Description - Inch Cape and Neart na Gaoithe Offshore Wind Farms". Report No: P1476_RN2728_Rev0. September 2011

v E-mail from SeaEnergy Renewables Ltd (Martina Gassner), dated 23rd May 2011 to Intertek METOC (Kevin McGovern), with attachment containing the modelling parameters for the Neart na Gaoithe development

vi COWRIE Ltd, ABPMer and HR Wallingford "Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide", COWRIE Ltd, September 2009

vii Letter from Marine Scotland (Leeanne Mullen) to SeaEnergy Renewables Ltd (Martina Gassner), dated 18th April 2011. Marine Scotland Ref: 005/OW/SER-10 and 008/OW/MainS-10

viii Letter from SeaEnergy Renewables Ltd and Mainstream Renewable Power Ltd (Martina Gassner) to Marine Scotland (Leeanne Mullen). Subject: "Response to Marine Scotland's comments on the STW regional metocean and coastal processes Methodology Statement.

ix Ramsay, D.L., and Brampton, A.H., "RSM 143 Coastal Cells in Scotland Cell 1", and "RSM 144 Coastal Cells in Scotland Cell 2". 2000

x DEFRA. "Flood and Coastal Defence Appraisal Guidance: FCDPAG3: Economic appraisal: Supplementary note to operating authorities – Climate change impacts". 9 pp. 2006

xi Seagreen Wind Energy. "Seagreen Phases 2 and 3 Scoping Report – Round 3 Firth of Forth". Document No: A4MR/SEAG-Z-DEC230-SRP-072. June 2011

xii A Framework for Marine and Estuarine Model Specification in the UK. Foundation for Water Research, March 1993

Appendix A Stakeholder Consultation

marinescotland

The Scottish Government

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Martina Gassner
EIA and Consents Coordinator
SeaEnergy Renewables Limited

Our Ref: 005/OW/SER-10
008/OW/MainS-10
18 April 2011

Dear Ms Gassner,

Thank you for your email requesting comments from Marine Scotland on the proposed Coastal Processes methodology. The document, *proposed methodology for metocean and coastal processes assessments* (p1476_rn2550_rev1), was circulated to consultees. Marine Scotland has the following comments to offer on your proposals.

The proposed methodology is rigorous and well thought out. The proposed modelling methodology is particularly impressive. Many statements within the document are, however, quite general and there is a lack of evidence that specific issues and *sensitive receptors* have been identified and considered. For example, it is mentioned that the impacts will be assessed "with specific reference to sensitive receptors" and how key sensitive receptors *will* be identified (pages 5 and 17). Also, whilst the proposed methodology is very rigorous, it is somewhat lacking in reasoning behind why certain things will be done. For example it is not clear why certain measurements will be taken during the survey campaign (page 13). Identifying specific issues and sensitive receptors at this early stage would probably enable a more rigorous assessment of what parameters need to be measured, monitored and/or modelled.

It is understood that the document outlines the methodology to be adopted during the coastal processes assessment for an EIA. The early identification of specific issues and sensitive receptors is, however, highly advised for the reasons given above.

One potential issue that is not mentioned within the document is that of the underlying sandbank stability. It is understood that is it intended that a literature review will help establish a good conceptual understanding of sediment transport rates, pathways, sources and sinks within the region. You may find that it will be

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necessary to address this issue within the survey campaign and modelling work. There is, for example, no mention of measurements being made of the bed forms and features that may change as a result of the construction of wind farms.

Finally, the proposed consideration of the cumulative impacts of multiple wind farms within the region is considered to be timely and a very important part of an EIA.

Specific comments about the document:

Please define "Sedimentological conditions/regimes/environment" in more detail. For example, does this include bed sediments; bed forms/features including sandbanks; and sediment transport including pathways, erosion, deposition, bed load and suspended load?

Please explicitly define the difference between "cumulative" and "in-combination" impacts. Within this document it seems to do with spatial scale, i.e. cumulative impacts of the individual pillions/gravity bases/foundations and in-combination effects due to multiple farms and other developments, but this is not clear from the outset.

P.8 (bottom of page) The different impact assessment scenarios are not in Section 3.6.

P.9 "Similarly, sediment transport, fluxes, sources, ..." Please rephrase this rather long sentence. If you mean to say that offshore wind developments are likely to have a small effect on large scale sediment pathways, please provide some justification.

P.31 Section 4.5.2 It is not clear whether the potential increase in suspended and bed load sediment transport as a result of scour is considered.

P.33 Section 4.5.3 (9) should "...developments will be **referred to** the baseline conditions ..." actually be "...developments will be **compared with** the baseline conditions ..."?

Sections 4.5.1 and 4.5.3 explicitly mention what range of conditions will be considered (i.e. meteorological and metocean conditions). For example in Section 4.5.1 "the range of current speeds and wave conditions likely to be encountered during installation" will be considered, and in Section 5.4.3 the "same range of environmental conditions will be modelled as during the baseline study". Please make similar explicit statements within Sections 4.5.2 and 4.5.4.

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If you require further clarification of any of the points made above please feel free to contact Marine Scotland.

Yours sincerely

Leeanne Mullan

Marine Scotland – Licensing Operations Team

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Subject - Response to Marine Scotland's comments on the STW regional metocean and coastal processes Methodology Statement

Dear Ms Mullan,

Thank you for providing a response on behalf of Marine Scotland and other consultees to our proposed coastal processes methodology:

> *Inch Cape and Neart na Gaoithe Offshore Wind Farms: Proposed Methodology for Metocean and Coastal Processes Assessments. Intertek METOC on behalf of SeaEnergy Renewables Limited. Report P1476_RN2550_Rev1, 16 February 2011.*

We were very pleased to see the positive acceptance of the significant aspects of the methodology and have addressed below the queries and clarifications that were raised.

__General Issues__

Sensitive receptors. A detailed list of sensitive receptors was not included in the methodology report because the data were still under review (for example, the results from some of the field surveys). This process is ongoing, but by way of guidance the coastal processes study, and the broader EIA, will consider:

- Designated and draft designated sites including SPAs, SACs, Ramsar sites, SSSIs, NNRs etc.
- Potential impacts on habitats and species not covered by existing designations, including, for example, fish spawning areas.
- Potential impacts on key anthropogenic sites, such as wrecks.
- Areas not covered by existing designations which are considered to be potentially sensitive to changes in the sedimentary environment, as determined during the coastal processes baseline assessment.

Please note, confirmation of the above sensitive receptors was requested from Marine Scotland on the 6th May, along with any further guidance, if considered necessary.

Measurement parameters. The purpose of the measurement campaign was to support the general characterisation of the wind farm areas. The parameters measured provide sufficient point references for input into the hydrodynamic model and sediment transport assessment such that these can then be used to extrapolate conditions across the sites, including any potentially environmentally sensitive areas.

The current and wave measurements provide site specific inputs into the hydrodynamic models and this will be fully referenced in the model build and calibration report.

The suspended sediment, grab samples and sediment trap data allow for the general characterisation of the sediment types and size distributions to be used in sediment transport predictions once the potential shear stress changes are known from the hydrodynamic model.

The water quality data collected was intended to confirm the expected levels of water quality parameters and the likely absence of specific issues. See also below for the geophysical measurements undertaken.

Sandbank stability. The issue of underlying sandbank stability will indeed be covered by the proposed assessment, in addition to sediment transport rates, pathways, sources and sinks. The presence of bed forms and features will be identified as part of the baseline assessment, based on available sources (literature review, historical data and field survey campaign). Geophysical measurements (including bathymetry, sidescan sonar and sub-bottom geology) have been undertaken at both sites which will inform the seabed features study. The potential impact of the wind farm developments on these bed forms will then be evaluated based on outputs from the modelling work.

Specific Issues

Sedimentological conditions/regimes/environments. The assessment will cover all aspects of the sedimentary environment and coastal processes regime that might be impacted by the proposed developments. This will include (but not necessarily be limited to): bed forms and features (including sandbanks); sediment transport pathways; erosion; deposition; bed load and suspended load.

"Cumulative" and "in-combination". The definitions of these as defined by the Forth and Tay Offshore Wind Developers Group are as follows:

> *Cumulative* – the effects of one type of development with other types of the same development (i.e. wind farms and other wind farms).
>
> *In-combination* – the effects of the above in combination with other, different projects and activities (e.g. wind farms in combination with dredging or wind farms in combination with shipping).

Section 2.2, bottom of page 8. "Note – a detailed list of the impact assessment scenarios is provided in Section 3.6." This should read Section 4.5.

Section 2.3, page 9. "Similarly, sediment transport, fluxes, sources...". We would rephrase this sentence as follows:

Information on sediments (including sediment type, transport pathways and bed forms) will typically be sparser in deeper water, offshore areas than in near-coast areas. The effects of the proposed developments on the sedimentary environment will be assessed as part of the proposed coastal processes study.

Section 4.5.2, page 31. The potential changes to bed load and suspended sediment concentrations will be considered as part of the general coastal processes assessment and the scour assessment.

Section 4.5.3 (9), page 33. The first sentence should read "...developments will be compared with the baseline conditions...", rather than "...developments will be referred to the baseline conditions...".

Sections 4.5.2 and 4.5.4. These sections refer to scour potential and post-construction, long-term impacts, respectively. For both of these impact assessments, we will model the same range of environmental (i.e. metocean) conditions as during the baseline study. This will allow the potential impacts of the developments to be determined.

The comments and text changes above will be reflected in both the hydrodynamic modelling and methodology sections of the technical report and environmental statement chapter respectively.

Additional Comments

Model resolution (Section 4.2.3). Construction and calibration of the Forth and Tay Modelling System is well underway, and we can offer more detail on the specification of the model than is included in the methodology report. Having evaluated a) the high resolution bathymetry and metocean data obtained across the development areas, and b) outputs from the model, we have determined our preferred model resolution. The spatial resolution will be approximately 70 m across the Inch Cape and Neart na Gaoithe development areas. This resolution is suitable for accurately representing wave and current processes, and for providing hydrodynamic input to the sediment studies. The stated resolution represents the optimum balance between the requirement for accuracy in modelling outputs, and the need for a model with manageable run-time and data storage requirements.

I hope that the above responses adequately address the points you have raised. Please contact me if you have any further queries.

Yours sincerely,

Martina Gassner

On behalf of STW offshore wind farm developers Mainstream Renewable Power and SeaEnergy Renewables

Appendix B Neart na Gaoithe Area Baseline Description

B.1 INTRODUCTION

This appendix presents an overview of the baseline (existing) oceanographic and coastal processes environment at the Neart Na Gaoithe OWF site. This assessment is performed where possible using site specific data collected during marine survey and oceanographic monitoring operations. However, it is supplemented by other knowledge (where relevant) and includes relevant information reviewed as part of the regional baseline assessment (Intertek METOC Report RN2728).

The summary of the baseline (existing) oceanographic and coastal processes environment at the Neart Na Gaoithe site is based on an analysis of the following topics:

- Bathymetry;
- Geology and surficial sediment cover, including sediment features (bedforms);
- Physical oceanographic conditions;
- Fluvial inputs; and,
- Sediment transport regime, including transport due to waves, currents and waves plus currents.

B.1.1 DATA SOURCES

A wide variety of sources have been used in this assessment. Site specific geophysical and metocean data sets have been extensively used, and these have been supported through inclusion of regional and site specific data from elsewhere. Table B-1 summarises the data sources used.

Table B-1: Summary of major data sources used.

Data Source	Study/Data Name	Data Theme(s)	Data Location
Mainstream / RNE UK	Scoping Studies	Environmental baseline	At Neart na Gaoithe site
FTOWDG (collected by Partrac)	Metocean monitoring survey	Metocean monitoring data (waves, tides, wind)	At Neart na Gaoithe site
Mainstream (collected by EMU)	Hydrographic, geophysical and benthic surveys	Bathymetry, geophysical and particle size data	At Neart na Gaoithe site
Mainstream (collected by Gardline)	Geotechnical survey	Geotechnical data	At Neart na Gaoithe site
HR Wallingford reports	Firth of Forth Water Quality Model Assessment of Field Data Scoping Support (2009) Various background reports (engineering and survey design)	Water quality (turbidity) Baseline	East coast of Scotland/At site
JNCC UK SeaMap	SeaMap 2010	Seabed habitats/landscapes	East coast of Scotland
Scottish National Heritage (SNH)	Coastal Cells in Scotland Cell 1 St Abb's Head to Fife Ness Cell 2 Fife Ness to Cairnburg Point	Shoreline processes	East coast of Scotland

Data Source	Study/Data Name	Data Theme(s)	Data Location
British Geological Society (BGS)	1986. Tay Forth, Sheet 56°N-04°W, Seabed Sediments, 1:250,000 series. 1987. Tay Forth, Sheet 56°N-04°W, Quaternary Geology, 1:250,000 series. 1986. Tay Forth, Sheet 56°N-04°W, Solid Geology, 1:250,000 series. General – geology and sediment maps; Holmes (1994); Holmes et al (1999) Pantin (1991); Gatliff et al., (1994) Core archive Surface grab sample archive (www.bgs.ac.uk)	Geology, sedimentology, sediment features, sediment thickness and sediment transport	Tay and Forth
UK Hydrographic Office (UKHO)	Various contemporary charts (Admiralty Charts 175 and 190); Tide Tables, Co-tidal Charts	Bathymetry & tidal streams, water levels	East coast of Scotland
British Oceanographic Data Centre (BODC)	Data Inventory Deployments	Current measurements Wave measurements Surge data	Various port sites
Scottish Environmental Protection Agency (SEPA)	River Inflows	Freshwater/sediment inputs	Major rivers
Cefas WaveNet	Data Inventory	Wave measurements	Directional waverider information from WaveNet from 19 August 2008 at 56^0 11.33'N. 2^0 30'W
UK Met Office (UKMO)	Data summary	Meteorological data	Eastern Scotland
Coastal Councils	SMPs	Shoreline processes, coastal processes	Tayside; Fife; East Lothian; Angus
Department of Trade and Industry (DTI) - Department for Business, Enterprise and Regulatory Reform (BERR)	SEA3, SEA 5; 2007/07 Atlas of Renewable Energy	Regional geomarine assessment; synoptic oceanographic parameters	Regional
UK Offshore Energy SEA (DECC 2009)		Regional geomarine assessment	Regional
Scottish Marine Renewables SEA (Faber Maunsell and Metoc 2007)		Regional geomarine assessment	Regional
The Tay Estuary Coastal References Database		Geology; sedimentology; fluvial flows	Tay and Forth
Intertek METOC	The Forth and Tay HD and SW Modelling System developed specifically for this assessment	Metocean (hydrodynamic and spectral wave conditions)	Regional and site-specific

B.2 BATHYMETRY

The proposed offshore wind farm is located offshore the east coast of Scotland in the central North Sea, 61 km northeast of Edinburgh at 52º16' N, 2º16' W. It is situated east of the firths of Forth and Tay and 13-30 km directly east of Fife Ness. A comprehensive high resolution hydrographic survey collected data on local water depths across the site.

The seabed forms an expansive, largely level seabed plain with no dramatic changes in bathymetry or seabed slope (Figure B-2). General water depths within the site boundary (~105 km^2) range between 40 and 58 m CD, with a mean of 50.6 m CD (mean Spring tide range is ~4.8 m). Deeper regions, extending to 58-60 m are found in the northwestern and western areas of the site. The shallowest depth is found in the southern half of the wind farm site where a linear ridge rises approximately 2 m above the adjacent seabed to 40.5 m. The greatest depth is at the western edge of the survey boundary, outside the wind farm site boundary, within a north-south trending trough where depths are up to 60.4 m.

The seabed is characterised by numerous low amplitude hummocks and mounds (over 25 mounds are present within the survey area). The mounds are commonly up to 4-6 m shallower than the surrounding seabed at depths of 40-48 m. They are sub-circular with an approximate diameter of 1 km. The seabed over these mounds is rough due to the presence of boulders in the Wee Bankie deposits whereas the surrounding seabed is relatively flat and smooth.

Frequency analysis of the depth data provides a distribution for the range of depths (Figure B-1). A summary of depth statistics is given in Table B-2. A representative value for a mean site depth is ~51 m.

Figure B-1: Histogram of water depths.

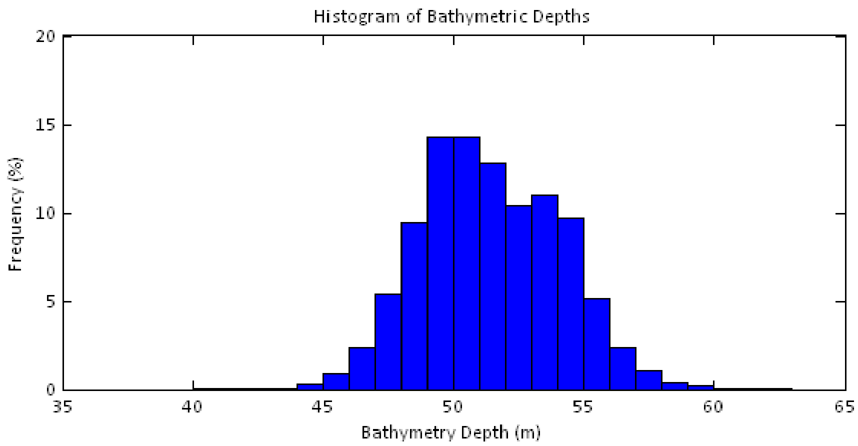
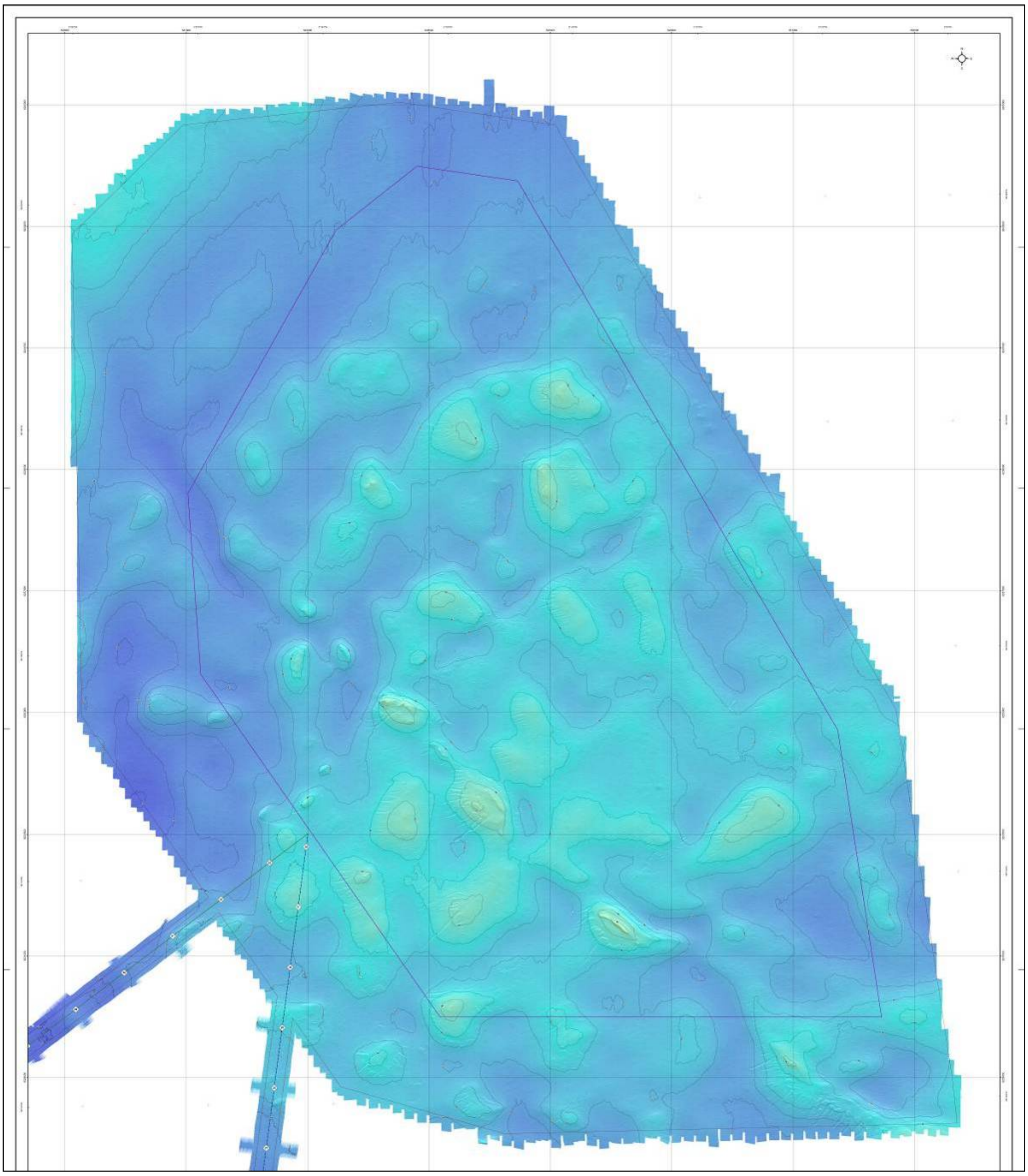


Table B-2: Statistical summary of water depth data

Statistic	Depth (m) CD
Mean depth (m)	51.43
Minimum depth (m)	40.44
Maximum depth (m)	57.70
Modal depth (m)	50.13
Median depth (m)	51.21

Figure B-2: Distribution of water depths (bathymetry) across the Neart Na Gaoithe site.



Note: Datum is m CD. Source: Geophysical Survey.

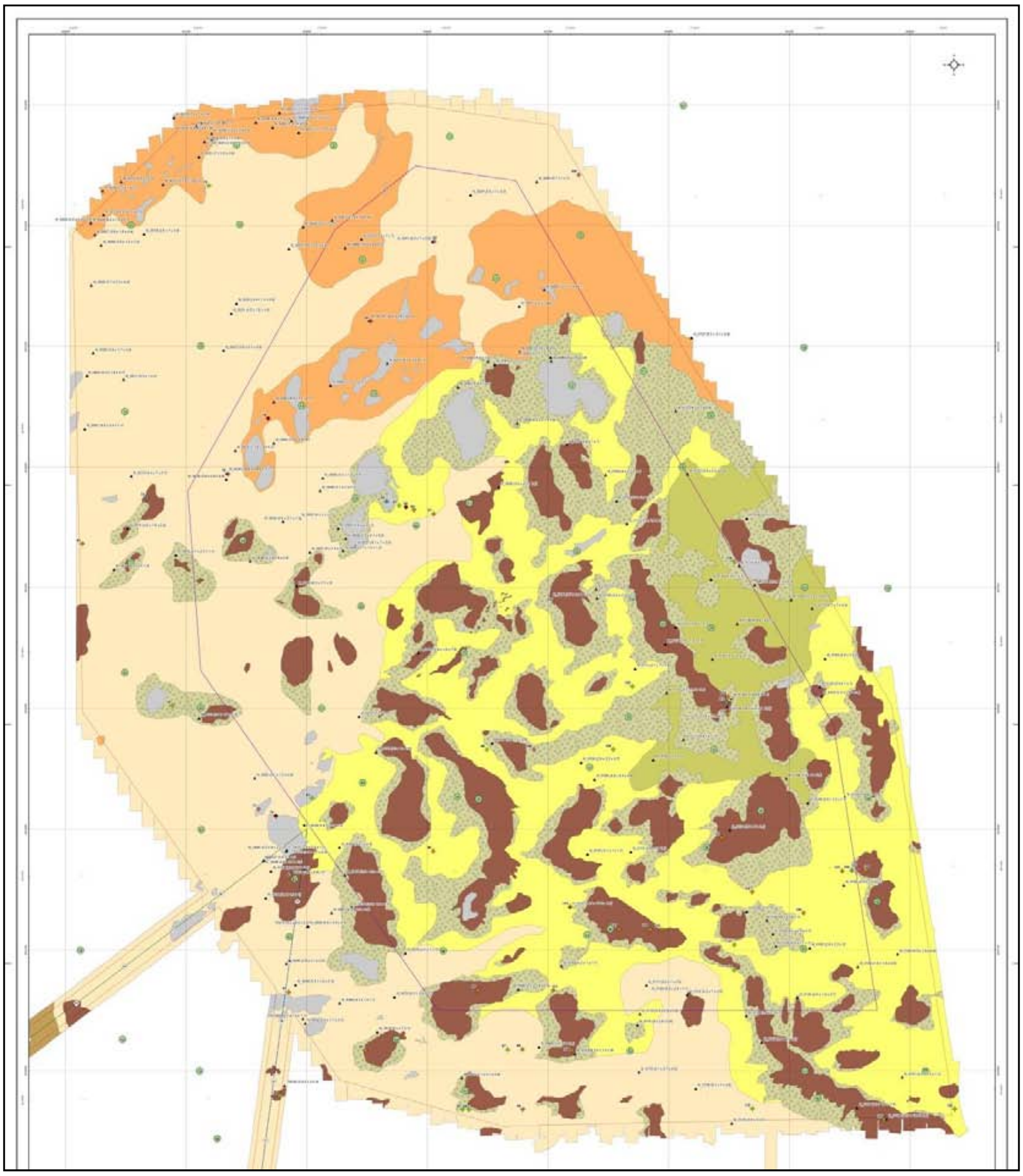
B.3 SEDIMENT COVER

B.3.1 SURFICIAL SEDIMENTS

Holmes, (1977) and Holmes et al., (2004) report Holocene (i.e. geologically recent) sediments comprising sand or gravelly sand present in a layer typically < 0.5 m thick across the site, overlying Quaternary sediments. The site geophysical survey, which uses non-intrusive measurement (remote sensing) methodology for investigating seabed type, indicates that the surficial sediments of the site are older, comprising exposed Quaternary sediments, specifically the Wee Bankie formation which elsewhere (e.g. at the Inch Cape) occurs largely if not wholly sub-surface. Figure B-3 illustrates the distribution of sediment types across the site.

The Wee Bankie sediments comprise gravelly muddy sand with boulders. Boulders are defined as clasts greater than 25 cm. Slightly gravelly muddy sand is most common across the western and southern parts of the survey area where water depths are generally slightly greater. Towards the north of the wind farm site the thickness of these sediments decrease and bedrock is close to the surface and the seabed type has been classified as muddy sand with occasional rock. From the centre and to east and southeast of the wind farm site the dominant sediment type is sand. The sand is commonly found where the seabed is flat and smooth in the troughs between mounds of Wee Bankie Formation deposits.

Figure B-3: Distribution of sediment type across the Neart Na Gaoithe site.



Note: Source: Geophysical Survey

The geophysical survey was supplemented by an environmental (benthic) sampling programme which collected seabed samples from various locations across the site. These samples have been analysed for the distribution of particle sizes present, and therefore form a useful quantitative dataset which can be compared with the acoustic classifications above to summarise sediment type for the site. 29 samples were collected in total within the site boundary (additional samples were collected along cable corridors and outwith the site to a distance corresponding to one tidal excursion). Figure B-4 shows the results of the size analyses in the form of pie charts for each sampled location in additional to the Folk (1954) textural classifications.

These data show that the dominant matrix across the site is sand, with generally a minor mud fraction found in the western, slightly deeper areas, and a gravel component found in samples in the central region and down the eastern fringe. The dominant Folk (1954) classification across the site is 'slightly gravelly sand', within which the sand content is usually > 90%, although coarser deposits ('gravelly sand') are found typically on topographic highs (i.e. on mounds with water depths of about 44–46 m). The sandier deposits are generally moderately well sorted, with the degree of sorting reducing for gravelly sands/sandy gravels and muddy gravelly sands.

Table B-3 summarises quantitative data from the particle size analysis tests. These data show that the sand is largely very fine to fine sand (0.063 to 0.250 mm). Where gravel is present in minor amounts it is generally very fine to fine (2 – 8 mm), whereas in richer gravel deposits particle sizes can range up to approximately 20 – 30 mm, or even greater in isolated pockets.

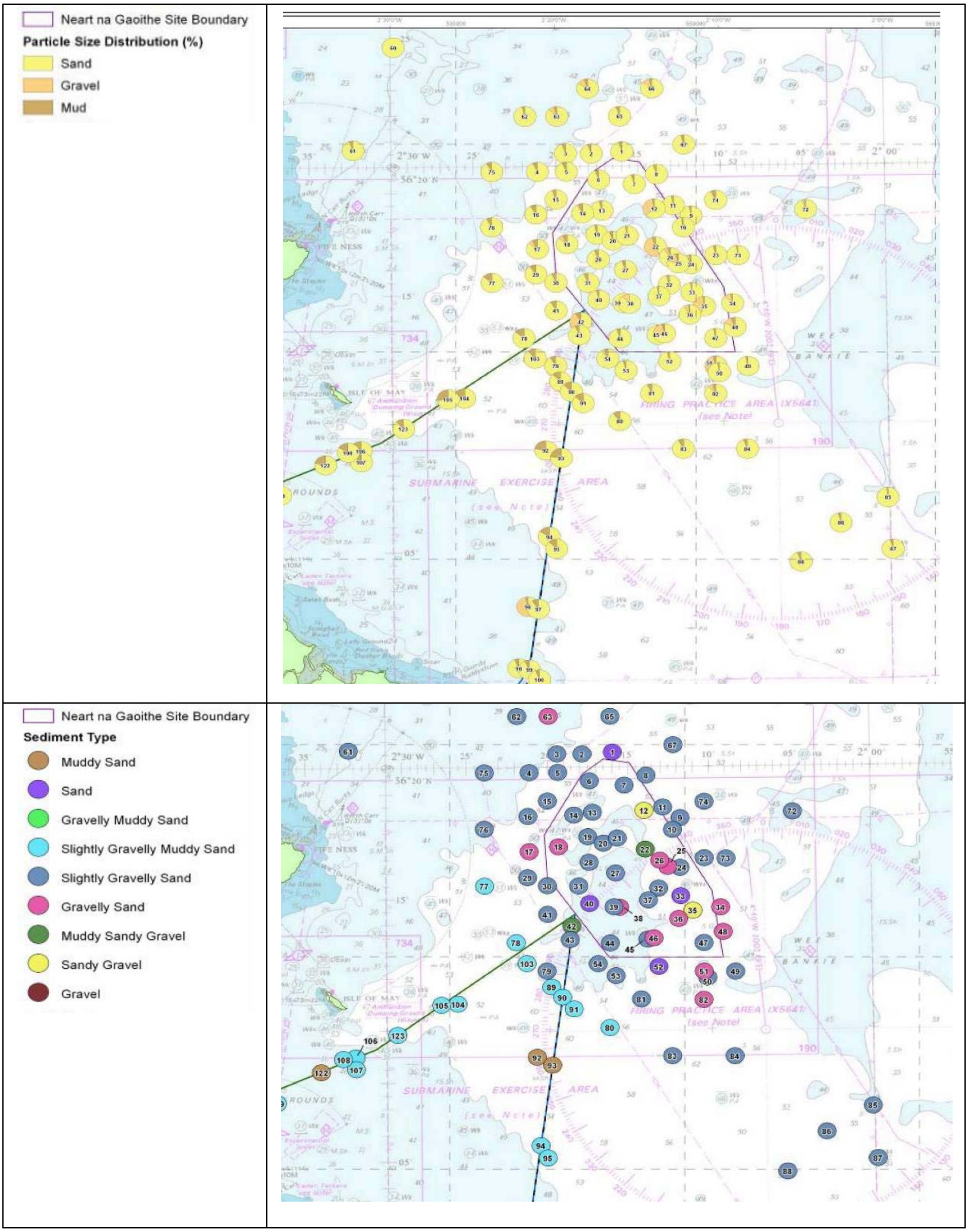
Table B-3: Summary of particle size distribution data.

Sample	% Gravel	% Sand	% Silt	Mean Grain Size (mm)	Sorting[1]	Folk Sediment Classification (Folk, 1954)
6	0.17	89.13	10.70	0.125	0.81	Slightly Gravelly Muddy Sand
7	0.03	91.27	8.70	0.141	0.91	Slightly Gravelly Sand
	0.03	94.21	5.76	0.152	0.79	Slightly Gravelly Sand
12	33.66	60.53	5.81	0.909	3.29	Sandy Gravel
13	0.21	91.92	7.87	0.185	1.12	Slightly Gravelly Sand
14	2.53	84.89	12.57	0.164	1.329	Slightly Gravelly Muddy Sand
18	7.29	79.00	13.72	0.174	1.68	Gravelly Muddy Sand
19	0.19	93.13	6.68	0.194	1.00	Slightly Gravelly Sand
20	0.05	89.93	10.02	0.134	0.89	Slightly Gravelly Muddy Sand
21	0.17	94.39	5.44	0.175	0.92	Slightly Gravelly Sand
22	51.94	38.10	9.96	2.593	3.89	Muddy Sandy Gravel
24	2.79	90.95	6.26	0.151	0.86	Slightly Gravelly Sand
25	16.06	75.80	8.14	0.341	2.64	Gravelly Sand
26	5.60	86.64	7.76	0.219	1.69	Gravelly Sand
27	1.09	89.89	9.02	0.188	1.25	Slightly Gravelly Sand
28	0.24	88.10	11.66	0.119	0.88	Slightly Gravelly Muddy Sand
31	0.04	88.01	11.94	0.118	0.80	Slightly Gravelly Muddy Sand
32	2.36	92.62	5.03	0.192	1.04	Slightly Gravelly Sand
33	0.00	95.65	4.35	0.194	0.83	Sand
35	41.63	54.39	3.98	1.145	2.71	Sandy Gravel
36	6.75	88.98	4.27	0.215	1.35	Gravelly Sand
37	0.00	94.98	5.02	0.157	0.75	Slightly Gravelly Sand
38	11.34	88.49	0.17	0.553	1.56	Gravelly Sand
39	0.10	99.29	0.61	0.253	0.77	Slightly Gravelly Sand
40	0.00	92.21	7.79	0.143	0.79	Sand
44	0.02	89.89	10.09	0.137	0.84	Slightly Gravelly Muddy Sand
45	0.62	94.28	5.11	0.176	0.87	Slightly Gravelly Sand
46	25.74	66.64	7.62	0.677	3.00	Gravelly Muddy Sand
47	0.01	94.25	5.74	0.141	0.69	Slightly Gravelly Sand

Note: Source: Environmental Survey.

[1] Sorting values correspond to: <0.35 very well sorted; 0.35-0.5 well sorted; 0.5-1.0 moderately well sorted; 1.0-2.0 poorly sorted; 2.0-4.0 very poorly sorted and >4.0 extremely poorly sorted.

Figure B-4: Gravel:sand:mud ratio (top panel) and Folk textural classifications (lower panel) across the Neart Na Gaoithe site and vicinity.



Note: includes export cable corridors, and surrounding area around site to approximately a single tidal excursion. Source: Environmental survey.

B.3.2 SUB-SURFACE SEDIMENTS

Total soft sediment thicknesses (equivalent to the depth to rockhead) across the site which includes the soft-sediment and underlying Wee Bankie Formation where present, range from 0 to 70 m with a mean of 13.4 m. Generally soft-sediments across the proposed offshore wind farm survey area (including site and buffer) range from 0 to 15 m thick with a mean of 3.4 m. Across large areas of the site, and surrounding the Wee Bankie Formation exposures, and occasional rock outcrops, the soft-sediment cover is ~ 0.2 to 1 m thick. In areas interpreted as zero sediment (particularly in the centre and east of the wind farm site) it is likely that a veneer of sediment (less than 0.3 m thick) is present over bedrock which cannot be resolved by the geophysical survey. Greater sediment thickness is seen at the northern and western extents of the site where soft-sediments are up to 8 m thick. The soft-sediment isopachyte highlights several channels across the site and buffer. One of these channels appears within sediments infilling a large valley incised into bedrock which trends northwest to southeast. Soft-sediment thicknesses here are up to 21 m. Two other smaller channels appear to cross this larger one perpendicularly and have sediments up to 8 m thick.

B.3.3 BED FEATURES

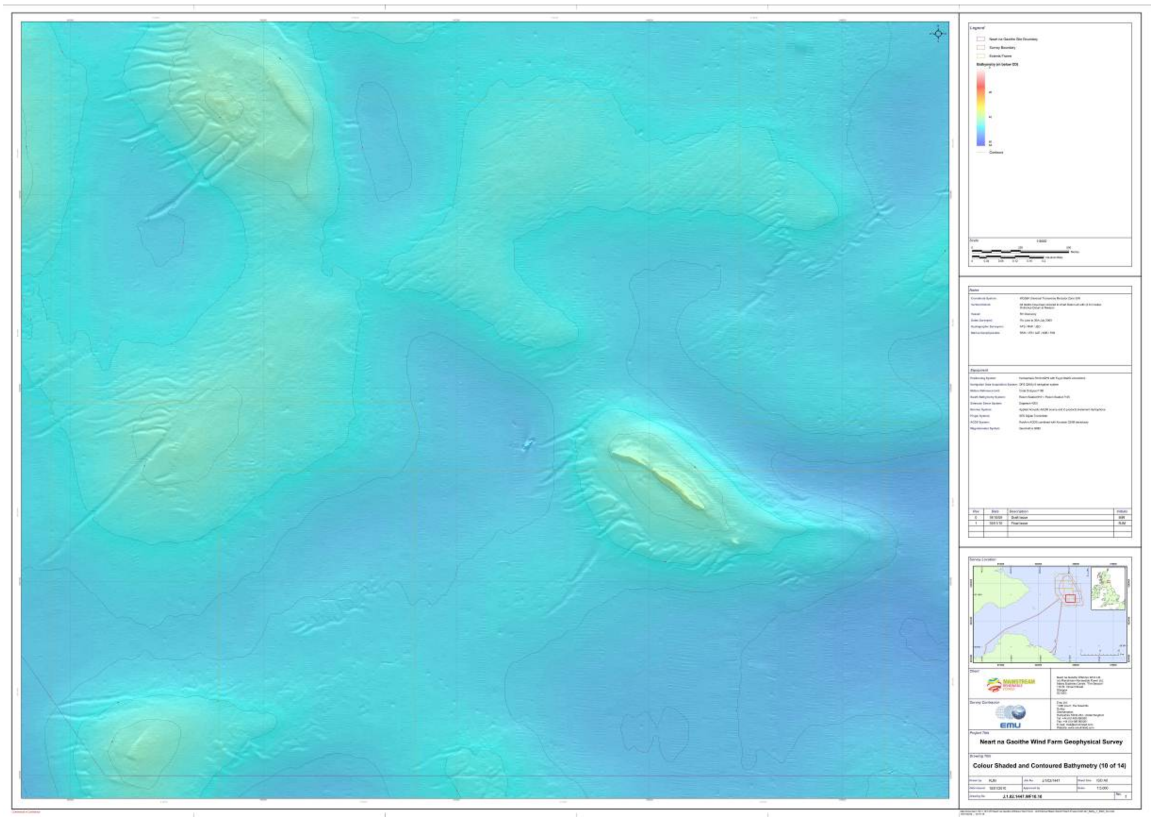
The geophysical survey includes high resolution mapping of the seabed topography (with scales of ~0.1 – 1 m), and also a side scan sonar survey. Side scan sonar produces photographic-quality images of the seabed in which acoustic shadows from the sensor array can be used to infer the shape, orientation and dimensions of features and structures on the seabed. Together these systems are useful in defining sedimentary bedforms (and other) seabed features, which may be related to mobilisation and transport of surficial sediments.

The primary bed feature across the site would appear to be linear troughs. These are shown in Figure B-5. An examination of the BGS Seabed Sediments Tay-Forth 1:250.000 Series (1986) map indicates the presence of sinuous sand waves/megaripples, extending as a narrow band across the central portion of the site. The sand waves/megaripples are oriented west-south-west/east-north-east, and are located in areas of both sandy and muddy sediments. A smaller band of linear sand waves/megaripples is located just to the south, and these are oriented mostly south-east/north-west. No other large-scale bedforms are apparent in the site. However, the geophysical survey does not report these features, and this may not be surprising given the date of the BGS dataset (1986).

The geophysical survey reports areas of gravelly muddy sand with small dunes, and side scan sonar example of these is shown in Figure B-6. However, although they indicate sediment mobility, these are reported only very rarely across the site and where they are their amplitude is not given. The bedform wavelength of such features is estimated to be 0.5 to 1 m. The seabed area between the mounds and hummocks over much of the site is described as ‘relatively flat and smooth’. The survey data describe some areas of the seabed as ‘undulating’ however this terminology suggests general topographic variability rather than that associated with bedform features per se.

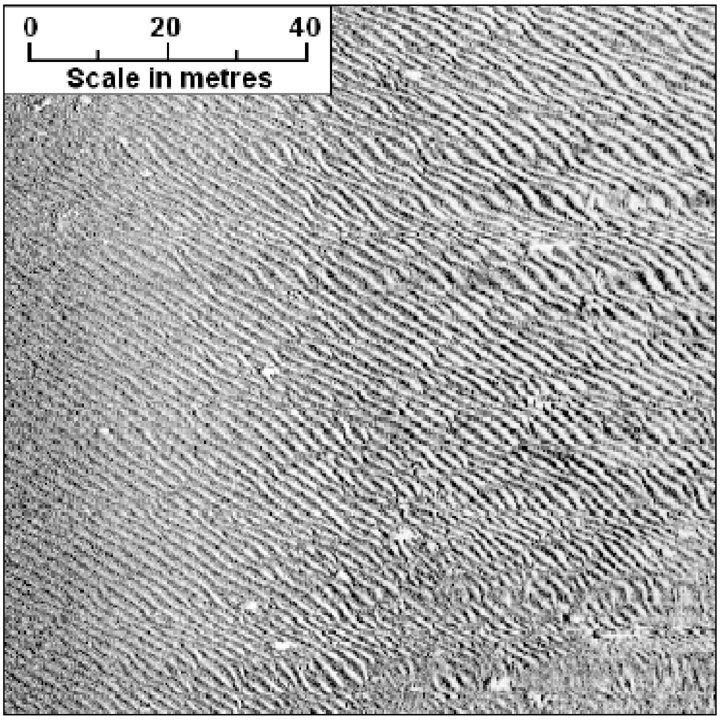
The linear trough bed features, found mostly in association with the shallower hummocks and mounds, are found across the site (see Figure B-5). The mounds (themselves exposures of firmer Quaternary sediments, often in the form of linear ridges) would appear to create an obstruction to (amplification of) the boundary layer flow, and the surrounding sediment is swept into linear trough features which radiate outwards from the perimeter of the mounds in the direction of dominant tidal currents (approximately southwest). The orientation of these ridges indicates that they are topographically controlled and not aligned with the regional current or wave approach axes. Excepting this localised scour around mounds and hummocks, the overwhelming conclusion from these data is the seabed across the site is probably largely stable.

Figure B-5: Bathymetry across the southern region of the Neart Na Gaoithe site showing linear ridge features around the periphery of exposed Quaternary sediment mounds.



Note: Source: Geophysical Survey.

Figure B-6: A side scan sonar image of a region of seabed judged GRAVELLY MUDDY SAND, showing dune features.



Note: No data of bedform amplitude are given in the source data but the wavelength is estimated to be 0.5 to 1 m. Source: Geophysical survey.

B.3.4 SEDIMENT QUALITY

Sediment quality can form an important issue if seabed sediments are found to be contaminated by chemical species. The chief issue arises where sediments might be resuspended during site development (e.g. due to foundation preparation and cable installation) or through scour around turbines, which would then release these sediments into suspension to be transported elsewhere. The term 'contaminated' may informally be designated here as exceeding the Cefas Action Level benchmark 1 (AL1) - this is a metric used by regulatory authorities to assess offshore disposal options for dredged sediment, within which values in excess of AL1 may not qualify for offshore disposal. Table B-4 summarises sediment quality data collected across the site and at 3 reference sites (outwith the Neart Na Gaoithe development footprint). These data indicate a largely uncontaminated seabed. However, cadmium is found in all locations sampled at concentrations up to and over 3 times the AL1 benchmark value. Elevated nickel concentrations are reported from 3 locations but concentrations are only slightly in excess of the AL1 value.

Table B-4: Sediment quality for turbine location and reference samples

Sample Location		Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Mercury	Total PAH	Total HC
		mg kg^{-1}								ng kg^{-1}	µh kg^{-1}
7	Turbine site	4.8	0.6	22.3	8	12.2	8.9	27.3	0.012	41.2	9556.7
13	Turbine site	7.1	0.8	29.6	10.3	13.3	10.6	23	0.014	79.3	13505.2
21	Turbine site	5.1	0.7	27.2	10.2	12.4	12.1	23.9	0.011	55.7	10101.3
26	Turbine site	5.3	0.5	25.5	8.6	12.2	9.7	18.5	<0.01	41.7	7668.8
28	Turbine site	4.5	0.6	23.6	9	12.8	8.7	20.9	0.012	115.6	16049.1
32	Turbine site	6.7	0.6	23.9	6.8	13.3	9.5	23.3	0.013	71.3	12807.3
36	Turbine site	6.6	0.5	23.7	7.8	12.7	9.7	21.5	0.025	39.4	8282.8
38	Turbine site	10.3	0.7	11.7	5.8	10.8	5.7	15.5	0.01	41.9	6773.5
46	Turbine site	4.5	0.7	17.5	14.6	12.3	10.8	18.9	0.014	58.8	8903.5
55	(Reference)	6.6	0.6	23.5	8.2	13.6	9.6	23.4	0.021	19.4	7227.1
61	(Reference)	5.1	1.2	26.3	17.9	15.9	11.4	30.8	0.018	80.4	10324.8
86	(Reference)	4.2	0.6	17.6	8.4	11.8	7.5	19.8	0.013	78.1	7651.3
Cefas	AL1	10	0.2	20	20	25	10	65	0.2	~	100000
Cefas	AL2	25 50	2.5	200	200	250	100	400	1.5	~	~
Canadian	ISQG	7.2	0.7	52.3	18.7	30.2	~	124	0.1	~	~
Canadian	PEL	41.6	4.2	160	108	112	~	271	0.7	~	

Note: Also shown are regulatory guidance benchmark values. Grey values indicate samples where concentrations exceed the Cefas Action Level 1 value. Levels for different species of tin and organochl

B.4 PHYSICAL OCEANOGRAPHY

A metocean data acquisition programme, commissioned by the Firth of Forth and Tay Windfarm Developers Group (FFTWDG) consortium, collected data on current magnitudes and wave parameters at the Neart Na Gaoithe OWF site. Data were collected using state-of-the-art wave buoys and acoustic current meters continuously through the period 10/12/09 - 26/06/10 – 14/07/10. The precise location of oceanographic monitoring equipment within the Neart Na Gaoithe site boundary is shown in Figure B-7 and summarised in Table B-5. Table B-6 summarises the wave and current statistical data from this monitoring campaign.

Figure B-7: Deployment locations for the oceanographic monitoring equipment at the Neart Na Gaoithe site.

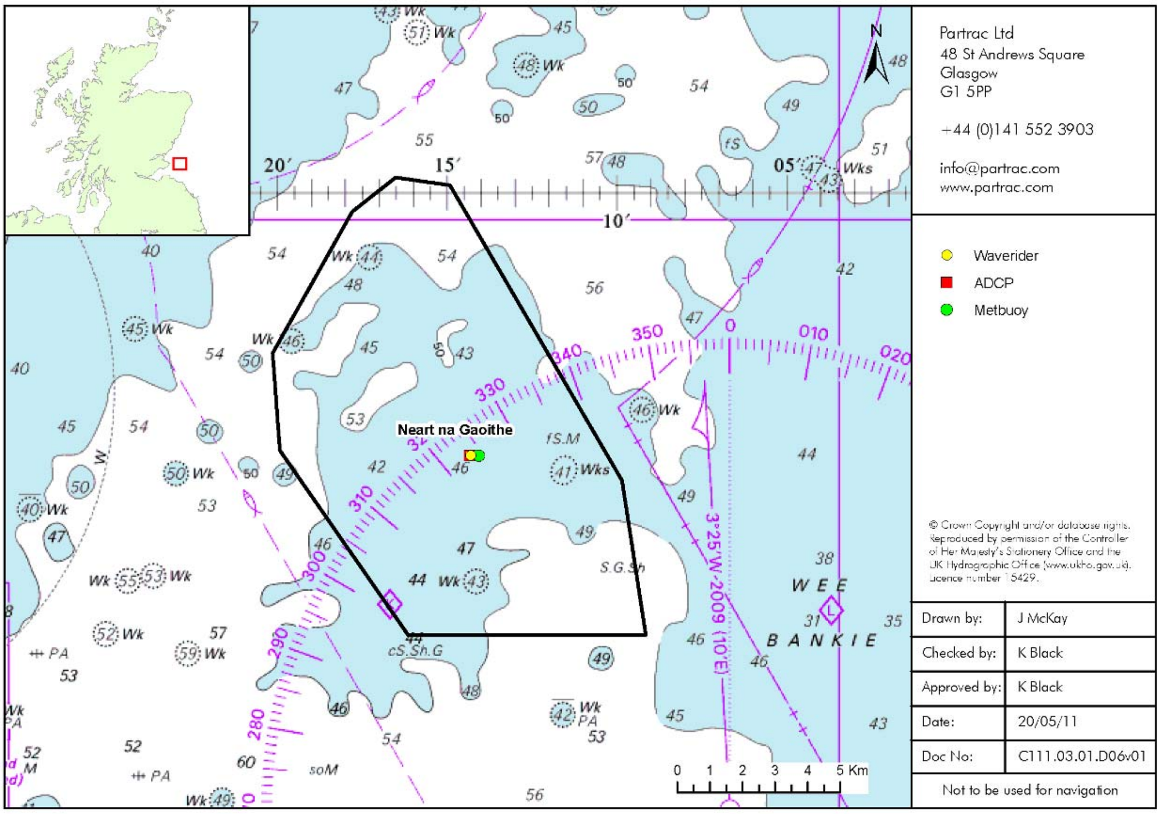


Table B-5: Details of Waverider, ADCP and AWAC deployment locations at the Neart Na Gaoithe site.

Site	Deployment Date/Time (UTC)	Deployment Date and Time (UTC)	Latitude (WGS84)	Longitude (WGS84)
Neart na Gaoithe	Waverider	10/12/09 15:56	56º 15.724 N	002º 14.298 W
Neart na Gaoithe	ADCP	10/12/09 15:31	56º 15.723 N	002º 14.330 W
Neart na Gaoithe	AWAC + turbidity	05/05/10 08:30	56°15.656' N	002°13.697' W

Table B-6: Summary of oceanographic statistical data at the Neart Na Gaoithe site from the monitoring campaign.

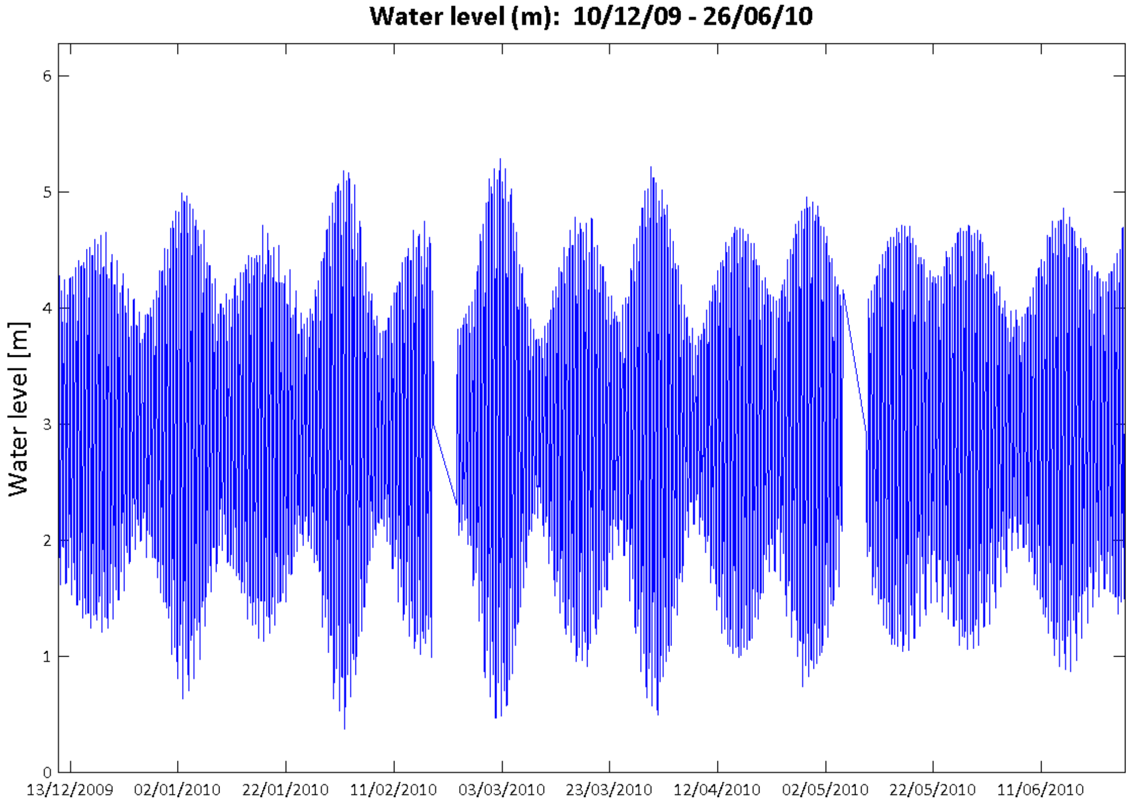
Parameter	Value
Maximum Significant Wave Height – Hm0 (m)	6.03
Mean Significant Wave Height – Hm0 (m)	1.13
Modal Peak Direction Dir_p (º)	26.2
Maximum Wave Period – T_z (s)	9.04
Minimum Wave Period – T_z (s)	2.18
Neap current (mean) m/s	0.18
Neap current (max) m/s	0.53
Spring current (mean) m/s	0.28
Spring current (max) m/s	0.82
Mean Current Velocity m/s	0.2
Principal Current Axis (˚)	N / S-SSW

Note: All current values are depth-averaged.

B.4.1 WATER ELEVATIONS

Tidal processes are characterised initially by, or related to, the nature of the tidal elevation signature. Down the north eastern seaboard of the British Isles, the tidal regime is semi-diurnal with a mean spring tide of about 4.5 m and a mean neap tide of about 2.2 m. During spring conditions a larger tidal volume is exchanged between high and low waters than during neaps for an equivalent tidal period (around 12.5 hours). This means that the rate of exchange of tidal water, and hence speed of flows, arriving (flood period) and departing (ebb period) in the Outer Forth and Tay estuaries is higher during springs than neaps. This feature of the tidal regime is important in influencing rates of, and net directions of, sediment transport. Figure B-8 shows water elevation data at the site collected during the oceanographic monitoring campaign. Table B-7 presents primary tidal information for the Proudman Oceanographic Laboratory (POL) 'standard port' closest to the site which operates a Class A tide gauge (Leith in the Firth of Forth).

Figure B-8: Time series of water elevation at the Neart na Gaoithe site.



Note: Datum is LAT. Gaps in data are due to service visits. Source: Metocean Campaign

Table B-7: Summary tidal elevation data for Leith

Tidal level (m ODN)		Leith 55°59'N 03°11'W
Highest Astronomical Tide	HAT	+3.40
Mean High Water Springs	MHWS	+2.70
Mean High Water Neaps	MHWN	+1.50
Mean Sea Level	MSL	+0.30
Mean Low Water Neaps	MLWN	-0.90
Mean Low Water Springs	MLWS	-2.10
Lowest Astronomical Tide	LAT	-3.00
CD to ODN	CD	+2.90
Peak Range (HAT – LAT)		6.40
Spring Range (MHWS - MLWS)		4.80
Neap Range (MHWN - MLWN)		2.40

Note: Datum is Ordnance Datum (Newlyn) (ODN). Leith is the primary port. Source: UKHO/POL.

An understanding of the spatial distribution i.e. the uniformity, of currents across the site is provided through use of the Forth Tay Modelling System (FTMS). Examples of model output for spring and neap high and low water are presented in Appendix C. These are useful to show whether the water elevations are uniform across the site. Uniform water elevations are present for spring high water, and both neap high and low water periods. During spring low water there is a decrease in water elevation in the western half of the site of about 0.4 m.

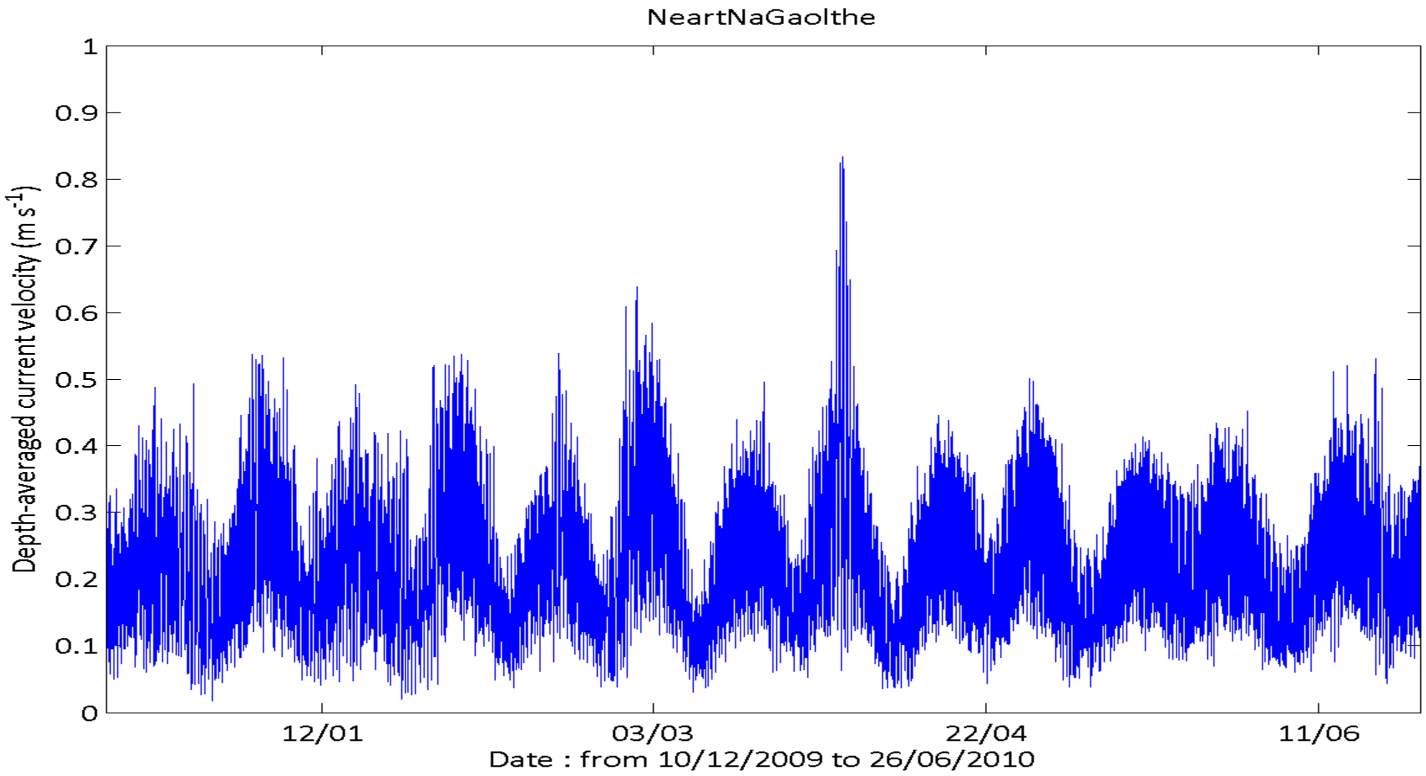
B.4.2 Tidal Currents

Figure B9 shows the time series for the depth average current velocity measured at the Neart na Gaoithe site, and Figure B10 depicts this data on a polar plot (current rose). The tidal currents are strongly rectilinear in form with a principal tidal axis oriented N / S-SSW. The tidal dynamics are highly consistent and the regular transition of neap and spring tides is clear. Depth-averaged mean current velocities of 0.2 m/s are recorded through the monitoring period, with typical peak spring tide currents about 0.5 m/s, occasionally approaching 0.6 m/s. Currents in excess of 0.8 m/s around the end of March are on spring tides and coincident with a storm period which generated approximately 6 m waves across the entire coastal region. The observed higher current velocities are therefore most likely due to superposition of the wave flows onto the tidal current flows.

An understanding of the spatial distribution i.e. the uniformity, of currents across the site is provided through use of the FTMS. The bathymetry data (see Figure B-2) are incorporated within the model and thus predictions of tidal and wave processes at the site reflect site bathymetric gradients and features. The uniformity (or otherwise) of currents across the site is central to understanding any differences in sediment transport across the site. Differences may arise due to such factors such as varying water depth, changes in seabed slope and the presence of medium to large scale bedforms and bed features. Tidal current vectors, which show the direction of the current and the magnitude (proportional to arrow length), are presented for peak currents during flood and ebb, and as percentiles of current speed (based on a mean spring and neap tide) are shown in Appendix C.

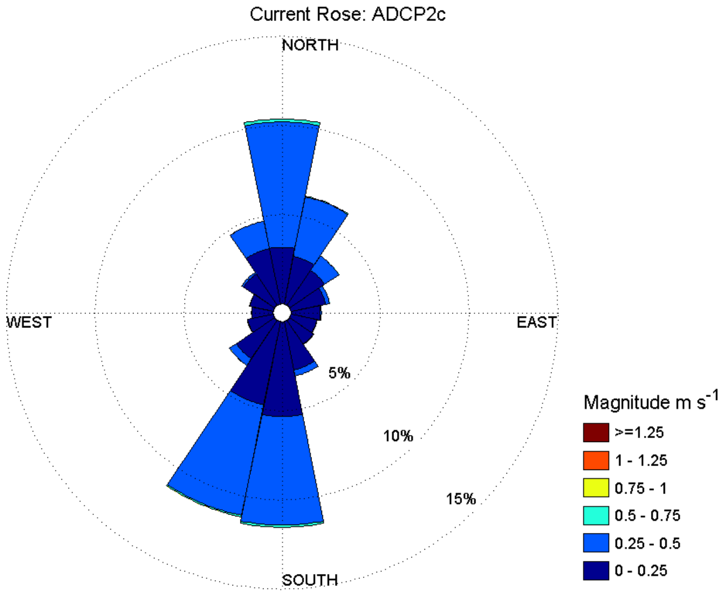
For spring tides, it is clear that both current magnitudes (0.4 to 0. 6 m/s) and flood-ebb current direction across the site are uniform and consistent. Similarly, the spatial current field for the neap flood period for both current magnitude and direction is uniform and consistent; however, there is a region of lower (< 0.2 m/s) current velocity at the southwest corner of the site during neap peak ebb. This forms an area of generally lower velocity to the south and west of the site during neap ebb tides. The seabed at this location comprises mounds and hummock, which shallow to about 46 m, and is an area characterised by boulder fields. The reason for the lower general velocity during this particular tidal phase is not clear. However, it is clear that lower currents will drive lower rates of sediment transport (if it occurs) and scouring around foundations in this area (if it occurs) would be expected to be less severe.

Figure B-9: Time series of depth averaged tidal flow velocity at the Neart na Gaoithe site.



Note: Source: Metocean Campaign. 2009 – 2010.

Figure B-10: Current roses of velocity magnitude (m/s) & direction (º).



Note: From ADCP2 deployment - Source: Metocean campaign.

B.4.3 CURRENT BED STRESS

The motion of the tidal currents exerts a frictional drag ('bed stress', $\tau_{0current}$) on the bottom sediments, and this is responsible for inducing sediment transport. The stress at the bed is a function of both the flow velocity, the roughness of the sediment-water interface and to a lesser extent water depth. Greater turbulence, and therefore greater stress, is generated over coarser sediments. The distribution of bed stress across the site (computed using the FTMS) is presented in Appendix C. An understanding of the spatial distribution i.e. the uniformity, of bed stress across the site is central to an evaluation of sediment transport potential.

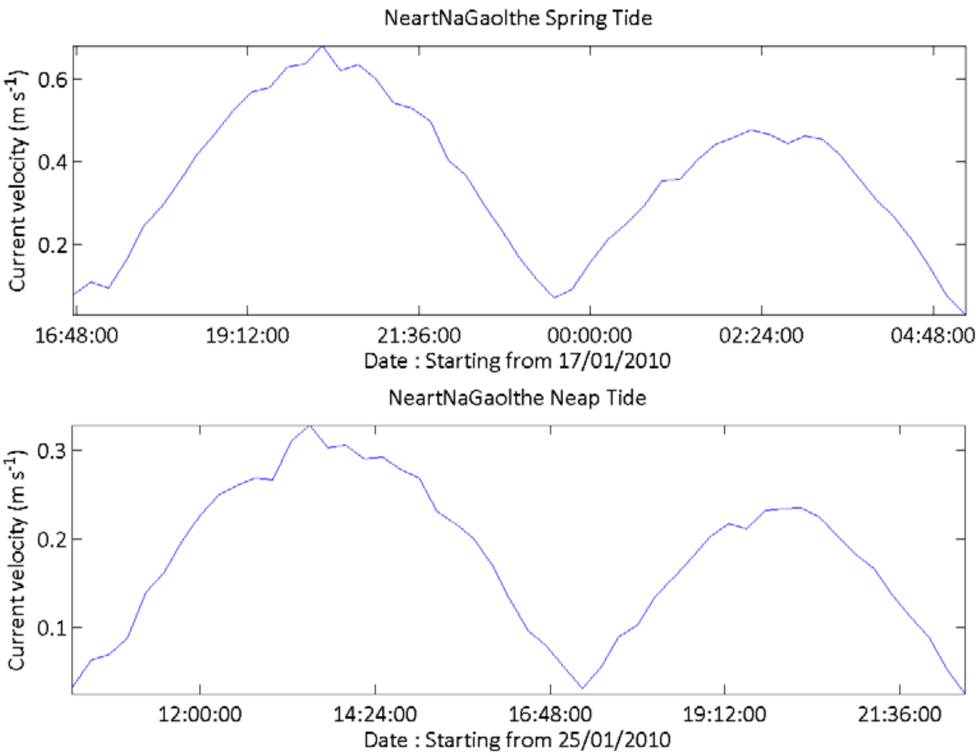
The 50th percentile $\tau_{0current}$ current data show that stress is non-uniform across the site, with higher stresses (0.056-0.1 N/m^2) across the eastern and southern region of the site. This distribution approximates on a general level with that of the bathymetry (see Figure B-2), with higher stress found on shallower parts of the site.

The 90th percentile $\tau_{0current}$ data indicate the maximum bed stress experienced by sediments across the site (during peak spring tides). With the exception of a small area in the northeast of the site (where $\tau_{0current}$ = 0.316-0.562 N/m^2) the distribution of bed stress is uniform across the site with a maximum value of 0.1-0.178 N m^{-2}.

B.4.4 TIDAL ASYMMETRY

Tidal asymmetry is where the currents are different in magnitude and duration for consecutive flood – ebb tides. Asymmetries such as this can drive a residual net direction to the sediment transport which to a first order is in the direction of the stronger of the two currents. At the Neart Na Gaoithe site flood currents are stronger than the ebb currents (Figure B-11), with the difference being slightly more pronounced for neap tides. The ratio of flood to ebb tide current magnitude for spring tides is 1.1 whereas that for the neap tide is 1.3. The durations of these respective tide phases is given in Table B-8.

Figure B-11: Depth-averaged current magnitudes during individual flood and ebb tides



Note: Upper panel = spring tides and lower panel = neap tides.

Table B-8: Durations of flood and ebb phases for spring and neap tides.

	Duration (hrs)	
	Flood	Ebb
Spring	5.75	6.75
Neap	5.25	7.00

B.4.5 TIDAL EXCURSION DISTANCES

Figure B-12 shows the tidal excursion distances during the spring tides. These represent the net horizontal distance a water particle moves during a tidal cycle. Distances during spring tides are 7.51 km during flood tides and 6.93 km during ebb tides. Equivalent excursion distances are naturally less for the neap tide and are 3.06 km during flood tides and 2.76 km during ebb tides. Knowledge of these distances is central to several areas. It provides an understanding of the maximum distances re-suspended sediment will be transported away from their source e.g. due to scour around structures. It is also important to assessments of the fate of any contaminants which might also be re-suspended, and it will provide an indication of the 'residence time' for other components e.g. river sediments, which may be transported into the Neart Na Gaoithe site boundary. Figure B-13 shows the excursion distance data schematically.

Figure B-12: Tidal excursion distances during flood (south flow) and ebb (north flow) tides during the spring tide phase.

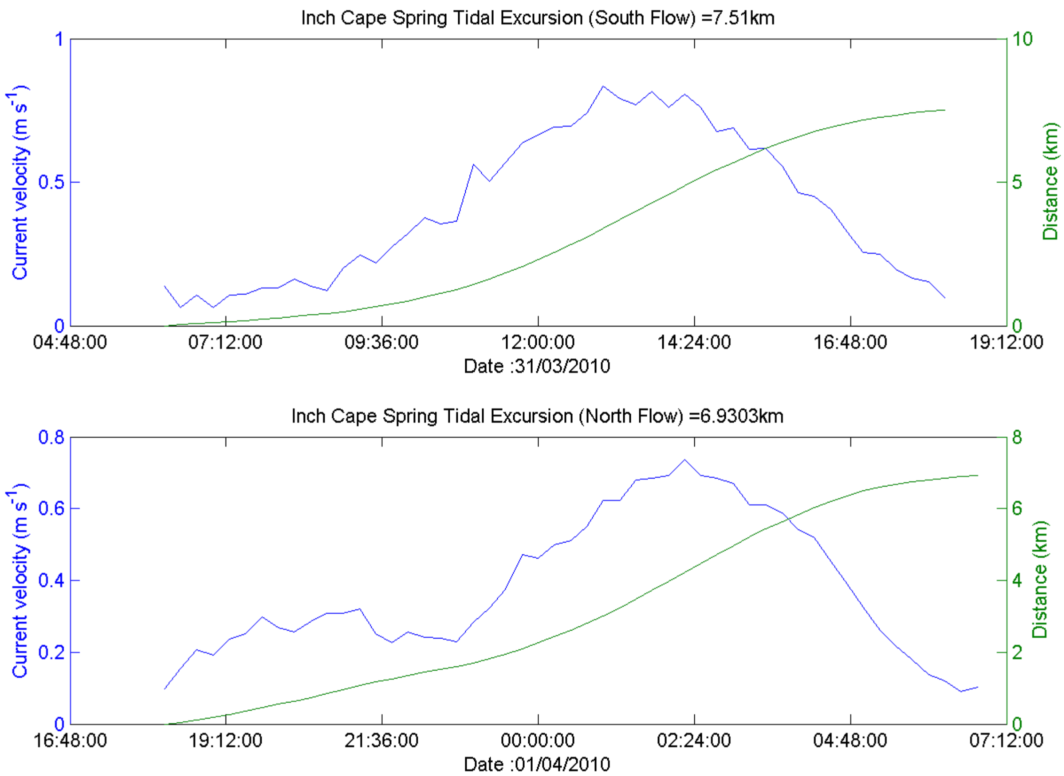
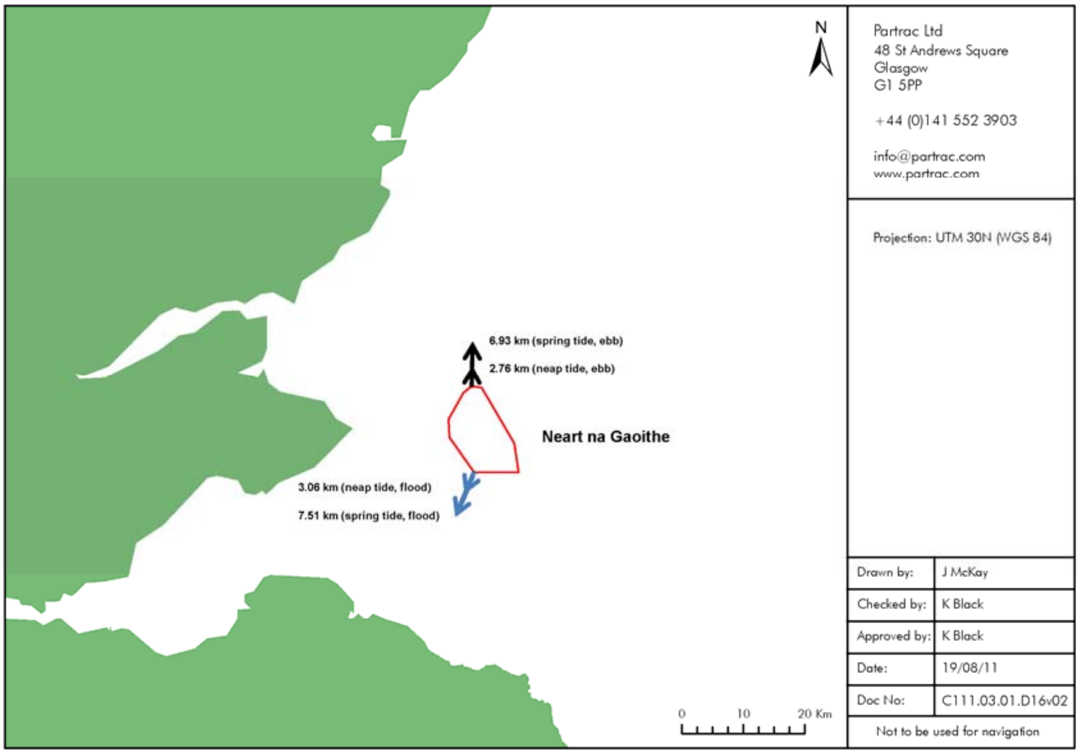


Figure B-13: Graphical representation of the spring-neap tidal excursion distances from the north-eastern and south-western boundaries of the Neart Na Gaoithe boundary.



B.4.6 NON TIDAL CURRENTS

Superimposed on the regular tidal behaviour, various random non-tidal effects may be present. Many of these non-tidal effects originate from meteorological influences. Persistent winds can generate wind-driven currents, set-up water levels and develop sea states that lead to wind-wave generation. The peak measured current velocity of 0.82 m/s at the Neart Na Gaoithe site, which is significantly above the mean peak spring tide current magnitude (about 0.5 m/s), is likely a function of such influences. Atmospheric pressure variations can also depress or raise the water surface to generate positive or negative surges, respectively, and surges can give rise to enhanced bottom current flows. Surges are formed by rapid changes in atmospheric pressure with an inverse relationship, i.e. low atmospheric pressure raises the water surface (positive surge) and high atmospheric pressure depresses the water surface (negative surge). These effects can cause water levels to fluctuate considerably above or below the predicted tidal level. The enhancement of bottom currents is not entirely understood by scientists, and it is not possible to predict (using simple approaches) the consequences of coastal tidal surges on bottom currents.

Table B-9 lists the top ten positive and negative surges obtained from existing tidal records at Leith. The maximum surge measured is 1.38 m (positive) i.e. local water levels were this amount above tidally expected values. At the Neart Na Gaoithe site such a surge would generate a difference in local water depth of about 2-3%.

Table B-9: Top ten positive surges recorded at Leith port.

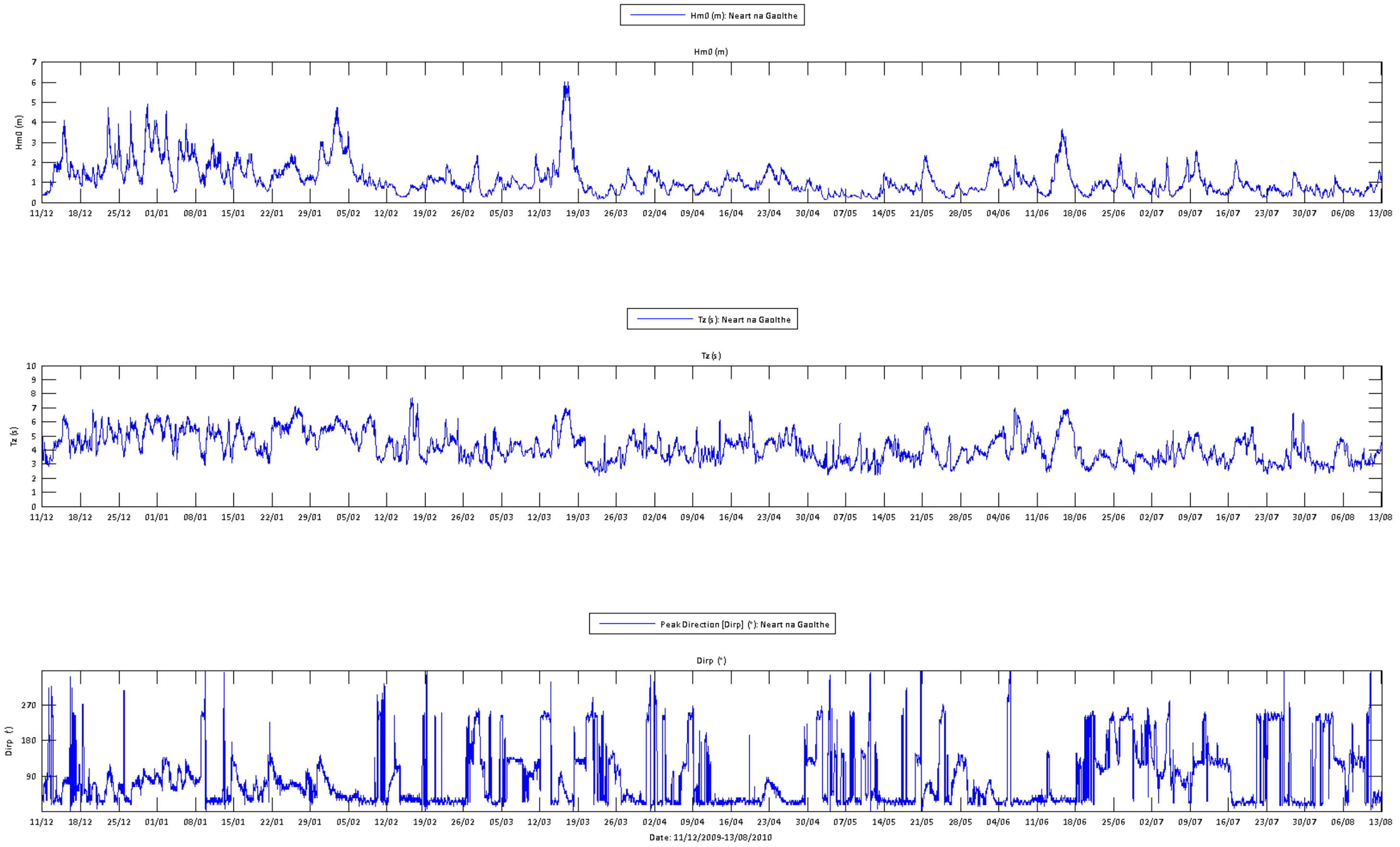
Date and Time	Surge (m)	Date and Time	Surge (m)
POSITIVE		NEGATIVE	
1989/02/14 02:00	1.38	1998/12/27 00:30	-1.36
1990/02/20 01:00	1.30	1996/11/06 08:30	-1.07
1998/11/10 02:00	1.26	1998/11/09 12:45	-0.87
1997/02/20 05:15	1.25	1996/03/12 07:00	-0.87
1993/02/20 22:30	1.15	1981/11/20 16:00	-0.85
1995/01/10 00:45	1.14	2006/10/26 17:30	-0.83
1991/12/19 20:00	1.13	1995/01/31 05:15	-0.80
1993/01/17 17:00	1.07	1993/01/24 00:15	-0.80
2006/01/11 07:15	1.06	1994/01/26 21:45	-0.79
2000/01/30 02:30	1.03	1994/01/29 12:30	-0.78

B.4.7 WAVE REGIME

Time series plots for the chief wave parameters (significant height, mean period, direction) are presented in Figure B-14. The time series wave records extend through the winter months through to June, and the greater frequency of storms during winter months is clear. Winter storms generate frequent higher energy episodes with significant heights centred on 3-4 m but approaching 5 m in some instances. In comparison, heights during summer months rarely exceed 2 m. The wave period data (Figure B-14) show that wave periods range between about 2 and 9 seconds. The longer period waves correspond to non-local swell waves which come from a north-northeasterly (22.5^{o}) direction, and this direction is the dominant wave direction (Figure B-15). As time progresses from winter to summer there is also a reduction in wave period from generally >6 s to generally <6 s.

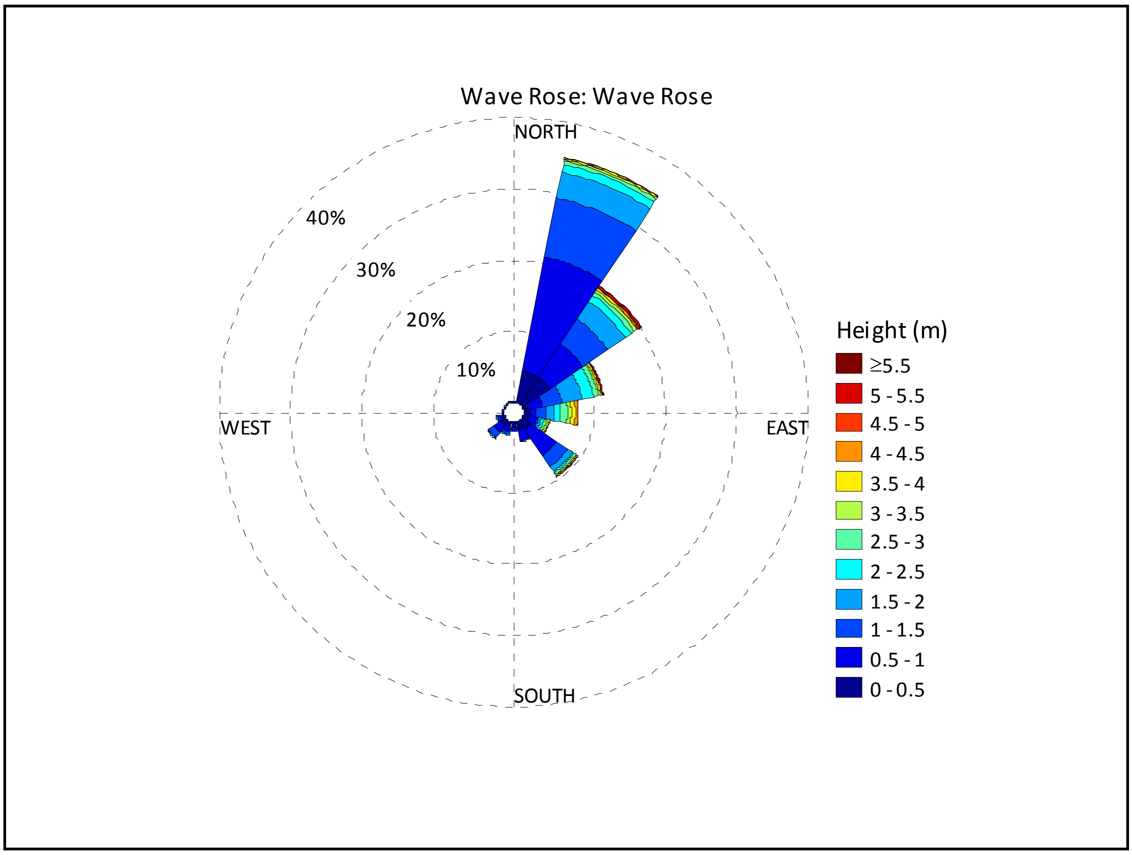
Waves occur from both the southeastern and southwestern quadrants but form only a minor component of the wave direction spectrum, especially those from the southwest which are fetch limited due to the presence of the land.

Figure B-14: Time series of wave parameters at the Neart na Gaoithe site



Note: Upper panel = Significant wave height; Middle panel = Mean (zero crossing) wave period; Lower panel = Mean direction. Source: Metocean Campaign.

Figure B-15: Wave rose plot of wave data showing the significant wave height, frequency and direction.



Note: Source: Metocean Campaign.

Table B-10: Wave frequency by direction.

Direction	Frequency of occurrence (%)
E	7.74
ENE	11.53
NE	20.23
NNE	35.13
N	0.22
NNW	0.35
NW	0.17
NWN	0.22
W	0.34
WSW	1.25
SW	3.16
SSW	1.98
S	1.31
SSE	2.924
SE	9.57
ESE	3.87

Note: Source Metocean campaign

An appreciation of wave conditions across the site i.e. any spatial variation, is available using the FTMS. Appendix C includes plots showing the distribution of significant wave height and wave period with respect to four percentile values (50, 90, 95, 99 %ile) across the Neart na Gaoithe site. These allow an assessment of the uniformity of wave conditions over the site, but also indicate the maximum expected value for each parameter on a long-term basis.

Irrespective of the wave period percentile value selected, the data indicate a uniform spatial distribution of wave period across the site. Wave periods expected at the site range from about 5-5.5 s for the 50%ile, to about 8-8.5 s for the 99%ile. Given that the penetration of wave energy to the seabed (and thus the potential to generate sediment transport) is strongly dependent upon wave period, the maximum value here can be considered as an upper limit to wave periods expected at the site over long timeframes. The absence of any non-uniformity of wave period across the site indicates, in addition, that shoaling effects (as waves shoal their period decreases) are negligible.

There is, however, some non-uniformity in conditions across the site if the wave height parameter is inspected for conditions other than the average (50%ile). Non-uniformity is evident but spatial differences are not large. As waves increase in size (> 2 m), wave heights down the western perimeter are smaller by about 0.5 m relative to the rest of the site; with further increases in size (> 3 m) waves are observed slightly higher across the southern of the site by 0.5-0.75 m i.e. at the more exposed offshore area. 99% of all waves expected at the site will have a significant wave height of no more than 5.2 to 5.4 m. During conditions which would occur under these largest waves, the wave heights across the site are uniform with the exception of the far northwestern periphery, where slightly smaller waves (about 5-5.2 m) are expected.

B.4.8 WAVE BED STRESS

In a similar manner to tidal currents, wave-related currents exert a frictional drag ('bed stress', τ_{0wave}) on the bottom sediments if the wave energy can penetrate to the bed, and this is also responsible for inducing sediment transport. The stress at the bed is a function of both the wave height and period, the roughness of the sediment-water interface and (unlike for tidal currents) water depth. Greater turbulence, and therefore greater stress, is generated over coarser sediments. The distribution of bed stress due to the native wave climate across the site (computed using the FTMS) is presented in Appendix C. An understanding of the spatial distribution i.e. the uniformity, of wave-related bed stress across the site is central to an evaluation of sediment transport potential.

The 50%ile τ_{0wave} data show that wave stress is largely uniform across the site (τ_{0wave} < 0.01 N/m^2). Three small areas are notable, with localised higher stress seen in each percentile plot. These are mound structures which stand proud of the seabed by up to 6 m and are at about 46 m depth. As the wave climate becomes increasingly energetic, the wave stress field becomes progressively non-uniform with some seabed areas experiencing greater stress than others. Higher stresses are found generally over the central, eastern and southern regions, and this pattern is generally correlated with the bathymetry (see Figure B2) as these areas are generally shallower. To the north and west, where the water is deeper, wave stresses are comparatively lower. The highest wave stresses are consistently found over the three shoal areas referred to above. Higher stresses generally indicate the potential for greater transport, but it is frequently not the case where the sediments might be exceptionally coarse (e.g. gravel lag deposits), and thereby have a higher critical shear stress for entrainment.

The 99th percentile plot corresponds to the most energetic wave climate for the site (wave heights >~5 m; periods > ~8 s). Maximum τ_{0wave} values are found over the three shoal areas and range between 1.00-1.78 N/m^2; over the central/southern/eastern regions τ_{0wave} values range between 0.562-1.00 N/m^2, and over the northern and western periphery τ_{0wave} = 0.316-0.562 N/m^2. This distribution of wave stress reflects, in part, the distribution of wave heights, which are slightly lower over the western part of the site

B.4.9 WAVE REFRACTION AND DIFFRACTION

As offshore waves move from deep water into shallower water a number of important modifications occur as they begin to interact with the seabed. These are:

- Shoaling and refraction (depth and current);
- Energy loss due to breaking;
- Energy loss due to bottom friction; and
- Momentum and mass transport effects.

Waves affected in this way are normally termed shallow water waves. From consideration of the incident wave heights and periods above, it is possible to determine whether the waves at the Neart Na Gaoithe site will 'feel' the seabed boundary, and from this information it is possible to judge if significant shoaling and refraction are likely, and whether dramatic steepening and wave breaking is also likely.

Waves produce an oscillatory velocity in the water column which is a function of wave properties (namely, height and period) and which decreases in amplitude (magnitude) with depth. Whether the seabed 'feels' this flow therefore depends on the ratio of the water depth to wave height and period. The wave bed stress is a parameter which integrates these influences. If the stress at the seabed is small for a combination of height/period/depth there will be a negligible feedback on the wave i.e. the above effects and processes will be minimal. This is the case for the median (50%ile) wave conditions at the site). With increasing energy, wave heights grow and frequently (but not always) wave period changes (increases). The most energetic conditions (e.g. during winter storms) at the site (shown in the 99%ile plots in Appendix C) give rise to quite high stresses on the seabed, and this indicates that significant shoaling and refraction are likely, or possibly dramatic steepening and wave breaking (see below).

Due to the numerous mounds and hummocks and the spatially variable seabed topography, it is difficult to judge whether some degree of refraction (wave ray convergence) of winter waves is expected. The FTMS model data shows largely uniform conditions during the most energetic storms with respect to both wave height and period, which indicates that if 'shallow water' effects are at work, the effect on the waves is negligible. This would be expected on a general basis given the water depths across the site.

B.4.10 WAVE BREAKING

As waves move into shallower water and begin to feel the sea bed, changes to wave length and period can occur which give rise to a steepening of the wave face. If this continues to occur eventually the wave over-steepens and will break. A means to assess whether waves at the Neart Na Gaoithe site will break is to determine the height at which a monochromatic wave of a given wavelength/period in a constant water depth breaks, and to compare this with wave spectra for the site.

The shallowest parts of the Neart Na Gaoithe site are the mound structures some of which are at about 40 m CD, extending down to about 57 m on the western fringe. Table B-11 summarises the result of this analysis for various site depths. These data show that mean annual significant wave climate across the site would not comprise breaking waves; only if the wave period of the peak recorded significant wave (6.03 m – see Figure B-14) was $\leq$ 5 s would this particularly large wave break. Even the highest waves expected during a 50 year storm (about 15.6 m high; Table B-12) are unlikely to break as these would likely be longer period (> 8 s) northerly swell waves rather than short sea waves. This analysis indicates that waves across the site are dominantly non-breaking for mean conditions and for most winter storms, and that very extreme circumstances are required to generate breaking waves.

Table B-11: Threshold heights for breaking waves in various water depths and for a range of wave periods.

Water Depth (m)	Wave Period (s)			
	5	7	9	11
40	5.54	10.77	16.45	20.78
45	5.54	10.82	16.95	22.05
50	5.54	10.84	17.3	23.09
55	5.54	10.85	17.53	23.93

Note: For example, a wave of period 7 seconds in 45 m water depth would need to be over 10.82 m high before it would steepen and break.

B.4.11 WAVE – CURRENT REGIME

In reality the fluid motions in the sea are a function of tidal, non-tidal and wave influences. Whereas non-tidal influences are generally infrequent, waves and tides are frequently co-occurring, particularly during winter months. When this happens, the bottom sediments experience of drag force ('bed stress', τ_{0wc}) which is a combination of that due to the wave component and that due to the tidal current component.

The distribution of (maximum) bed stress due to the waves and currents in combination across the site (computed using the FTMS) is presented in detail in Appendix C. An understanding of the spatial distribution i.e. the uniformity, of wave-current bed stress across the site is central to an evaluation of sediment transport potential.

The wave-current stress maps for each percentile metric closely resemble the corresponding wave only stress maps both qualitatively and quantitatively. This reflects the fact that the wave stress component generally dominates over the tidal stress component. For median conditions (50%ile) the wave-current stress is largely uniform and everywhere < 0.1 N/m^2. As the hydrodynamic energy level increases, stress distribution is less uniform, with the deeper areas to the north and west generally experiencing lower stress and the central, eastern and southern regions experiencing higher stress. For the 90%ile and 95%ile conditions both stable areas and areas where sediments will be mobilised are identifiable, and as expected the 95% conditions potentially mobilise sediments over a wider area in comparison to the 90% condition. For the 99%ile condition (corresponding to the most energetic conditions expected in a 10 year period) wave-current stresses exceed critical entrainment stresses for the bottom sands across the entire site. However, the critical entrainment stresses for gravels are never exceeded.

The 99%ile plot corresponds to the most energetic wave climate for the site (wave heights >~5 m; periods > ~8 s). Maximum τ_{0wc} values are found over the three discrete shoal areas alluded to previously, and range between 1.00-1.78 N/m^2; over the central/southern/eastern regions τ_{0wc} values range between 0.562-1 N/m^2, and over the northern and western periphery τ_{0wc} = 0.316-0.562 N/m^2.

B.4.12 EXTREME EVENTS

Additional analysis was carried out on the oceanographic monitoring data collected to evaluate the nature of extreme events (i.e. extreme water levels, extreme currents, extreme waves). Extreme value predictions for significant and maximum wave height, mean (zero crossing) wave period, depth-averaged tidal and surge current velocity and water level (surge height) were computed for return periods of 1, 10, 25, 50 and 100 years for the site (Table B-12). These values can be compared to the 'business as usual' values presented in Table B-6; for the 1:1 year return period the predicted values compare favourably with those collected within the metocean campaign.

Table B-12: Compilation of offshore extreme marine statistics for the Neart Na Gaoithe site

Return Period (Years)	Hm0 (m)	H_{max} (m)	Maximum observed crest Height to LAT (m)	T_z (s)	Depth Averaged Maximum Tidal Current Speed(m s^{-1})	Surge Current Speed (m s^{-1})	Total Current Speed (m s^{-1})
1	6.9	11.8	7.3	8.4	0.58	0.40	0.99
10	8.2	14.1	8.7	9.2	0.58	0.52	1.07
25	8.7	14.9	9.2	9.4	0.58		
50	9.1	15.6	9.6	9.7	0.58	0.60	1.12
100	9.5	16.2	10.0	9.9	0.58	0.63	1.14

Source: Partrac/PhySe (2010)*.

*Note these values were delivered as part of a preliminary study and may be revised.

B.5 FLUVIAL INPUTS

B.5.1 INTRODUCTION

Various rivers and estuaries discharge into the study area (Table B-13). The Scottish Environment Protection Agency (SEPA) monitors flow in these rivers with gauging stations at strategic points commonly upstream of tidal limits. Of greatest relevance to the Neart Na Gaoithe locality are the Forth and the Tay and to a lesser extent the Eden and the Tyne. This is because the Rivers Tay and Forth are the dominant sources of freshwater flow into the proposed development area, accounting for around 97% of the total mean flow, and therefore it also might be expected that these rivers contribute the most to fluvial sediment input into the coastal zone.

In relation to the Neart Na Gaoithe site, it is considered that the volume of freshwater received into the inshore zone is small in relation to the tidal (marine) volume and the conclusion is that these rivers do not form significant freshwater influences at the site.

Sediment concentration data have been provided by SEPA for the three main rivers (Tay, Forth and Eden - Table B-13), and these reveal universally low concentrations (< 50 mg/l, maximum). The gauging sites are upstream (beyond the tidal limit) and therefore the concentration data represent the true sedimentary inputs from the river catchment to the estuarine zone and beyond (i.e. into nearshore coastal waters). The data indicate delivery of low sediment loads, with highly similar mean concentrations amongst the three rivers. Since the freshwater inputs into the coastal region are negligible it may be concluded also that input of fluvial sediments is also negligible.

Table B-13: River and suspended solids inputs to the development area

River	Catchment area (m^2)	Mean flow (m^3/s)	95% exceedence (m^3/s)	10% exceedence (m^3/s	TSS Gauging Station	Monitoring Period	Total Suspended Solids Conc. (mg/l)		
							Min	Max	Average
Forth	1036.0	46.98	5.50	115.50	Craigforth	17.01.10 – 22.11.10	1	28	10
Tay	4587.1	169.20	43.04	335.20	Queens Bridge	4.02.08 – 22.08.11	1	26	5
Eden	307.4	3.93	0.96	8.06	Kemback	17.08.11 – 20.09.10	2	43	10
Total	5930.5	220.11	49.5	458.76					

Note: Source: National Rivers Archive website, 2009; query to SEPA July, 2011.

Sparse data sources generally support this view. Axial concentration data in the Forth estuary from Stirling to about 50 km downstream show water column concentrations as < 50 mg/l with only slight increases near the bed. Data from Balls (1992) indicates very low concentrations of suspended sediments (about 20 mg/l) in the outer Firth of Forth area, and these data sets both suggest that riverine sediment (mud in this case) does not transport offshore in significant quantities. Geological evidence (Pantin, 1981) suggests that most is either trapped in the estuaries or deposited in nearshore muddy deposits (including mudflats), examples of which can be found in the Forth of Firth and offshore of Montrose. McManus (1986) notes that about 50% of sedimentary inputs to the Forth and Tay are low settling velocity, organic particles, which are not liable to accumulate permanently in the Neart Na Gaoithe site region, and which will eventually be mineralised (transformed into dissolved material). Further, silts are found in bottom sediments at the Neart Na Gaoithe site (about 1-6%) but mineralogical and tracer studies by McManus et al., (1993) assert that these derive from the offshore region itself (e.g. seabed redistribution; erosion of Quaternary sediments).

B.5.2 SUSPENDED SEDIMENT CONCENTRATIONS

Only very limited data on near-bed and water column suspended sediment concentrations at the Neart Na Gaoithe site are available, but some were collected within the oceanographic monitoring campaign (Table B-14). Although these data are not time-stamped i.e. they contain no information about when in the tide cycle they were collected, the data indicate universally extremely low concentrations. It can be assumed that the conditions were calm during sampling (in order that good quality samples could be collected), and thus these can be regarded as fair-weather summer-time concentrations. Maximum concentrations of 8 mg/l were recorded, but in many instances near bottom concentrations of 3 mg/l or less were recorded. Such low concentrations are consistent with the relatively coarse nature of the bottom sediments, which would not remain in suspension very long if they were suspended.

Table B-15 shows the results of particle size analysis on sediments captured by a near-bottom sediment trap. These indicate that although particles up to 250 µm are found in suspension, these are rare and the most frequent size is within the range 3.9-15.59 µm (i.e. very fine to fine silts). This indicates, at least in summer months when these samples were collected, only fine-grained sediments are found in the water column at the Neart Na Gaoithe site.

The source of this material cannot be inferred from this data. Sediment may derive from fluvial sources (see Section B5), from autochthonous sources such as plankton blooms, or from re-suspended/eroded bottom sediments. Table B-3 indicates that there is a very minor silt (< 63 µm) fraction in all bottom samples (1-10 % generally), and this fine material will be susceptible to re-suspension by waves and currents.

Table B-14: Suspended solids concentration at the Neart Na Gaoithe

Depth	Suspended Solids Concentration (mg/l)
Near bottom	<3
25 m	<3
10 m	4
Near bottom	8
25 m	3
10 m	8
Near bottom	3
25 m	3
10 m	3
Near bottom	4
25 m	3
10 m	7
Near bottom	<3
25 m	<3
10 m	<3
Near bottom	4
25 m	4
10 m	5

Note: collected on 12.07.10 during the oceanographic monitoring campaign. Source Metocean Campaign.

Table B-15: Distribution of particle size within a sediment trap sample at the Neart Na Gaoithe site

Size Fraction	%
Grain Size Fraction : 125 to 249 microns	0.87
Grain Size Fraction : 63 to 125 microns	5.38
Grain Size Fraction : 32 - 62.9 microns	11.2
Grain Size Fraction : 15.06 - 31.99 microns	25
Grain Size Fraction : 7.8 - 15.59 microns	30.9
Grain Size Fraction : 3.9 - 7.79 microns	17.9
Grain Size Fraction : > 63000 microns	0.0
Grain Size Fraction : > 8000 microns	0.o
Grain Size Fraction : < 63 microns	93.8
Grain Size Fraction : < 20 microns	68.1
Grain Size Fraction : <3.9 microns	8.86
Particle Diameter : Mean	0.021
Particle Diameter : Median	0.013

Note: Source Metocean Campaign.

B.6 SEDIMENT TRANSPORT REGIME

B.6.1 INTRODUCTION

Integration of information and data from the sources reviewed provide an assessment of the baseline sediment transport regime across the Neart Na Gaoithe site. The chief questions that arise in relation to an assessment of the sediment transport regime across the site include:

- Are the tidal currents at the site sufficient to generate sediment transport?
    - If so, what is the percentage of time during which current conditions exist that are sufficiently powerful to generate transport?
    - If so, what are the rates of suspension and bedload transport?
    - Are there asymmetries in transport which create a net transport direction? and
    - Are there differences in expected transport rate across the site in relation to differing sediment types and water depths?
- Is the wave climate sufficient to generate sediment transport?
    - If so, what are the critical height-periods which do so, therefore when seasonally is transport expected to occur?
    - What is the percentage of time during which wave conditions exist that are sufficiently powerful to generate transport
    - How variable across the site is transport expected to be? and
    - How do wave and tide currents combine to generate sediment transport, and how important is this?

The following assessment includes information derived from the oceanographic monitoring data, data from the geophysical and environmental surveys, data arising from the application of the FTMS, and empirical analysis.

B.6.2 MORPHOLOGICAL EVIDENCE FOR SEDIMENT TRANSPORT

The presence of bedforms on the seabed provides indications as to the severity of sediment transport at the site and also provide clues as to the predominant transport direction[s]. Across the Neart Na Gaoithe site there is an almost complete absence of bedform features, except for scour features which are explicitly associated with localised flow accelerations. This suggests that near bed flows are not sufficiently powerful to generate sediment transport across the wider area, and will only do so when amplified by the presence of bluff seabed structures, such as mounds and hummocks. Thus, the morphological evidence indicates a largely stable seabed. This information can be used in conjunction with a more quantitative analysis, particularly using oceanographic data collected during the monitoring campaign, to provide a conceptual model of the sediment transport regime at the site.

B.6.3 SEDIMENT TRANSPORT BY TIDES AND WAVES

Tidal Re-suspension and Transport

Seabed sediments are susceptible to re-suspension by tidal currents. Re-suspension occurs when the frictional drag (the 'bed stress'; τ_o) exerted by the currents exceeds the submerged weight of particles, which act to retain particles on the bed; the stress at which sediment motion is first produced is called the 'critical bed stress', denoted τ_{crit}[1]. When $\tau_o > \tau_{crit}$[2]. sediments are mobilised, and for many coastal environments this is evidenced by an increase in the concentration of sediments in suspension.

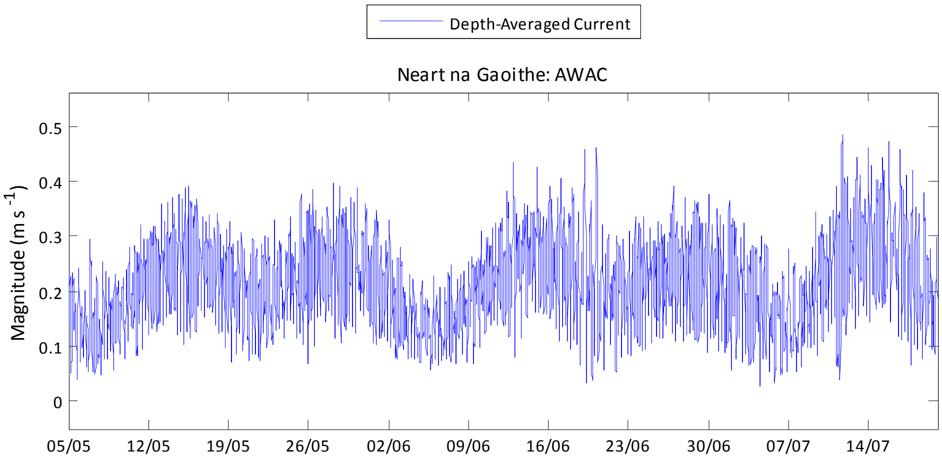
Some limited data on near-bed sediment concentrations were collected during the oceanographic monitoring campaign, which are useful in determining whether seabed sediment transport is generated on a regular basis (i.e. daily, or within the spring-neap tidal phasing) by the tidal currents. Figure B-16 shows time series of depth-averaged current velocity and total suspended solids (TSS) concentration measured at 0.5 m above the bed.

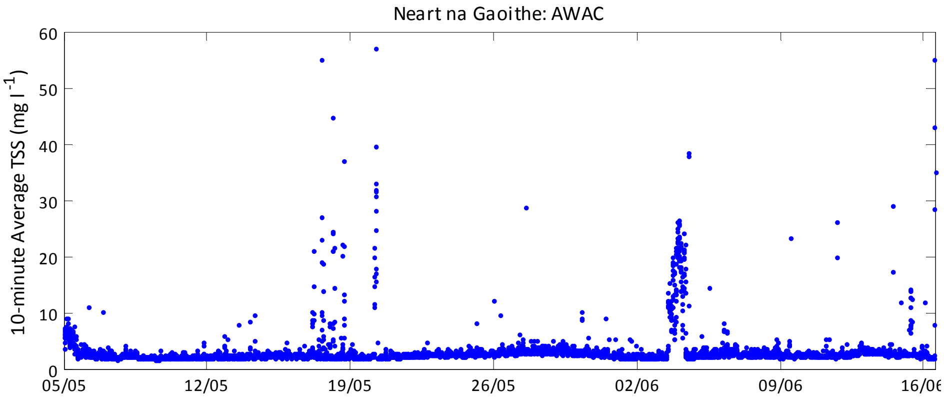
There is an extremely weak tidal signal in the data within which suspended sediment concentrations increase from a baseline of about 1-2 mg/l to about 4 mg/l during spring tides. It is likely the friction due to these currents re-suspends the finer sediments within the bed only (i.e. silts rather than sands; see Tables B-3/B-14/B-15). More substantial bed re-suspension, giving rise to near-bed sediment concentrations of about 25 to 50 mg/l, is observed to occur only intermittently. Identifiable periods of re-suspension (around 19/05/10 and 05/06/11) are observed, and thus re-suspension is clearly unrelated to the tidal phasing. The immediate conclusion from this assessment is that the tidal currents are not sufficiently powerful to generate significant sediment transport on either the neap or spring tidal phases. This is not unexpected given the relatively weak currents at the site (Table B-6).

A second check can be performed to examine whether the ambient tidal currents are able to entrain and re-suspend the bottom sediments. Figure B-17 shows the results from a semi-theoretical analysis in which the bed stress due to tides ($\tau_{ocurrent}$) has been derived from the oceanographic monitoring current data and compared with the critical bed stress (τ_{crit}) for both fine and medium sand, and intermediate size (8 mm) gravel. The plots show clearly that the sand fraction is only marginally mobilised by tidal currents and the gravel component is entirely stable under the tidal regime. Table B-16 summarises the proportion of time for both spring and neap tides, and for a year, during which $\tau_{ocurrent} > \tau_{crit.}$. for these three major sediment types found at the site. This analysis supports the foregoing conclusions from the oceanographic monitoring data that only a minimal and infrequent level of entrainment of seabed sediment occurs at the site.

[1] The following are provided for comparative purposes: fine sand $\tau_{crit} = 0.176$ N m^{-2}; medium sand $\tau_{crit} = 0.230$ N m^{-2}; fine (8 mm) gravel $\tau_{crit} = 6.93$ N m^{-2}.
[2] The quantity (τ_o - τ_{crit}) is frequently referred to as the 'excess stress'. Sediment transport rate is often $\propto (\tau_o - \tau_{crit})^n$ where n is usually >1.

Figure B-16: Time series of depth-averaged current magnitude and total suspended solids concentration



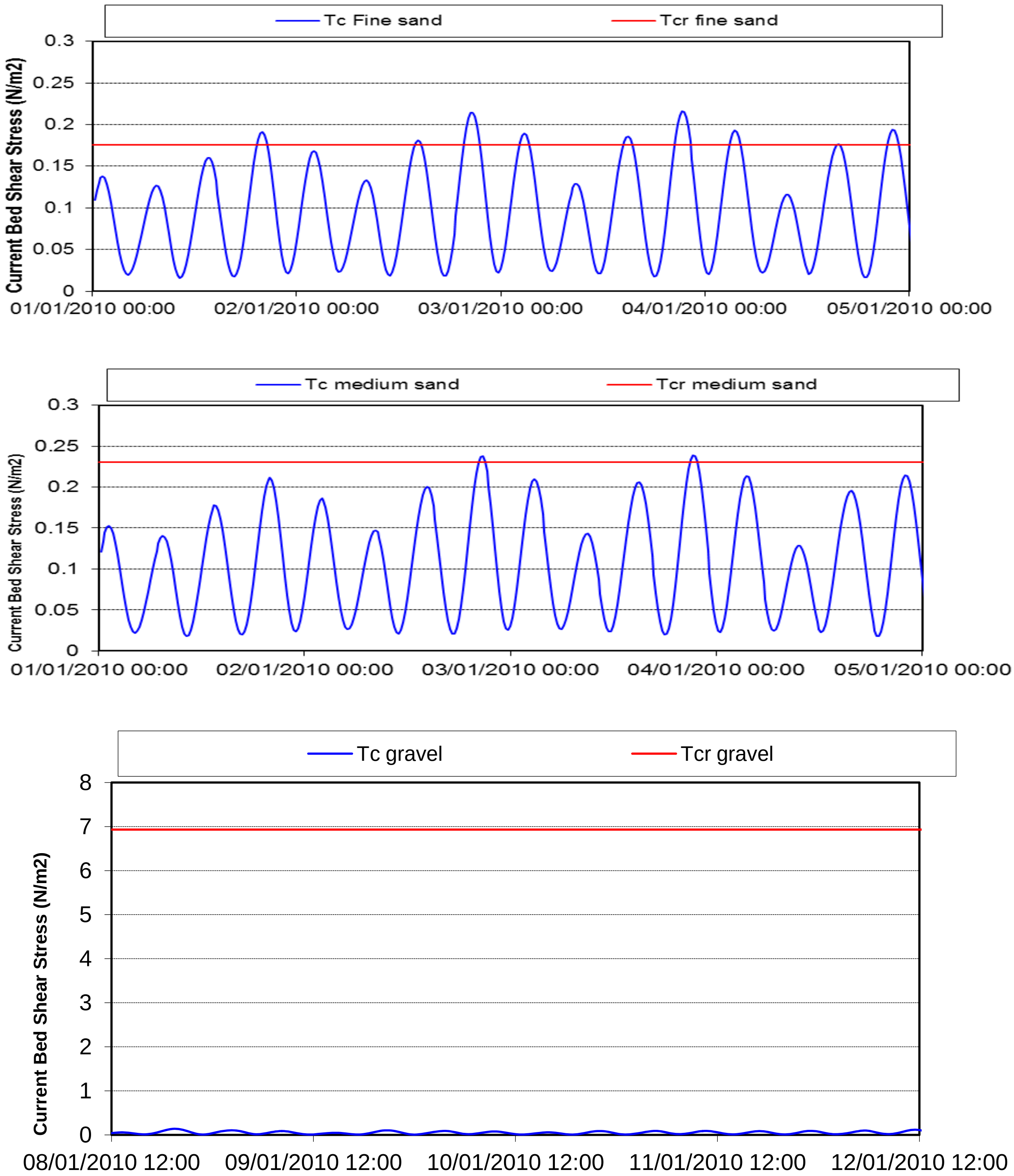


Note: Upper panel = Depth-averaged current magnitude and Lower panel = Total suspended solids concentration. Source: Metocean Campaign.

Table B-16: Percentage of time by tide and per year that sediments are mobilised by ambient tidal currents

Sediment	Exceedence %		
	Year	Spring tide	Neap tide
Fine sand	1.24	11.46	0.00
Medium sand	0.15	1.82	0.00
Gravel (8 mm)	0.00	0.00	0.00

Figure B-17: Time series of computed tidal bed stress and critical bed stress for different sediments



Note: Blue line = tidal bed stress and Red line = the critical bed stress (red line). Upper panel = fine sand; Middle panel = medium sand, Lower panel = 8 mm gravel. Source: Metocean Campaign.

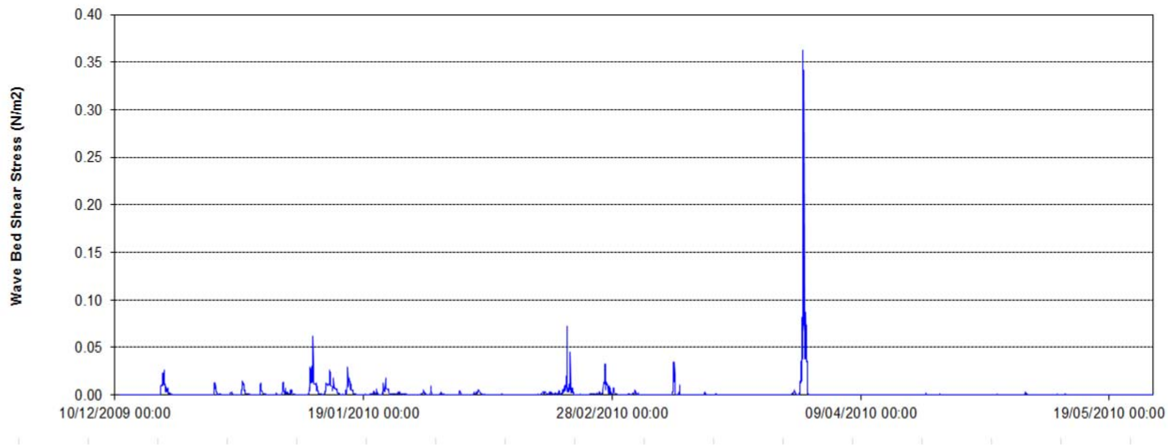
The foregoing analysis can be up-scaled to indicate the degree of sediment mobilisation across the site as a whole. The percentile plots of bed shear stress derived from the FTMS (see Appendix C) indicates the distribution of bed stress is uniform across the site with a maximum value of 0.1-0.178 N/m^2 (with the exception of a small area in the northeast of the site - where $\tau_{0current}$ = 0.316-0.562 N/m^2). Given the value of τ_{0crit}. for fine sands is 0.176 N/m^2 these sediments are expected to be generally mostly stable across the site (although mobilisation may occur on a very local basis where topography gives rise to near-bed flow accelerations (e.g. around hummocks).

The conclusions derived from the various lines of evidence above support the general inference from inspection of seabed morphological features of a largely stable bed under tidal currents. It also concurs with the site definition derived from biotope mapping (low energy, deep water [circalittoral] seabed environment) and it is consistent with very low sediment concentrations measured through direct water sampling. On this basis, the observed higher sediment concentrations are likely to be due to surface waves.

Wave Re-suspension and Transport

In shallow continental shelf environments waves, created by the wind blowing across the ocean surface, can also give rise to sediment transport if the energy associated with the wave is able to penetrate to the seabed. First insight is provided through computation of the bottom stress exerted by waves recorded within the oceanographic monitoring campaign (Figure B-18), and comparison with the critical entrainment stress for fine sand (0.176 N/m^2). This approach shows that for the majority of the time re-suspension of bottom sands by waves does not occur, indicating a largely stable seabed in terms of wave processes; only once during the monitoring period are bed stresses sufficiently high to generate sediment transport (sands across the wider part of the site would have been mobilised during this event, though the wave stress was not sufficiently high to mobilise gravels). This event was caused by waves of significant height 6.03 m and period 8.05 s, which is quite an extreme and infrequent event.

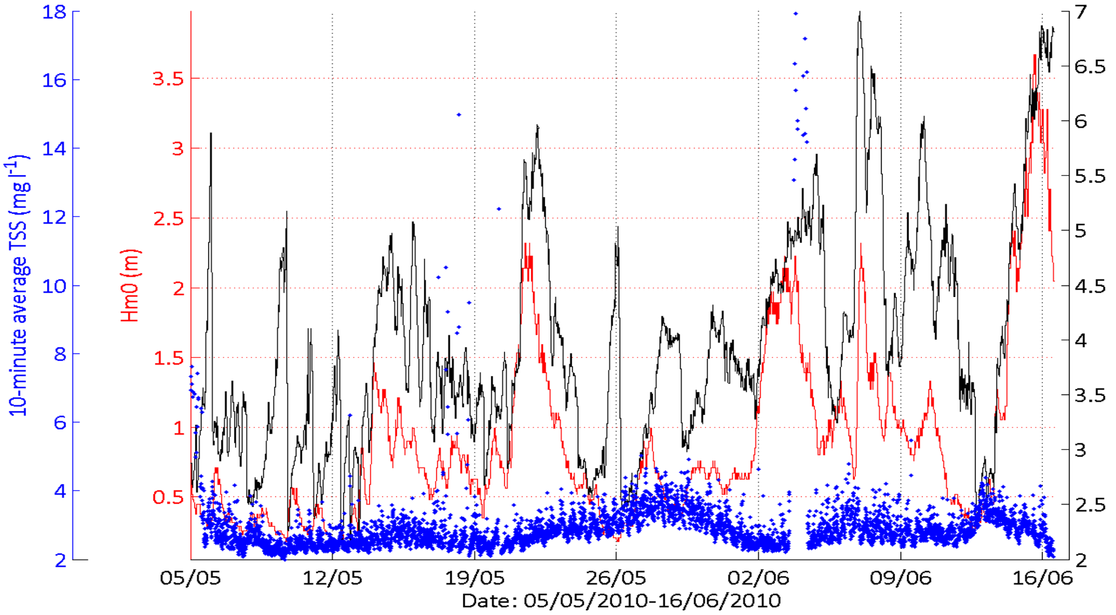
Figure B-18: Time series of bed stress due to waves



Note: bed stress computed from the wave data collected during the oceanographic monitoring. Critical shear stress for fine sand is 0.176 N/m^2. Source: Metocean Campaign

Although useful as a guide, it is preferable to use data collected than to rely upon semi-theoretical inferences. The only period for which there are synchronous wave and turbidity data is during the summer months (05/05/10 to 18/06/10) is shown in Figure B-19. Unfortunately there are no data for winter months.

Figure B-19: Time series of significant wave height, mean wave period and total suspended sediments



Note: Red = significant wave height (Hm0 (m)), Black = mean (zero-crossing) wave period Tz (s), and Blue = total suspended sediment (TSS (mg/l)) for the period 05/05/10 to 18/06/10. Source: Metocean Campaign.

Periods of re-suspension are not clearly related to wave height; but there would appear to be a dependence on wave period. Around periods of re-suspension (06 to 07/05/10, 05/06/10 and 18/06/10) wave heights are < 1 m, but wave periods are elevated to between 6 s and 7 s. These waves come predominantly from the northeast. These observations indicate a marginal, but measureable, influence of comparatively small, long period northeasterly waves on bottom re-suspension. It is likely the friction due to these waves re-suspends the finer sediments within the bed (i.e. silts rather than sands; see Table B-14).

Table B-16 presents results from a theoretical analysis of the stresses created by waves of varying height and period over a fine sand bed at 50 m water depth. The coloured shaded areas indicate when transport due to waves will occur. The dependence on wave period is clear, and using the data in Table B-8, the longer waves (≥ 9 s) have increasingly low return values (> 1 in every 10 years). The FTMS provides the most reliable estimate for the maximum expected values for wave period and height at the site: the model indicates that 99% of all waves expected at the site will have a significant wave height of no greater than 5.2-5.4 m and a period of no more than 8-8.5 s (see Appendix C). This comparison suggests that sediment (sand) mobilisation by waves can occur by such waves but on an infrequent basis only (i.e. only during extreme storm events); gravel-rich sediments would be entirely stable even under energetic storm conditions. Inspection of the spatial distribution of bed stress during the more energetic conditions (Appendix C - 95 and 99%iles), shows that when waves are sufficiently powerful to mobilise sediments, mobilisation (for sand sediments) is expected to occur across the entire site, including the deeper waters to the north and west of the site.

On this basis the site can be considered as largely stable under waves.

Table B-17: Wave-induced bed stresses over fine sand in relation to wave period and wave height.

Wave Height (m)	Wave Period (T_z)						
	5	6	7	8	9	12	14
	Fine Sand (τ_{0crit}=0.176 N m^{-2})						
6	0.000	0.002	0.016	0.314	0.516	1.036	1.314
5	0.000	0.002	0.012	0.049	0.377	0.752	0.951
4	0.000	0.001	0.009	0.034	0.257	0.509	0.642
3	0.000	0.001	0.006	0.022	0.158	0.309	0.388
2	0.000	0.001	0.003	0.011	0.103	0.154	0.192

Note: The coloured shaded areas indicate when transport due to waves will occur.

Sediment Transport by Waves and Tides in Combination

In most coastal and shelf seas around the UK, both waves and currents play important roles in the mobilisation and transport of bottom sediments. Tides are a regular, predictable phenomenon throughout the year whereas waves are stochastic and occur only on occasion. As demonstrated, not all waves will penetrate through the water column to exert influence on bottom currents. However, where energy can penetrate to the bottom boundary layer (i.e. Hm0>~3 m, Tz > 8-9 s; Table B17) at the Neart na Gaoithe site then the wave energy (via orbital velocities) will add to the stress exerted by the tidal current; for a given wave the magnitude of the stress coupling, and the resultant drag on the seabed, will vary depending on the phase of the tide (spring, neap, intermediate) and this interaction is also non-linear. Transport rates are expected to be at their greatest following superposition of the larger/longer waves on peak springs, largely during the winter period.

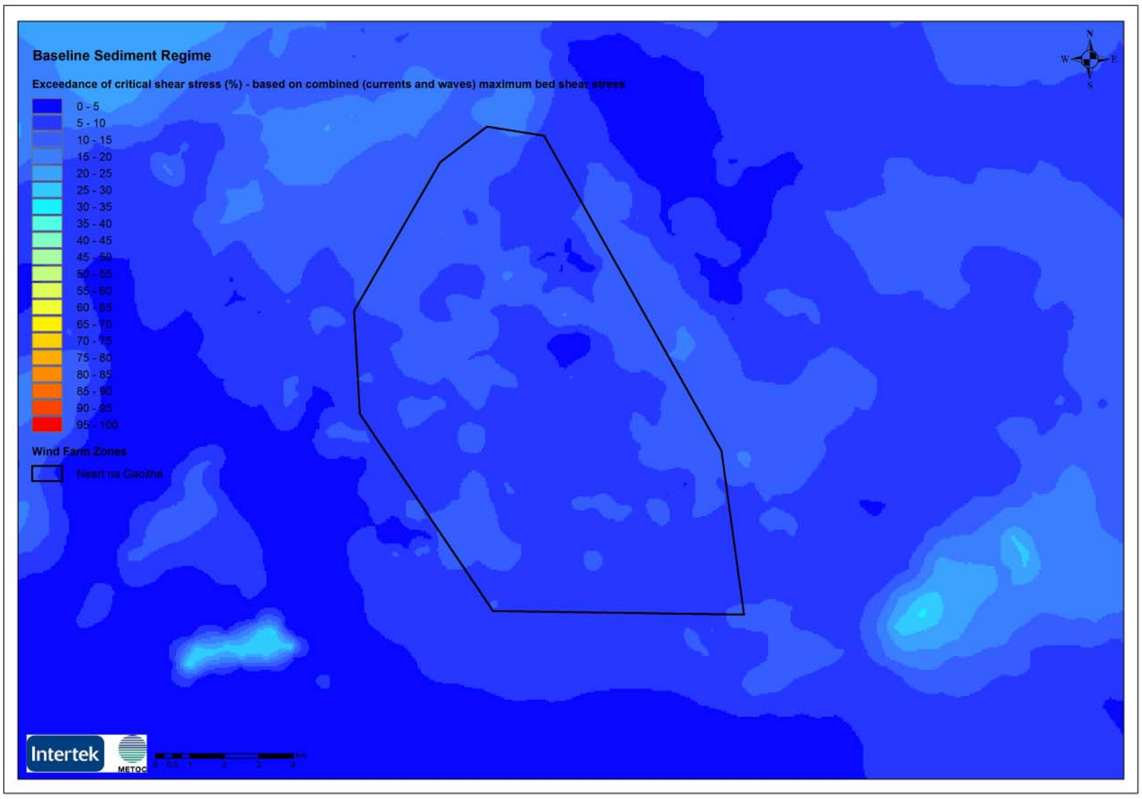
Appendix C includes percentile plots of combined (wave+current) bed stress as derived from the FTMS. These show that ‘average’ (50%ile) conditions cannot mobilise sediments at the site but the upper 5-10% of occurring wave+current conditions exert stresses at the seabed which are of a sufficient magnitude to mobilise sands, but not (8 mm) gravels. In other words, the combined bed stress (due to waves plus currents) exceeds the critical shear stress for entrainment during more energetic marine conditions. During the most energetic conditions, sands across the entire site can be mobilised. Figure B-20 makes use of derived bed shear stress from the FTMS (Appendix C), together with grain size statistics for every location sampled (Table B-3) and information on the statistical frequency of occurrence of specific wave heights and periods from the FTMS 10 year model data. The plot illustrates specifically the proportion of time that stresses due to both waves and currents in combination exceed the critical entrainment stress for the sediments.

Representing the information in this way facilitates the same summary description of the general site stability on the basis of the frequency of sediment mobilisation as undertaken for currents and waves separately (e.g. Table B-16). For instance, if combined stress is greater than the critical value[s] for bottom sediments for much of the time (e.g. >75% of the time), then clearly the inference is that the site is dynamic and sediment transport would be a prevalent and recurrent feature of the site.

This analysis, however, indicates that over the greater extent of the central and southern parts of the site the exceedance of critical shear stress is 5 - 10%. To the north of the site, down the eastern periphery, and at an area to the southwest of the site, sediments are mobilised for up to 10 – 15% of the time (there are two small areas in the site centre/northeast where the exceedence is < 5%). Since sediment mobilisation is a complex function of water depth, wave energy penetration, sediment type and bed roughness, it is not possible to deduce an over-arching explanation for the pattern observed. However, in general terms the more mobile areas are slightly deeper and less complex topographically and comprise slightly gravelly muddy sands, whereas the more stable areas correspond generally to the area of hummocks and mounds (which are shallower) and the sediments in many areas are coarser (refer to Figures B3&4, and Table B-4). It is interesting to note the combination of waves and currents gives a slightly greater exceedence proportion than due to waves alone i.e. the addition of tidal currents to waves gives slightly more frequent sediment transport, which is not unexpected.

Though there are spatial differences in the exceedence duration across the site, these are not large. Therefore, based upon this evidence the site can be classified as slightly mobile under waves and currents combined.

Figure B-20: The proportion of time that bed stresses due to both waves and currents in combination exceed the critical entrainment stress for the sediments at the site.



Note: The time frame for this scenario is a nominal 10 year period. Source: FTMS.

Since there is no winter storm data with which to judge sediment concentrations arising from the action of waves and currents, a semi-theoretical analysis has been undertaken. Table B-17 presents expected sediment concentrations at 1 m above the seabed for a selection of 'representative' wave plus current interactions. This analysis shows that all wave-current conditions give rise to bed stress values in excess of critical values, and sediment re-suspension (of sands) is expected to occur. Differences in sediment concentration broadly reflect the degree of excess stress, and the predictions agree reasonably well with measured concentrations at the site during conditions approximating the ‘mean annual wave’ condition.

Table B-18: Bed stress and predicted suspended sediment concentration for a range of representative wave-current combinations over a sand bed

Description	Wave Parameters		Tidal Current Velocity (m/s)		Resulting Bed Stress (N/m^2)		Suspended Sediment Concentration (mg/l)	
	Hm0 (m)	T_z (s)	Peak Spring	Peak Neap	Peak Spring	Peak Neap	Peak Spring	Peak Neap
Mean annual wave	1.13	4.0	0.82	0.53	1.446	0.604	20	11
‘Average’ winter storm wave**	3.0	6			1.446	0.604	20	20
Largest winter wave*	6.03	9.04			1.919	0.989	110	68
1:50 year return wave	8.42	10.63			2.655	1.409	230	101

Note: Assumed 52 m depth. Method: Soulsby (1995) DATA13. τ_{0crit}. for medium sand is = 0.230 N/m^2; for 8 mm gravel is 6.93 N/m^2.
*from oceanographic monitoring dataset
**assumed

B.6.4 BEDLOAD TRANSPORT

Bedload transport is the process of sediment motion in which grains move by rolling and bouncing along the bed, or as the migratory movement of bedforms. In conventional assessments bedload is the predominant mode of transport for grains coarser than about 2 mm (i.e. all gravel size material), and suspended load for grains finer than about 0.2 mm. Bedload transport of sediments by tidal currents is not judged to occur across the Neart Na Gaoithe site on account of the relatively low tidal current velocities across the site; the exception to this is in the vicinity of topographic highs (mounds; hummocks) where flow amplification appears to drive the development of bedforms (Figure B-5).

Excess stress due to wave action may induce wave-driven bedload transport of coarser sediments. However, the comparatively short duration of storms capable of producing high stress, and the infrequent occurrence through time (see Section B6.3), means that bedload transport will not be significant.

B.6.5 NET SEDIMENT TRANSPORT DIRECTION

The foregoing analysis indicates a net directional sediment transport in the direction of the flood tidal axis (S - SSW). Tidal bedload transport is not considered to occur, and tidal re-suspension of finer sediments is measureable but extremely low. Therefore, the asymmetrical transport will refer to the flux of sediments re-suspended during winter storms only. Since wave action sufficient to generate significant re-suspension at the bed occurs very infrequently (see Section B.6.4) it may be judged that residual tidal transport of suspended fine sediments is not large on an annual basis.

B.6.6 BED LEVEL (MORPHOLOGICAL) CHANGE

Sediment transport over extended timeframes gives rise to natural changes in bed level i.e. the depth of the sediment-water interface. Changes occur as a result of differential erosion and deposition of sediments across the site and, not surprisingly, the largest changes are found following storm events. Information on the magnitude bed level changes around the UK coastline is extremely rare, and such information is amenable only through recurrent bathymetric survey[3], or highly sophisticated 3D, coupled hydrodynamic-geomorphological models. The largest scales of bed level change are usually associated with shallow coastal sandbank regions exposed to winter wave action.

Natural changes in bed level are important for foundation structures as they are key to understanding local scour processes (which also change bed level, locally) and classifying these in relation to natural changes which might occur. It is not possible from the oceanographic data collected to discern the magnitude of bed level change across the site. However, any changes are not envisaged to be large, certainly through most of the year, on account of an overall very low mobility of the sandy surficial sediments and immobility of coarser gravel lags. Singular winter storm events may induce some degree of morphological change across the non-gravel regions, but wave periods in excess of 10 s would be required and these do not have a high frequency of occurrence. A preliminary overview based on the extreme value analysis (Table B-11) would suggest that storm events with a return period greater than 10 years only might generate noticeable bed level change.

B.6.7 SHORELINE PROCESSES

The Neart Na Gaoithe site is located some 15 km east of Fife Ness, and almost midway between the northern East Lothian coastline and the Angus coastline. The location of the site, and the direction of the incident waves, means that, in concept at least, the development might influence shoreline processes along each of these coasts through modification of waves. An overview of shoreline processes at all these coastlines has been provided within the Regional Baseline Assessment report, and greater detail specifically on the Angus shoreline may be found in an a similar baseline report for the Inch Cape OWF development (not yet issued). Finally, far more detailed summaries are available within the regional Shoreline Management Plans[4]. It is not considered necessary to re-present this information within this appendix. Shoreline processes, in particular beach profile/topography data and net sediment drift information, can be considered in detail if it is demonstrated that the presence of the Neart Na Gaoithe development gives rise to changes (e.g. in significant wave height) in the incident waves along any of these shorelines.

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[3] Some information is available on this from submerged scour sensors attached to marine structures. This is because not only do they measures the dimensions of any scour pit but extend outwards to measure also unaffected seabed.

[4] 1. http://www.angus.gov.uk/ac/documents/roads/SMP/default.html.
2. http://cmis.eastlothian.gov.uk/CMISWebPublic/Binary.ashx?Document=4117.
3.http://fifedirect.org.uk/minisites/index.cfm?fuseaction=page.display&siteID=C03E446A-0241-A6A5-7462DD169B215841&pageid=C040877C-B767-3F71-8454BE5167C5BC58.

B.6.8 CONTAMINANT MOBILISATION AND TRANSPORT

It is clear that any sediment-associated contamination (metals, TBT etc.) has the potential to be mobilised, albeit infrequently, by both tidal and wave currents, at the site. This potential rises substantially where seabed structures exist, due to the amplification of near-bed currents around the foundation. Table B4 indicates a largely uncontaminated seabed region excepting cadmium and, to a lesser extent, nickel.

Once brought into suspension the tidal currents are able to laterally transport the contamination across and potentially to transport it outwith the site. The transport distance and geographical fate is a function of the absolute tidal current magnitude and direction for coarser sediments, and also the excursion distance and residual current magnitude and direction for finer sediments. Figure B-12 gives a scaled schematic of the maximum (i.e. during spring tides) horizontal transport distances for re-suspended fine particles.

A more detailed assessment of the transport and fate of sediments, including dilution magnitudes, mobilised by construction/decommissioning activities and foundation scour is provided in Appendix I.

B.7 SUMMARY OF COASTAL PROCESSES REGIME

The following provides a general summary of the coastal processes regime for the Neart Na Gaoithe site.

1) The seabed forms an expansive, largely level seabed plain with no dramatic changes in bathymetry or seabed slope. General water depths within the site boundary (about 105 km^2) range between 40 and 58 m CD, with a mean of 50.6 m CD

2) Mean spring tide range is ~4.8 m.

3) The seabed is characterised by numerous low amplitude hummocks and mounds (over 25 mounds are present within the survey area). The mounds are commonly up to 4-6 m shallower than the surrounding seabed at depths of 40 to 48 m.

4) The sediments comprise gravelly muddy sand with boulders. Slightly gravelly muddy sand is most common across the western and southern parts of the survey area where water depths are generally slightly greater. Towards the north of the wind farm site the thickness of these sediments decrease and bedrock is close to the surface, where the seabed type has been classified as muddy sand with occasional rock. From the centre and to east and southeast of the wind farm site the dominant sediment type is sand.

5) Across the site there is an almost complete absence of bedform features, except for scour features which are explicitly associated with localised flow accelerations. This suggests the site is largely a stable seabed.

6) The ambient tidal current regime is not sufficiently powerful to generate significant sediment transport on either the spring or neap tidal phases.

7) The site can be classified as 'slightly mobile' under the combined effects of waves and currents. Storm conditions with waves in excess of 5.2 to 5.4 m significant wave height, and a mean wave period of >8-8.5 s only are predicted to mobilise sediments across the site, and such conditions have a return period of > 1 in 10 years.

8) The site receives waves most frequently from a north-northeasterly direction (22.5 degrees); wave periods range between 2 and 9 seconds; and significant heights up to about 6 m. Waves also arrive from both the southeastern and southwestern quadrants but these form only a minor component of the wave direction spectrum.

9) Fair-weather suspended sediment concentrations are very low (< 10 mg/l) and comprise dominantly silts; concentrations are expected to rise generally only during storm conditions.

10) Large-scale (vertical) changes to general seabed level are not anticipated, except during sever storms.

11) A net directional (suspended) sediment transport in the direction of the flood tidal axis (S – SSW) exists, but residual tidal transport of suspended fine sediments is not judged to be significant on an annual basis

12) Tidal bedload transport is not considered to occur, except in the vicinity of mound structures; wave-driven bedload transport may occur during storms but is not significant.

13) Information is available on shoreline sediment transport processes via regional Shoreline Management Plan documentation (but this will be used only if it is demonstrated that site development gives rise to changes to far-field hydrodynamics).

B.8 REFERENCES

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b) http://cmis.eastlothian.gov.uk/CMISWebPublic/Binary.ashx?Document=4117.

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Appendix C Baseline Modelled Outputs

C.1 HYDRODYNAMIC REGIME

C.1.1 Regional Area - Far-Field Scale

Figure C-1: Mean spring tide, high water (HW) level (m) – Regional

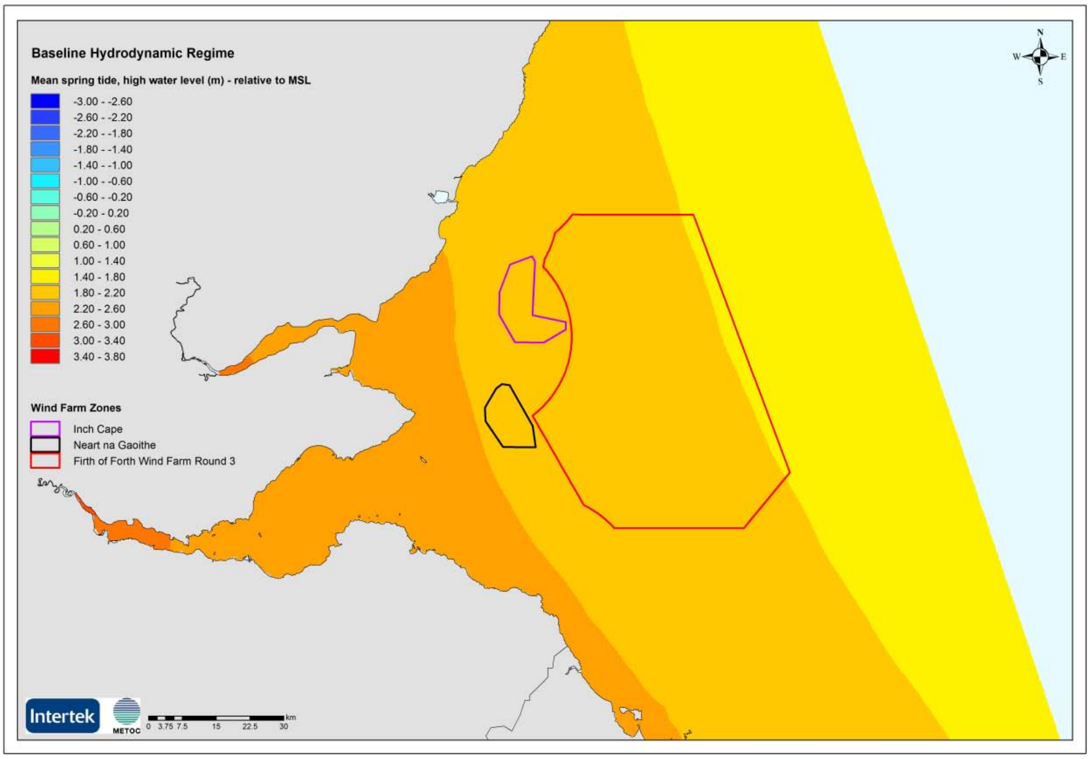


Figure C-2: Mean spring tide, low water (LW) level (m) – Regional

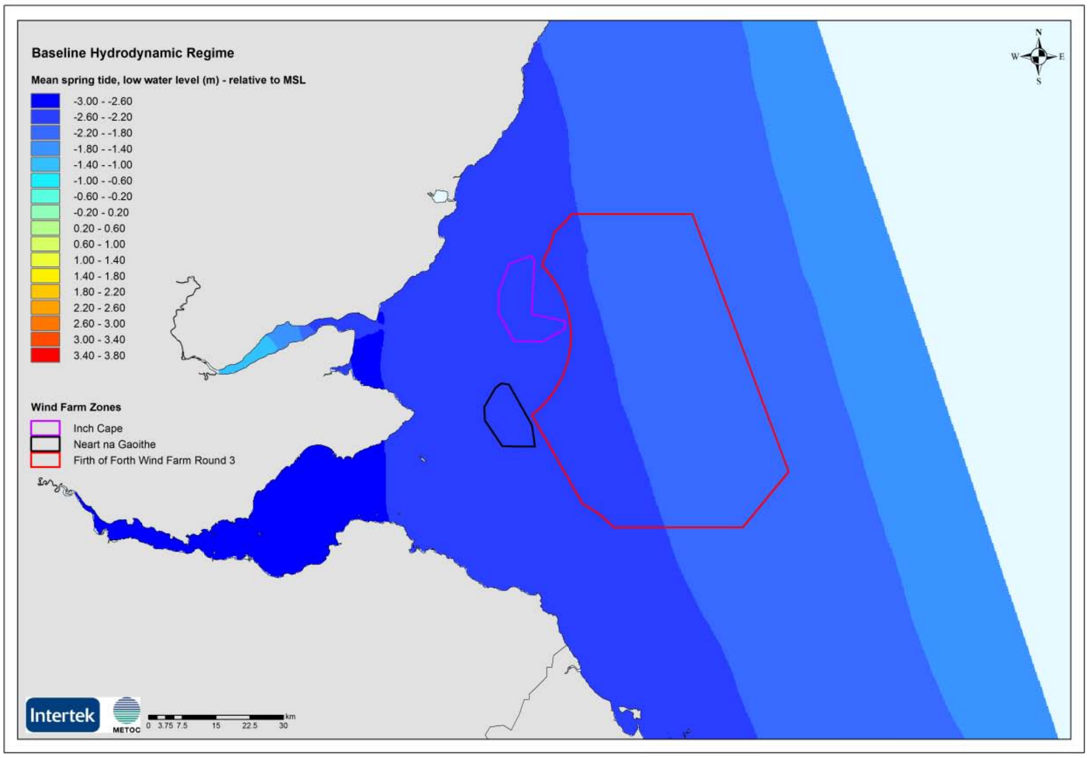


Figure C-3: Mean neap tide, high water (HW) level (m) – Regional

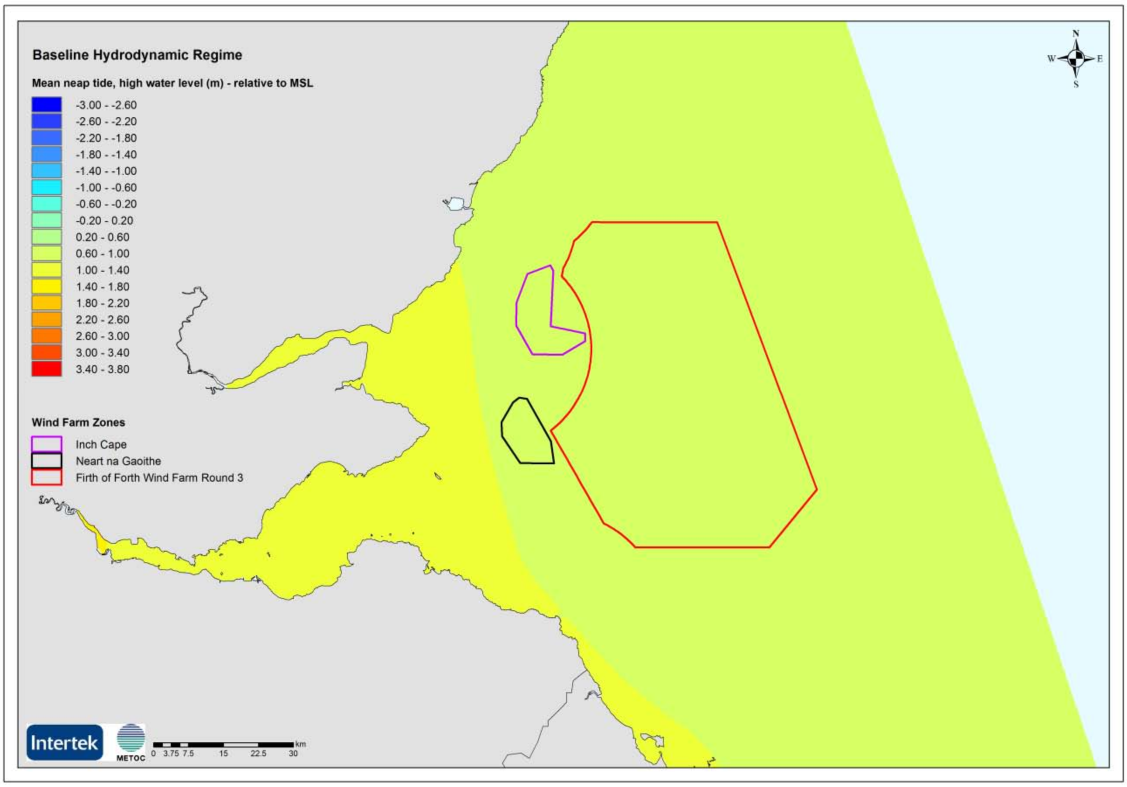


Figure C-4: Mean neap tide, low water (LW) level (m) – Regional

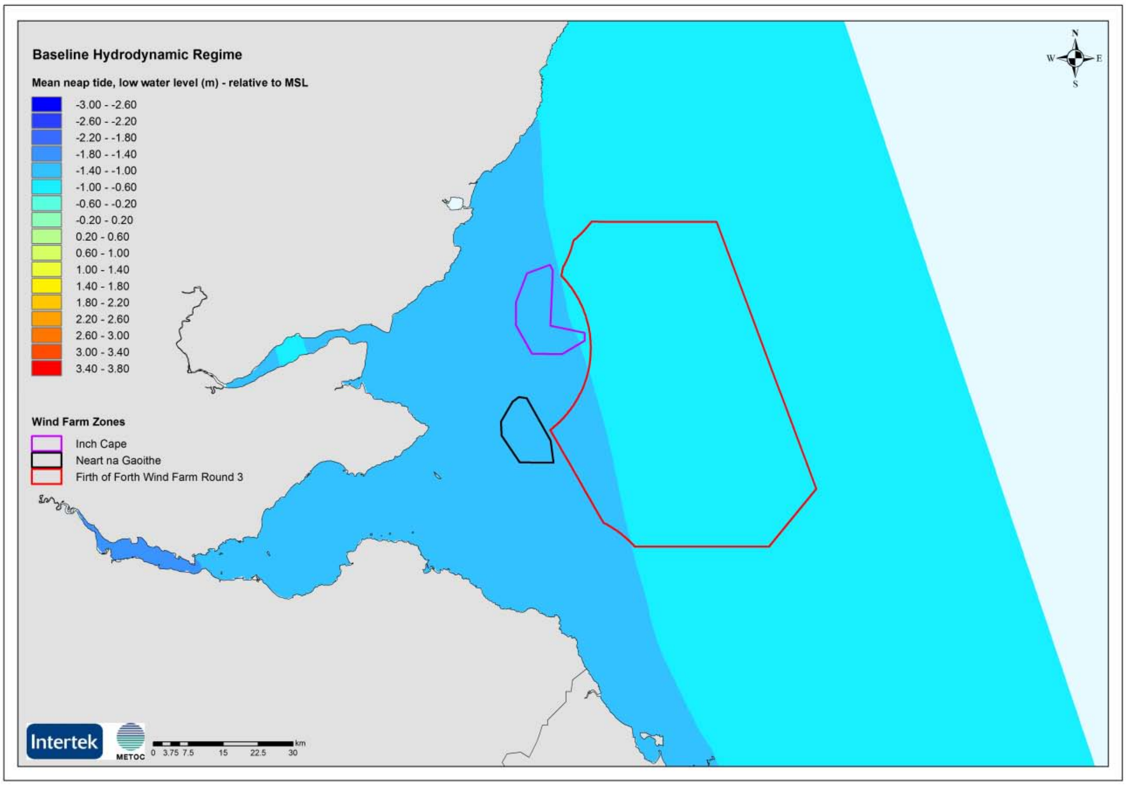


Figure C-5: Mean spring tide, peak flood currents (m/s) – Regional

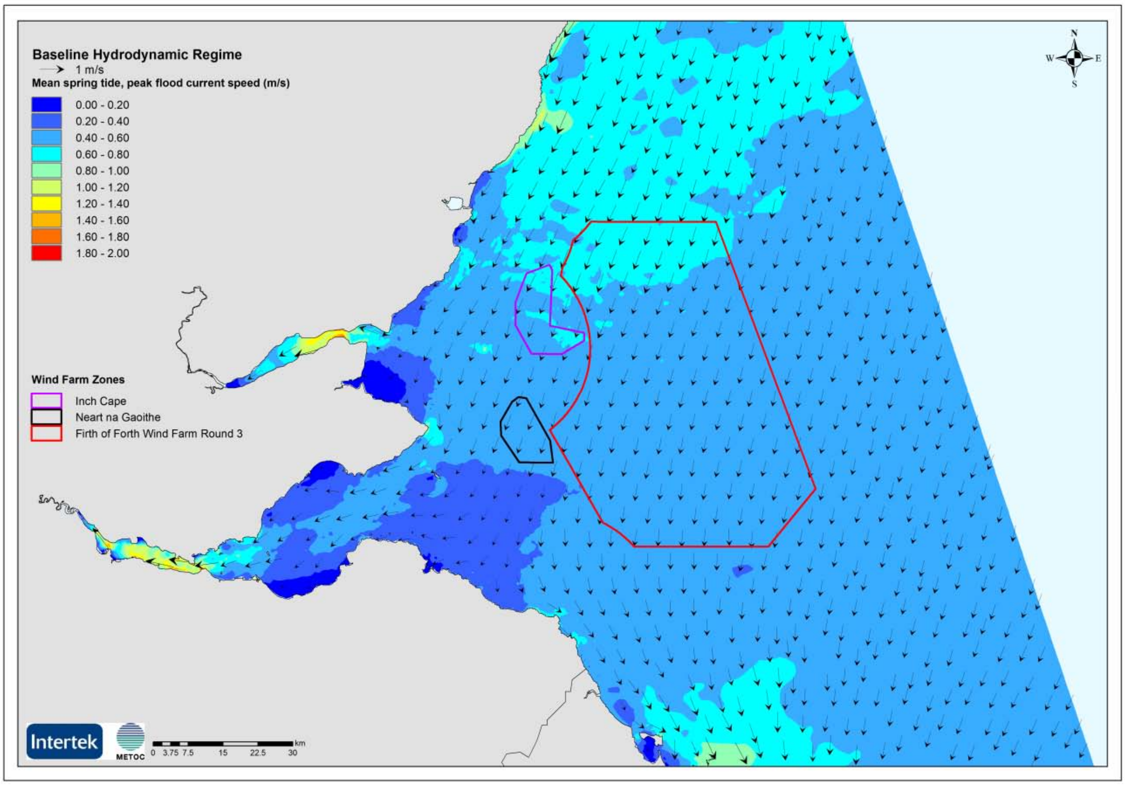


Figure C-6: Mean spring tide, peak ebb currents (m/s) – Regional

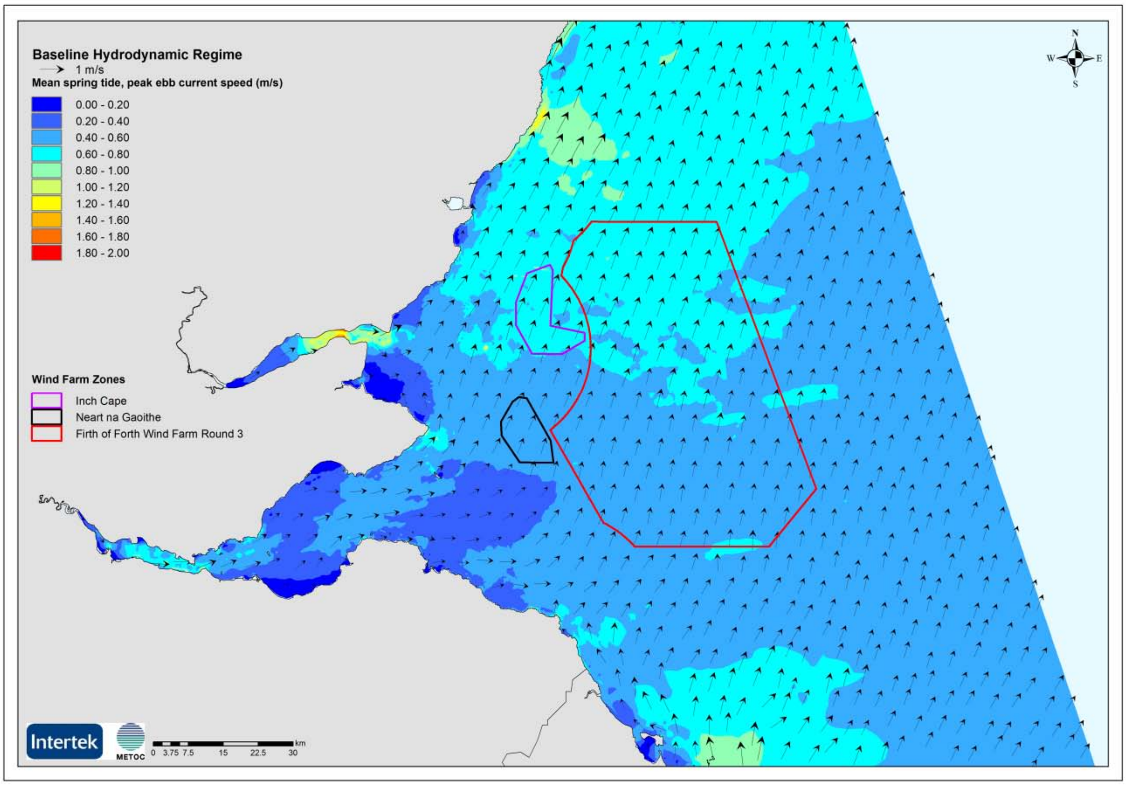


Figure C-7: Mean neap tide, peak flood currents (m/s) – Regional

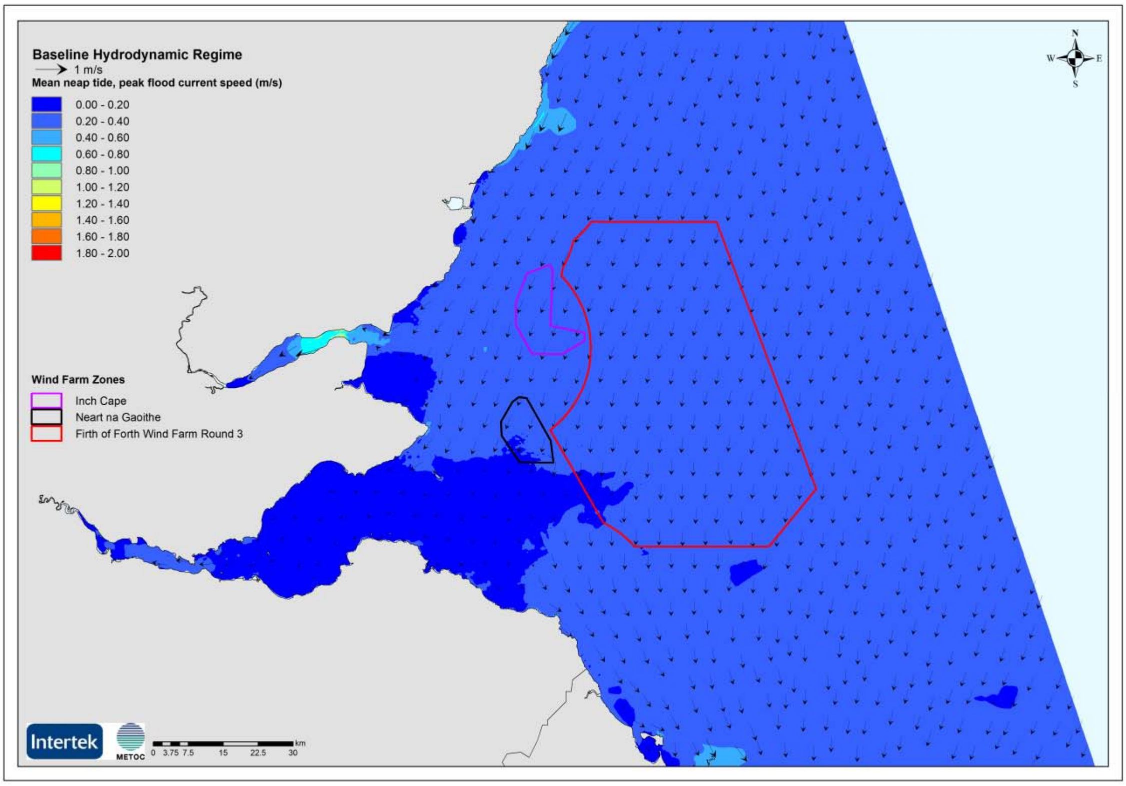


Figure C-8: Mean neap tide, peak ebb currents (m/s) – Regional

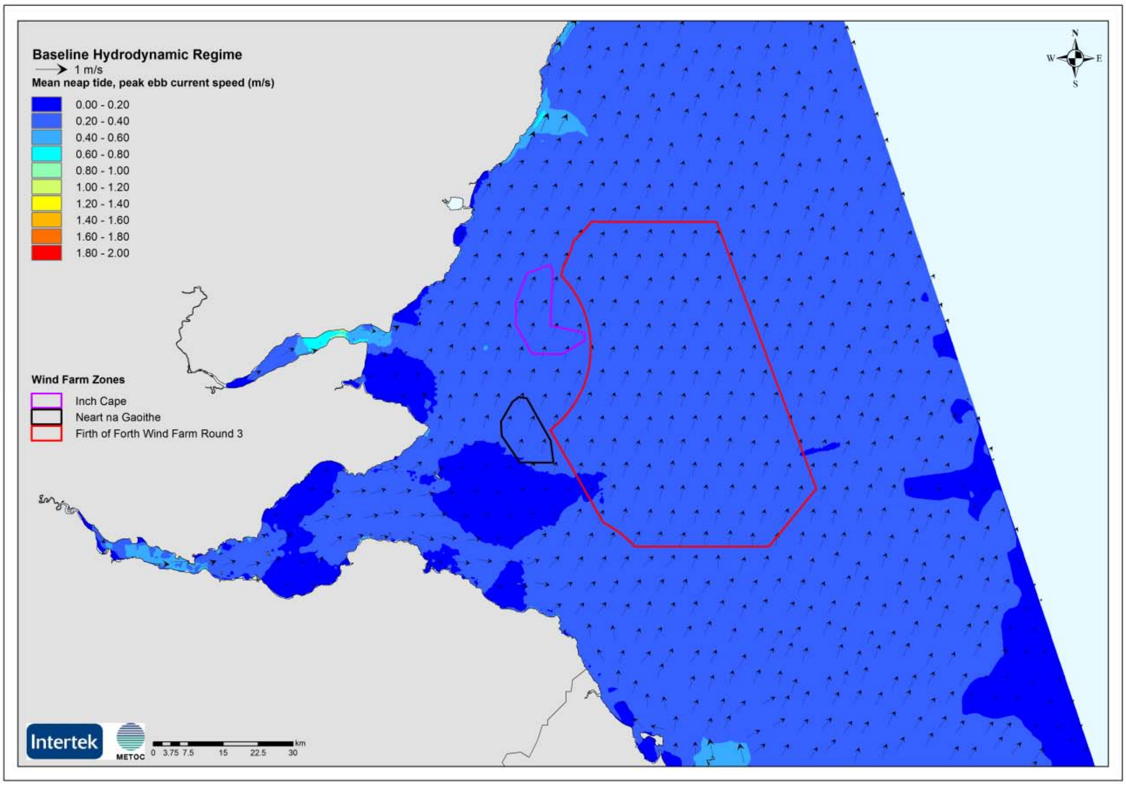


Figure C-9: 50-percentile currents (m/s) over a mean spring and neap tide – Regional

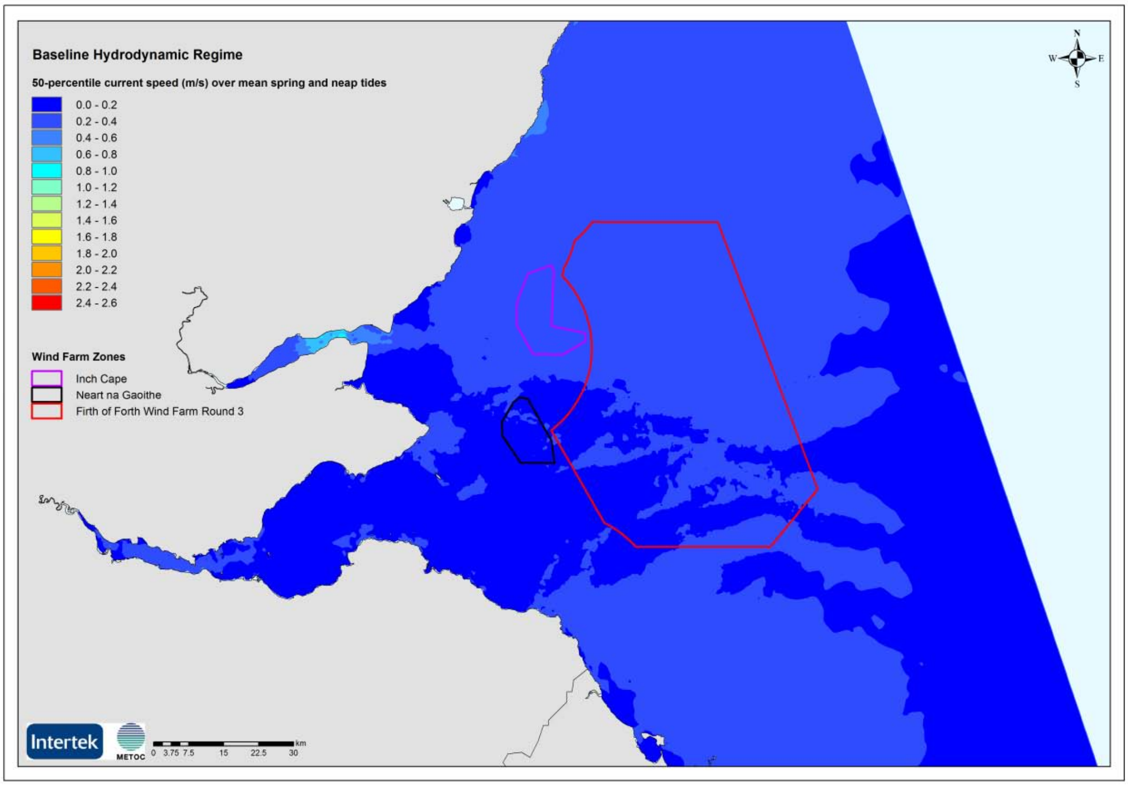


Figure C-10: 90-percentile currents (m/s) over a mean spring and neap tide – Regional

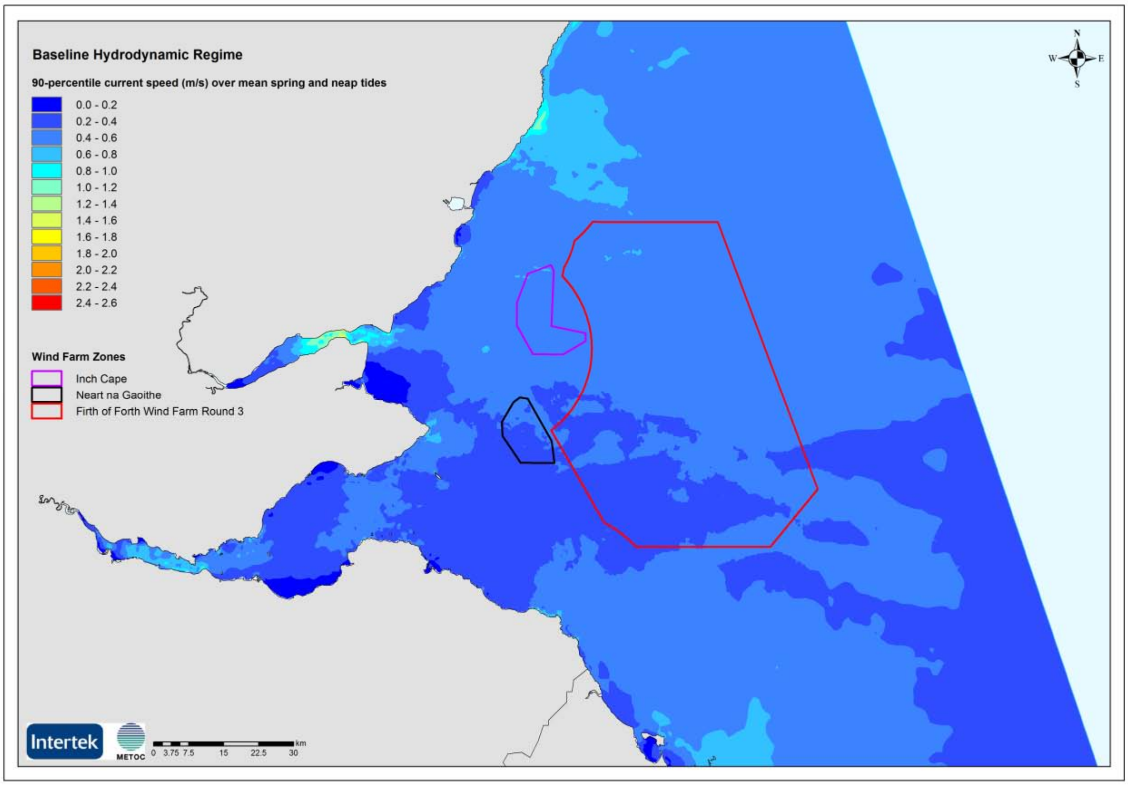


Figure C-11: 95-percentile currents (m/s) over a mean spring and neap tide – Regional

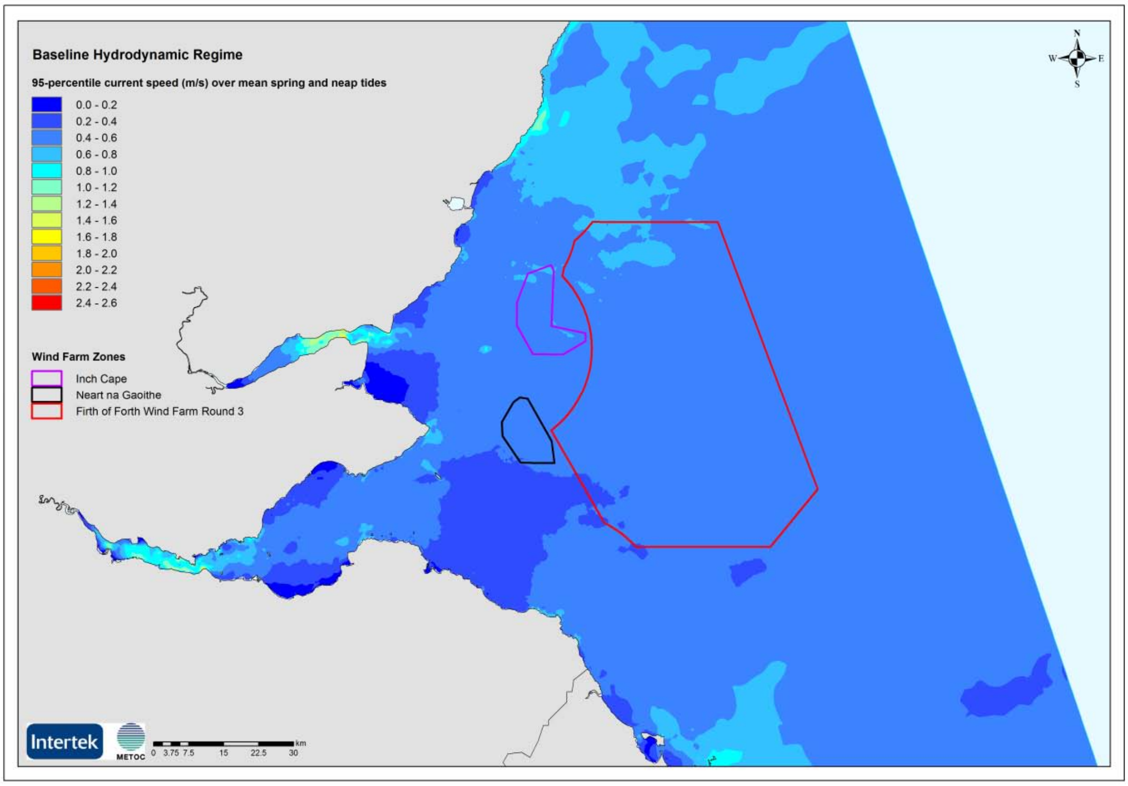
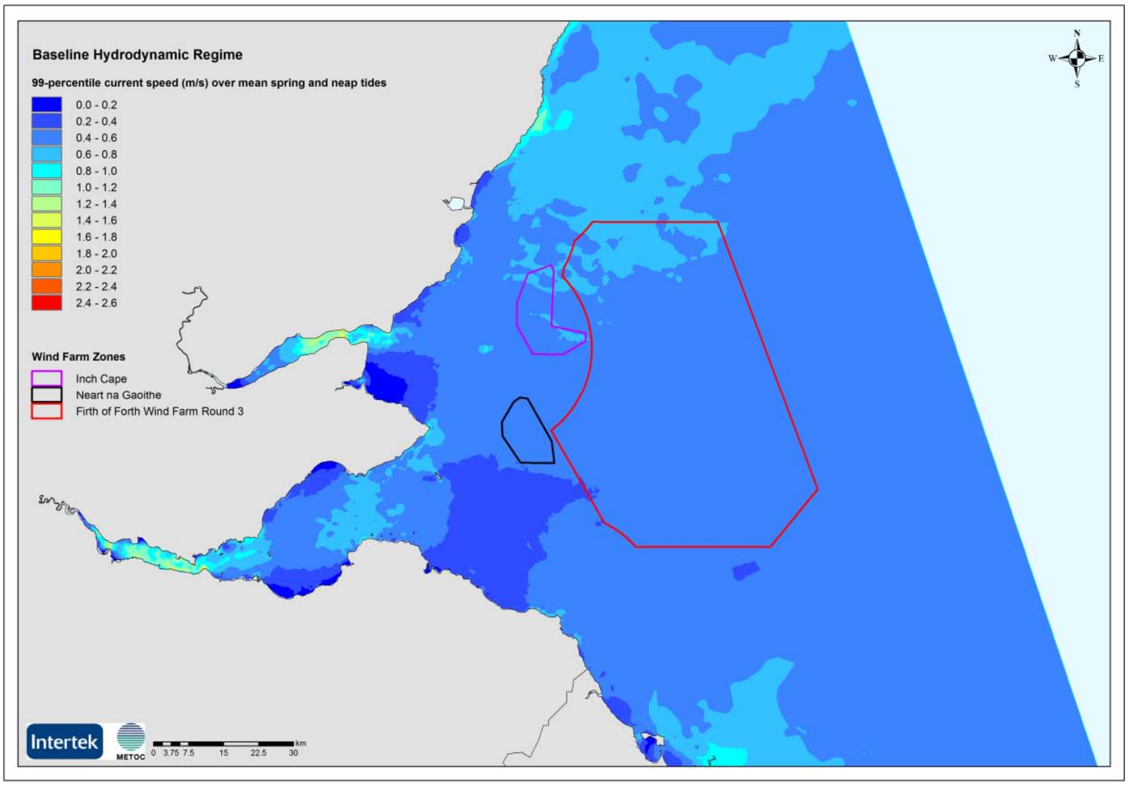


Figure C-12: 99-percentile currents (m/s) over a mean spring and neap tide – Regional



C.1.2 Neart na Gaoithe Offshore Wind Farm Area - Near-Field Scale

Figure C-13: Mean spring tide, high water (HW) level (m) – Neart na Gaoithe OWF (near-field) scale

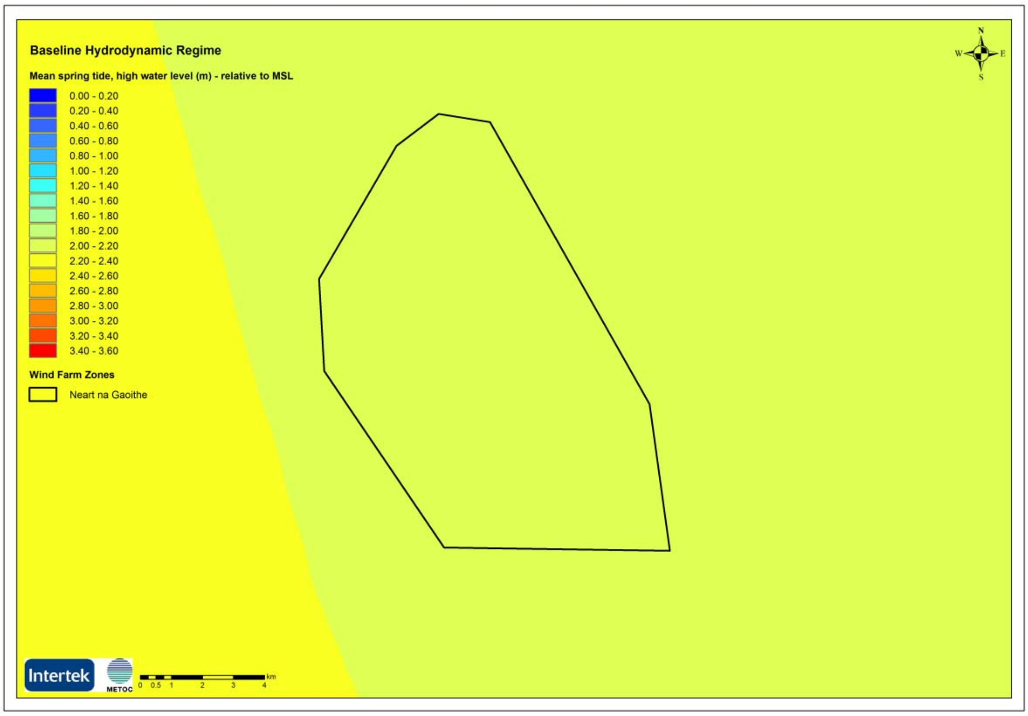


Figure C-14: Mean spring tide, low water (LW) level (m) – Neart na Gaoithe OWF (near-field) scale

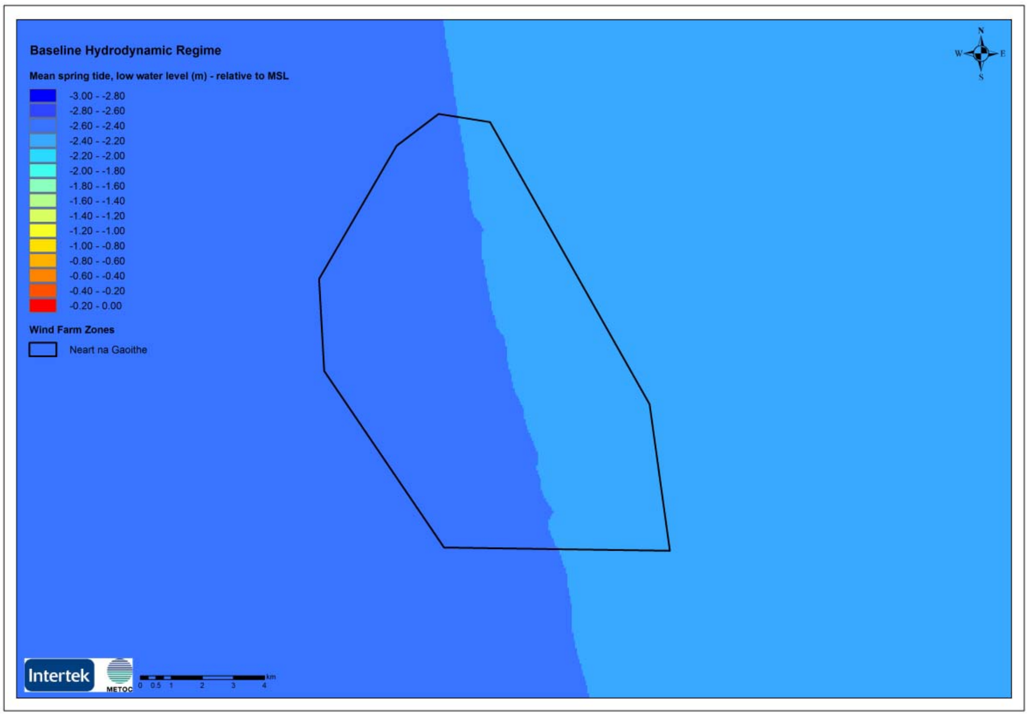


Figure C-15: Mean neap tide, high water (HW) level (m) – Neart na Gaoithe OWF (near-field) scale

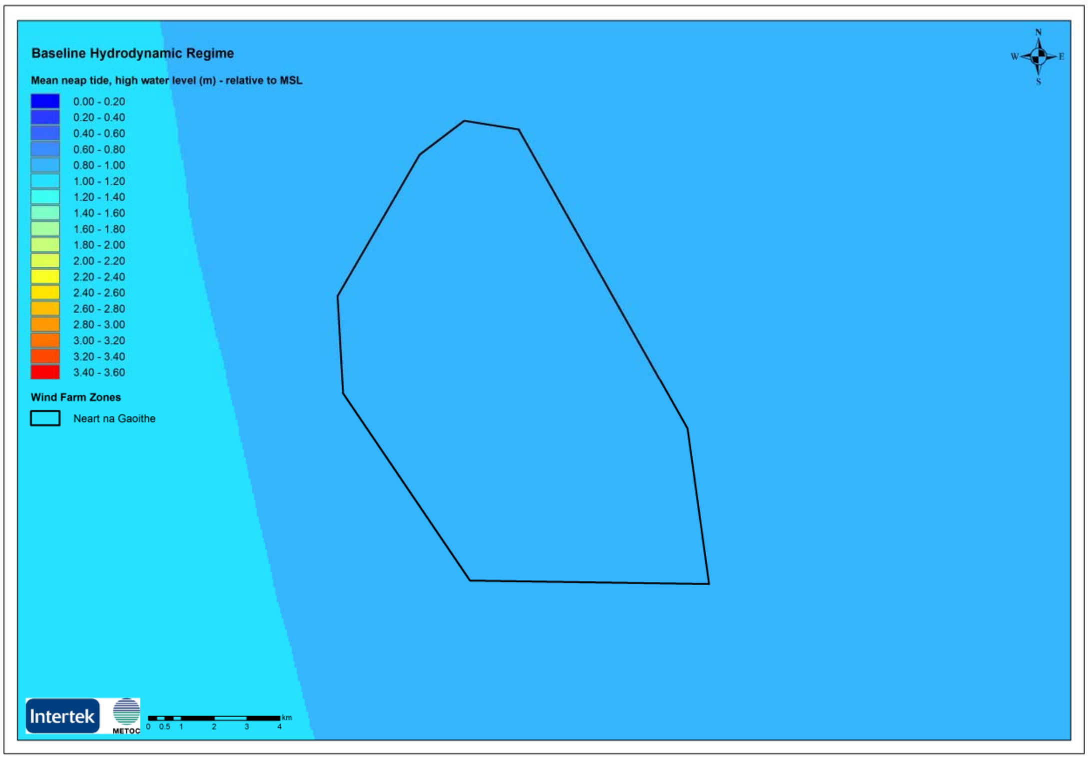


Figure C-16: Mean neap tide, low water (LW) level (m) – Neart na Gaoithe OWF (near-field) scale

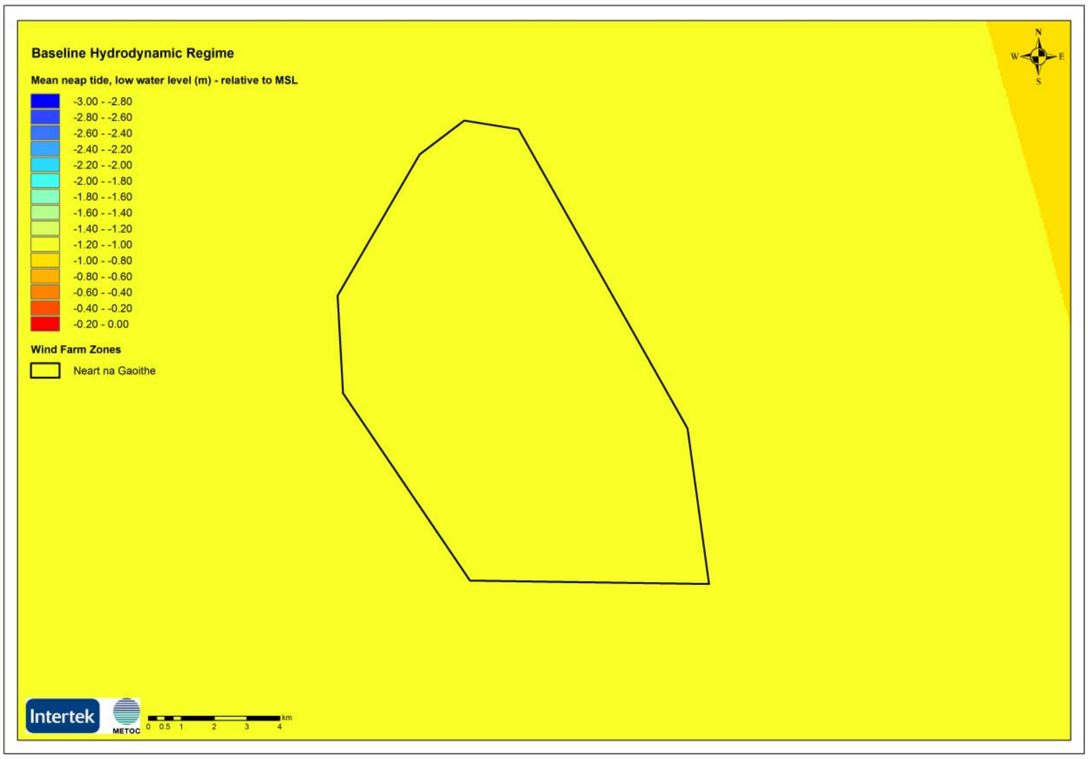


Figure C-17: Mean spring tide, peak flood currents (m/s) – Neart na Gaoithe OWF (near-field) scale

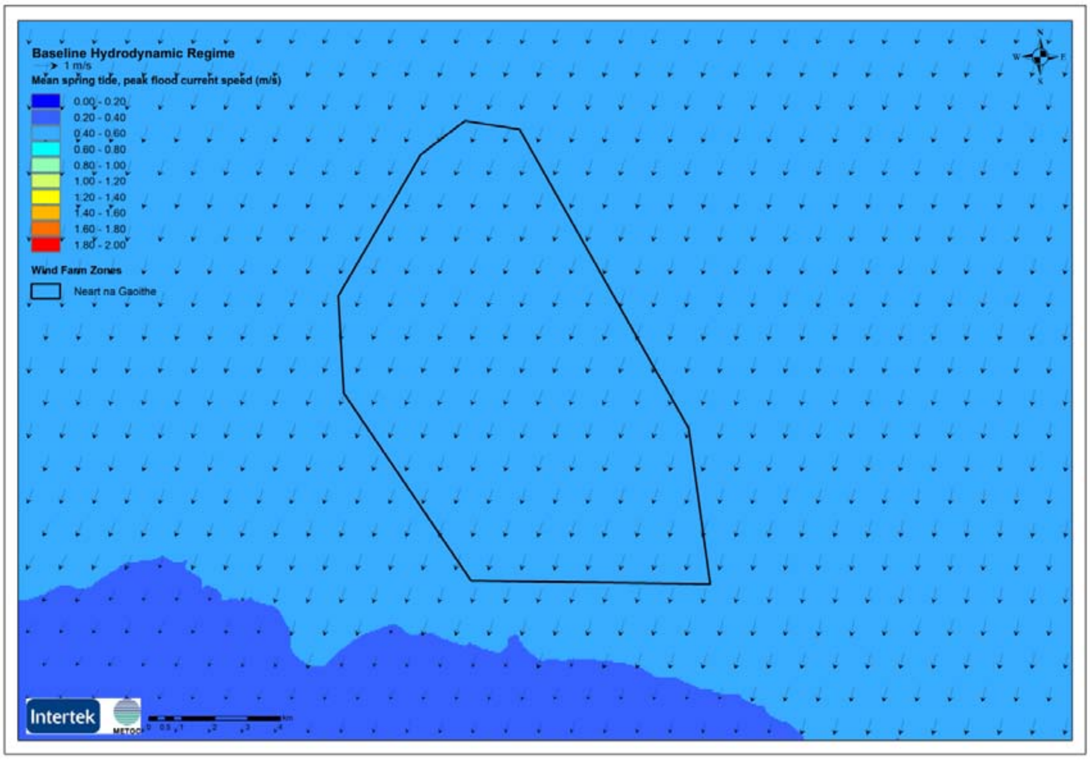


Figure C-18: Mean spring tide, peak ebb currents (m/s) – Neart na Gaoithe OWF (near-field) scale

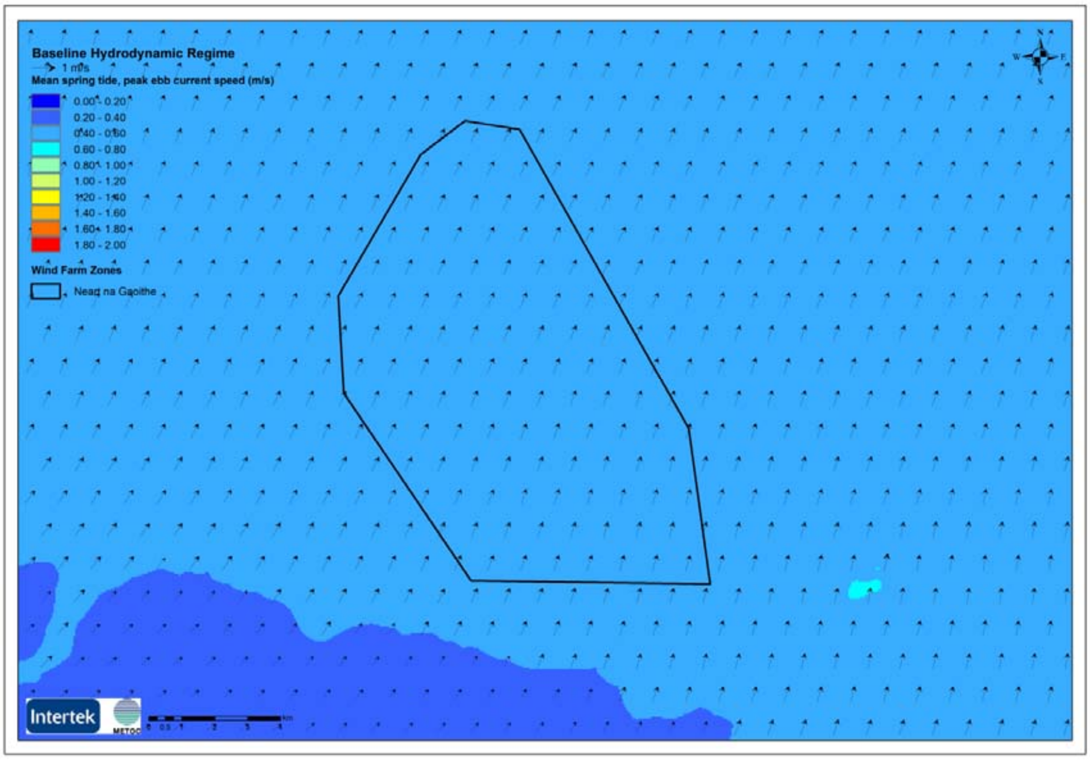


Figure C-19: Mean neap tide, peak flood currents (m/s) – Neart na Gaoithe OWF (near-field) scale

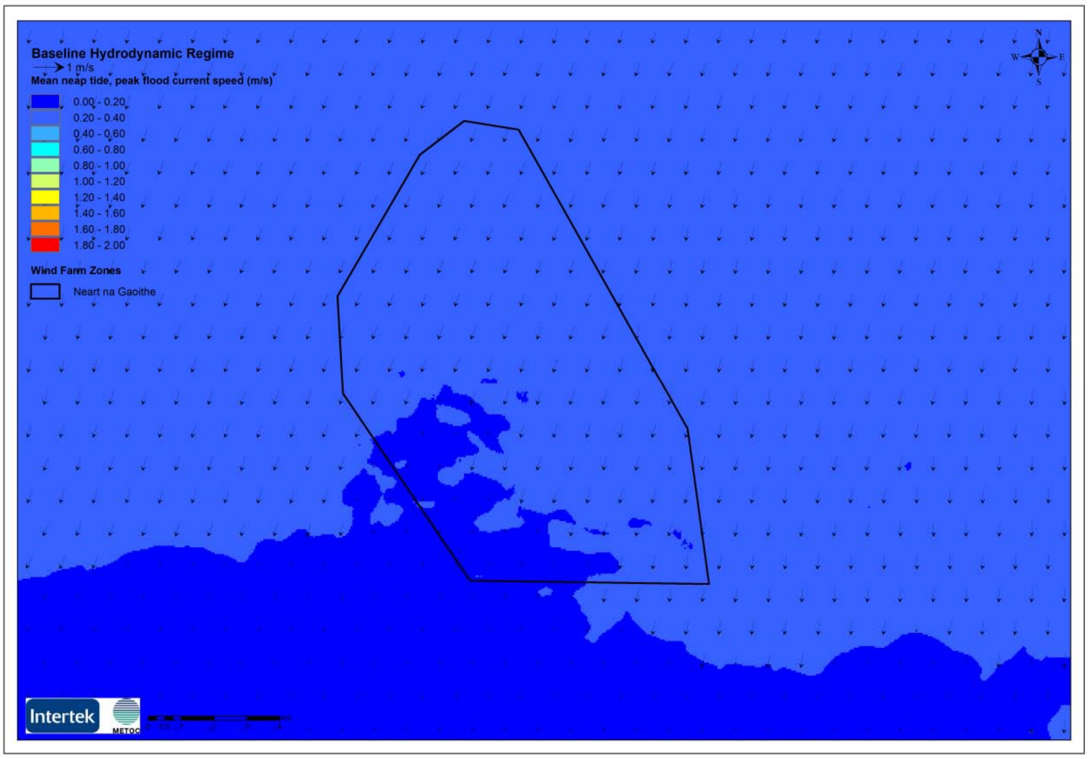


Figure C-20: Mean neap tide, peak ebb currents (m/s) – Neart na Gaoithe OWF (near-field) scale

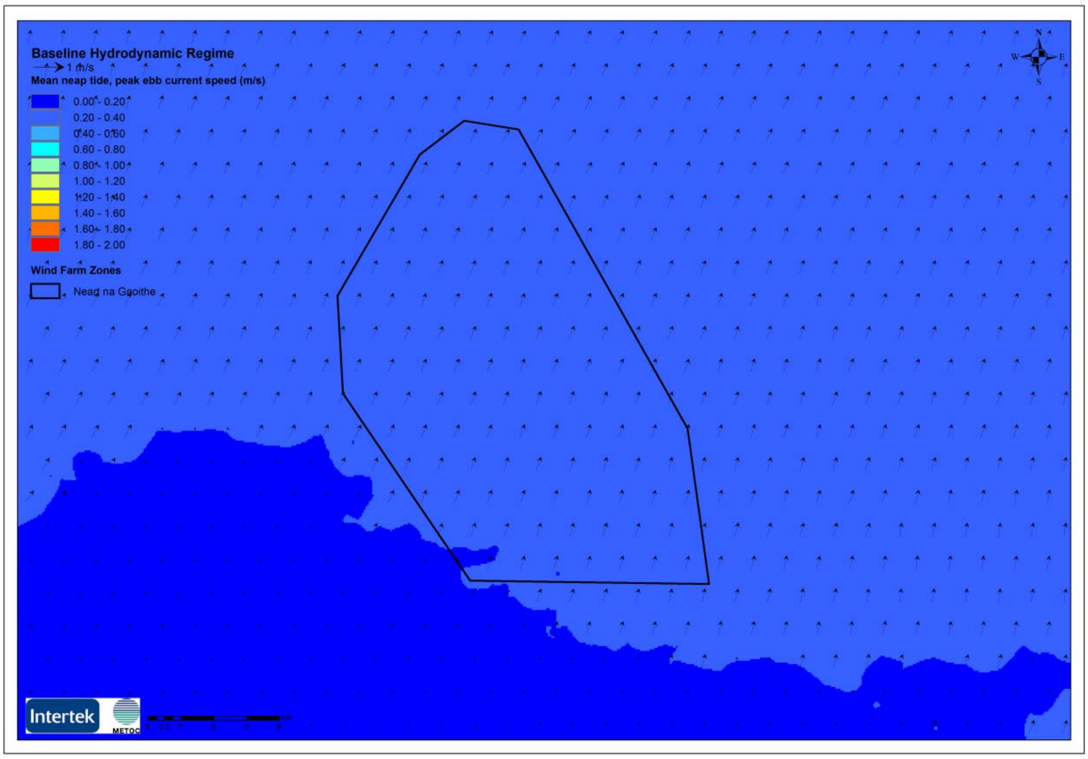


Figure C-21: 50-percentile currents (m/s) over a mean spring and neap tide – Neart na Gaoithe OWF (near-field) scale

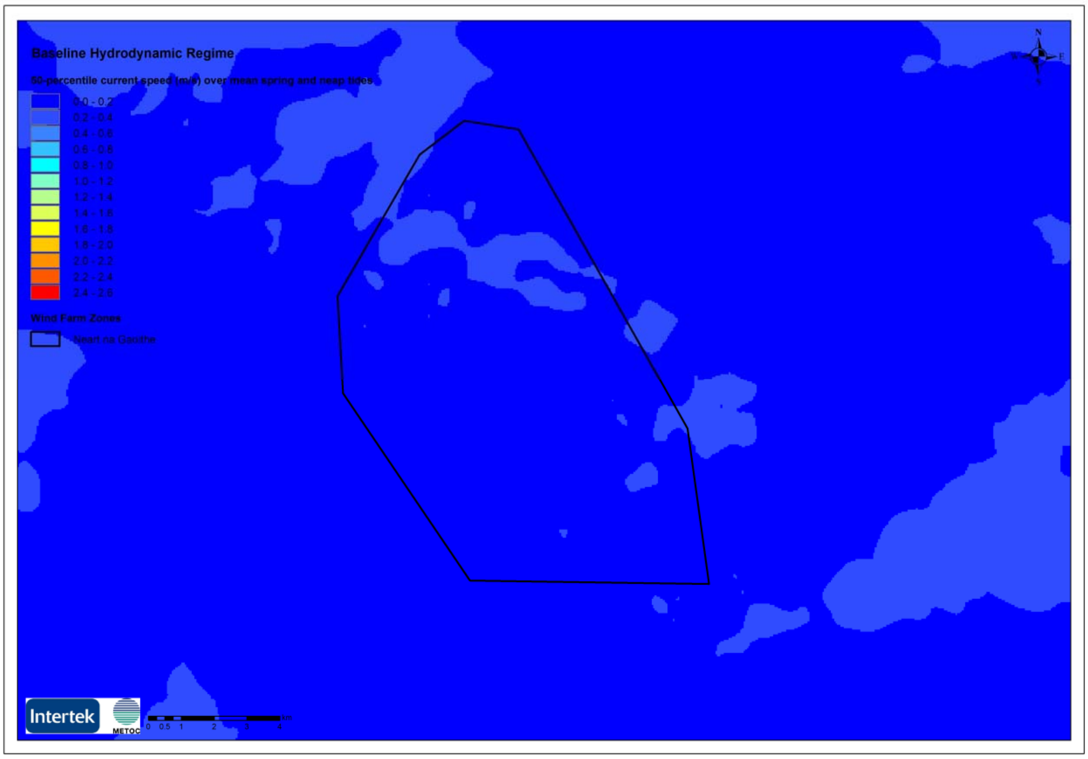


Figure C-22: 90-percentile currents (m/s) over a mean spring and neap tide – Neart na Gaoithe OWF (near-field) scale

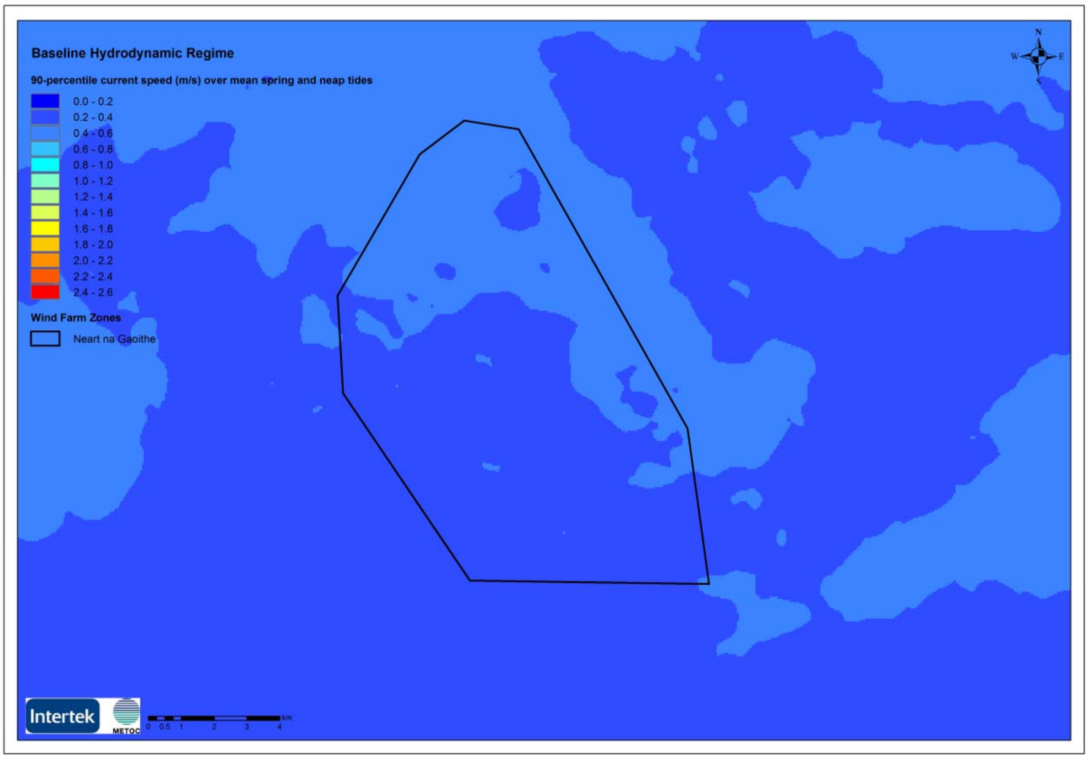


Figure C-23: 95-percentile currents (m/s) over a mean spring and neap tide – Neart na Gaoithe OWF (near-field) scale

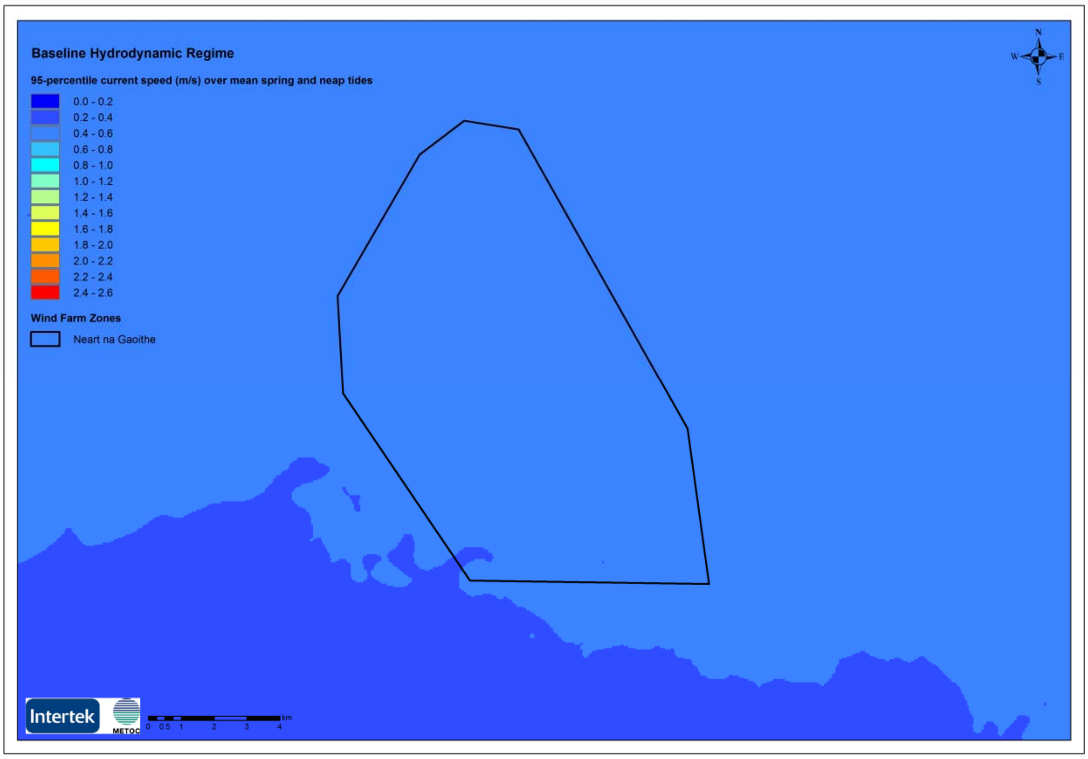
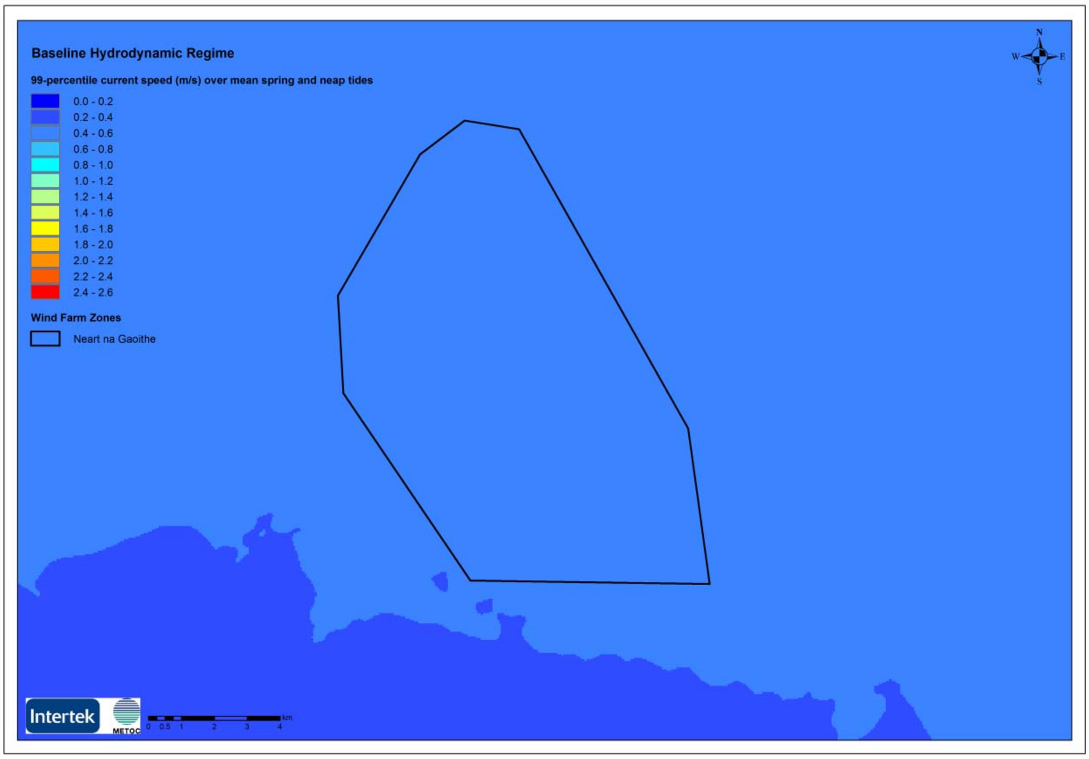


Figure C-24: 99-percentile currents (m/s) over a mean spring and neap tide – Neart na Gaoithe OWF (near-field) scale



C.2 WAVE CLIMATE

C.2.1 Regional Area - Far-field Scale

Figure C-25: 50%ile significant wave height (m) – Regional (far-field) scale

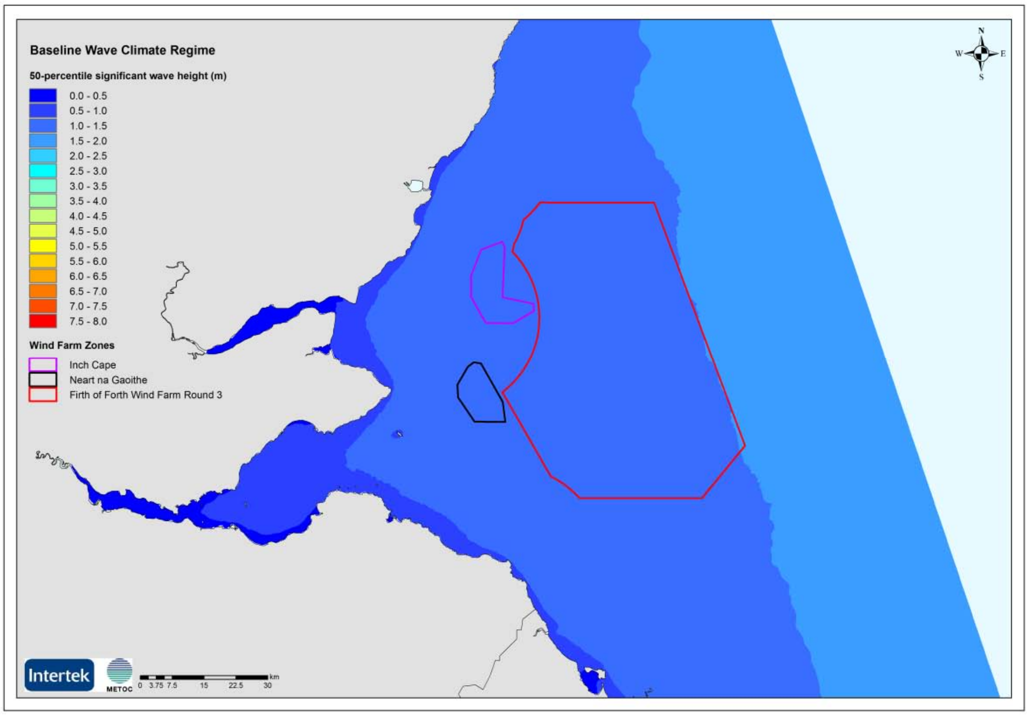


Figure C-26: 90%ile significant wave height (m) – Regional (far-field) scale

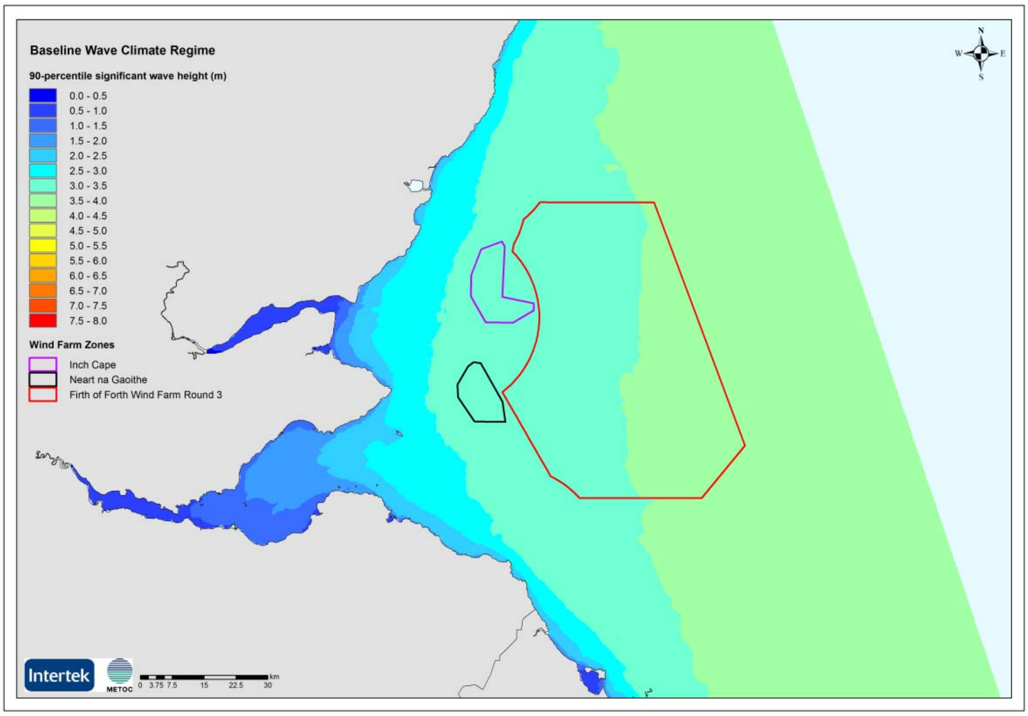


Figure C-27: 95%ile significant wave height (m) – Regional (far-field) scale

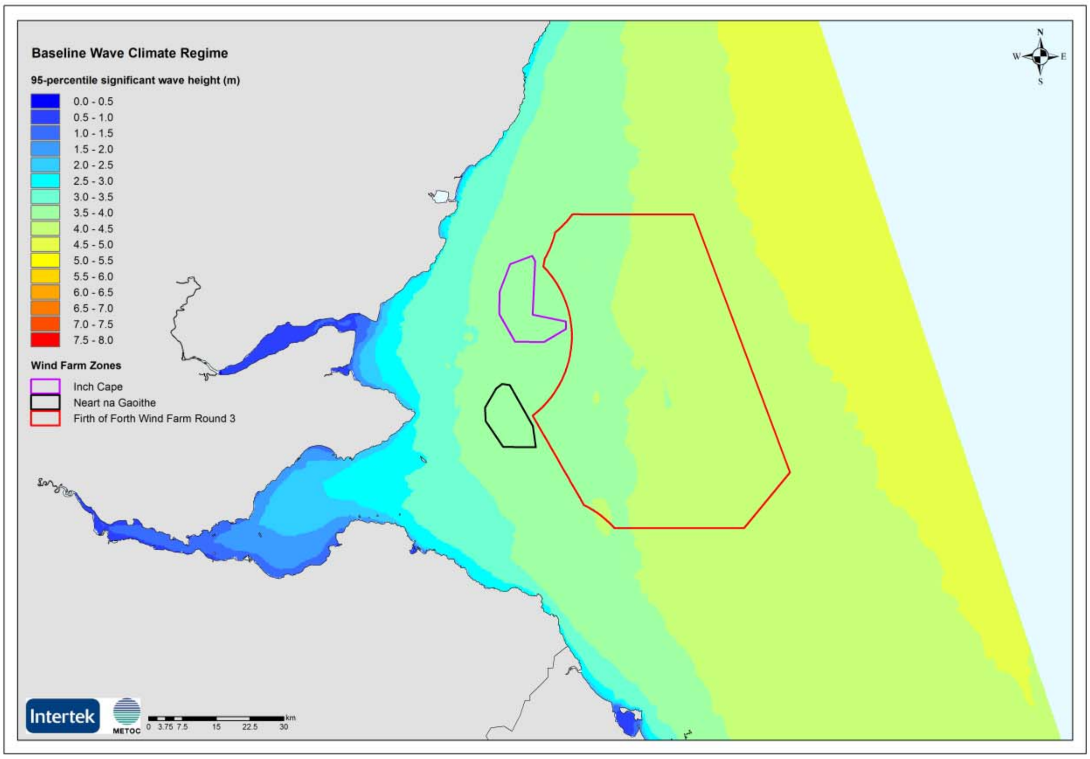


Figure C-28: 99%ile significant wave height (m) – Regional (far-field) scale

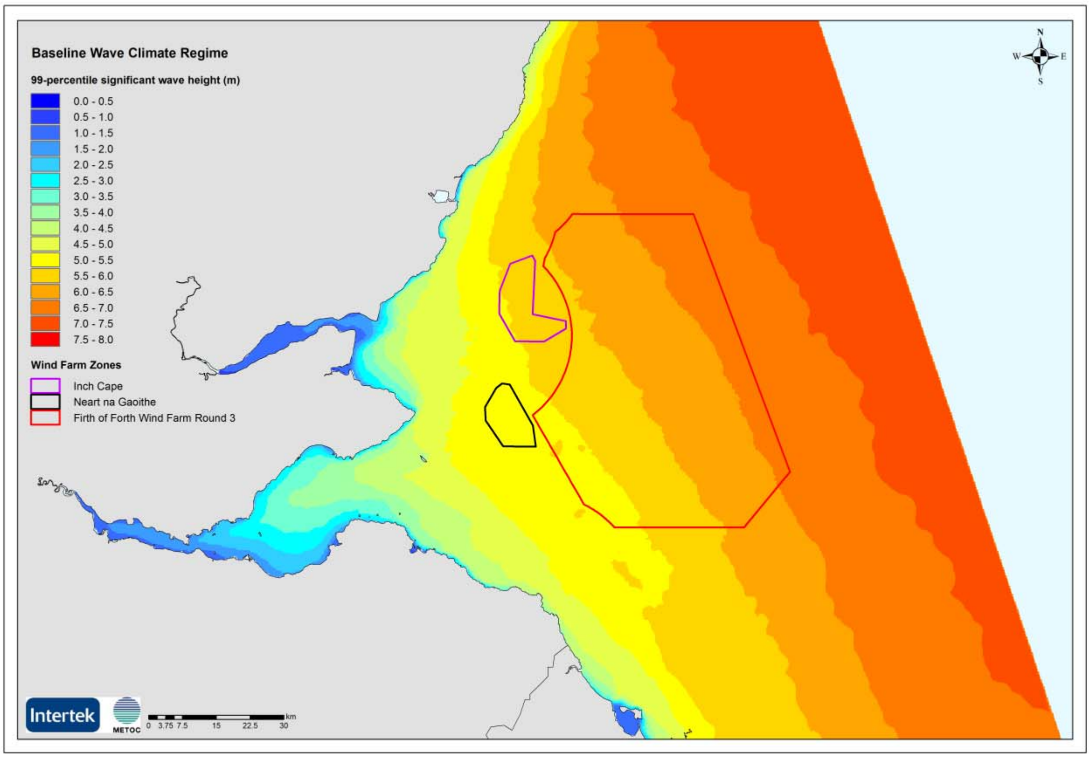


Figure C-29: 50%ile mean wave period (s) – Regional (far-field) scale

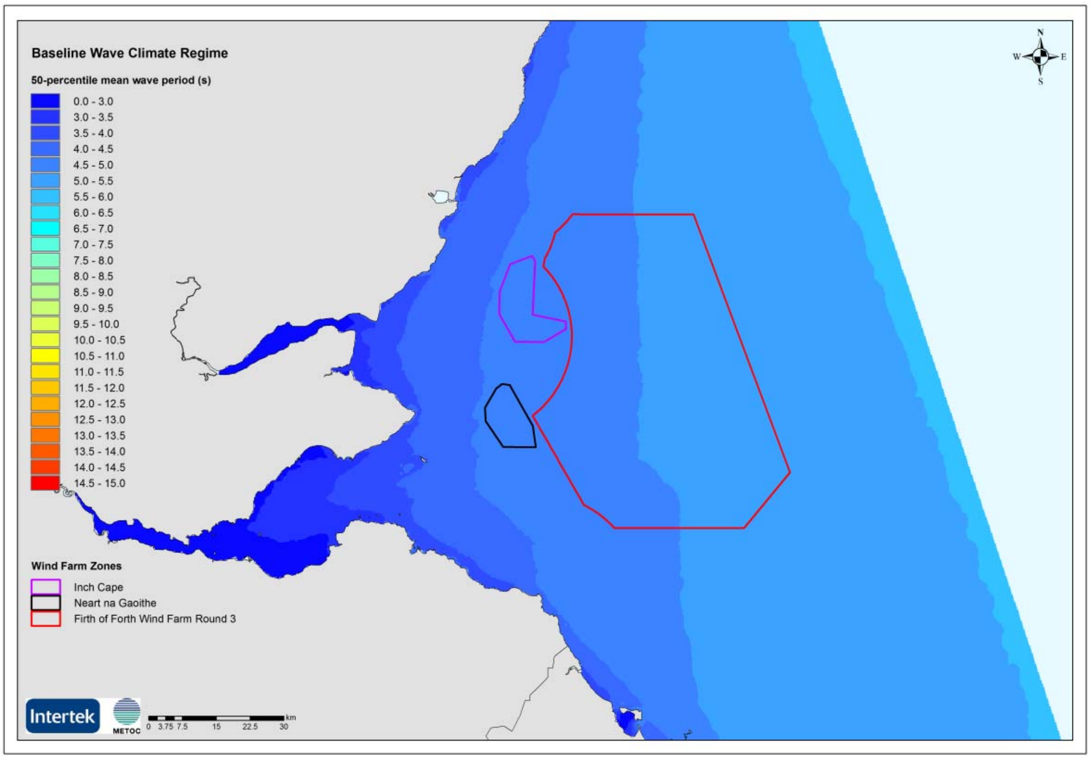


Figure C-30: 90%ile mean wave period (s) – Regional (far-field) scale

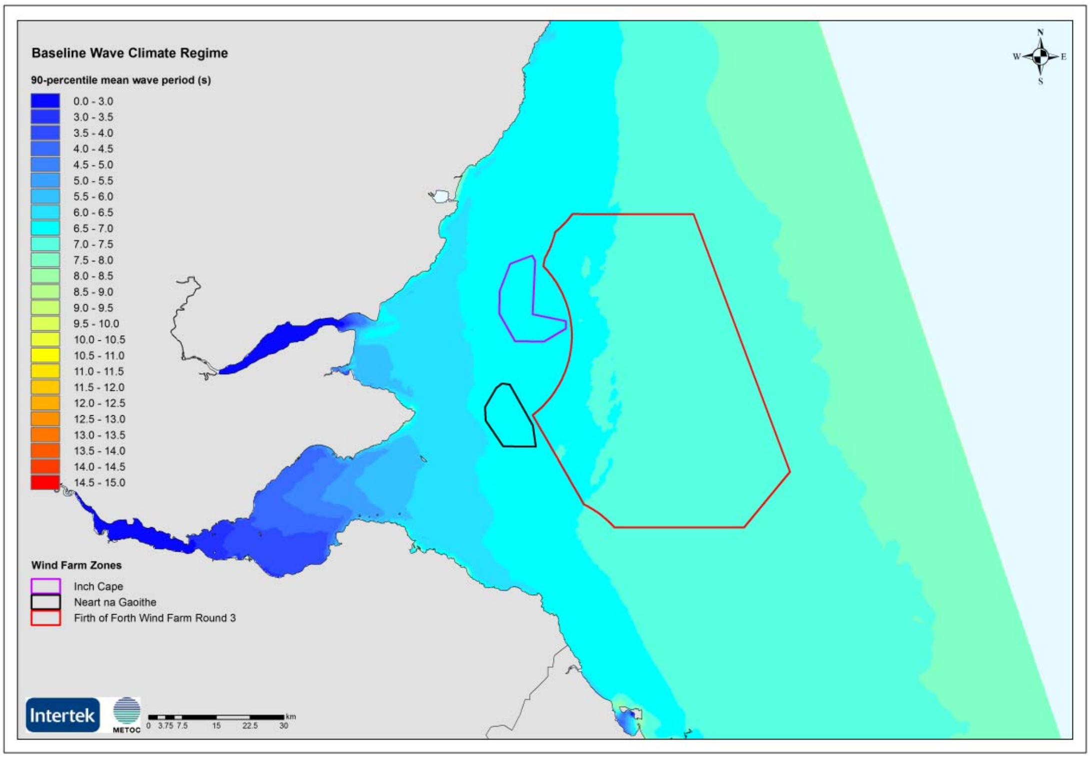


Figure C-31: 95%ile mean wave period (s) – Regional (far-field) scale

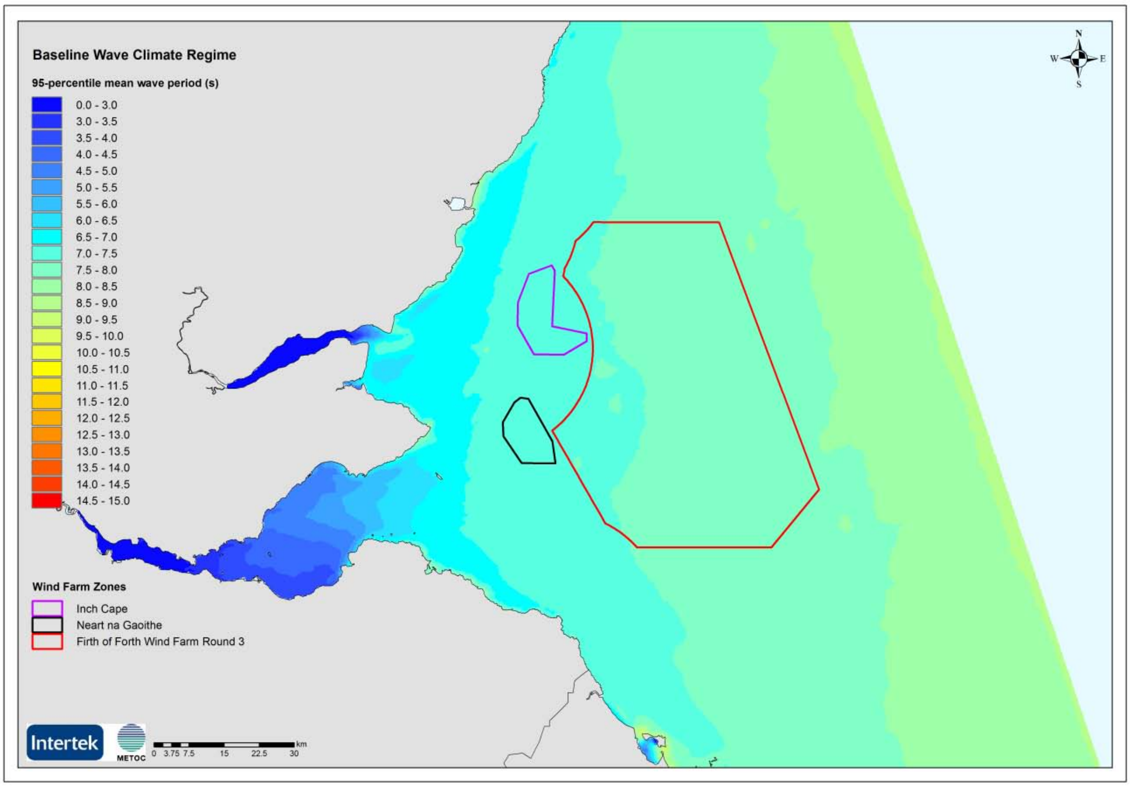


Figure C-32: 99%ile mean wave period (s) – Regional (far-field) scale

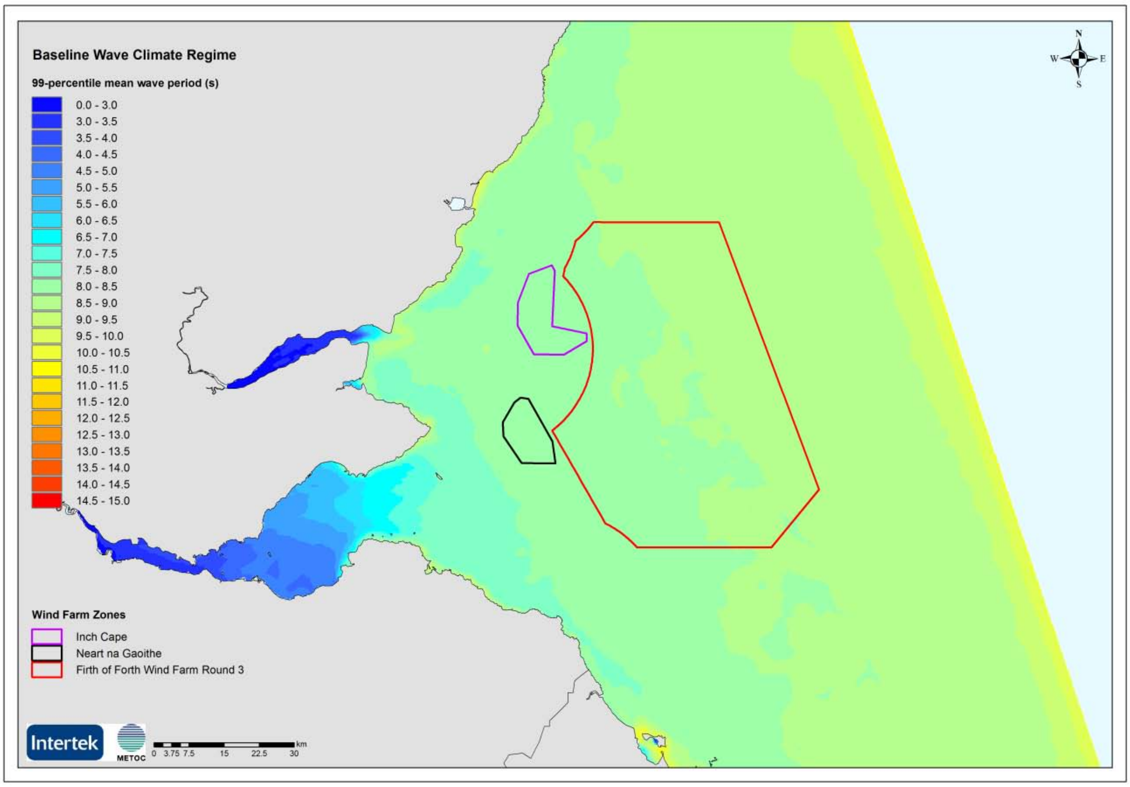


Figure C-33: 50%ile peak wave period (s) – Regional (far-field) scale

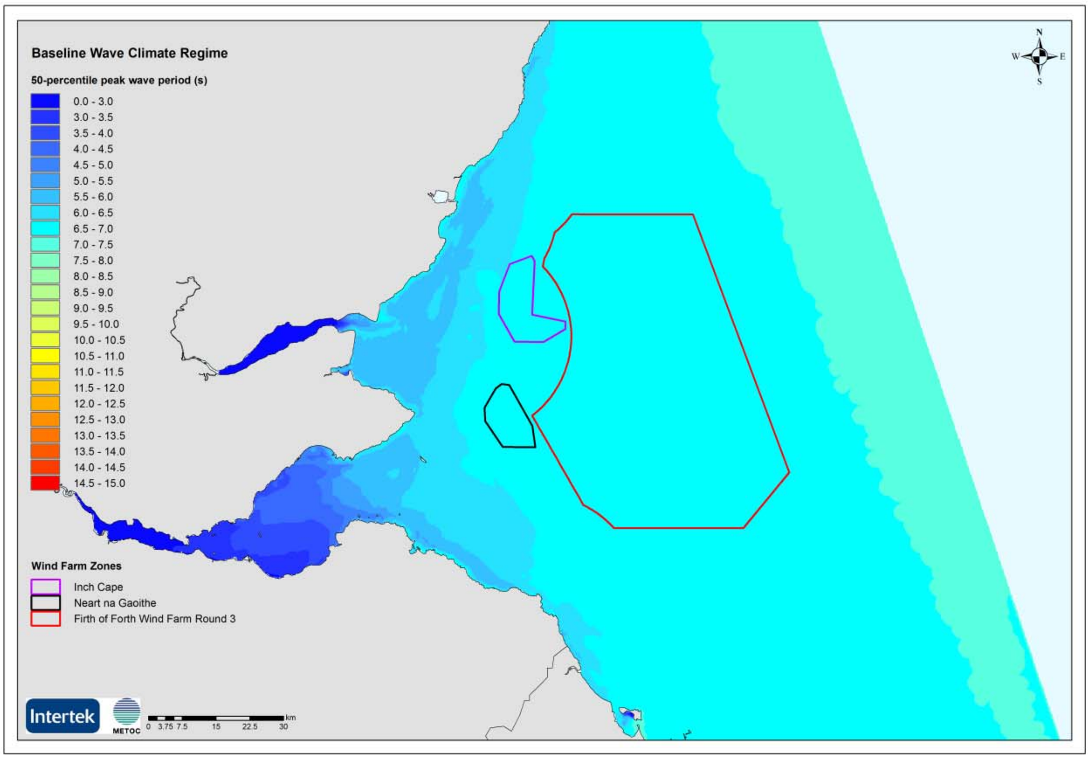


Figure C-34: 90%ile peak wave period (s) – Regional (far-field) scale

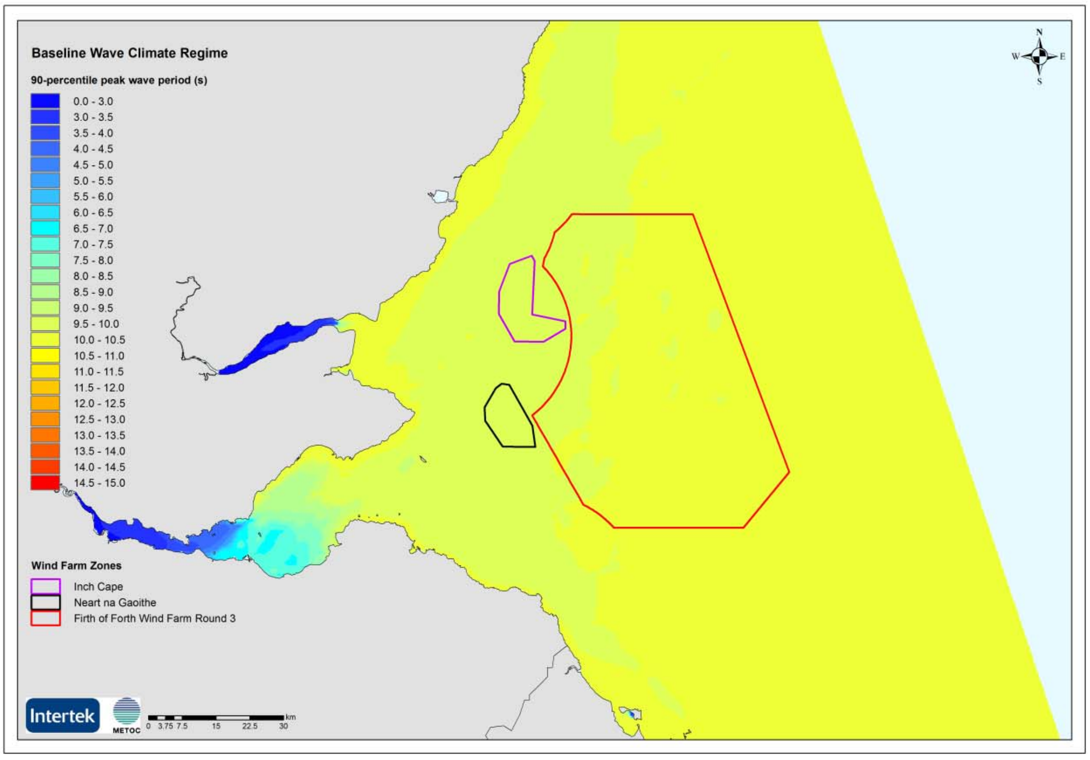


Figure C-35: 95%ile peak wave period (s) – Regional (far-field) scale

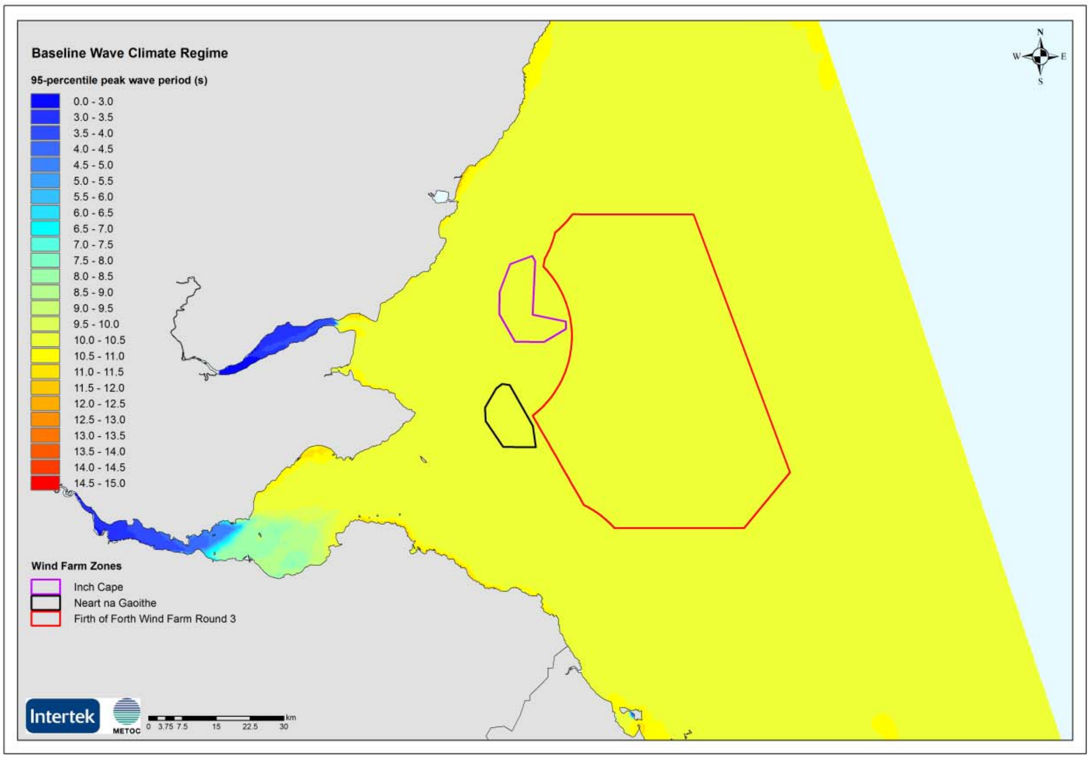
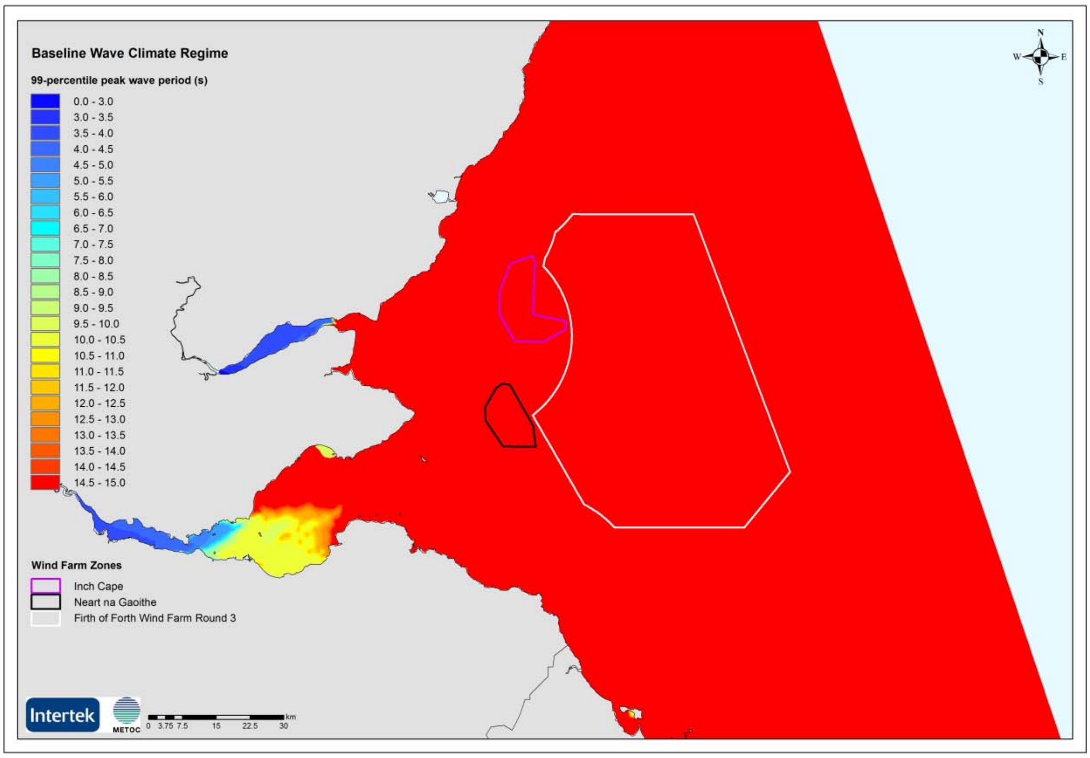


Figure C-36: 99%ile peak wave period (s) – Regional (far-field) scale



C.2.2 Neart na Gaoithe Offshore Wind Farm Area - Near-field Scale

Figure C-37: Baseline 50%ile significant wave height (m) – Neart na Gaoithe OWF (near-field) scale

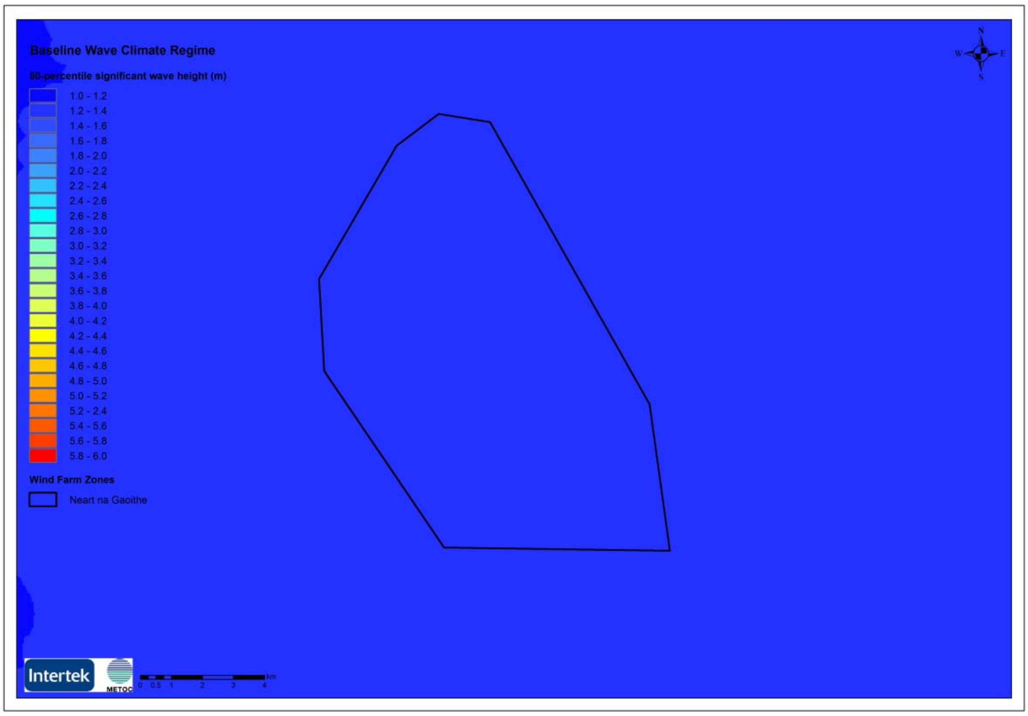


Figure C-38: Baseline 90%ile significant wave height (m) – Neart na Gaoithe OWF (near-field) scale

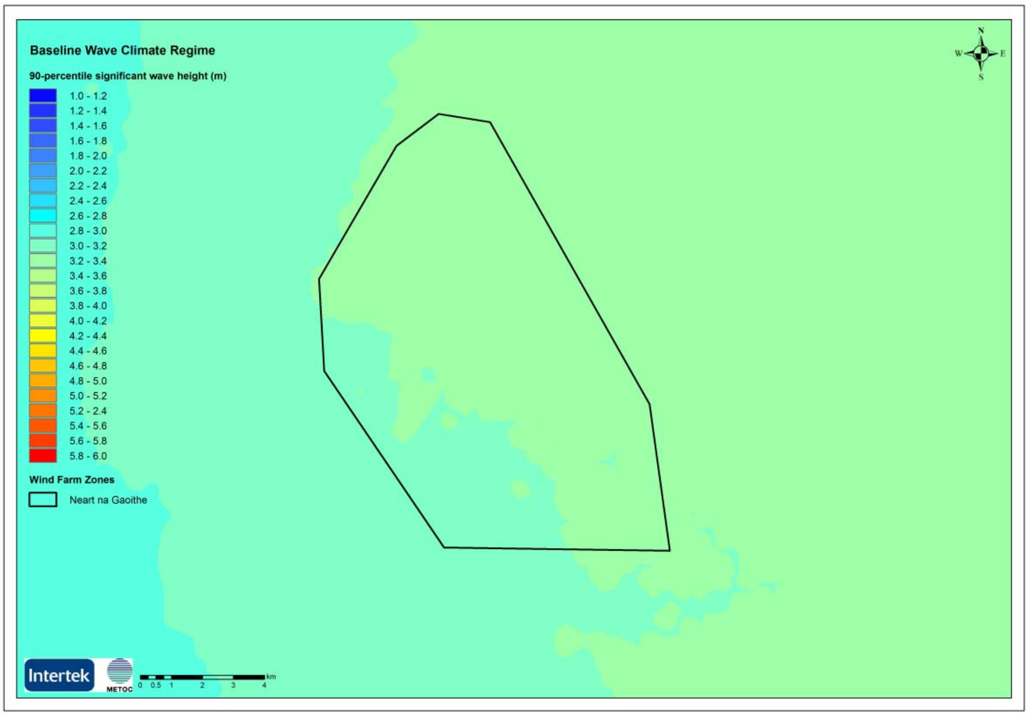


Figure C-39: Baseline 95%ile significant wave height (m) – Neart na Gaoithe OWF (near-field) scale

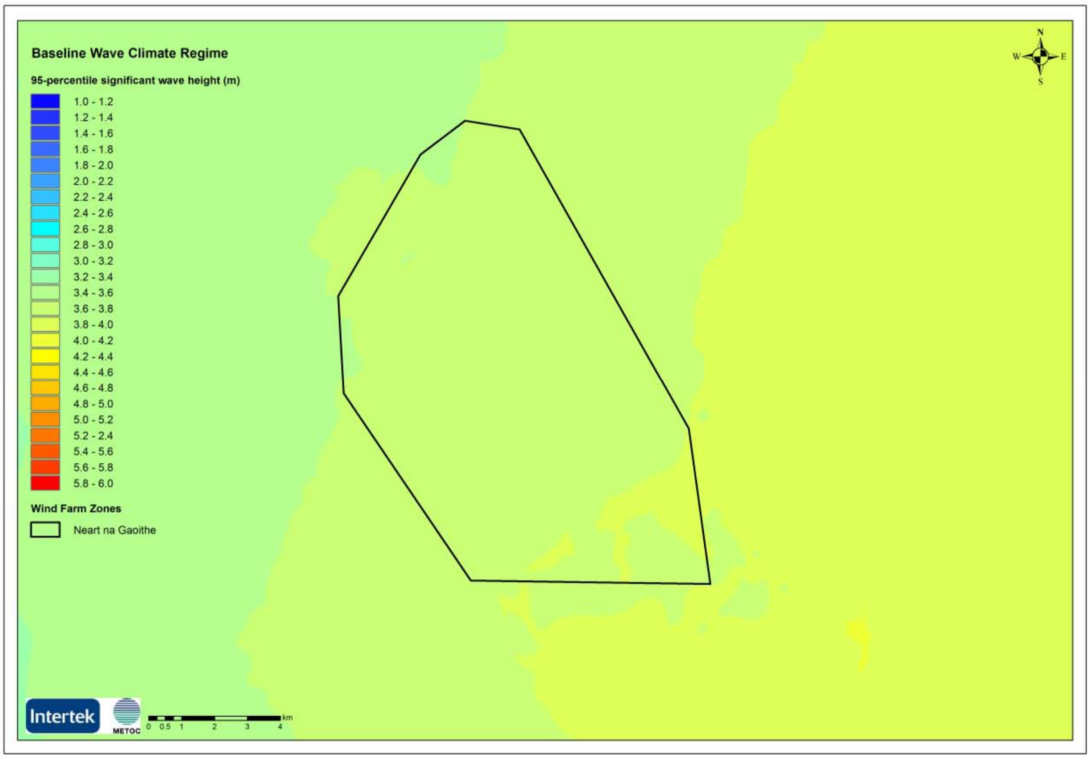


Figure C-40: Baseline 99%ile significant wave height (m) – Neart na Gaoithe OWF (near-field) scale

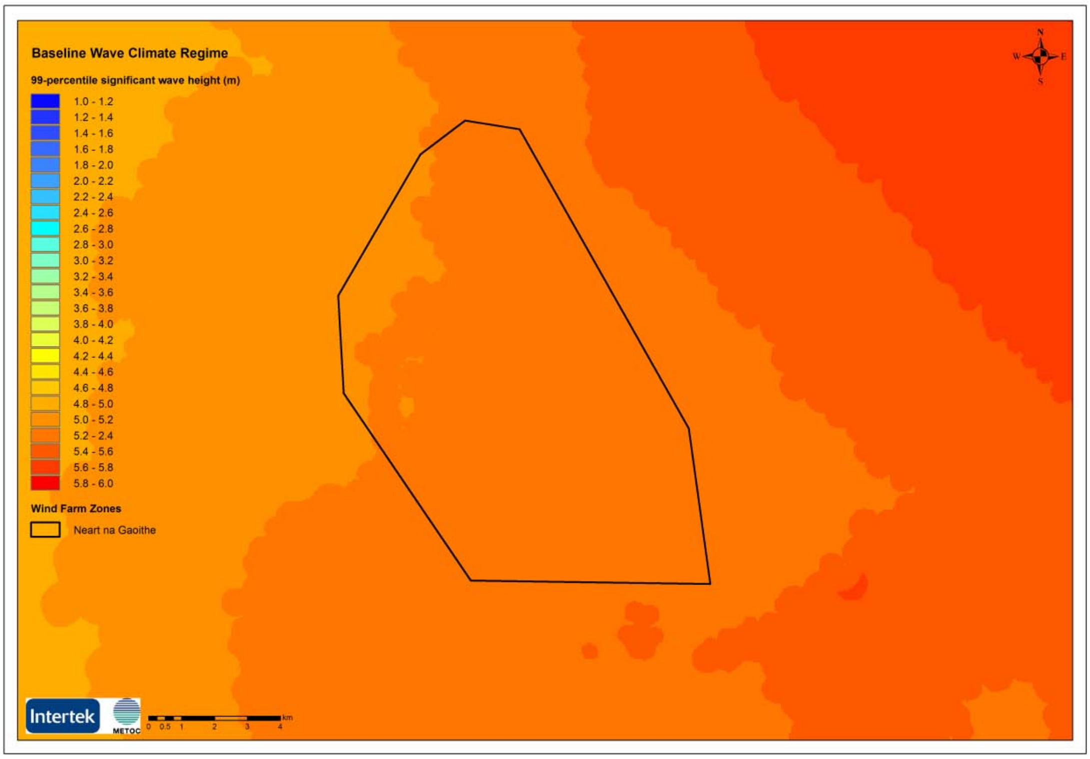


Figure C-41: Baseline 50%ile mean wave period (s) – Neart na Gaoithe OWF (near-field) scale

Figure C-42: Baseline 90%ile mean wave period (s) – Neart na Gaoithe OWF (near-field) scale

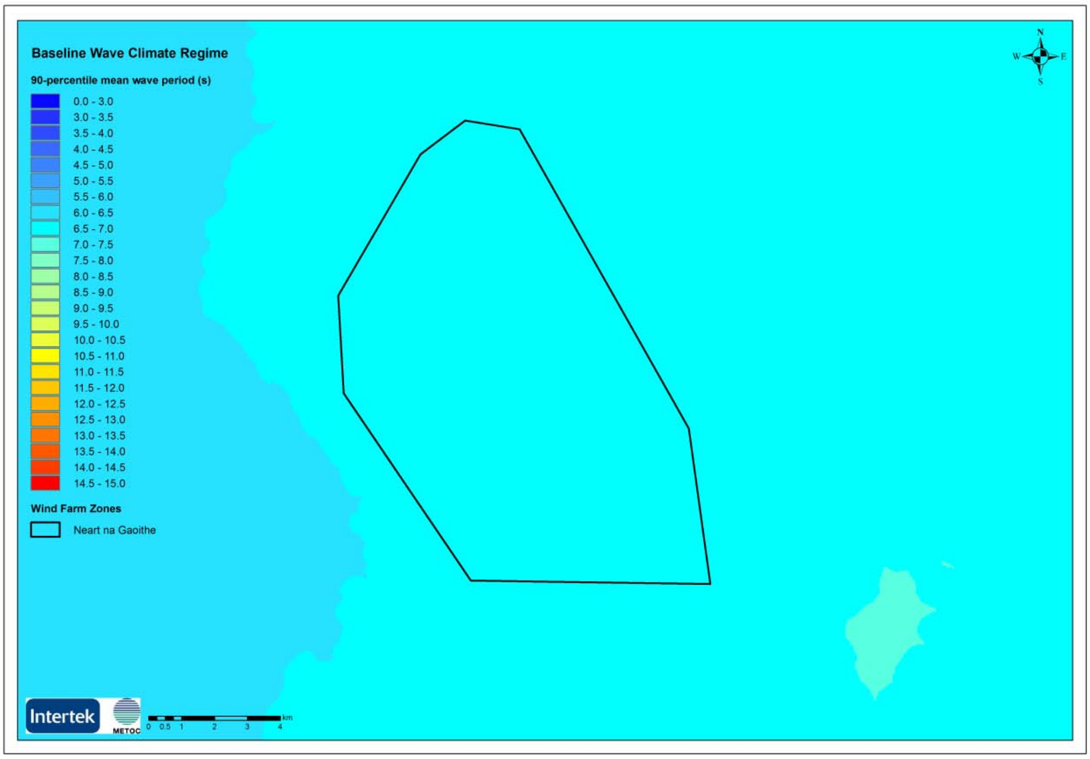


Figure C-43: Baseline 95%ile mean wave period (s) – Neart na Gaoithe OWF (near-field) scale

Figure C-44: Baseline 99%ile mean wave period (s) – Neart na Gaoithe OWF (near-field) scale

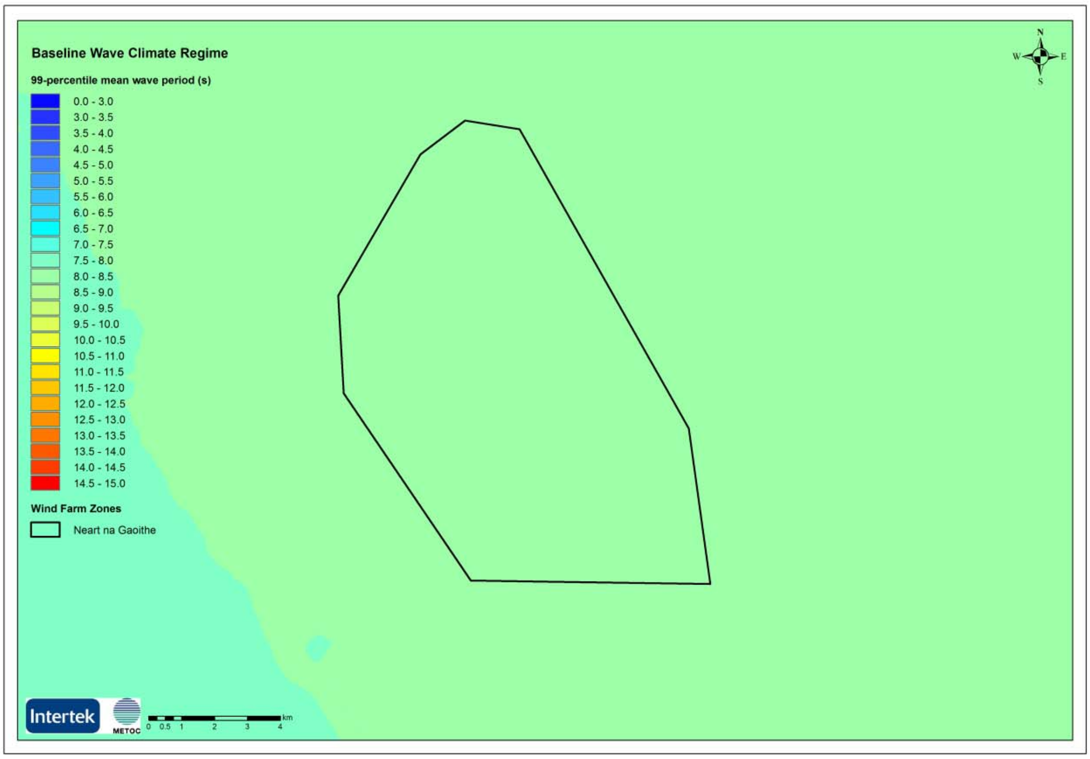


Figure C-45: Baseline 50%ile peak wave period (s) – Neart na Gaoithe OWF (near-field) scale

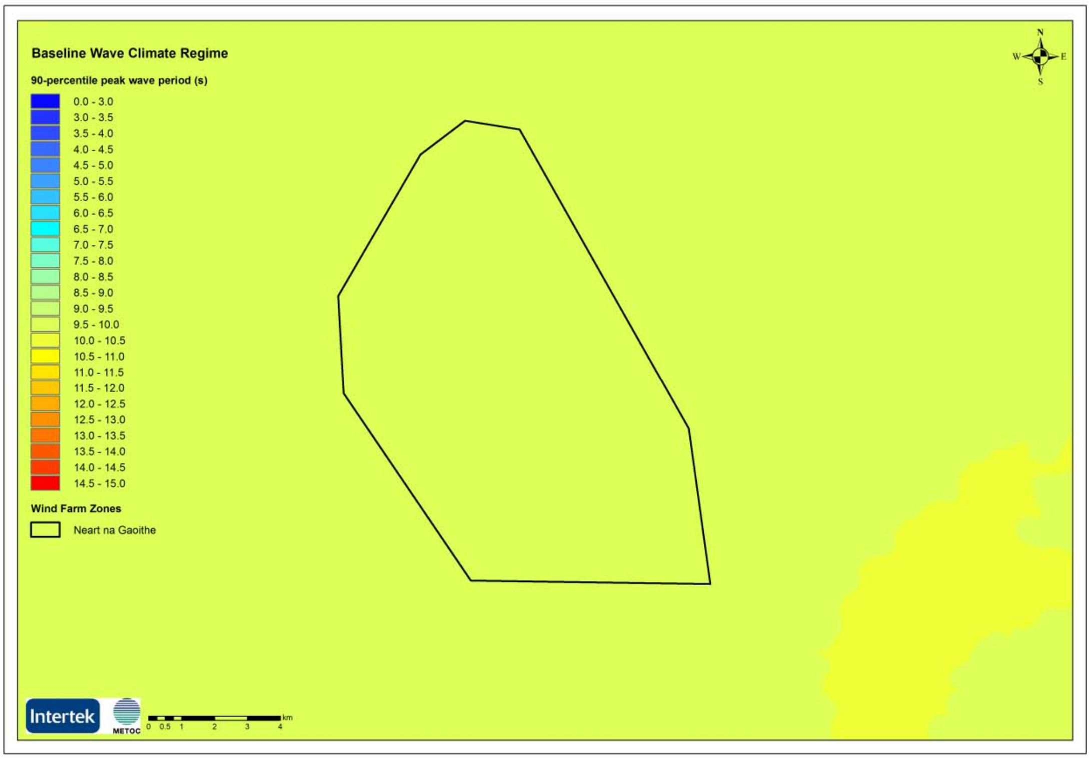


Figure C-46: Baseline 90%ile peak wave period (s) – Neart na Gaoithe OWF (near-field) scale

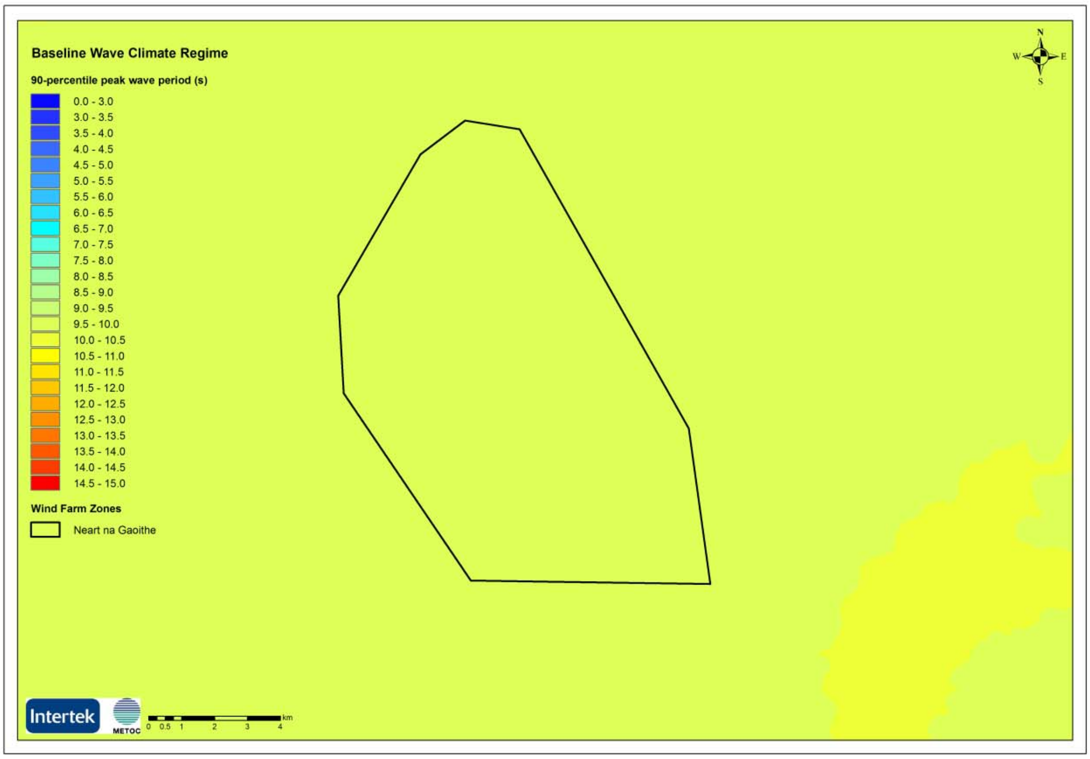


Figure C-47: Baseline 95%ile peak wave period (s) – Neart na Gaoithe OWF (near-field) scale

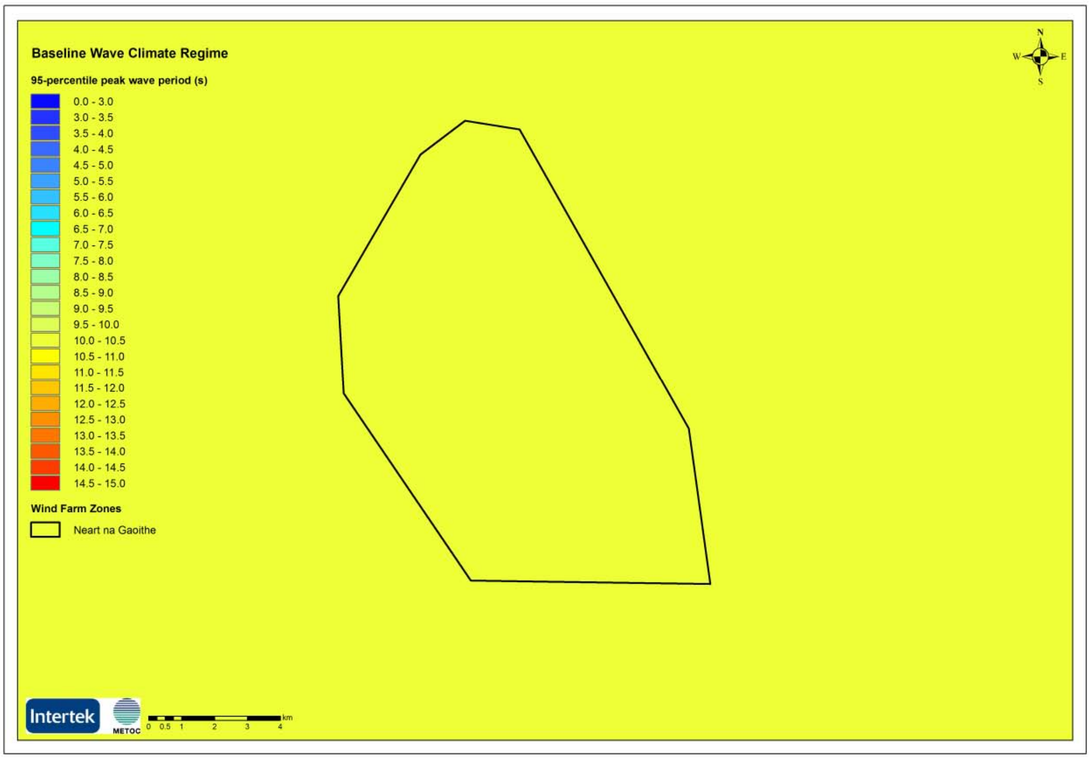
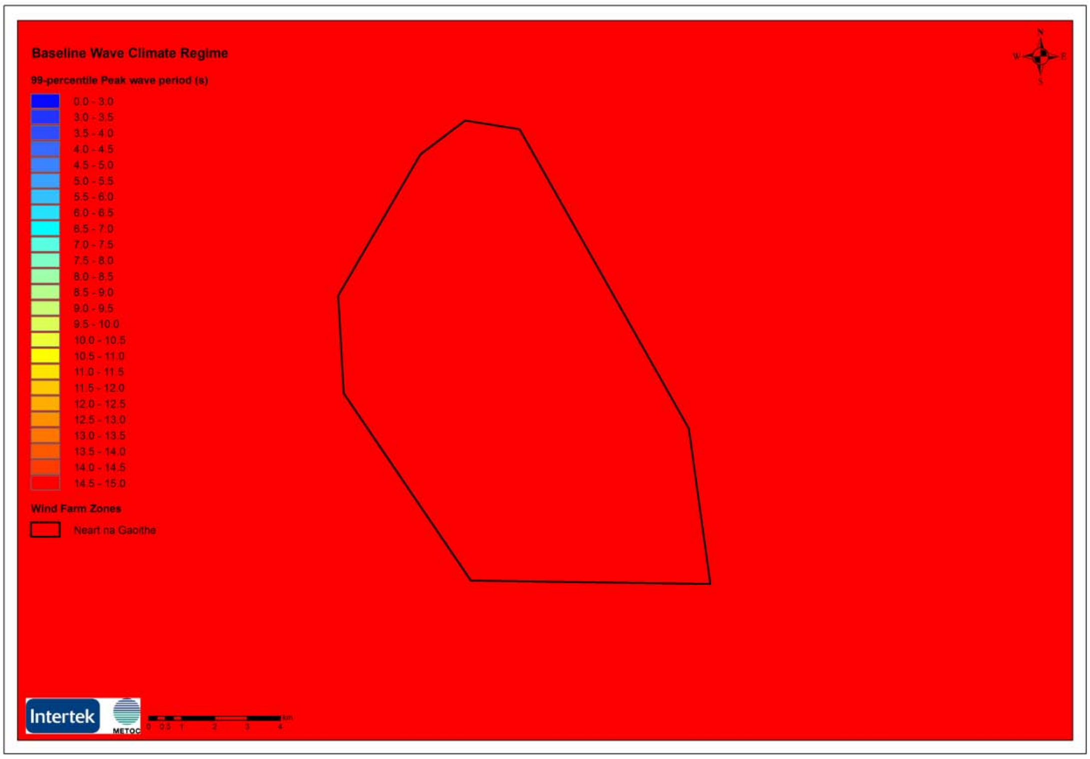


Figure C-48: Baseline 99%ile peak wave period (s) – Neart na Gaoithe OWF (near-field) scale

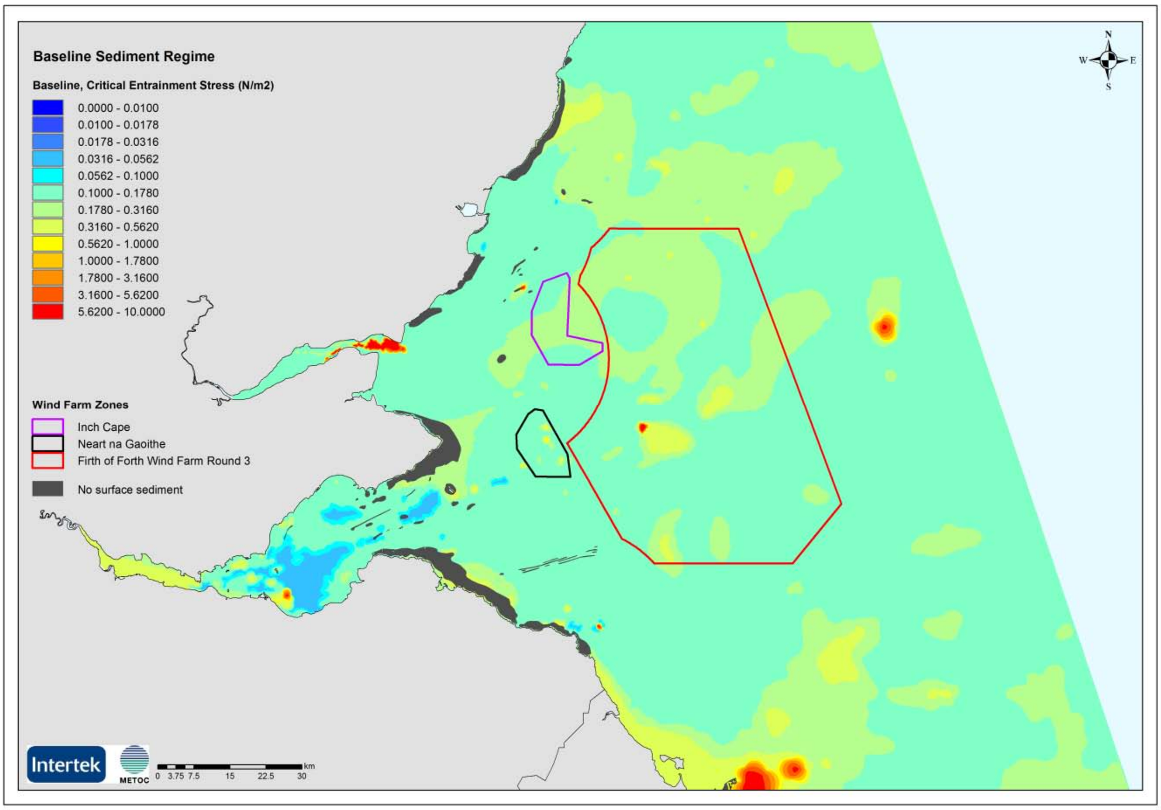


C.3 SEDIMENT REGIME

C.3.1 Regional Area - Far-field Scale

C.3.1.1 Baseline sediment map and critical shear stress – Regional Area

Figure C-49: Critical shear stress for entrainment (N/m^2) – Regional (far-field) scale



C.3.1.2 Baseline bed shear stress due to currents only – Regional Area

Figure C-50: 50%ile bed shear stress - due to currents (N/m^2) – Regional (far-field) scale

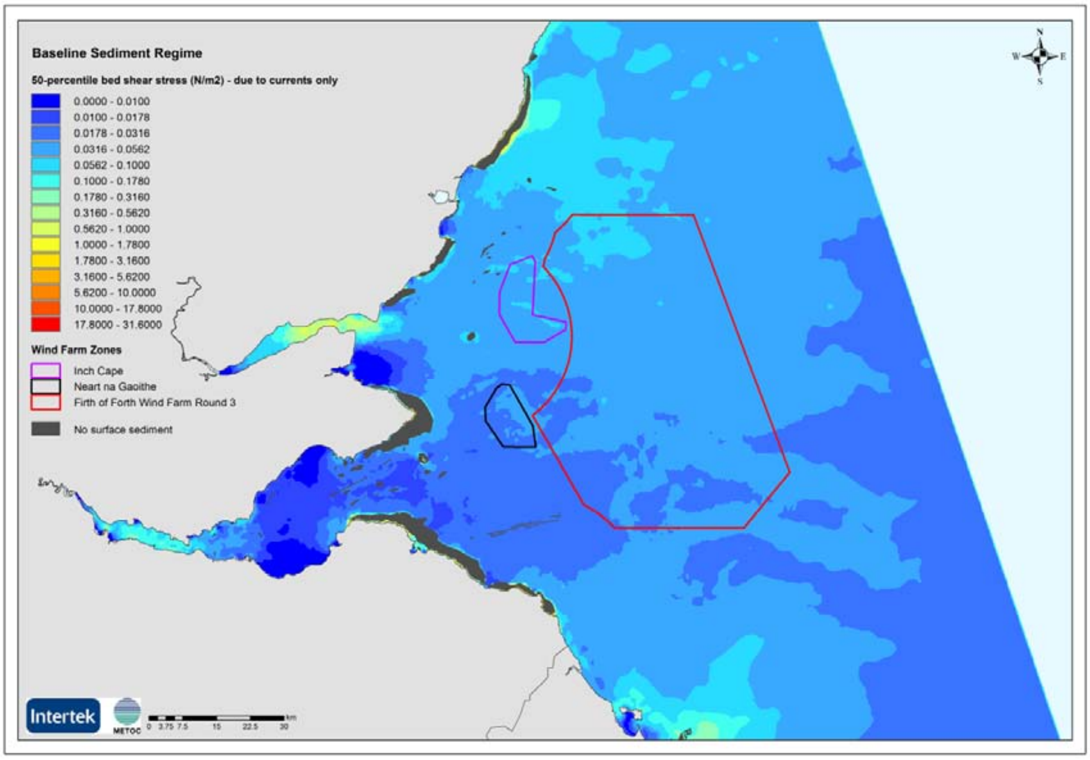


Figure C-51: 90%ile bed shear stress - due to currents (N/m^2) – Regional (far-field) scale

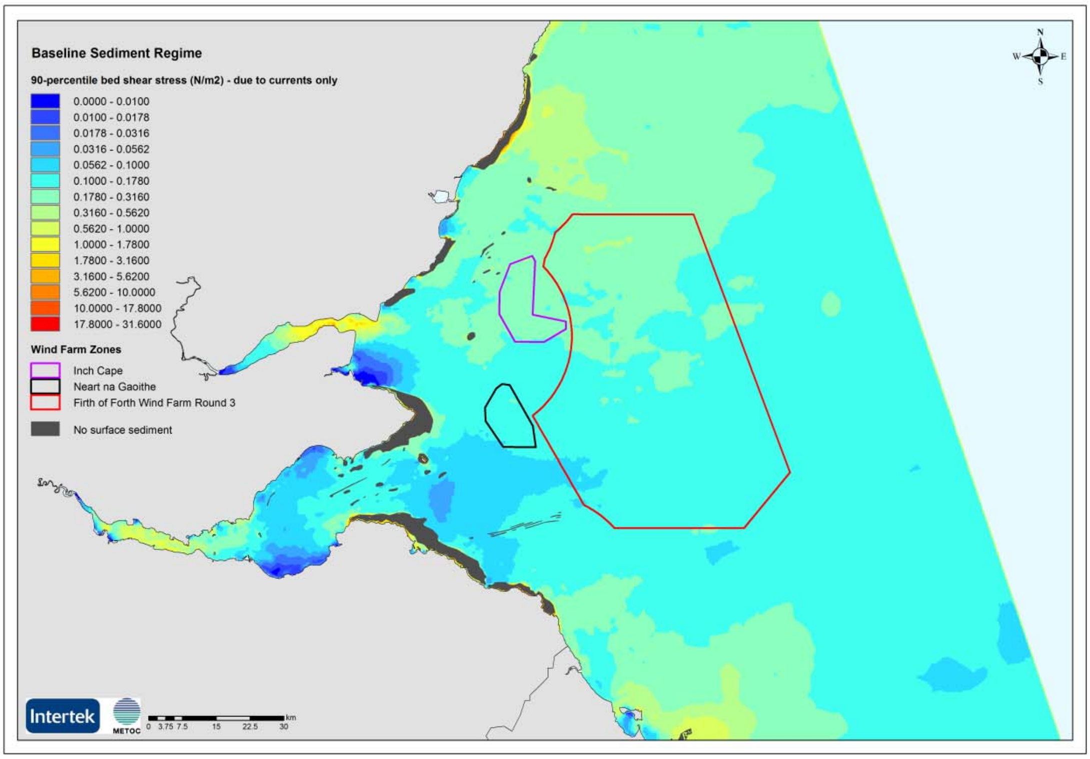


Figure C-52: 95%ile bed shear stress - due to currents (N/m^2) – Regional (far-field) scale

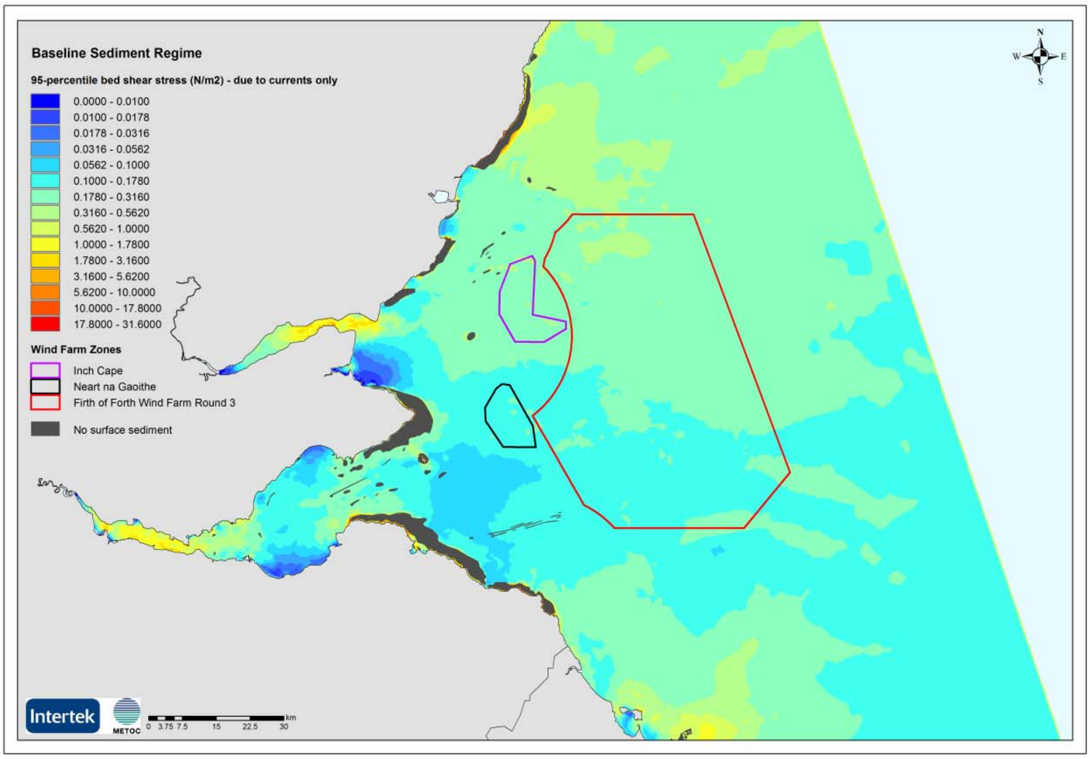
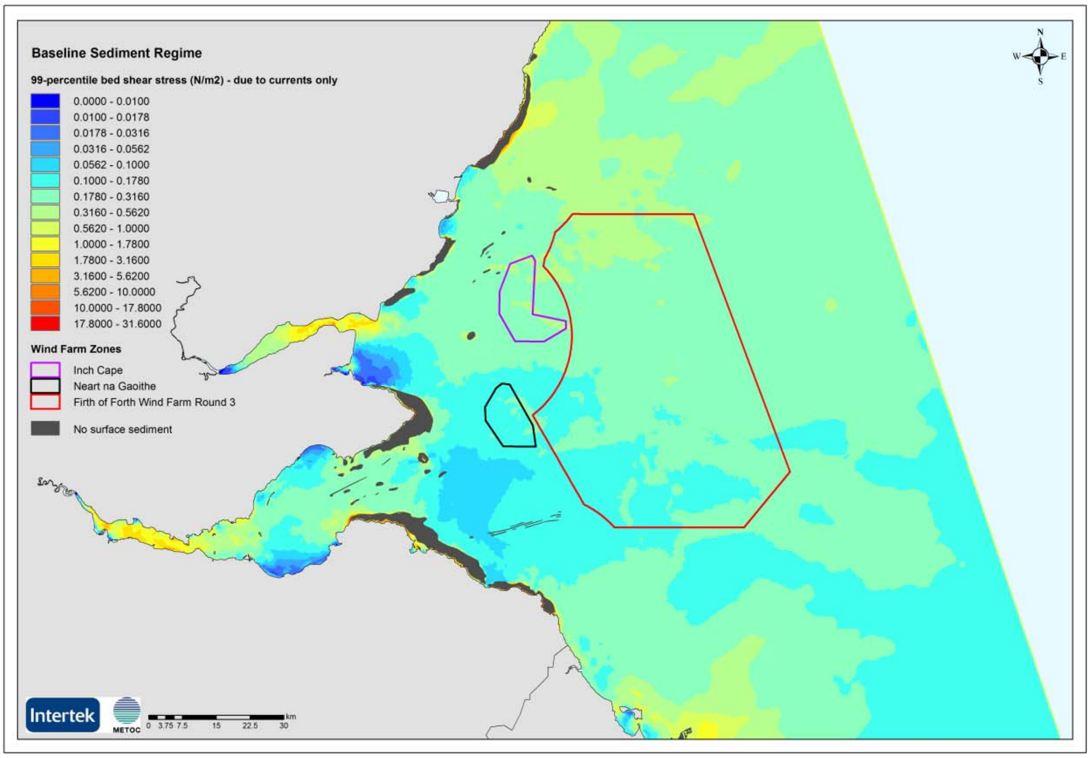


Figure C-53: 99%ile bed shear stress - due to currents (N/m^2) – Regional (far-field) scale



C.3.1.3 Baseline bed shear stress due to waves only – Regional Area

Figure C-54: 50%ile bed shear stress - due to waves (N/m^2) – Regional (far-field) scale

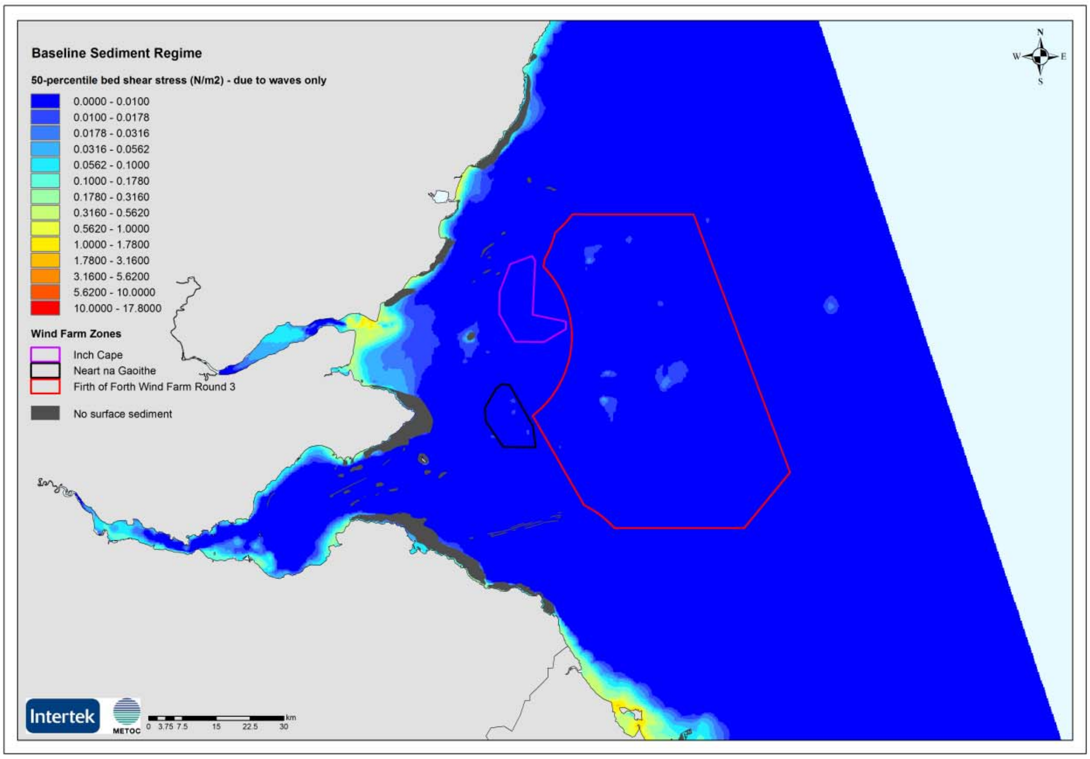


Figure C-55: 90%ile bed shear stress - due to waves (N/m^2) – Regional (far-field) scale

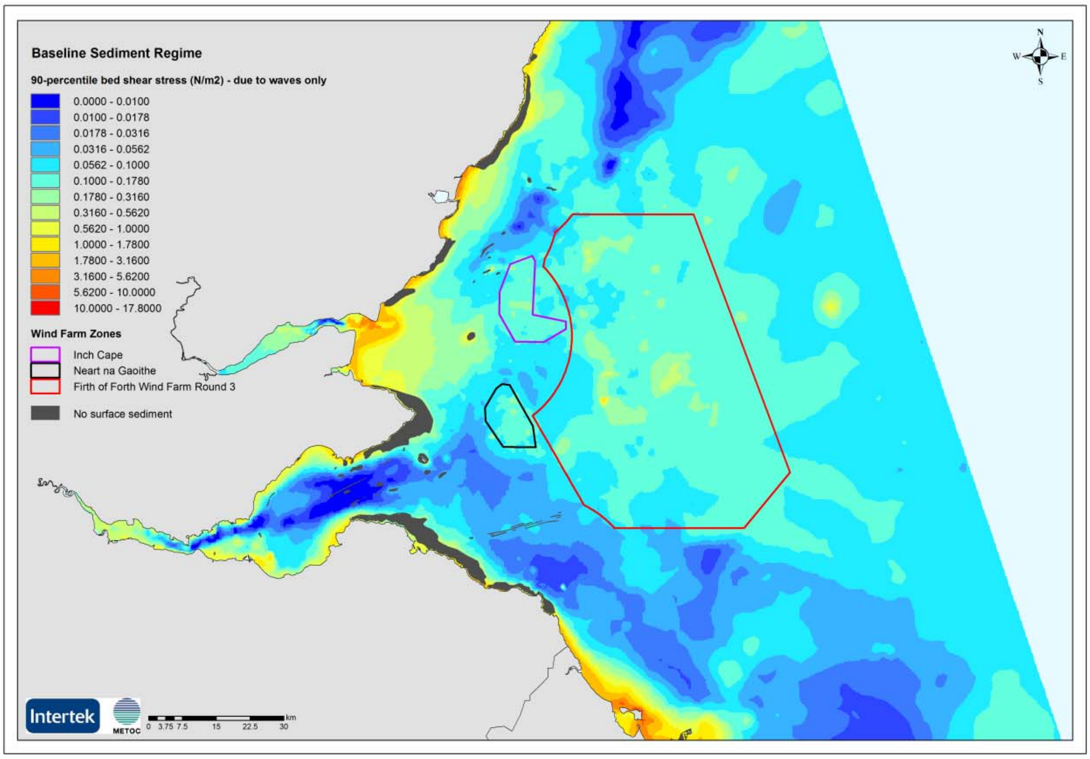


Figure C-56: 95%ile bed shear stress - due to waves (N/m²) – Regional (far-field) scale

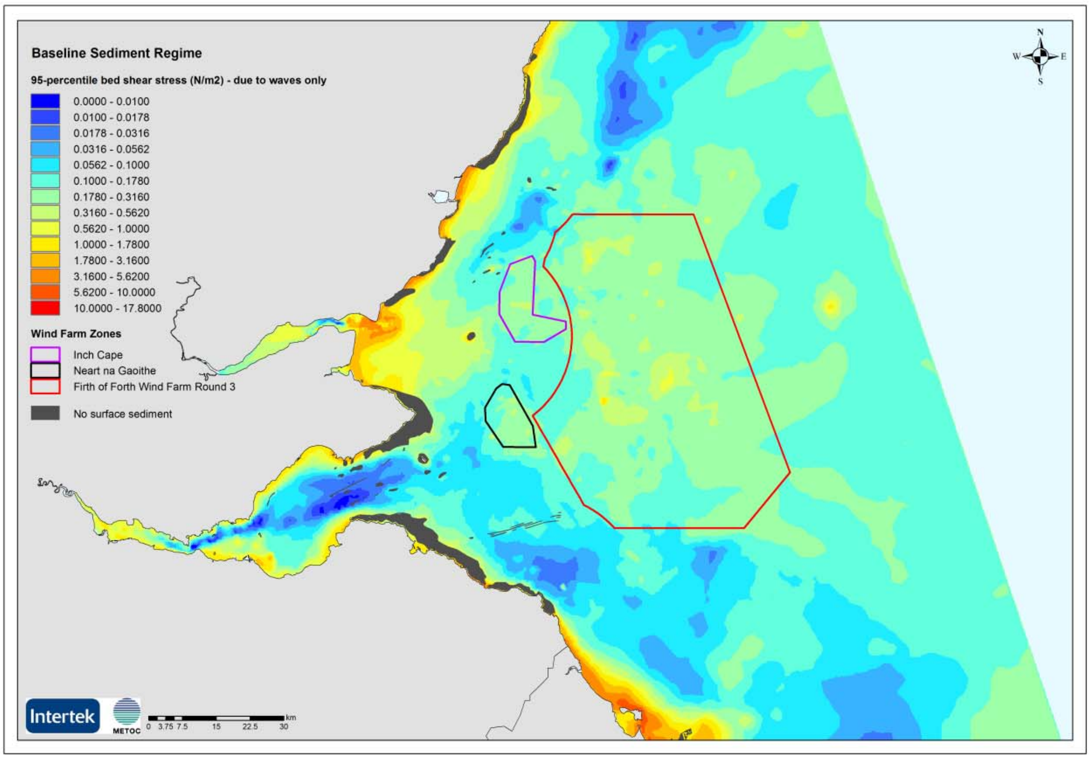
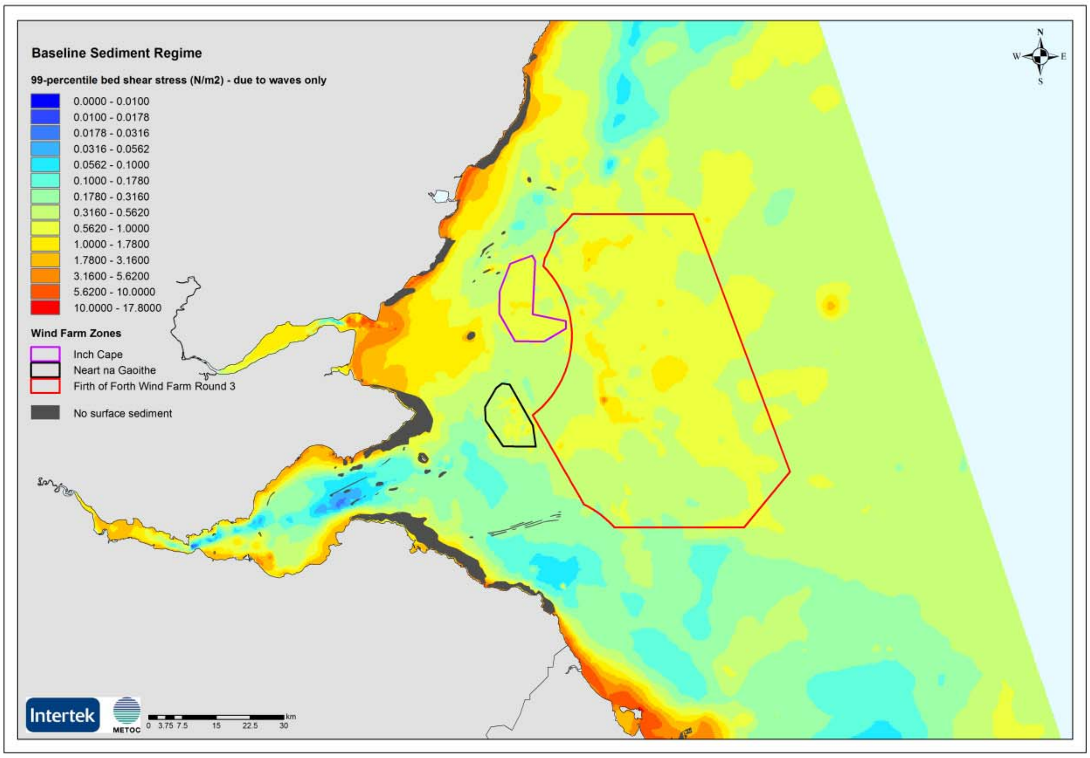


Figure C-57: 99%ile bed shear stress - due to waves (N/m²) – Regional (far-field) scale



C.3.1.4 Baseline bed shear stress due to combined currents plus waves – Regional Area

Figure C-58: 50%ile bed shear stress - due to mean combined current and waves (N/m^2) – Regional (far-field) scale

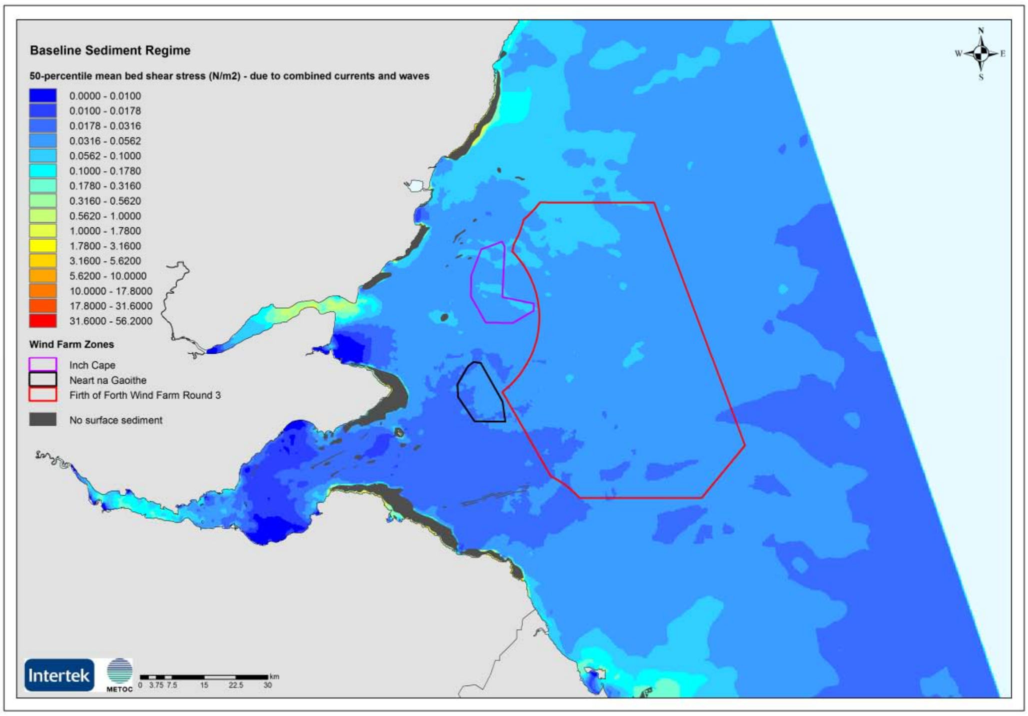


Figure C-59: 90%ile bed shear stress - due to mean combined current and waves (N/m^2) – Regional (far-field) scale

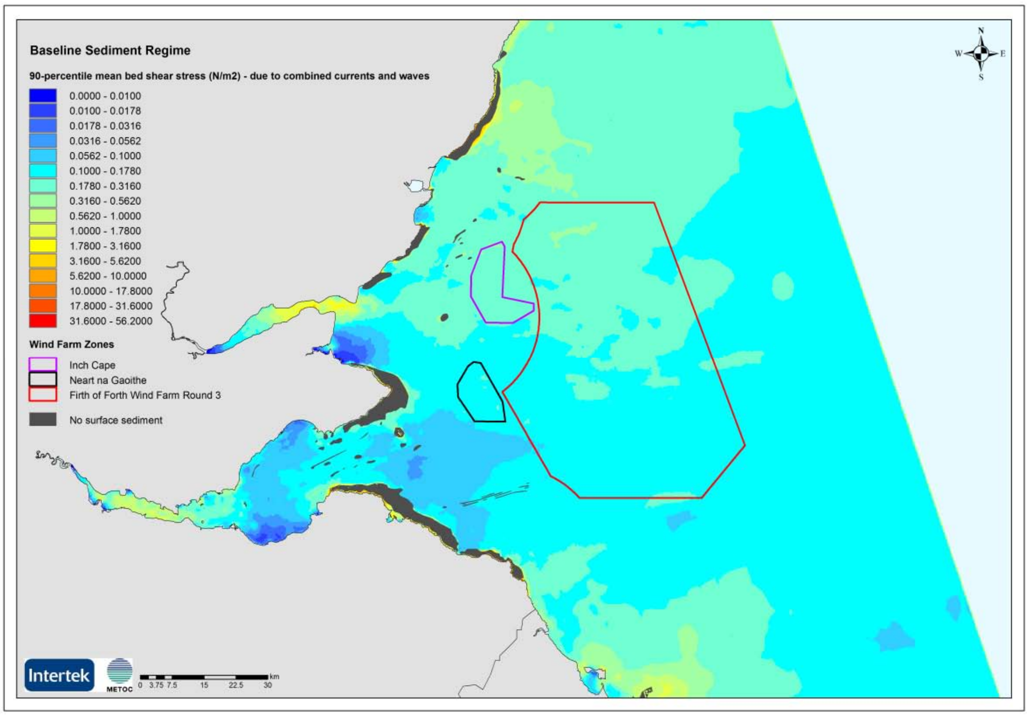


Figure C-60: 95%ile bed shear stress - due to mean combined current and waves (N/m^2) – Regional (far-field) scale

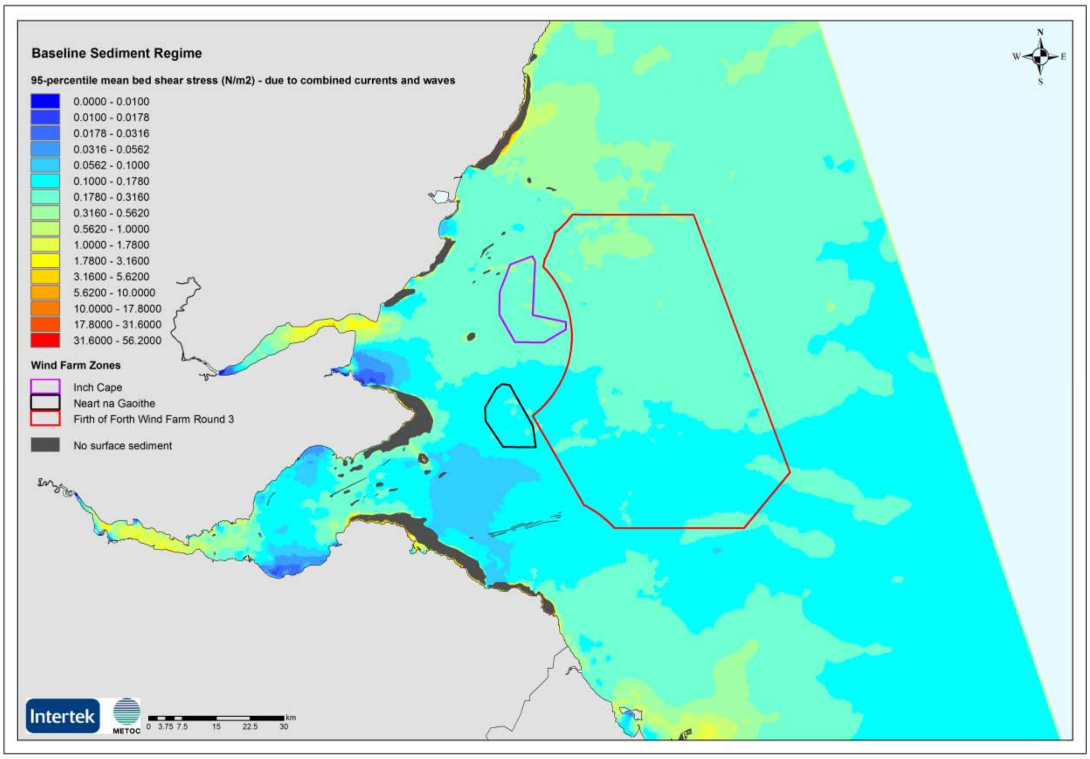


Figure C-61: 99%ile bed shear stress - due to mean combined current and waves (N/m^2) – Regional (far-field) scale

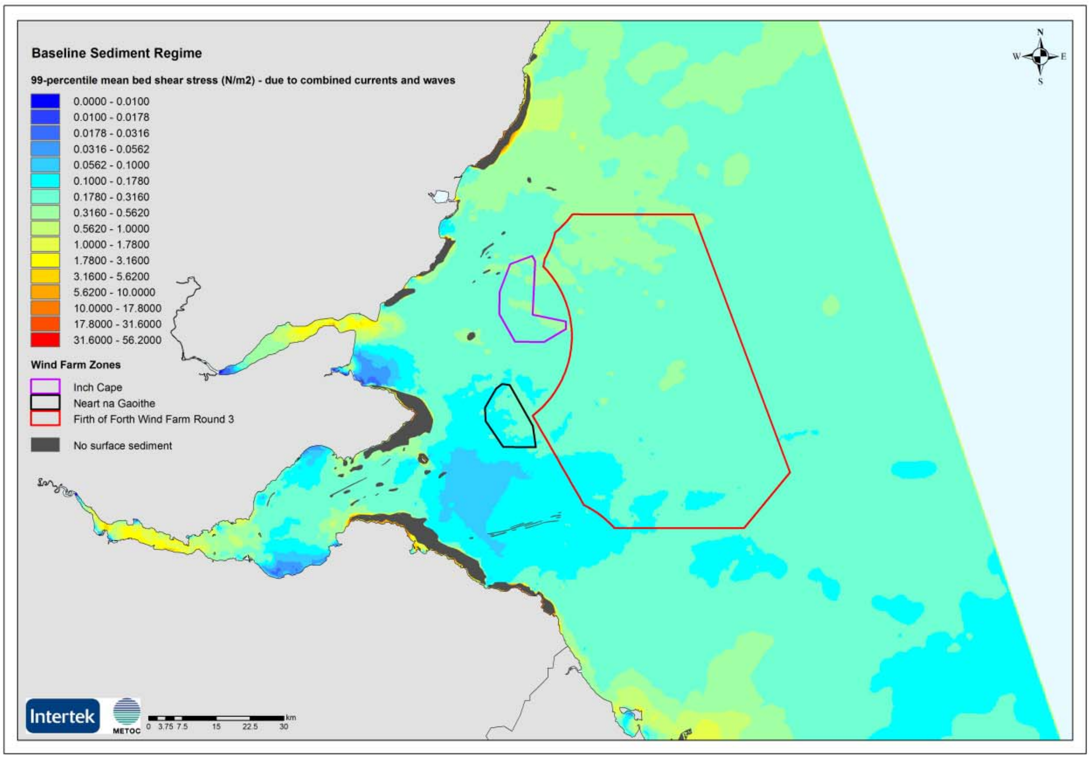


Figure C-62: 50%ile bed shear stress - due to maximum combined current and waves (N/m^2) – Regional (far-field) scale

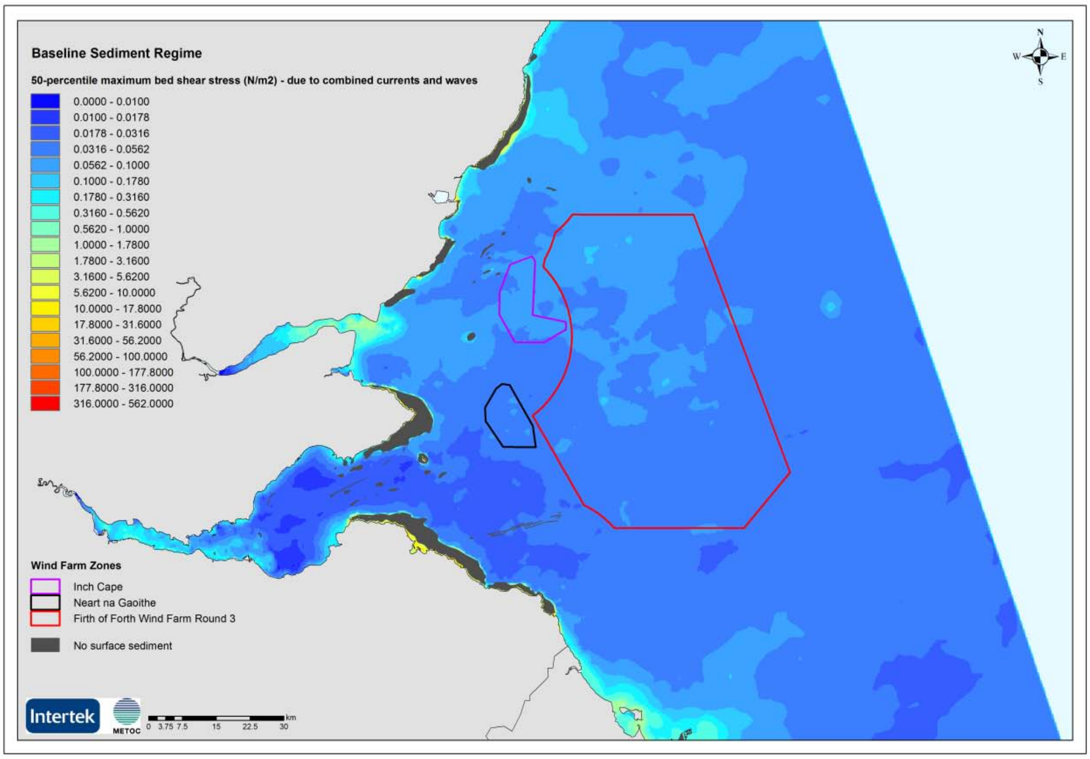


Figure C-63: 90%ile bed shear stress - due to maximum combined current and waves (N/m^2) – Regional (far-field) scale

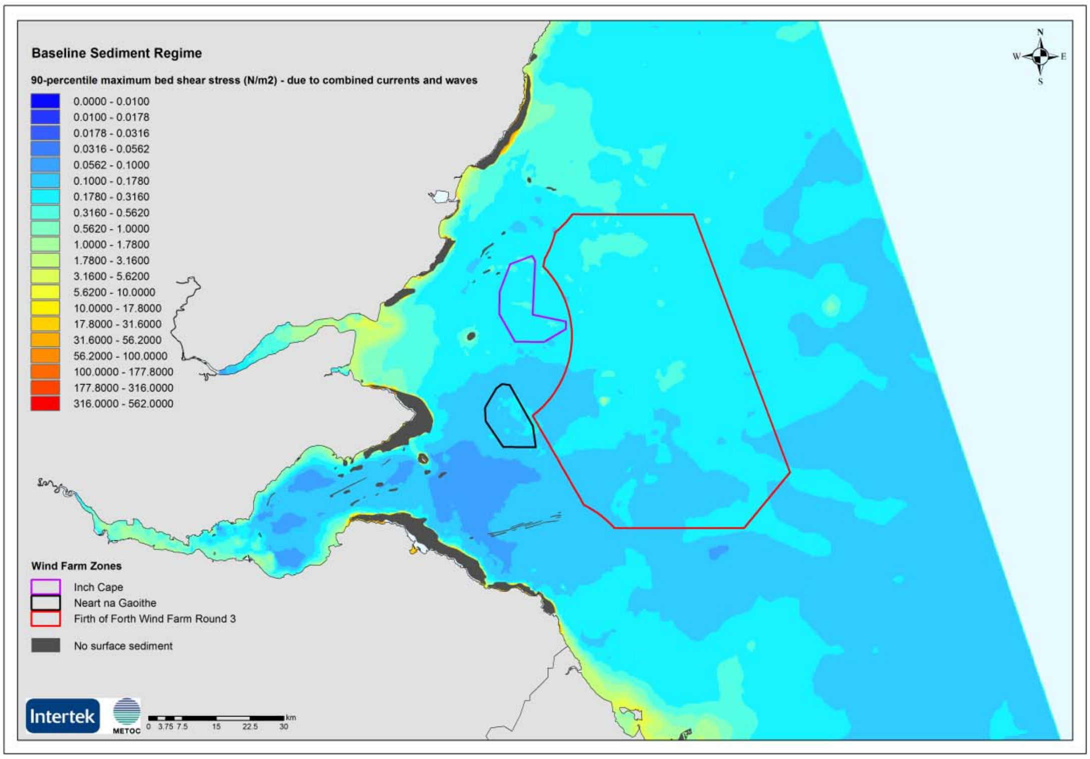


Figure C-64: 95%ile bed shear stress - due to maximum combined current and waves (N/m^2) – Regional (far-field) scale

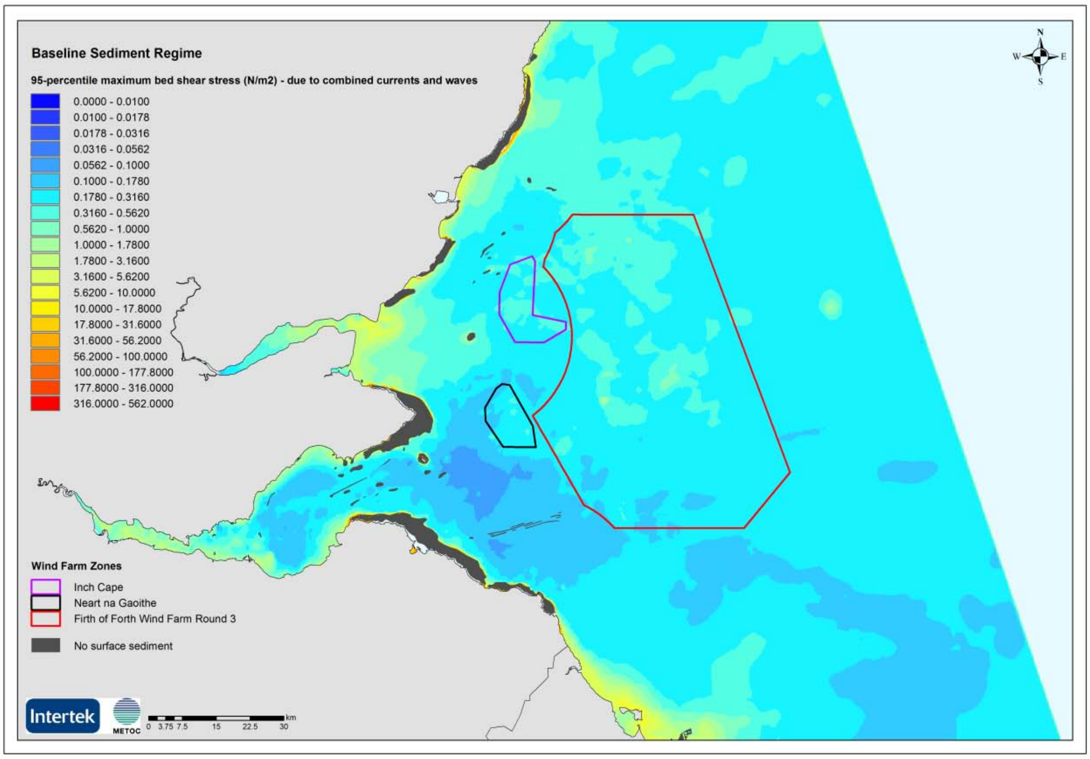
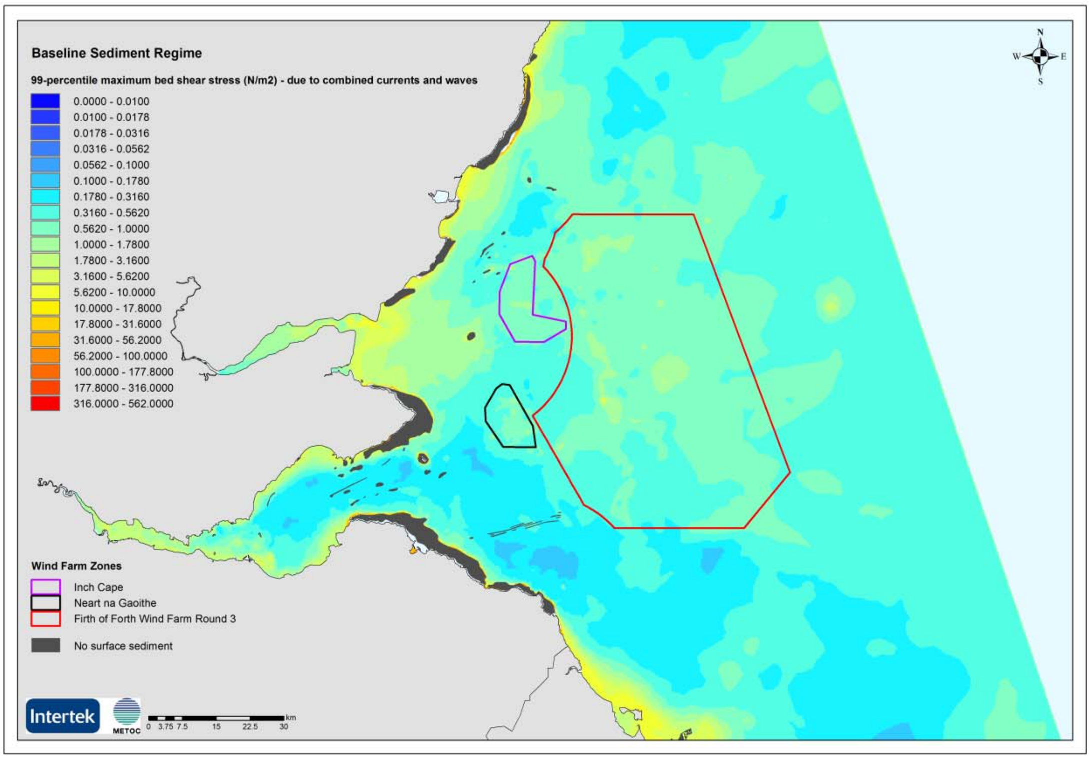


Figure C-65: 99%ile bed shear stress - due to maximum combined current and waves (N/m^2) – Regional (far-field) scale



C.3.1.5 Exceedance of Critical Shear Stress – Regional Area

Figure C-66: Exceedance of the critical shear stress for entrainment due to mean combined bed shear stress – Regional (far-field) scale

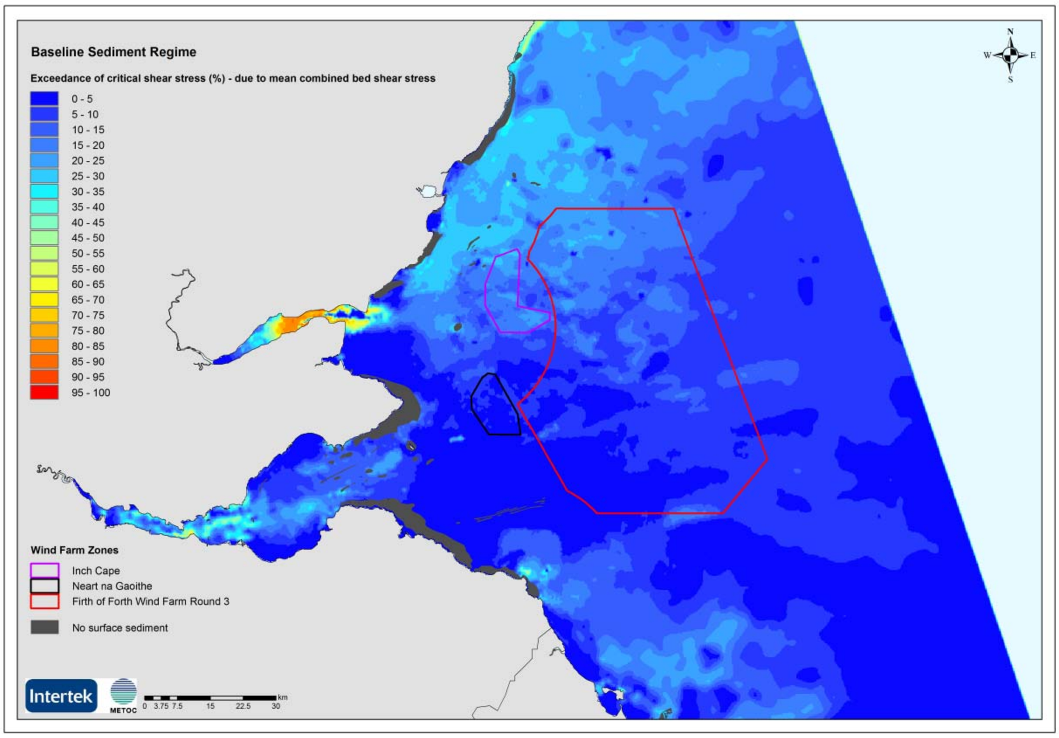
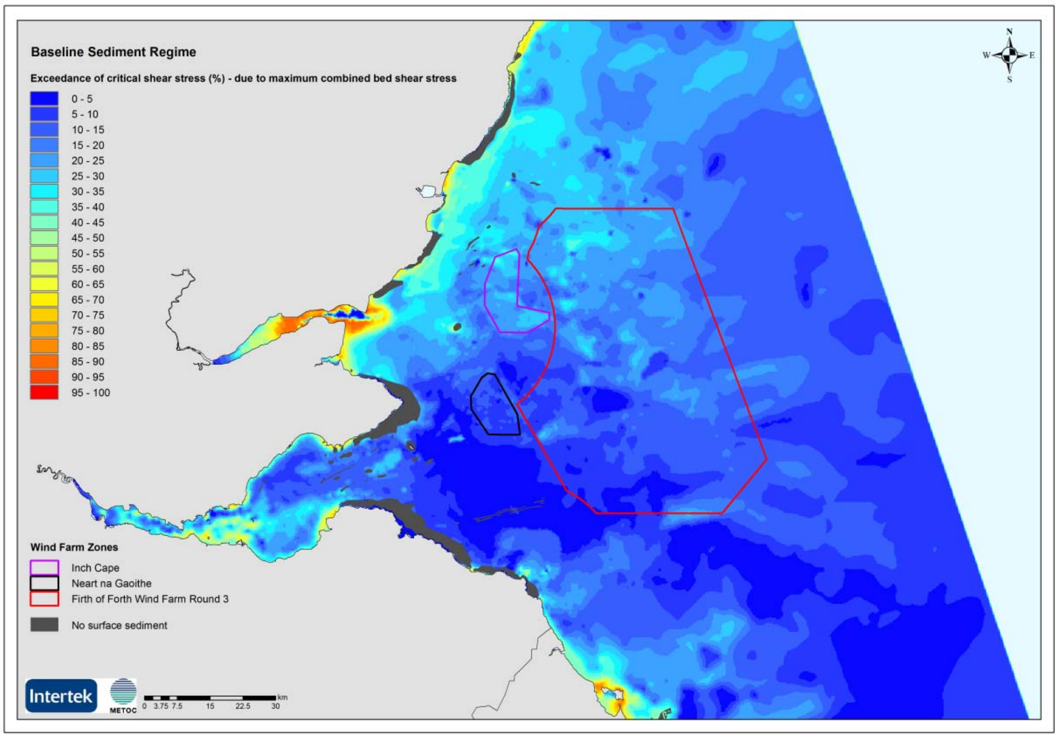


Figure C-67: Exceedance of the critical shear stress for entrainment due to maximum combined bed shear stress – Regional (far-field) scale



C.3.1.6 Long-Term Suspended Sediment Pathways – Regional Area

Figure C-68: Far-field suspended sediment transport pathway – 7 days after release

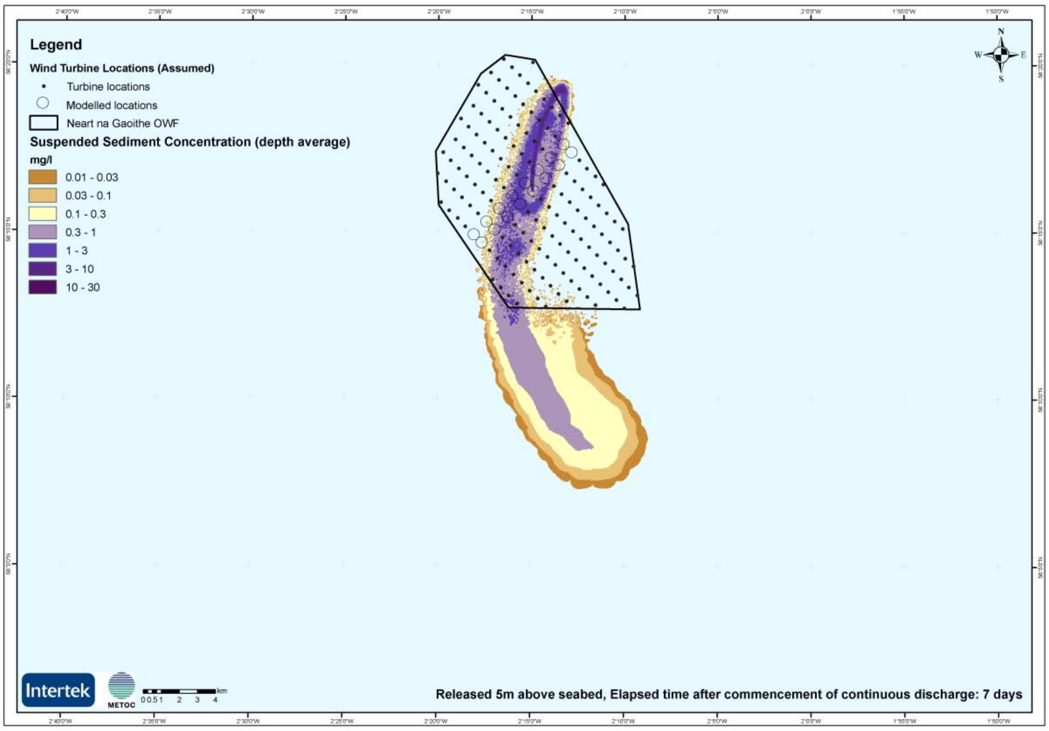
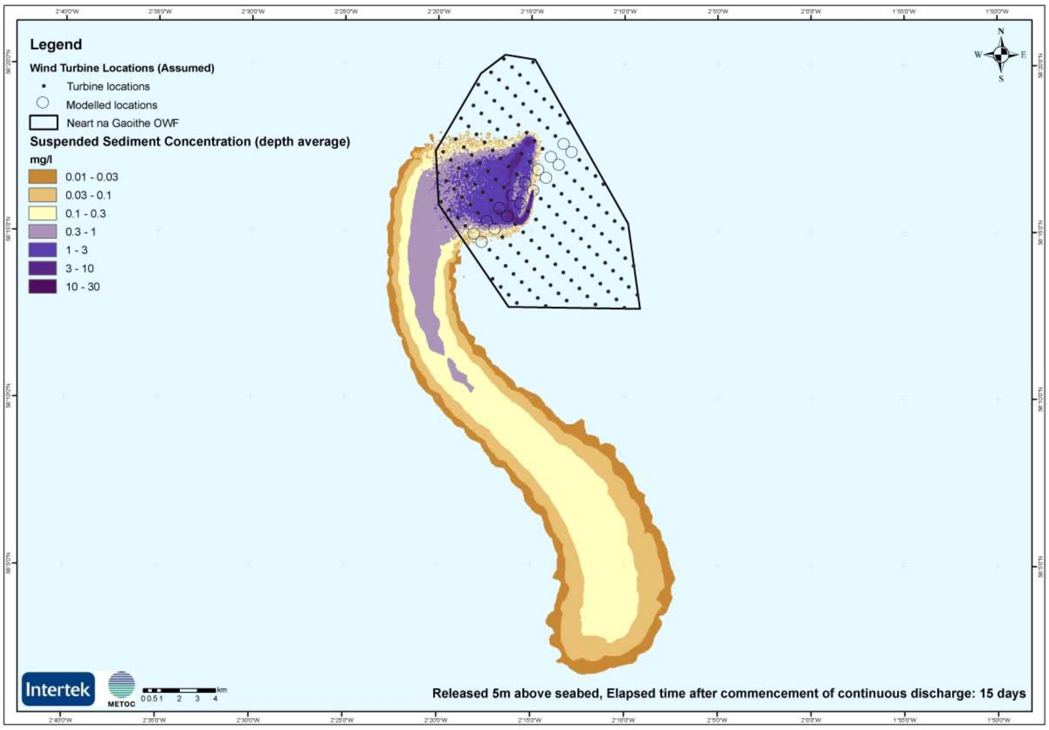


Figure C-69: Far-field suspended sediment transport pathway – 15 days after release



C.3.2 Neart na Gaoithe Offshore Wind Farm Area - Near-field Scale

C.3.2.1 Baseline sediment map and critical shear stress – Neart na Gaoithe Area

Figure C-70: Critical shear stress for entrainment (N/m^2) – Neart na Gaoithe OWF (near-field) scale

C.3.2.2 Baseline bed shear stress due to currents only – Neart na Gaoithe Area

Figure C-71: 50%ile bed shear stress - due to currents (N/m^2) – Neart na Gaoithe OWF (near-field) scale

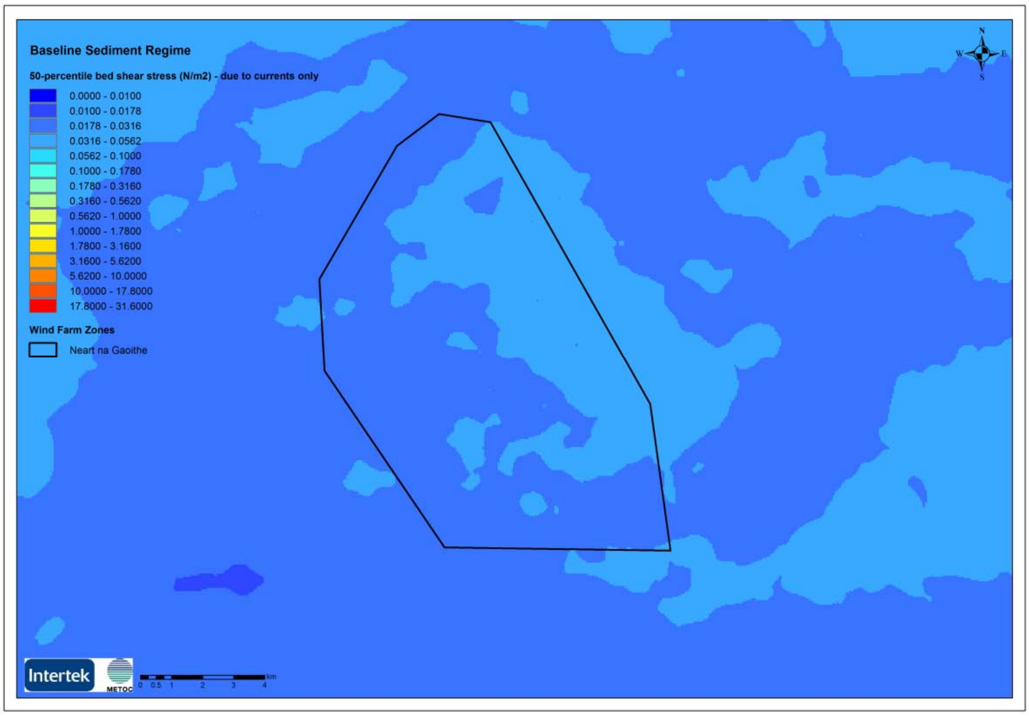


Figure C-72: 90%ile bed shear stress - due to currents (N/m^2) – Neart na Gaoithe OWF (near-field) scale

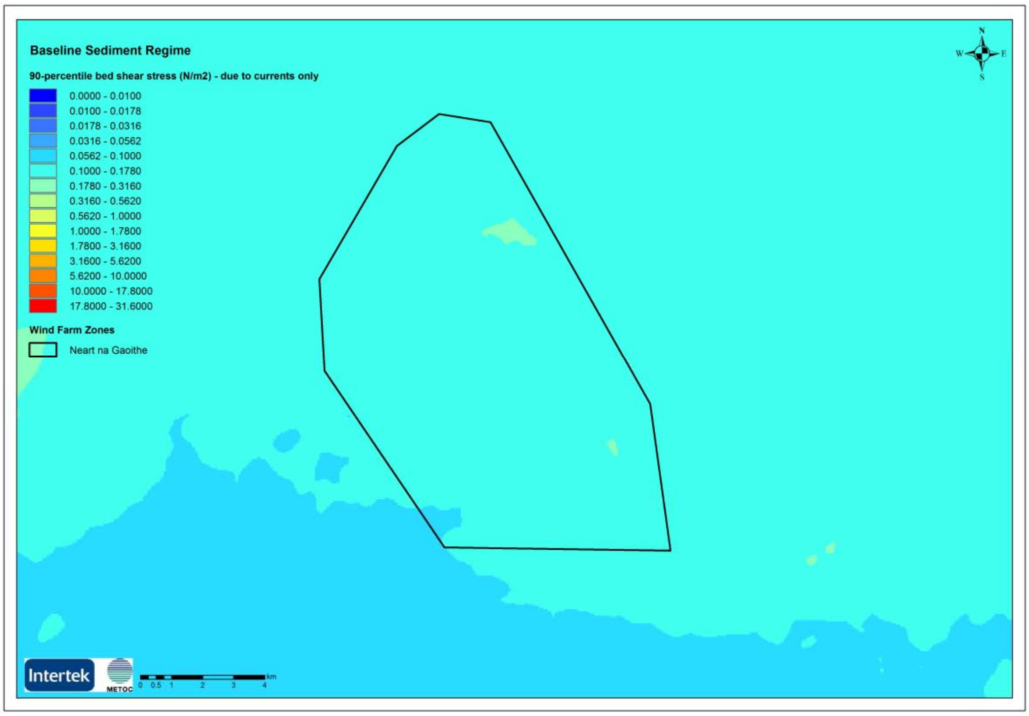


Figure C-73: 95%ile bed shear stress - due to currents (N/m^2) – Neart na Gaoithe OWF (near-field) scale

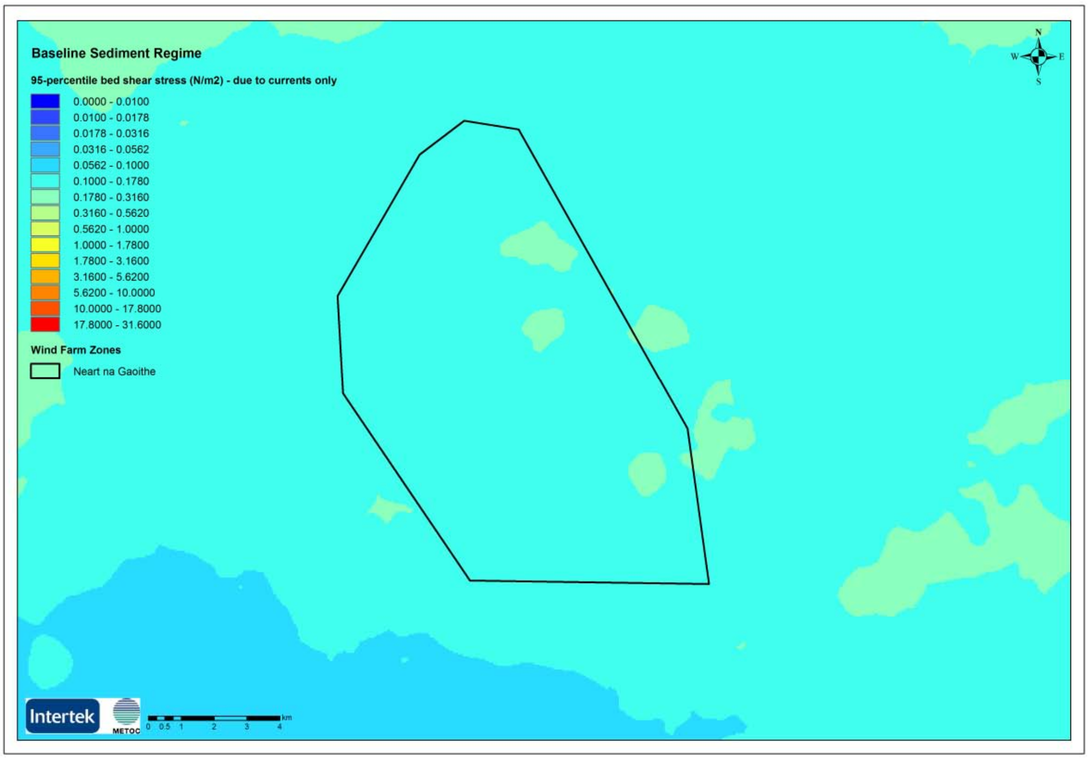
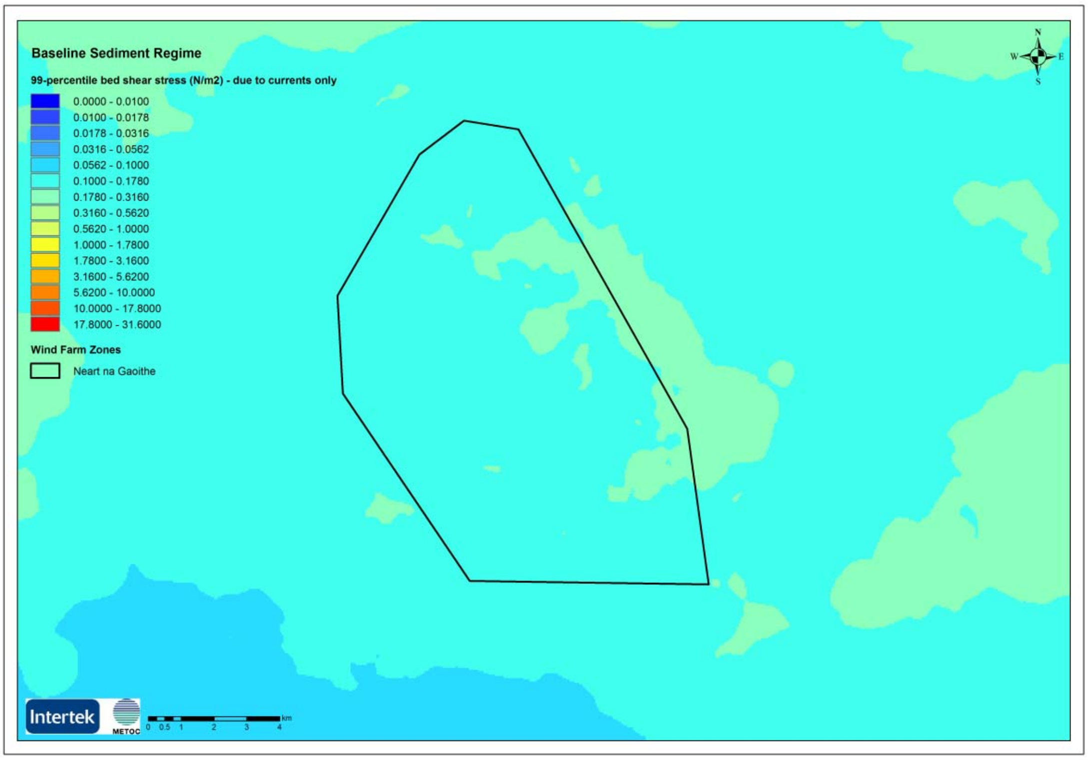


Figure C-74: 99%ile bed shear stress - due to currents (N/m^2) – Neart na Gaoithe OWF (near-field) scale



C.3.2.3 Baseline bed shear stress due to waves only – Neart na Gaoithe Area

Figure C-75: 50%ile bed shear stress - due to waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

Figure C-76: 90%ile bed shear stress - due to waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

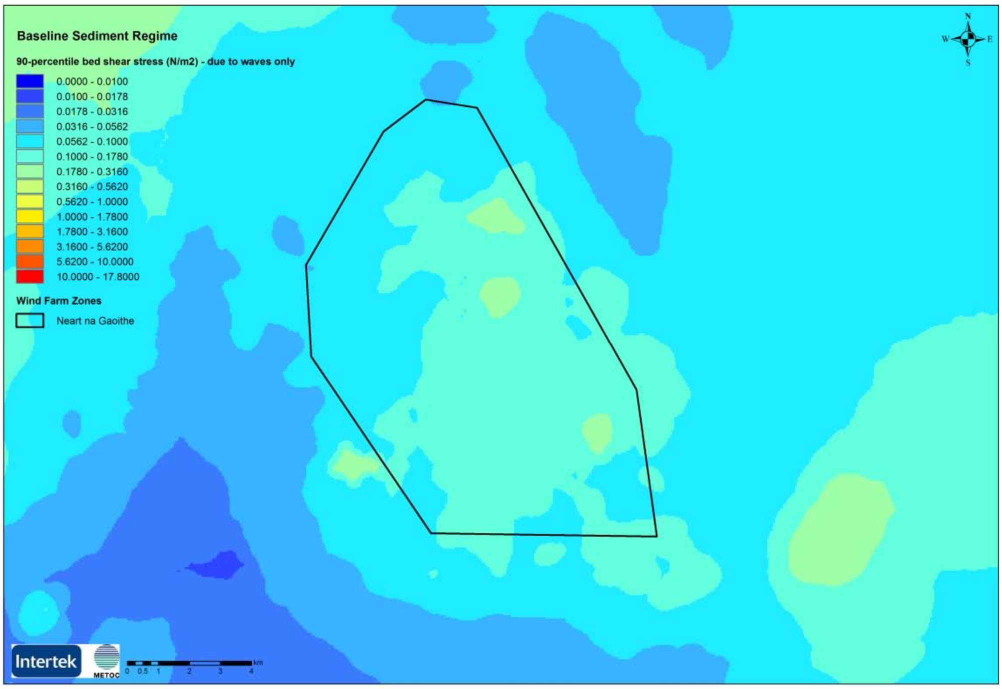


Figure C-77: 95%ile bed shear stress - due to waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

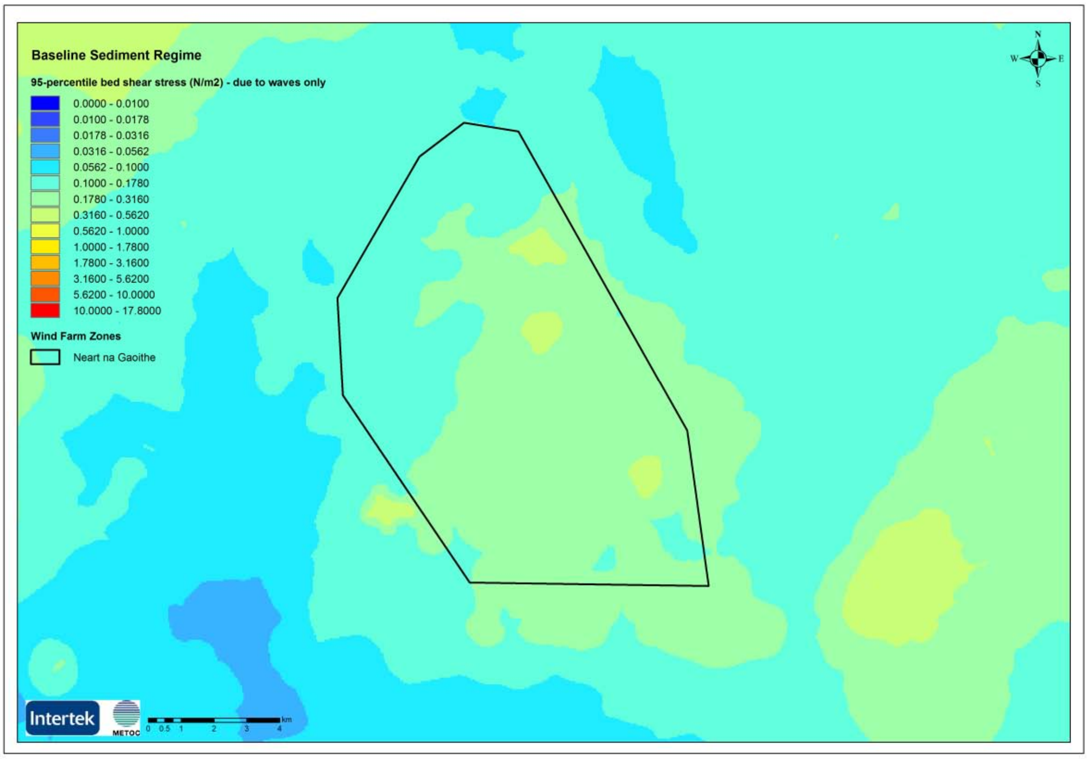
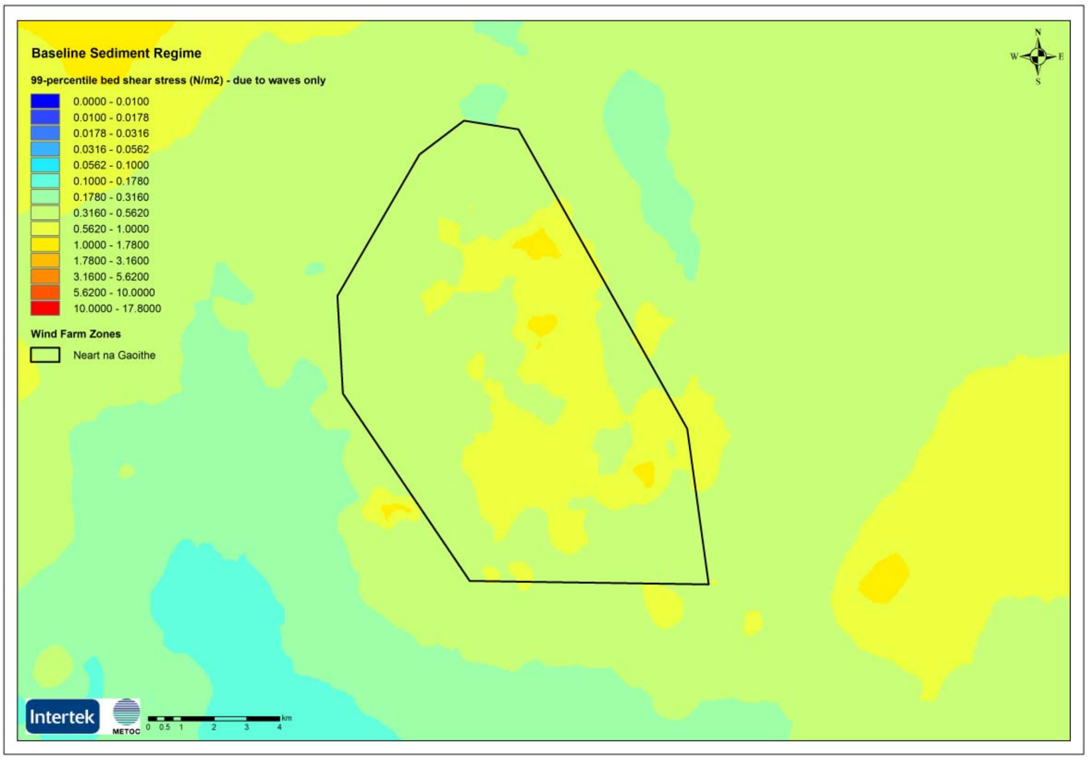


Figure C-78: 99%ile bed shear stress - due to waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale



C.3.2.4 Baseline bed shear stress due to combined currents plus waves – Neart na Gaoithe Area

Figure C-79: 50%ile bed shear stress - due to mean combined current and waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

Figure C-80: 90%ile bed shear stress - due to mean combined current and waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

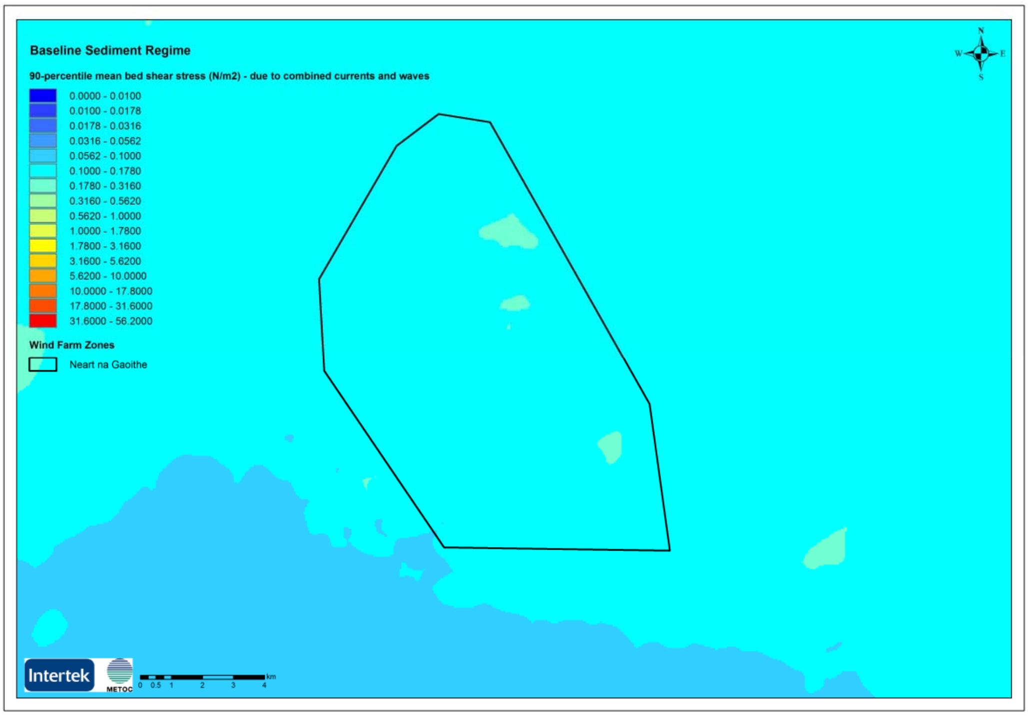


Figure C-81: 95%ile bed shear stress - due to mean combined current and waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

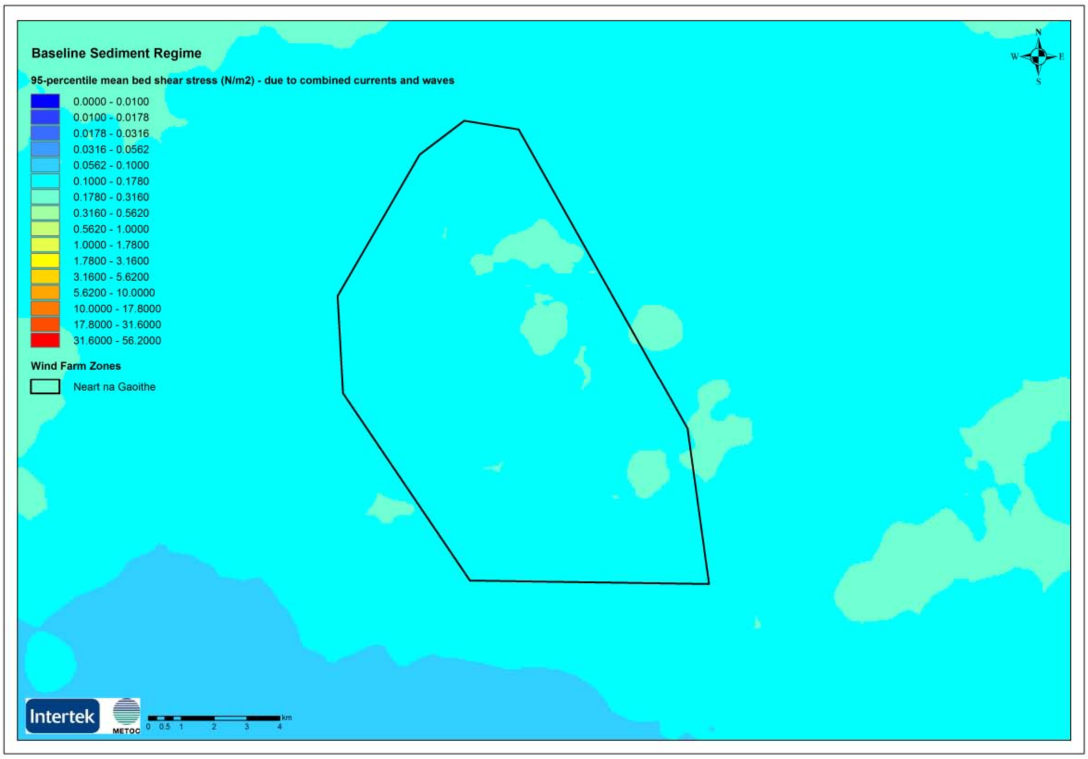


Figure C-82: 99%ile bed shear stress - due to mean combined current and waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

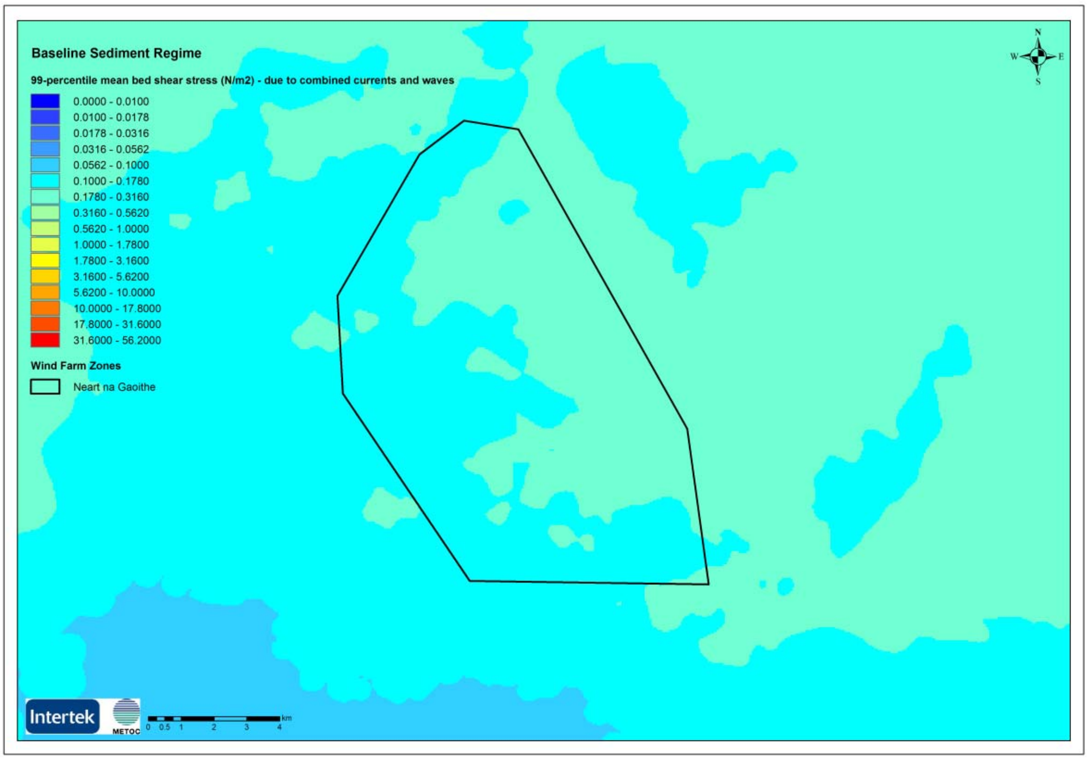


Figure C-83: 50%ile bed shear stress - due to maximum combined current and waves (N/m²) – Neart na Gaoithe OWF (near-field) scale

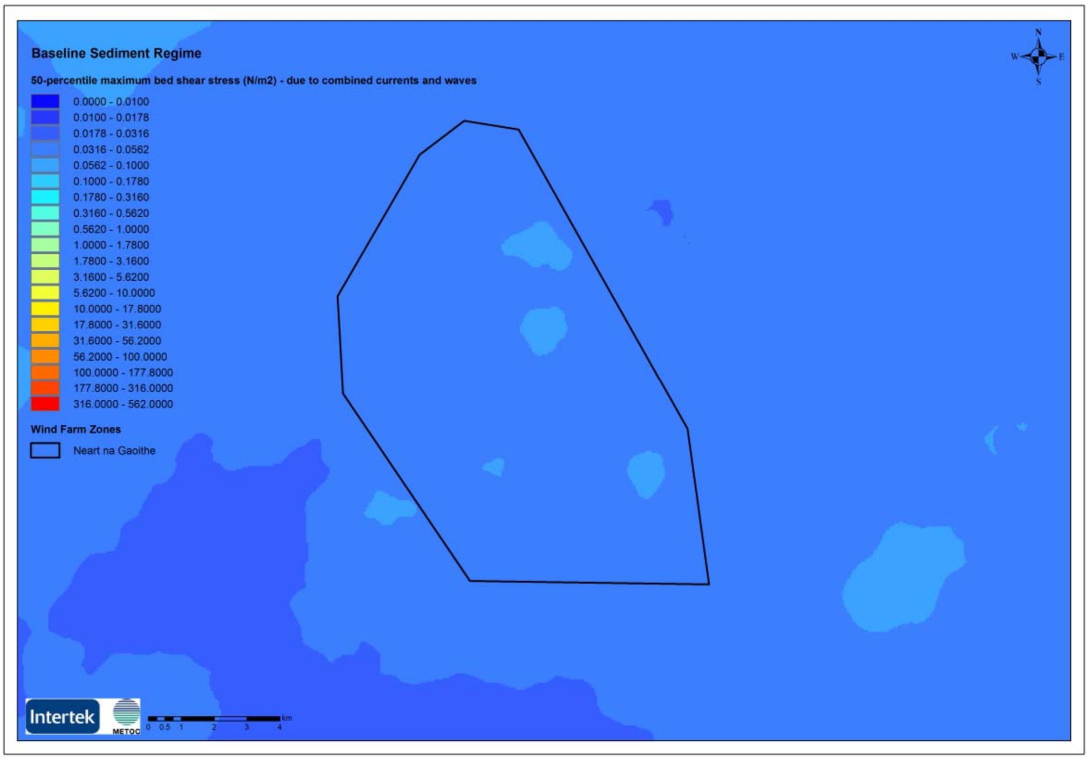


Figure C-84: 90%ile bed shear stress - due to maximum combined current and waves (N/m²) – Neart na Gaoithe OWF (near-field) scale

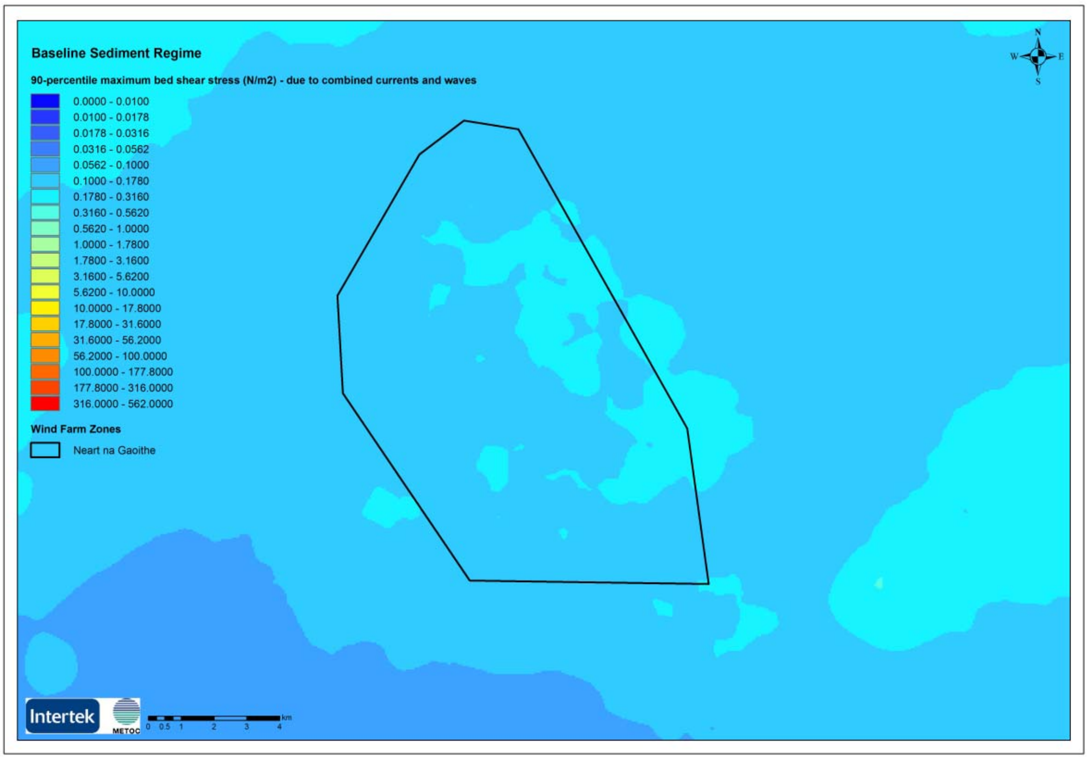


Figure C-85: 95%ile bed shear stress - due to maximum combined current and waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale

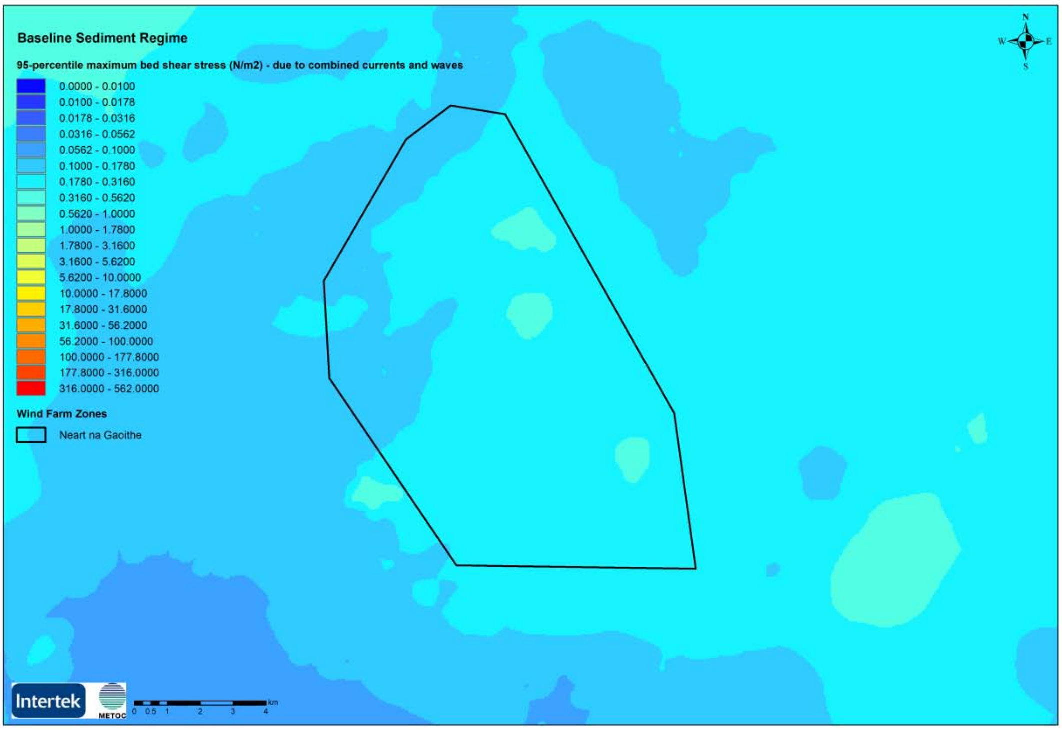
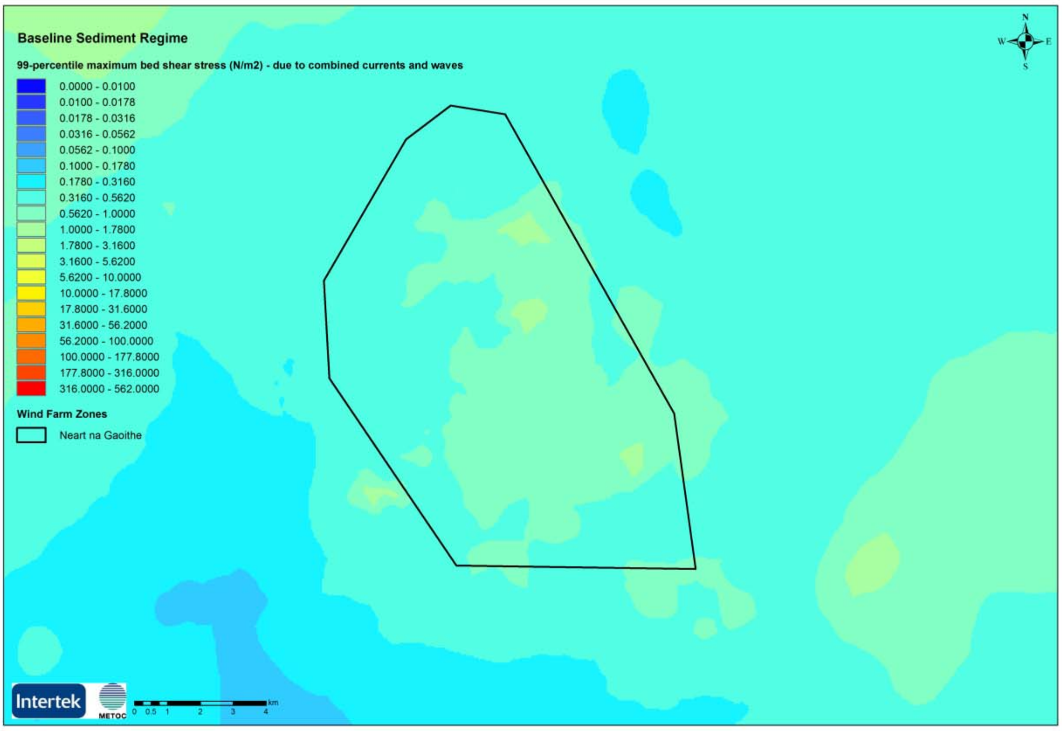


Figure C-86: 99%ile bed shear stress - due to maximum combined current and waves (N/m^2) – Neart na Gaoithe OWF (near-field) scale



C.3.2.5 Exceedance of Critical Shear Stress – Neart na Gaoithe Area

Figure C-87: Exceedance of the critical shear stress for entrainment due to mean combined bed shear stress – Neart na Gaoithe OWF (near-field) scale

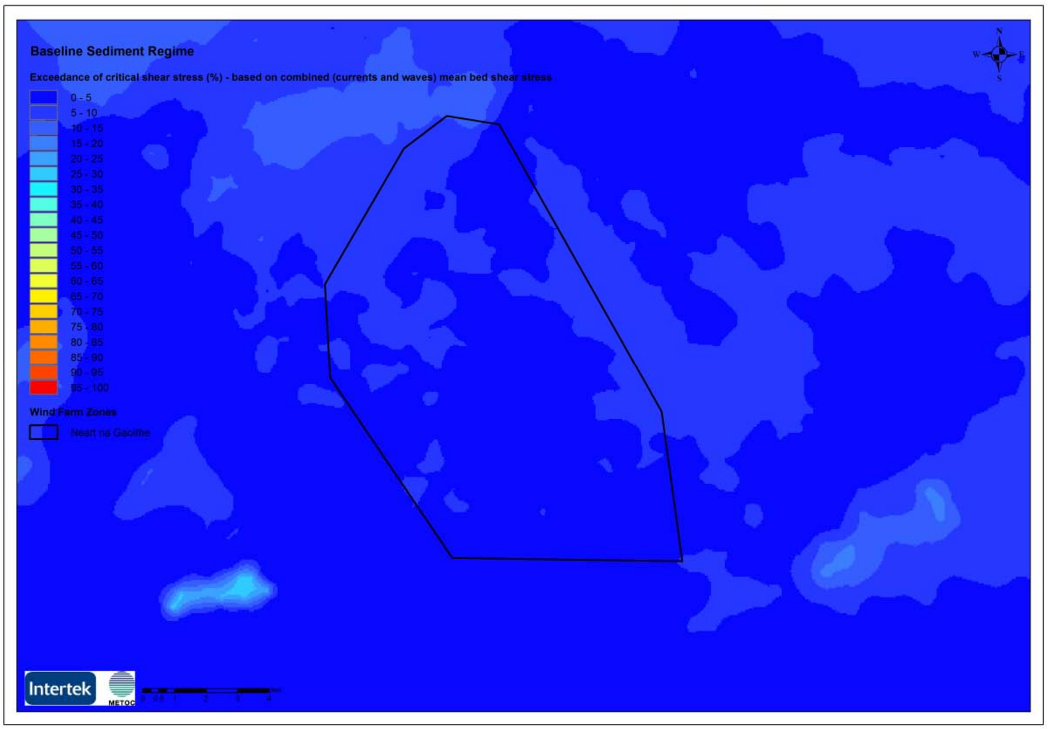
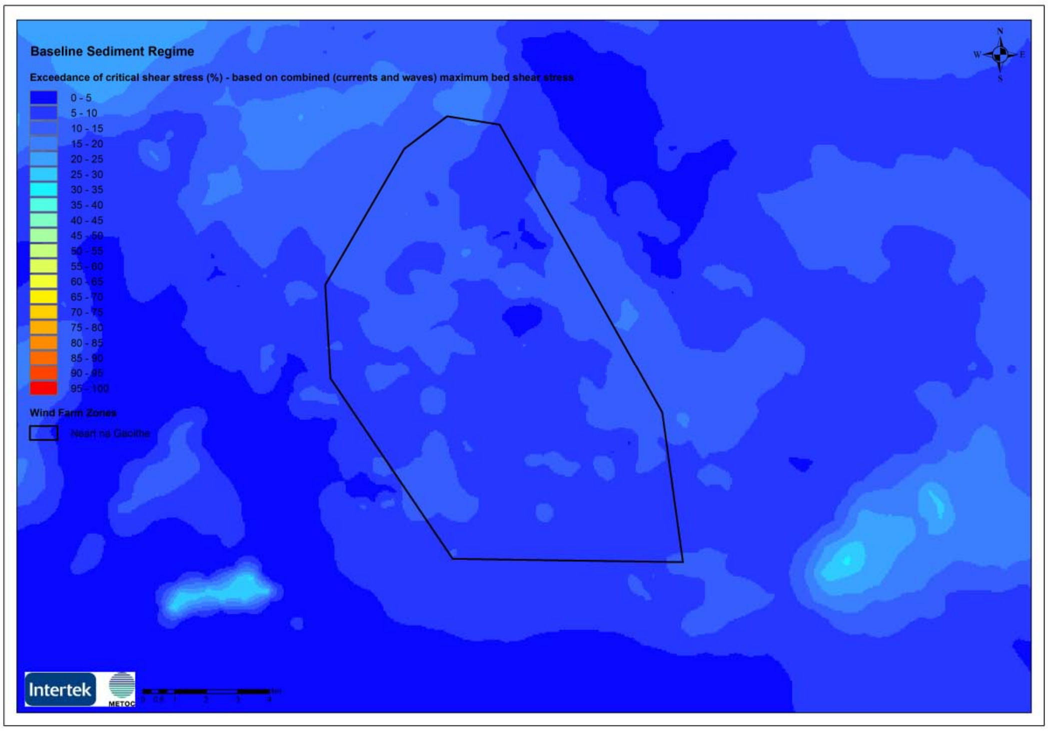


Figure C-88: Exceedance of the critical shear stress for entrainment due to maximum combined bed shear stress – Neart na Gaoithe OWF (near-field) scale



C.4 SUMMARY OF MODEL PERFORMANCE AT THE NEART NA GAOITHE SITE

Figure C-89: Neart na Gaoithe ACDP Spring Modelled Tidal Elevations against Predicted Field Data

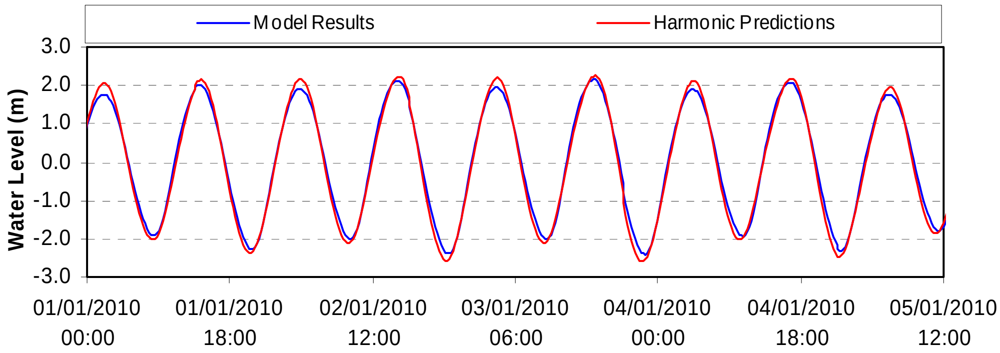


Figure C-90: Neart na Gaoithe ADCP Spring Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

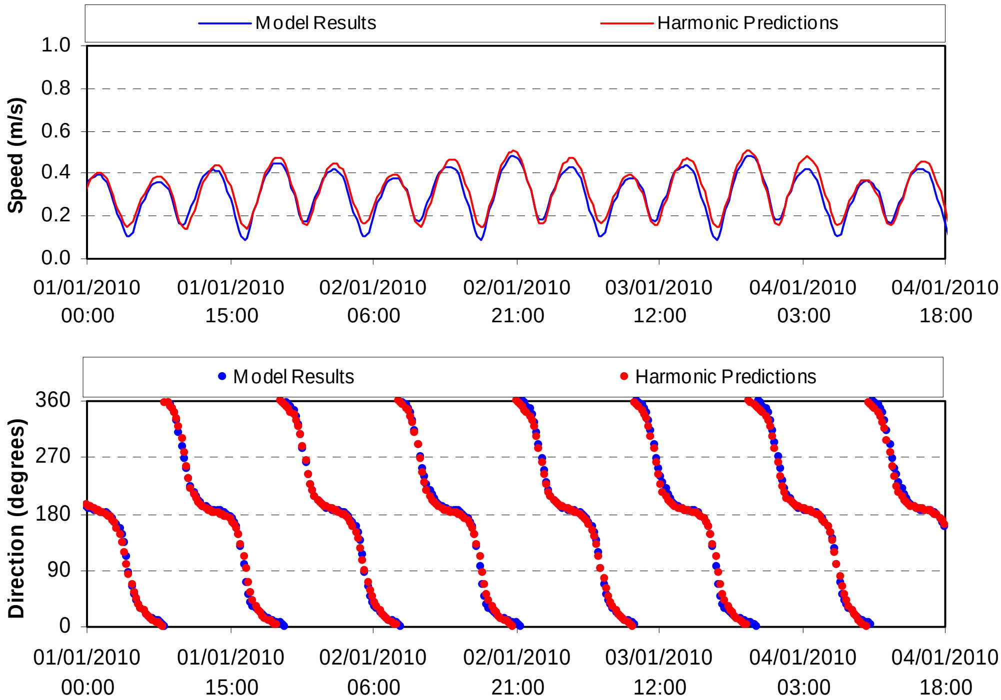


Figure C-91: Neart na Gaoithe ACDP Neap Modelled Tidal Elevations against Predicted Field Data

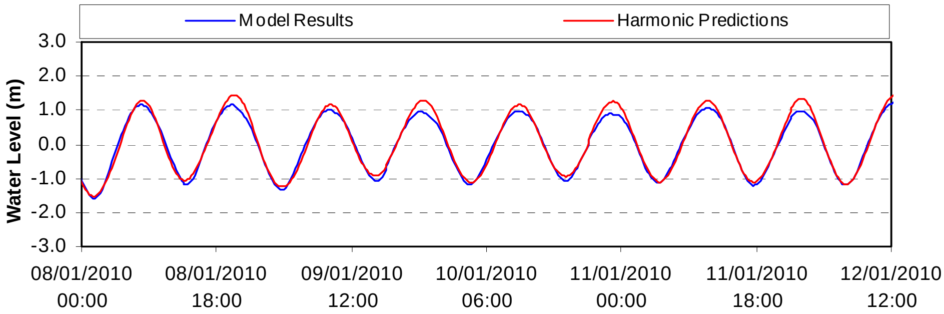


Figure C-92: Neart na Gaoithe ADCP Neap Modelled Tidal Currents Speed (ms-1) and Current Direction (deg T) against Predicted Field Data

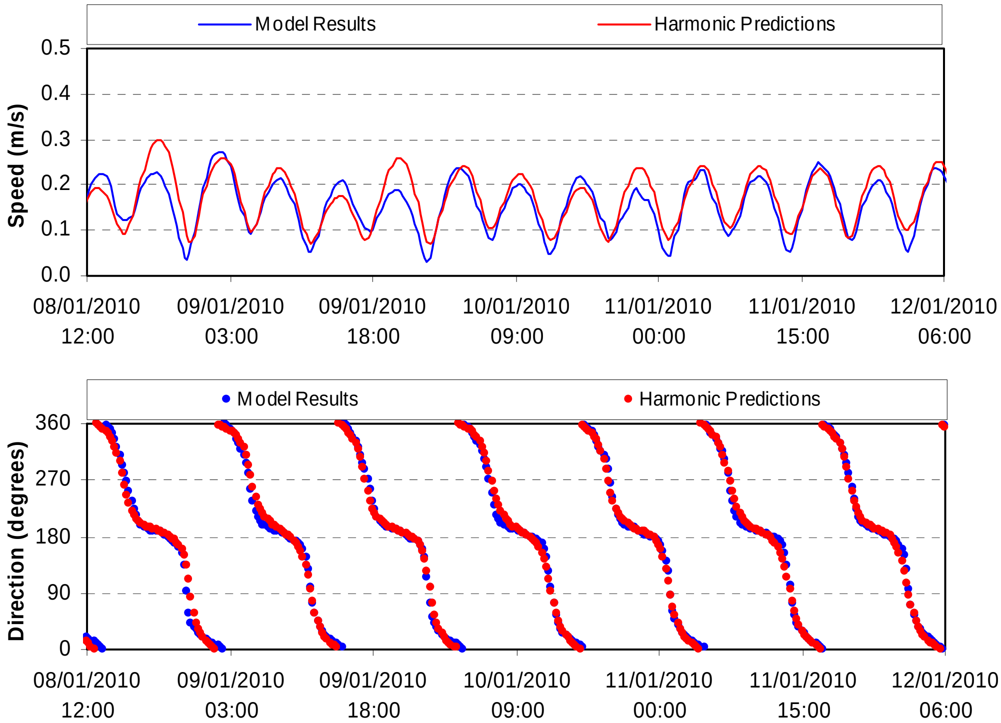


Figure C-93: Easterly Storm Event - Neart na Gaoithe, Waverider Buoy Modelled Hs (m), Tp (s) and Wave Direction (deg T) against Measured Field Data

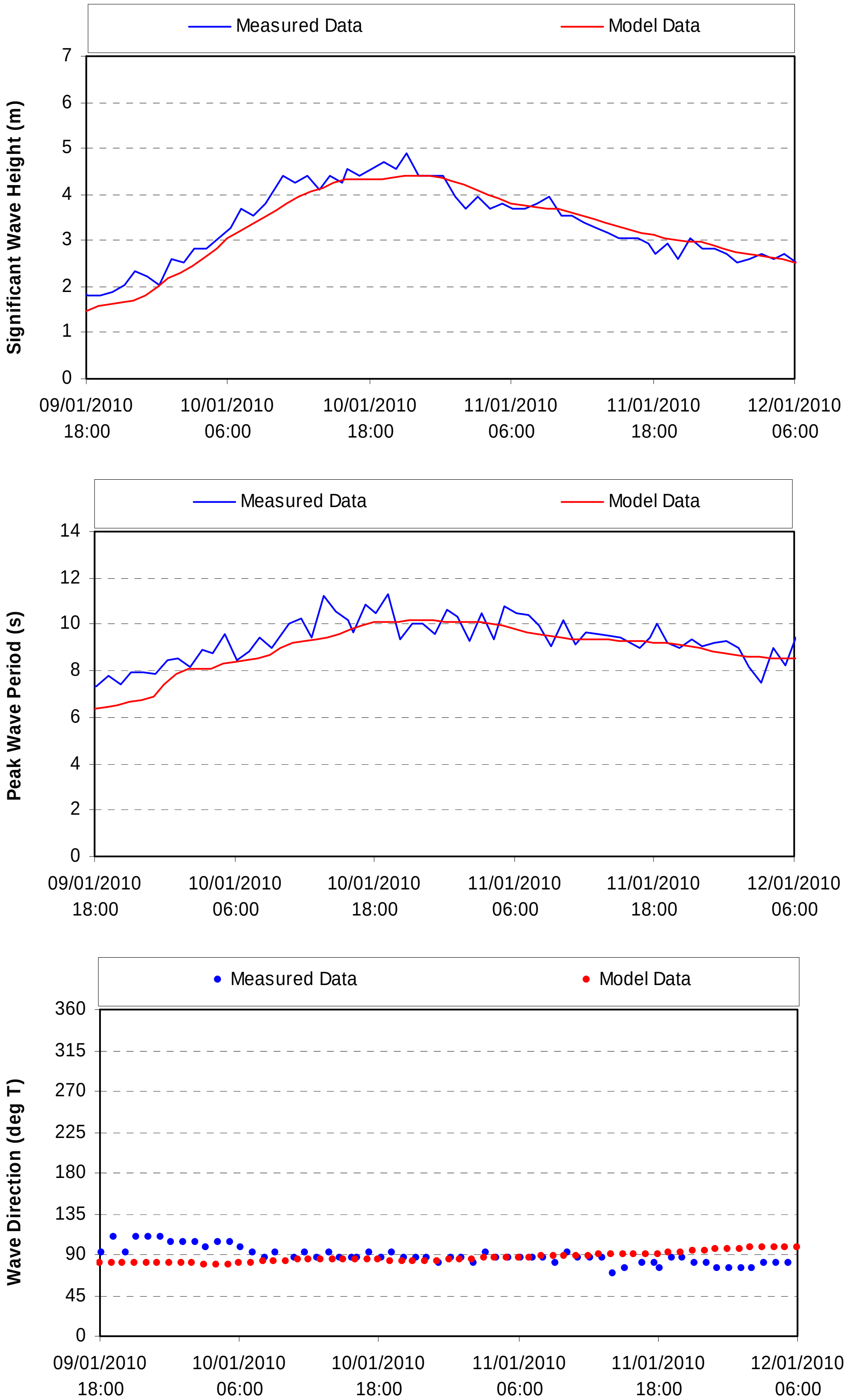


Figure C-94: Offshore Wind Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

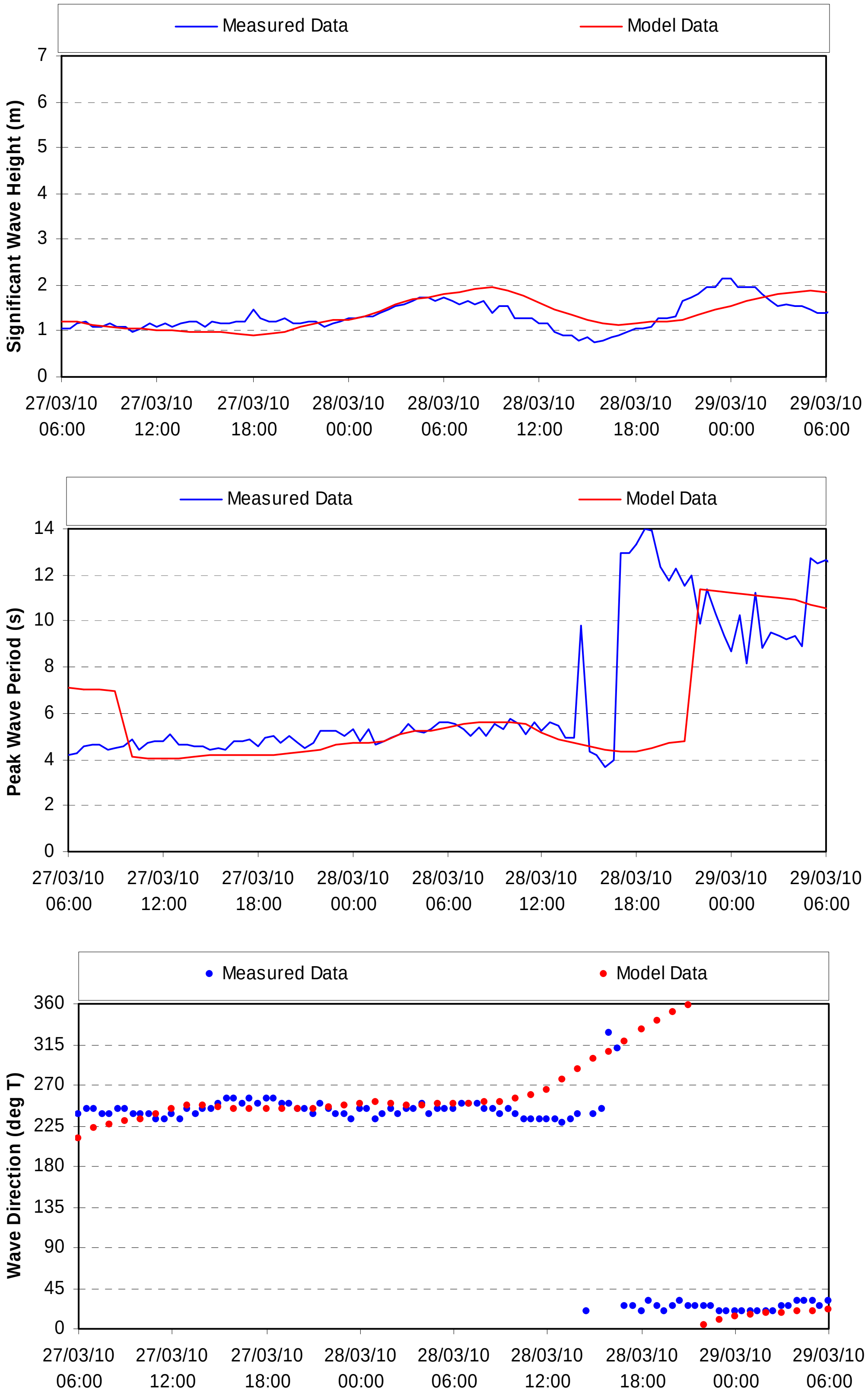


Figure C-95: Northerly Storm Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data

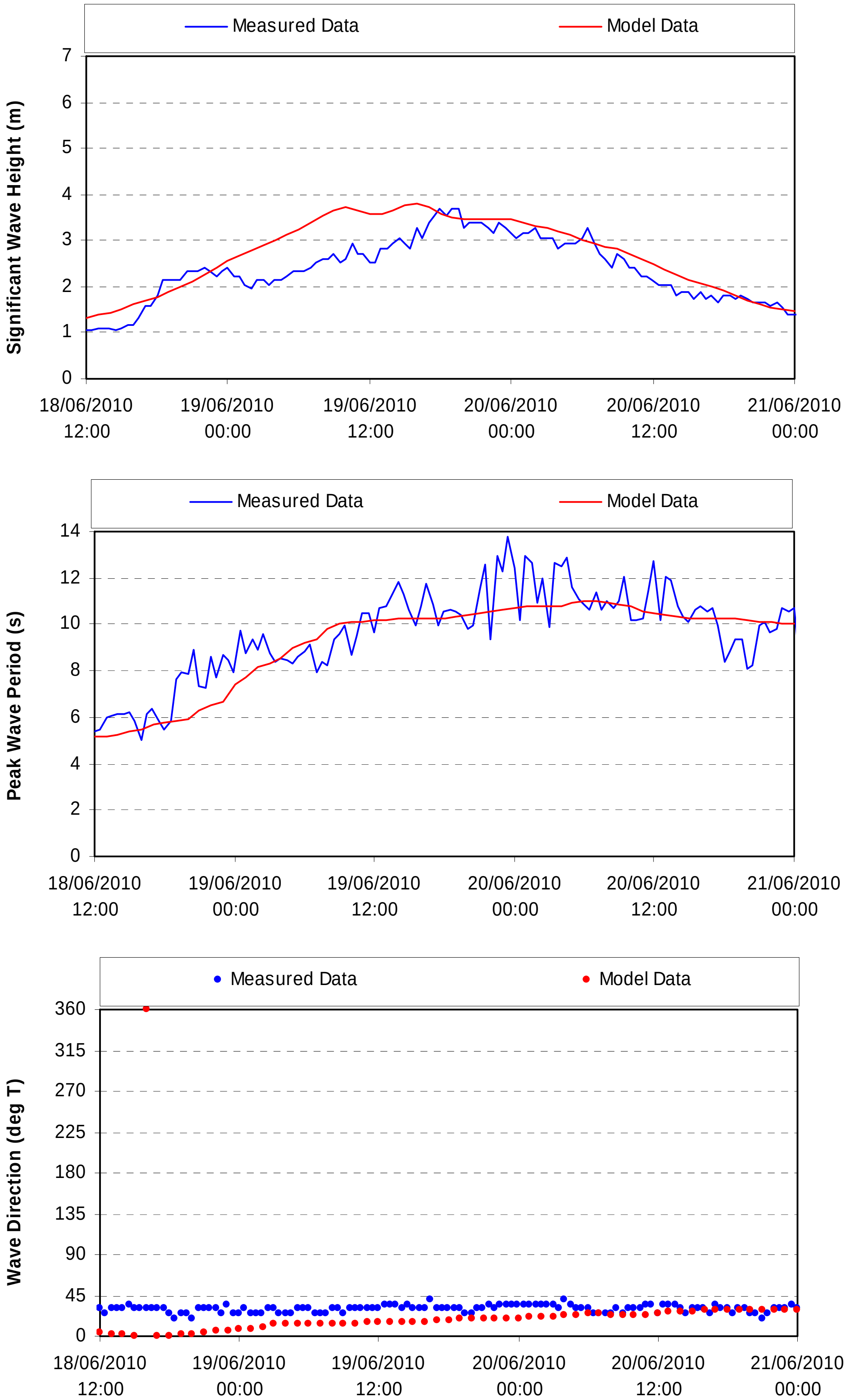


Figure C-96: Southeasterly Storm Event – Neart na Gaoithe, Waverider Buoy Modelled Hs (m), Tp (s) and Wave Direction (deg T) against Measured Field Data

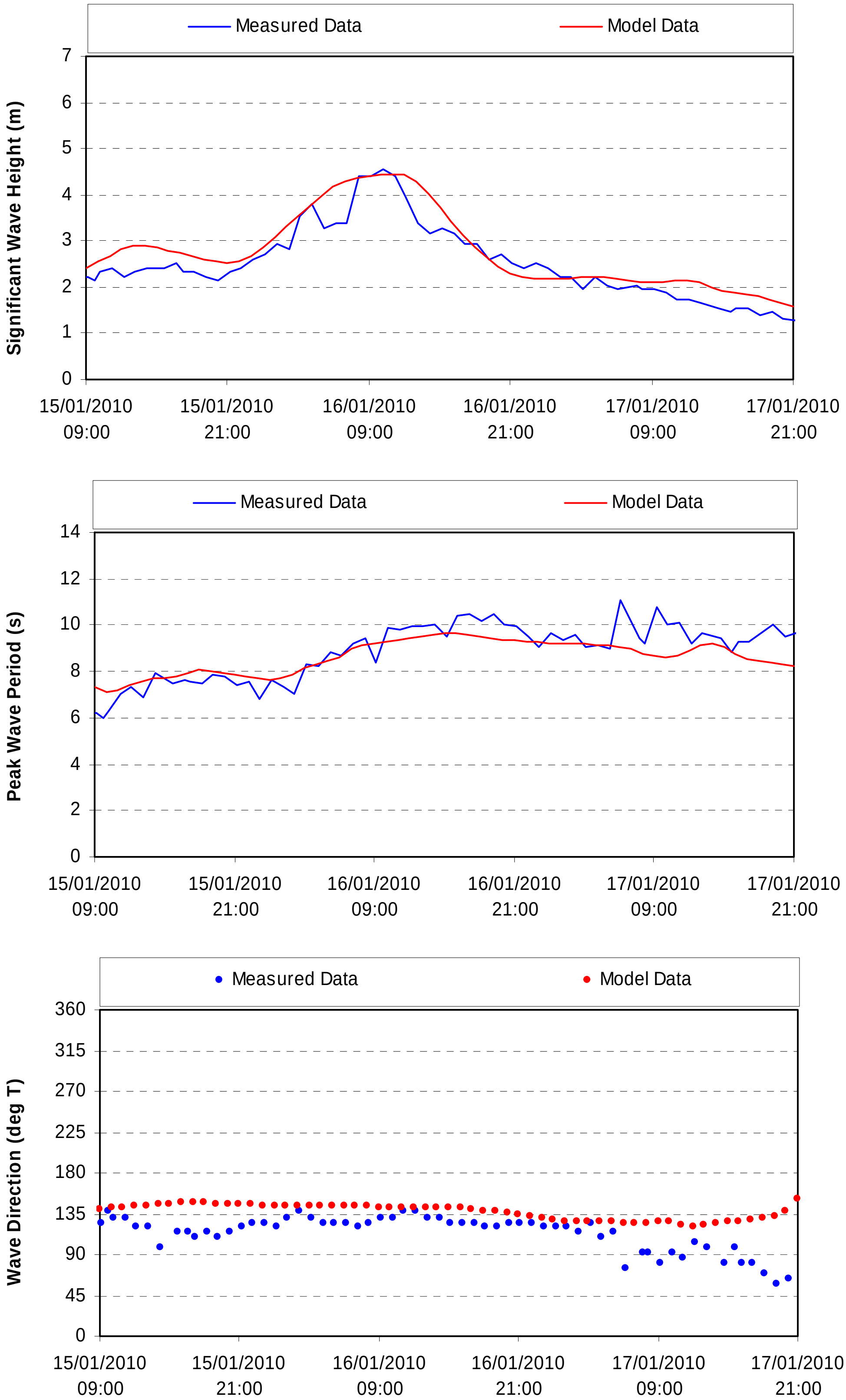
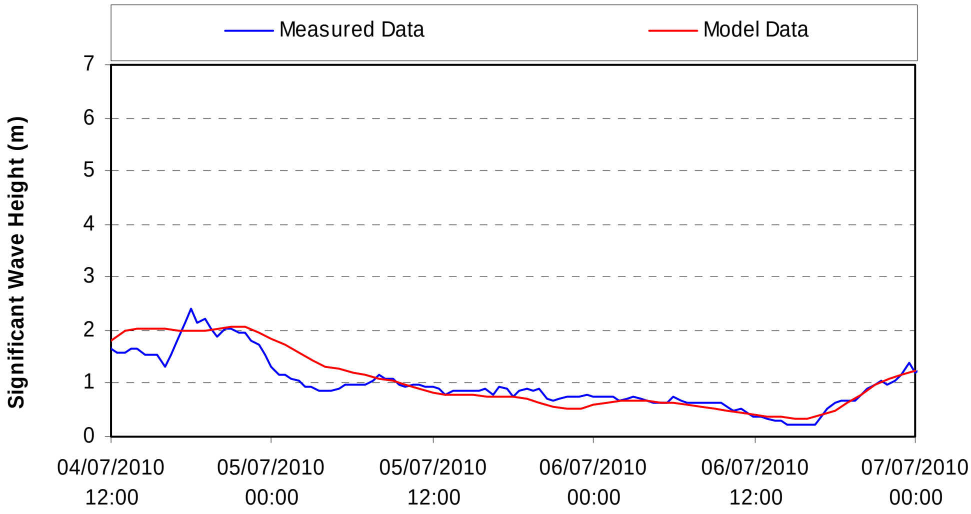
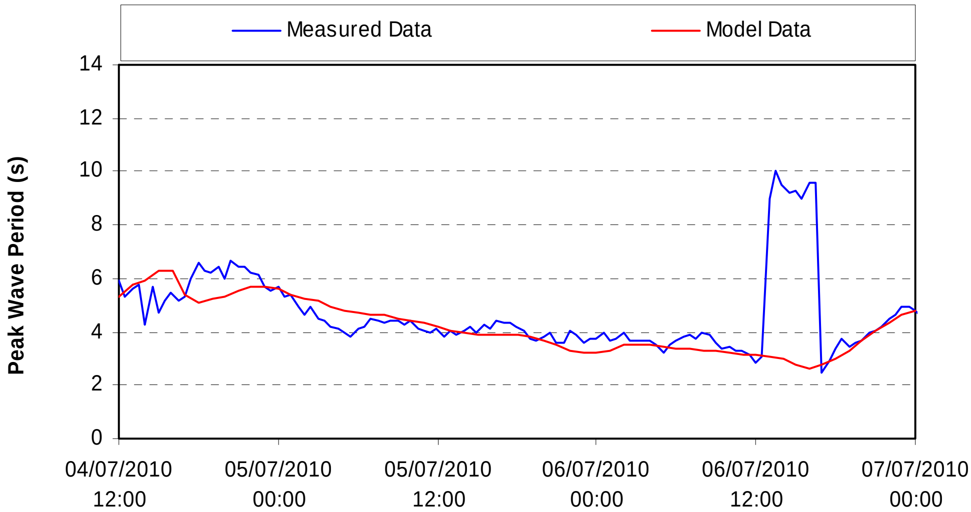
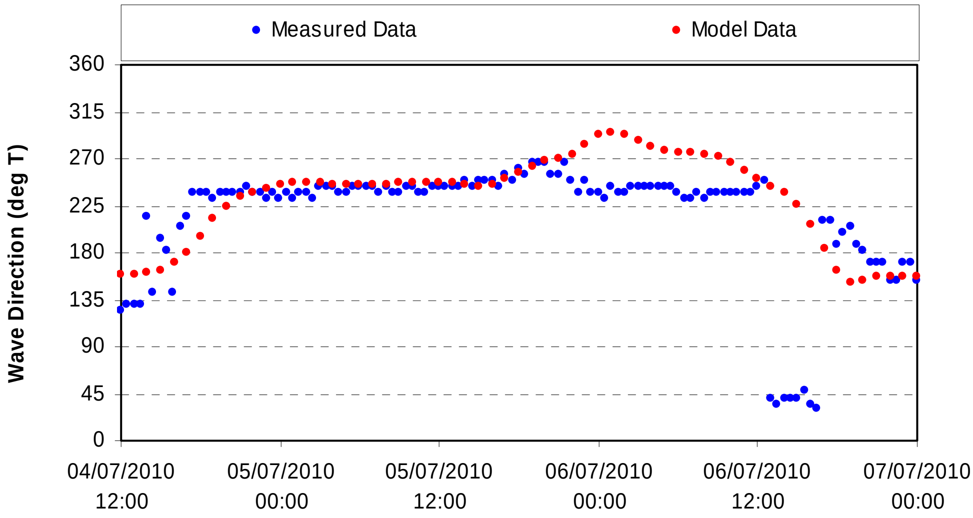


Figure C-97: Offshore Wind Event – Neart na Gaoithe, Waverider Buoy Modelled H_s (m), T_p (s) and Wave Direction (deg T) against Measured Field Data







Appendix D Wave Climate Analysis

An analysis of the wave climate at the offshore boundaries of the Forth and Tay Modelling System (FTMS) was required for two principal reasons:

- to provide FTMS model boundary inputs in the form of time series, for calibration and validation of the spectral wave model; and
- to provide FTMS model boundary inputs in the form statistical wave climate tables, for undertaking the long-term metocean and coastal processes assessment.

The wave climate analysis used hindcast model output from the UK Meteorological Office (UKMO) 12 km UK Waters model (up to November 2008) and 12 km Wave Watch III model (from December 2008 onwards). Data from these models were amalgamated into a single time series to form 11 years of wind and wave data spanning the period March 2000 to April 2011.

Data were obtained for two selected locations (UKMO model grid points) on the eastern offshore boundary of the FTMS. During calibration and validation of the FTMS spectral wave model, time series inputs were required in order to run discrete events through the FTMS wave model. Both of the UKMO model grid points were used in order to provide temporally and spatially varying boundary conditions. Conversely, for the metocean and coastal processes impact assessment, it was necessary to model the general long-term wave climate, rather than specific events. In order to do this, data from just one of the UKMO model locations were used (named Grid Point 1, at location 488161E, 698382N). This location was selected as being the most suitable for delivering an accurate representation of wave conditions across the Neart na Gaoithe development area and the wider study region.

In order to identify a set of boundary conditions that could be used to adequately represent the long-term wave climate, the time series data for UKMO model Grid Point 1 were initially analysed using a set of joint frequency tables. The five parameters analysed were:

- significant wave height (H_s), analysed in 0.5 m bands;
- peak wave period (T_p), analysed in 0.5 s bands;
- mean wave direction (H_{dir}), analysed in 16 sectors of 22.5°;
- mean wind speed (W_s), analysed in 1 m s^{-1} bands; and
- wind direction (W_{dir}) , analysed in 16 sectors of 22.5°.

The following joint frequency tables were produced:

- H_s versus H_{dir};
- H_s versus T_p for each H_{dir} sector;
- H_s versus W_s for each H_{dir} sector; and
- H_{dir} versus W_{dir}.

Frequencies were calculated as percentage occurrence.

From the frequency analysis, two main types of scenario were identified. Wave conditions at the Neart na Gaoithe site from roughly the eastern hemisphere are caused by waves propagating into the model domain fro the North Sea. Conversely, waves from roughly the western hemisphere are caused by wind blowing over the sea between the coast and the study area.

For the waves coming from the eastern hemisphere, a number of combinations of H_s, T_p and H_{dir} were selected that would fully represent the various combinations of these conditions that could occur throughout the lifetime of the development. For each one of these wave conditions, a suitable wind speed was also chosen, based on the observed relationship between wave height and wind speed. Finally, the wind direction was set equal to the mean wave direction, since analysis of the UKMO model data demonstrates that these two parameters are strongly correlated.

For waves coming from the western hemisphere, it was primarily necessary to specify wind speed and direction. Once more, a suitable number of wind conditions was selected based on the calculated joint frequency distributions of W_s and W_{dir}.

This analysis initially resulted in the identification of a large number of scenarios representing the wave/wind climate – primarily wave-driven from the east, and primarily wind-driven from the west. Each one of these scenarios has an associated frequency of occurrence. In order to focus on the scenarios of most significance to the metocean and coastal processes assessment, emphasis was placed on:

- those scenarios with a relatively high frequency of occurrence; and
- those scenarios of potential importance to the wider study (e.g. higher wave heights and longer periods, which are most likely to affect sediment movement at the seabed in the relatively deep waters of the Neart na Gaoithe development site).

Scenarios with similar values for wave height, period and direction were grouped together, so as to minimise model runs times while ensuring that the full long-term wave climate was suitably modelled. In this way, 196 separate model scenarios were identified, each with an associated frequency of occurrence, and each with a specific H_s, T_p, H_{dir}, W_s and W_{dir}. The 196 representative wave/wind conditions were modelled using a quasi-stationary solution to the spectral wave model, whereby each condition was modelled discretely. The wave conditions predicted across the study domain were subsequently analysed to determine the percentile values (50, 90, 95 and 99%ile) for significant wave height, taking into account the percentage frequency of occurrence for each separate model scenario.

Table D-1 provides the results of the joint frequency analysis of the UKMO hindcast model data (Grid Point 1).

Total obs. 31845

	Wave Direction (°) upper								
Hs (m) upper	45	90	135	180	225	270	315	360	Total
0.5	0.87	0.28	0.34	0.25	0.18	0.14	0.06	0.74	2.86
1.0	5.29	1.62	2.15	2.61	2.28	2.03	0.63	3.12	19.74
1.5	6.25	1.93	2.27	3.25	2.89	3.36	0.68	3.23	23.86
2.0	4.16	1.70	2.04	2.66	2.27	3.58	0.45	2.68	19.54
2.5	2.59	1.18	1.48	1.76	1.83	2.07	0.25	2.19	13.36
3.0	1.42	0.68	1.19	1.36	1.27	1.25	0.19	1.27	8.63
3.5	0.81	0.41	0.73	0.97	0.75	0.41	0.03	1.05	5.15
4.0	0.52	0.19	0.48	0.52	0.46	0.21	0.02	0.59	2.99
4.5	0.47	0.17	0.27	0.34	0.23	0.08	0.02	0.31	1.88
5.0	0.18	0.07	0.19	0.19	0.14	0.01	0.00	0.28	1.07
5.5	0.05	0.04	0.13	0.07	0.07	0.00	-	0.19	0.55
6.0	0.08	0.01	0.05	0.03	0.03	0.00	-	0.04	0.24
6.5	0.05	0.01	0.01	0.01	0.01	-	-	0.01	0.08
7.0	0.01	-	0.00	0.00	0.01	-	-	0.02	0.05
7.5	0.00	-	-	0.00	-	-	-	-	0.01
8.0	-	-	-	-	-	-	-	-	-
Total	22.75	8.30	11.33	14.01	12.41	13.15	2.33	15.71	100.00

Wave Dir (°) 0-45
Total obs. 7246

	Tp (s) upper																																				
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.01	0.07	0.10	0.12	0.18	0.18	0.65	0.30	0.37	0.21	0.17	0.40	0.25	0.01	0.41	-	-	0.01	0.23	-	0.01	-	0.03	0.08	0.01	-	-	-	-	-	-	-	-	-	-	-	3.82
1.0	-	0.01	0.76	2.04	0.03	1.53	0.39	2.84	0.68	4.22	0.79	0.61	3.96	0.21	0.26	2.04	-	0.03	-	1.50	-	0.03	-	-	0.98	0.01	0.01	-	0.01	-	0.28	-	0.01	-	-	-	-	23.24
1.5	-	-	0.03	0.21	0.08	2.59	0.28	2.59	0.26	4.65	0.75	0.99	6.64	0.58	0.23	3.66	0.04	0.10	0.03	2.19	-	0.06	-	-	1.09	-	-	-	-	-	0.41	-	-	-	-	-	0.01	27.48
2.0	-	-	-	0.01	0.03	0.21	0.14	2.69	0.14	1.75	0.23	0.68	4.78	0.87	0.32	3.11	0.29	0.26	0.04	1.79	-	0.03	-	-	0.80	-	-	-	-	-	0.14	-	-	-	-	-	-	18.30
2.5	-	-	-	-	-	0.03	0.07	0.35	0.15	2.50	0.17	0.17	2.43	0.39	0.28	2.32	0.15	0.22	0.04	1.35	0.03	0.03	-	-	0.59	-	-	-	-	-	0.14	-	-	-	-	-	0.01	11.40
3.0	-	-	-	-	-	-	0.01	0.11	0.03	0.88	0.19	0.22	1.64	0.14	0.17	1.32	0.15	0.25	0.03	0.69	-	0.01	-	0.01	0.28	-	-	-	-	-	0.08	-	-	-	-	-	-	6.22
3.5	-	-	-	-	-	-	-	-	0.01	0.19	0.08	0.11	1.26	0.15	0.18	0.86	-	0.04	0.04	0.48	0.01	0.01	-	0.01	0.11	-	-	-	-	-	-	-	-	-	-	-	-	3.56
4.0	-	-	-	-	-	-	-	-	-	-	0.15	0.03	0.62	0.10	0.04	0.92	0.03	0.06	-	0.29	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	2.26
4.5	-	-	-	-	-	-	-	-	-	-	-	0.03	0.12	0.15	0.11	1.24	0.06	0.10	-	0.22	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	2.07
5.0	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	0.07	0.55	0.01	-	-	0.12	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	0.80
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.21
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.36
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.19	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	0.21
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.03	0.86	2.36	0.26	4.54	1.06	9.23	1.57	14.57	2.57	2.99	21.86	2.84	1.67	16.51	0.73	1.05	0.19	9.65	0.04	0.18	-	0.06	4.03	0.03	0.01	-	0.01	-	1.05	-	0.01	-	-	-	0.03	100.00

Wave Dir (°) 46-90
Total obs. 2642

	Tp (s) upper																																				
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	-	0.19	0.64	0.42	0.83	0.26	0.61	0.04	0.23	0.08	-	0.04	-	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.41
1.0	-	0.15	1.17	2.95	0.19	3.79	0.68	4.92	0.49	3.26	0.11	0.08	1.32	0.08	0.11	0.08	-	-	-	0.04	-	-	0.04	-	0.08	-	-	-	-	-	-	-	-	-	0.04	-	-	19.57
1.5	-	-	0.04	0.57	0.08	3.63	0.23	3.48	0.61	8.25	0.76	0.30	4.50	0.26	0.04	0.53	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.32
2.0	-	-	-	-	0.15	0.30	0.08	3.71	0.26	5.11	2.12	0.57	6.06	0.04	0.08	1.97	0.04	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.51
2.5	-	-	-	-	-	-	-	0.45	0.26	4.31	0.79	1.10	4.39	0.19	0.08	2.38	-	0.04	0.08	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.27
3.0	-	-	-	-	-	-	0.04	0.04	-	1.51	0.19	0.49	2.80	0.19	-	2.54	-	-	0.04	0.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.14
3.5	-	-	-	-	-	-	-	-	-	0.04	-	0.23	1.78	0.19	-	1.85	-	0.04	-	0.76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.88
4.0	-	-	-	-	-	-	-	0.04	-	-	0.08	0.08	0.49	0.23	-	0.95	-	-	-	0.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.31
4.5	-	-	-	-	-	-	-	-	-	0.04	0.04	-	0.08	0.23	-	0.91	-	-	-	0.72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.01
5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.19	-	0.23	-	-	-	0.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.83
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.15	-	-	-	0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.49
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.15
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.15	1.40	4.16	0.83	8.55	1.29	13.25	1.67	22.75	4.16	2.84	21.46	1.59	0.30	11.58	0.08	0.11	0.11	3.48	0.08	-	0.04	-	0.08	-	-	-	-	-	-	-	-	-	0.04	-	-	100.00

Wave Dir (°) 91-135
Total obs. 3608

	Tp (s) upper																																				
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.22	0.22	0.67	0.39	0.89	0.06	0.17	0.03	0.11	0.03	-	-	-	-	0.03	-	0.08	0.03	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.97
1.0	-	0.08	1.27	3.88	0.17	6.26	0.75	3.88	0.06	1.50	0.06	-	0.50	0.06	0.14	0.03	-	0.03	-	0.06	0.03	0.06	0.06	0.03	-	0.06	-	0.06	-	-	-	-	-	-	-	-	-	18.99
1.5	-	-	0.08	0.47	0.17	5.49	1.05	4.68	0.50	5.16	0.08	0.14	1.80	0.11	0.08	0.14	-	0.08	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.07
2.0	-	-	-	0.03	0.17	0.64	0.30	6.21	0.80	5.49	0.67	0.08	3.19	0.11	0.03	0.25	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.02
2.5	-	-	-	-	-	0.06	0.30	0.80	0.17	7.37	1.03	0.30	2.69	0.03	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13.08
3.0	-	-	-	-	-	0.03	0.06	0.11	0.42	2.88	1.33	0.30	4.85	0.06	-	0.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.48
3.5	-	-	-	-	-	-	-	0.03	0.06	0.30	0.53	0.61	4.13	0.03	0.06	0.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.43
4.0	-	-	-	-	-	-	-	-	-	0.06	0.39	0.39	2.27	0.14	0.03	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.27
4.5	-	-	-	-	-	-	-	-	-	-	0.03	0.11	0.19	0.11	-	1.91	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.41
5.0	-	-	-	-	-	-	-	-	-	-	-	0.06	0.17	0.44	-	1.00	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.69
5.5	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.22	-	0.67	-	-	-	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.11
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	-	0.03	-	-	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.42
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.30	1.58	5.04	0.89	13.36	2.52	15.88	2.02	22.87	4.13	2.00	19.82	1.36	0.33	6.51	-	0.25	0.03	0.83	0.03	0.06	0.06	0.03	-	0.06	-	0.06	-	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 136-180
Total obs. 4462

	Tp (s) upper																																				
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.25	0.56	0.58	0.09	0.09	0.04	0.02	0.04	0.02	-	-	-	-	-	0.02	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.77
1.0	-	0.13	3.05	7.35	0.69	4.57	0.40	1.32	0.13	0.54	-	0.07	0.13	0.04	-	-	-	0.02	-	-	0.02	-	-	-	0.02	-	0.02	0.09	0.02	-	-	-	-	-	-	-	-	18.65
1.5	-	-	0.09	1.59	1.21	11.16	0.87	5.11	0.29	1.61	0.09	0.16	0.78	0.02	0.07	0.07	-	0.02	-	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	23.20
2.0	-	-	-	-	0.47	1.70	1.17	10.35	0.31	3.20	0.16	0.13	1.21	0.02	0.09	0.11	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.96
2.5	-	-	-	-	0.02	0.16	0.63	1.43	0.09	8.67	0.18	0.04	0.94	0.02	-	0.27	-	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.55
3.0	-	-	-	-	-	0.02	0.11	0.45	0.43	3.97	0.31	0.11	3.88	-	-	0.36	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.68
3.5	-	-	-	-	-	-	-	0.02	0.09	0.63	0.31	0.13	5.45	-	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.90
4.0	-	-	-	-	-	-	-	-	0.04	0.31	0.40	0.11	2.26	-	-	0.61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.74
4.5	-	-	-	-	-	-	-	-	-	-	0.22	0.16	0.49	-	-	1.52	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.42
5.0	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-	-	1.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.37
5.5	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.09	-	0.31	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	-	0.07	-	-	-	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.20
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.38	3.70	9.52	2.49	17.71	3.23	18.71	1.43	18.96	1.68	1.01	15.17	0.25	0.16	4.91	0.02	0.18	-	0.25	0.02	-	-	-	0.02	0.04	0.02	0.09	0.02	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 181-225
Total obs. 3952

	Tp (s) upper																																					
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.33	0.51	0.18	0.03	0.03	-	0.05	0.03	0.03	0.03	-	-	0.03	-	-	-	0.05	0.03	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.42
1.0	0.03	0.48	3.64	11.34	0.08	2.15	0.05	0.25	0.03	0.05	0.03	0.10	-	0.03	0.10	-	-	-	-	-	-	-	-	0.03	-	-	-	0.03	-	-	-	-	-	-	-	-	-	18.40
1.5	-	-	0.08	3.52	1.24	14.88	0.05	2.73	0.05	0.30	0.05	0.08	0.05	0.03	0.03	0.05	0.03	0.03	-	-	-	-	0.03	-	-	0.03	-	0.05	-	-	-	-	-	-	-	-	-	23.28
2.0	-	-	-	0.05	1.54	2.07	0.33	12.80	0.03	1.06	0.10	-	0.05	0.03	0.03	0.13	-	0.03	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.27
2.5	-	-	-	-	0.03	0.66	0.89	2.40	0.03	10.32	0.05	0.05	0.25	0.05	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.75
3.0	-	-	-	-	-	0.03	0.33	0.23	0.35	7.34	0.08	0.08	1.82	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.27
3.5	-	-	-	-	-	-	0.05	0.13	0.10	0.58	0.03	-	5.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.05
4.0	-	-	-	-	-	-	-	-	0.08	0.18	-	-	3.31	-	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.69
4.5	-	-	-	-	-	-	-	-	-	0.08	-	-	1.01	-	-	0.73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.82
5.0	-	-	-	-	-	-	-	-	-	-	0.05	-	0.10	-	-	0.99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.14
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.58
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.23
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.03	0.81	4.23	15.08	2.91	19.81	1.70	18.60	0.68	19.94	0.40	0.30	11.77	0.15	0.15	2.96	0.03	0.13	0.03	-	0.05	-	0.05	0.03	-	0.03	-	0.08	-	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 226-270
Total obs. 4189

	Tp (s) upper																																					
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.07	0.31	0.31	0.05	0.02	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	0.05	0.02	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	1.07
1.0	0.02	0.17	1.93	9.69	0.10	2.70	-	0.07	0.05	0.12	0.02	0.02	0.10	0.05	0.07	-	0.02	-	-	0.10	0.05	0.07	0.05	-	-	0.02	-	0.02	-	-	-	-	-	-	-	-	-	15.45
1.5	-	-	0.07	2.20	2.08	16.52	0.02	3.94	0.02	0.07	-	0.02	0.07	0.19	0.07	0.07	-	0.05	0.07	0.02	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25.54
2.0	-	-	-	0.10	1.48	3.77	0.64	20.24	-	0.67	0.07	0.02	0.07	0.05	-	0.02	0.02	0.02	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.21
2.5	-	-	-	-	0.02	0.33	1.62	3.39	-	10.24	-	-	-	-	0.02	0.05	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.73
3.0	-	-	-	-	-	-	0.33	0.95	0.02	7.90	-	-	0.29	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.52
3.5	-	-	-	-	-	-	-	0.10	0.17	0.98	-	-	1.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.10
4.0	-	-	-	-	-	-	-	-	-	0.10	0.02	-	1.48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.60
4.5	-	-	-	-	-	-	-	-	-	0.05	0.02	-	0.48	-	-	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.62
5.0	-	-	-	-	-	-	-	-	-	-	0.02	-	0.02	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.02	0.24	2.32	12.29	3.72	23.35	2.63	28.72	0.26	20.12	0.17	0.07	4.37	0.29	0.17	0.31	0.10	0.10	0.07	0.12	0.10	0.12	0.12	0.02	-	0.02	-	0.02	-	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 271-315
Total obs. 743

	Tp (s) upper																																					
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.13	0.27	-	-	-	-	0.40	0.27	-	-	0.13	-	0.27	0.13	-	0.13	0.40	-	-	-	0.27	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.69
1.0	-	0.13	3.36	13.06	0.40	2.15	-	0.27	0.40	-	0.67	0.40	-	0.94	0.40	0.67	0.54	0.67	0.27	0.13	0.13	0.13	0.40	0.40	0.67	0.27	0.13	0.27	-	-	-	-	-	-	-	-	-	26.92
1.5	-	-	0.13	3.36	1.35	14.94	-	1.08	-	0.40	0.94	0.67	0.54	1.48	0.67	0.81	0.13	0.94	0.54	0.54	0.27	-	-	-	-	-	-	-	0.13	-	-	-	-	-	-	-	-	28.94
2.0	-	-	-	-	1.21	1.62	0.13	11.04	-	0.67	0.13	0.13	0.54	1.75	0.54	0.54	-	0.54	0.13	0.13	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.38
2.5	-	-	-	-	0.13	0.67	0.81	3.63	-	3.90	-	0.13	0.13	-	0.40	0.27	0.27	-	-	0.27	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.77
3.0	-	-	-	-	-	0.13	0.13	0.13	-	7.00	-	-	0.67	-	-	-	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.34
3.5	-	-	-	-	-	-	-	0.13	-	0.67	-	-	0.54	-	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.48
4.0	-	-	-	-	-	-	-	-	0.27	0.13	-	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67
4.5	-	-	-	-	-	-	-	-	-	-	-	-	0.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67
5.0	-	-	-	-	-	-	-	-	-	-	-	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.27	3.77	16.42	3.10	19.52	1.08	16.69	0.94	12.79	1.75	1.48	3.50	4.44	2.15	2.42	1.08	2.83	0.94	1.08	0.40	0.81	0.67	0.40	0.67	0.27	0.13	0.27	0.13	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 316-360
Total obs. 5003

	Tp (s) upper																																					
Hs (m) upper	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	Total
0.5	-	0.08	0.10	0.16	0.06	0.08	0.12	0.32	0.18	0.22	0.24	0.20	0.52	0.24	0.10	0.52	0.20	0.22	0.10	0.38	0.06	0.10	0.14	0.08	0.26	-	0.02	-	-	-	0.04	-	-	-	-	-	-	4.74
1.0	0.04	0.14	0.94	2.58	0.18	1.28	0.16	1.08	0.28	1.66	0.32	0.42	3.96	0.42	0.28	2.36	0.06	0.32	0.14	1.46	0.18	0.08	0.14	0.14	0.92	0.08	0.06	0.10	0.02	-	0.06	-	-	-	-	-	-	19.85
1.5	0.02	-	0.10	0.56	0.34	4.12	0.28	2.24	0.08	1.96	0.24	0.24	3.36	0.70	0.44	3.26	0.22	0.10	0.20	1.42	0.04	0.02	0.04	0.02	0.46	-	-	-	-	-	0.10	-	-	-	-	-	-	20.55
2.0	-	-	-	0.08	0.08	0.48	0.42	7.70	0.16	1.46	0.12	0.22	1.66	0.64	0.60	1.62	0.26	0.42	0.08	0.68	0.02	0.04	0.08	-	0.20	-	-	-	-	-	0.02	-	-	-	-	-	-	17.03
2.5	-	-	-	-	0.02	0.04	0.20	0.92	0.14	8.63	0.08	0.08	0.74	0.58	0.28	0.98	0.24	0.24	0.12	0.50	0.02	0.08	0.02	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	13.93
3.0	-	-	-	-	-	-	-	0.08	0.08	4.52	0.16	0.04	2.00	0.10	0.06	0.40	0.08	0.26	0.08	0.18	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.08
3.5	-	-	-	-	-	-	-	0.02	-	0.22	0.16	0.10	5.64	0.08	0.12	0.14	0.06	0.06	0.02	0.02	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.68
4.0	-	-	-	-	-	-	-	-	-	0.02	0.04	0.04	2.92	0.02	0.06	0.38	0.02	0.08	0.10	0.04	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.74
4.5	-	-	-	-	-	-	-	-	-	-	-	-	0.40	0.04	-	1.36	0.02	0.08	-	0.06	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.98
5.0	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.06	1.56	-	0.02	-	0.08	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.78
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	1.10	-	-	0.04	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.22
6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.18	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.24
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04
7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.06	0.22	1.14	3.38	0.68	6.00	1.18	12.35	0.92	18.69	1.36	1.34	21.21	2.84	2.02	13.85	1.16	1.80	0.88	5.12	0.34	0.42	0.44	0.24	1.84	0.08	0.08	0.10	0.02	-	0.24	-	-	-	-	-	-	100.00

Wave Dir (°) 0-45

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	0.01	0.15	0.40	0.81	0.95	0.79	0.37	0.17	0.12	0.03	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.82
1	0.04	0.48	2.00	3.55	4.35	4.79	4.57	2.40	0.86	0.19	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.24
1.5	0.04	0.25	1.44	2.53	3.55	4.11	3.93	5.27	3.82	1.68	0.66	0.17	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.48
2	-	0.12	0.75	1.13	1.63	1.50	2.25	2.75	2.61	2.66	1.71	0.81	0.30	0.04	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.30
2.5	-	0.12	0.12	0.44	0.55	0.62	0.99	1.38	1.44	1.60	1.49	1.31	0.84	0.33	0.11	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.40
3	-	-	0.03	0.06	0.17	0.18	0.23	0.43	0.51	0.80	0.98	1.08	0.79	0.62	0.21	0.10	0.01	0.01	0.01	-	0.01	-	-	-	-	-	-	-	-	-	-	6.22
3.5	-	-	-	0.01	0.10	0.07	0.08	0.18	0.21	0.40	0.43	0.54	0.47	0.44	0.28	0.19	0.08	0.04	0.04	-	-	-	-	-	-	-	-	-	-	-	-	3.56
4	-	-	-	-	-	0.01	0.01	0.10	0.11	0.10	0.22	0.22	0.28	0.36	0.39	0.23	0.17	0.04	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-	2.26
4.5	-	-	-	0.01	-	-	-	0.03	0.03	0.04	0.08	0.07	0.17	0.29	0.30	0.39	0.33	0.25	0.07	0.01	-	-	-	-	-	-	-	-	-	-	-	2.07
5	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	0.10	0.21	0.17	0.14	0.08	0.06	-	0.03	-	-	-	-	-	-	-	-	-	-	0.80
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.06	0.07	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	0.21
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.10	0.17	0.04	0.01	0.01	-	-	-	-	-	-	-	-	-	0.36
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	0.03	0.01	0.03	0.06	0.04	0.01	-	-	-	-	-	-	-	-	0.21
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	0.01	0.03	-	-	-	-	-	-	-	-	0.06
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	0.01
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.10	1.13	4.73	8.54	11.29	12.08	12.45	12.70	9.70	7.51	5.60	4.21	2.87	2.19	1.53	1.19	0.84	0.62	0.40	0.10	0.11	0.07	0.04	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 46-90

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	-	0.08	0.68	0.76	0.68	0.76	0.23	0.15	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.41
1	-	0.34	1.59	2.61	4.35	3.79	3.67	1.97	0.91	0.23	0.08	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.57
1.5	0.08	0.30	0.91	2.27	2.69	3.60	3.37	4.43	2.95	2.01	0.53	0.11	0.04	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.32
2	-	0.19	0.38	1.14	1.89	2.23	2.50	2.99	2.50	3.10	2.01	1.25	0.23	0.04	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.51
2.5	-	0.08	0.30	0.76	0.95	0.95	1.44	1.82	1.89	1.85	1.93	1.29	0.53	0.26	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.27
3	-	0.04	0.08	0.19	0.42	0.19	0.53	0.87	0.98	1.17	1.06	1.44	0.53	0.34	0.15	0.04	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.14
3.5	-	-	0.04	0.04	0.15	0.30	0.15	0.30	0.49	0.68	0.72	0.57	0.49	0.34	0.26	0.30	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	4.88
4	-	-	0.04	0.04	-	0.08	0.08	0.11	0.23	0.15	0.30	0.08	0.23	0.42	0.34	0.15	0.04	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	2.31
4.5	-	-	-	-	-	0.04	0.19	0.08	0.08	0.08	0.15	0.11	0.15	0.42	0.30	0.23	-	0.08	0.04	0.04	0.04	-	-	-	-	-	-	-	-	-	-	2.01
5	-	-	-	-	-	-	0.08	-	-	0.08	-	0.08	0.08	0.08	0.08	0.15	0.11	0.08	-	-	0.04	-	-	-	-	-	-	-	-	-	-	0.83
5.5	-	-	-	-	-	-	-	-	-	-	0.04	-	-	0.08	0.04	0.11	0.04	0.08	0.11	-	-	-	-	-	-	-	-	-	-	-	-	0.49
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	-	0.08	-	0.04	-	-	-	-	-	-	-	-	-	-	-	0.15
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-	0.04	0.04	-	-	-	-	-	-	-	-	-	0.11
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.08	1.02	4.01	7.80	11.13	11.92	12.23	12.72	10.11	9.35	6.81	4.96	2.27	2.01	1.48	1.02	0.30	0.42	0.15	0.08	0.11	0.04	-	-	-	-	-	-	-	-	-	100.00

Wave Dir (°) 91-135

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	-	0.11	0.50	0.75	0.67	0.39	0.28	0.11	0.08	0.06	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.97
1	0.06	0.33	1.03	2.69	3.82	3.58	3.52	2.52	1.25	0.17	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.99
1.5	-	0.08	0.28	1.16	1.94	2.52	3.30	2.97	3.35	2.94	1.08	0.36	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.07
2	-	0.03	0.17	0.42	0.91	1.08	1.91	2.36	2.72	2.63	2.61	1.91	0.94	0.22	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.02
2.5	-	0.06	0.06	0.22	0.36	0.33	0.58	0.86	1.19	2.08	2.22	1.94	1.69	0.94	0.30	0.14	0.06	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	-	13.08
3	0.03	-	0.03	-	0.03	0.19	0.19	0.47	0.55	1.00	1.47	1.88	2.05	1.36	0.64	0.36	0.17	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	-	10.48
3.5	-	-	0.08	0.08	0.03	0.11	0.17	0.11	0.19	0.47	0.69	1.00	1.11	1.00	0.72	0.36	0.14	0.08	0.06	0.03	-	-	-	-	-	-	-	-	-	-	-	6.43
4	-	-	-	-	0.03	0.03	-	-	0.14	0.11	0.17	0.33	0.47	0.69	1.08	0.50	0.39	0.25	0.06	-	0.03	-	-	-	-	-	-	-	-	-	-	4.27
4.5	-	-	-	-	-	-	-	-	-	-	0.08	0.22	0.19	0.33	0.50	0.33	0.42	0.17	0.14	0.03	-	-	-	-	-	-	-	-	-	-	-	2.41
5	-	-	-	-	-	-	-	-	0.03	-	-	-	0.08	0.11	0.17	0.50	0.22	0.22	0.30	0.06	-	-	-	-	-	-	-	-	-	-	-	1.69
5.5	-	-	-	-	0.03	-	-	-	-	-	0.03	0.03	-	-	0.11	0.08	0.28	0.22	0.22	-	0.11	-	-	-	-	-	-	-	-	-	-	1.11
6	-	-	-	-	-	-	-	0.03	-	0.03	-	-	-	-	0.03	-	0.03	0.06	0.11	0.03	0.06	0.06	-	-	-	-	-	-	-	-	-	0.42
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	0.03	-	-	-	-	-	-	-	-	-	0.06
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	0.03
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.08	0.61	2.13	5.32	7.82	8.23	9.95	9.42	9.51	9.48	8.40	7.68	6.62	4.66	3.66	2.27	1.69	1.08	0.94	0.14	0.19	0.08	-	0.03	-	-	-	-	-	-	-	100.00

Wave Dir (°) 136-180

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	-	0.02	0.22	0.25	0.27	0.63	0.29	0.04	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.77
1	-	0.07	0.56	1.46	2.13	3.14	3.83	3.72	2.76	0.65	0.18	0.11	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.65
1.5	-	0.02	0.18	0.38	0.81	1.34	1.79	3.23	4.80	5.18	3.65	1.37	0.31	0.11	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.20
2	-	0.04	0.04	0.11	0.18	0.47	0.76	1.10	1.52	3.16	4.68	3.79	1.84	0.85	0.18	0.20	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.96
2.5	-	-	0.02	0.04	0.13	0.22	0.16	0.34	0.61	0.96	1.64	1.86	2.78	2.17	0.99	0.40	0.18	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	12.55
3	-	-	-	0.02	0.04	0.09	0.11	0.16	0.36	0.45	0.43	0.72	1.37	1.88	1.97	1.08	0.63	0.25	0.11	0.02	-	-	-	-	-	-	-	-	-	-	-	9.68
3.5	-	-	-	-	0.02	-	-	0.07	0.13	0.20	0.20	0.31	0.58	0.76	1.41	1.32	1.19	0.49	0.11	0.04	0.02	0.02	-	-	-	-	-	-	-	-	-	6.90
4	-	-	-	-	-	-	-	0.04	0.02	0.04	0.07	0.04	0.07	0.27	0.45	0.74	0.90	0.40	0.43	0.11	0.11	0.04	-	-	-	-	-	-	-	-	-	3.74
4.5	-	-	-	-	-	-	-	-	-	0.04	0.02	0.07	0.04	0.13	0.13	0.18	0.38	0.40	0.47	0.13	0.27	0.11	0.02	-	-	-	-	-	-	-	-	2.42
5	-	-	-	-	-	-	-	-	-	-	-	0.02	-	0.02	-	0.09	0.09	0.07	0.34	0.13	0.34	0.16	0.07	0.04	-	-	-	-	-	-	-	1.37
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.07	0.04	0.04	0.07	0.13	-	0.02	0.02	0.02	-	-	-	-	-	0.47
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.09	0.02	-	0.02	0.02	-	-	0.04	-	-	-	-	-	0.20
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	0.04
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	0.02
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	0.02
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.16	1.03	2.26	3.59	5.89	6.95	8.70	10.24	10.69	10.87	8.29	7.04	6.21	5.15	4.01	3.43	1.73	1.59	0.52	0.81	0.49	0.16	0.07	0.02	0.07	0.02	-	-	0.02	-	100.00

Wave Dir (°) 181-225

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	-	0.03	0.05	0.20	0.20	0.43	0.35	0.13	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.42
1	-	0.03	0.28	0.66	0.96	2.13	3.54	5.36	3.31	1.62	0.46	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.40
1.5	-	-	0.05	0.15	0.28	0.35	0.61	2.00	4.73	6.88	4.76	2.40	0.84	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.28
2	-	-	-	-	0.03	0.08	0.15	0.35	0.76	1.87	3.87	5.16	3.44	1.77	0.51	0.20	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.27
2.5	-	-	-	-	-	0.03	0.08	0.08	0.25	0.25	1.06	1.95	3.49	3.37	2.51	1.19	0.35	0.10	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	14.75
3	-	-	-	-	-	-	-	0.03	0.03	0.03	0.18	0.48	1.16	2.10	2.48	2.28	1.09	0.33	0.08	0.03	-	-	-	-	-	-	-	-	-	-	-	10.27

3.5	-	-	-	-	-	-	-	-	-	-	0.03	0.03	0.18	0.40	1.01	1.44	1.27	1.11	0.40	0.13	0.03	0.03	-	-	-	-	-	-	-	-	-	6.05
4	-	-	-	-	-	-	-	-	-	-	0.05	-	-	0.15	0.23	0.35	0.66	0.81	0.66	0.30	0.38	0.08	0.03	-	-	-	-	-	-	-	-	3.69
4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.03	0.05	0.18	0.23	0.46	0.28	0.30	0.15	0.08	0.03	0.03	-	-	-	-	-	-	1.82
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.08	0.13	0.13	0.15	0.30	0.18	0.05	0.10	-	-	-	-	-	-	1.14
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.03	-	0.03	0.08	0.20	0.13	0.08	-	0.03	-	-	-	-	0.58
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.03	0.05	0.08	-	-	-	-	-	0.23
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	0.05
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	0.03	0.05
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.05	0.38	1.01	1.47	3.01	4.73	7.95	9.11	10.65	10.40	10.05	9.13	8.05	6.76	5.52	3.64	2.68	1.77	0.89	0.89	0.63	0.56	0.23	0.25	0.08	0.03	0.05	0.03	-	0.03	100.00

Wave Dir (°) 226-270

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	-	-	0.12	0.24	0.21	0.24	0.17	0.07	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.07
1	-	0.02	0.41	0.91	1.34	1.53	3.27	4.06	2.55	0.98	0.33	-	0.02	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.45
1.5	-	0.02	0.07	0.14	0.24	0.45	0.76	2.10	5.11	6.97	6.52	2.46	0.67	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25.54
2	-	-	-	-	0.07	0.14	0.14	0.43	0.93	2.53	5.66	7.23	6.47	2.70	0.76	0.12	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.21
2.5	-	-	-	0.05	-	0.02	-	-	0.10	0.21	0.50	1.22	3.56	4.58	3.27	1.81	0.31	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	15.73
3	-	-	-	-	-	-	-	0.02	-	0.05	0.02	0.14	0.60	1.38	2.20	2.89	1.46	0.69	0.07	-	-	-	-	-	-	-	-	-	-	-	-	9.52
3.5	-	-	-	-	-	-	-	-	-	-	-	-	0.07	0.07	0.14	0.26	0.91	0.95	0.53	0.10	0.07	-	-	-	-	-	-	-	-	-	-	3.10
4	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.05	0.07	0.19	0.33	0.33	0.36	0.19	0.02	0.02	-	-	-	-	-	-	-	-	1.60
4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.02	0.14	0.10	0.12	0.10	0.07	0.02	-	-	-	-	-	-	-	0.62
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.05	-	-	-	-	-	-	-	0.10
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	0.02
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	0.02
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.05	0.60	1.34	1.86	2.39	4.34	6.68	8.69	10.77	13.03	11.05	11.39	8.78	6.42	5.20	2.91	2.10	1.07	0.55	0.38	0.14	0.12	0.12	-	-	-	-	-	-	-	100.00

Wave Dir (°) 271-315

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	-	0.13	0.13	0.54	0.81	0.13	0.67	0.13	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.69
1	-	-	1.21	1.88	2.56	3.10	4.58	7.13	4.04	1.88	0.40	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26.92
1.5	-	-	0.13	0.27	0.40	0.67	2.29	4.58	6.33	7.40	4.04	1.62	0.67	0.27	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28.94
2	-	-	-	-	-	-	0.27	0.40	1.35	3.63	4.71	3.63	4.04	0.67	0.54	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.38
2.5	-	-	-	-	-	-	0.13	-	0.13	0.40	2.02	1.08	2.29	2.69	1.21	0.67	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	10.77
3	-	-	-	-	-	0.13	-	-	-	-	0.27	-	1.62	1.88	2.42	0.94	0.40	0.54	0.13	-	-	-	-	-	-	-	-	-	-	-	-	8.34
3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	0.27	0.40	0.40	0.13	-	-	-	-	0.13	0.13	-	-	-	-	-	-	-	-	1.48
4	-	-	-	-	-	-	-	-	-	-	0.13	-	-	-	-	0.13	-	-	0.40	-	-	-	-	-	-	-	-	-	-	-	-	0.67
4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.40	-	0.13	-	0.13	-	-	-	-	-	-	-	-	0.67
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13	-	-	-	-	-	-	-	0.13
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	0.13	1.48	2.69	3.77	4.04	7.94	12.25	11.84	13.46	11.57	6.46	8.61	5.79	4.85	2.29	0.54	0.67	0.94	-	0.13	0.13	0.27	0.13	-	-	-	-	-	-	-	100.00

Wave Dir (°) 316-270

	Wind Speed (m/s) upper																															
Hs (m) upper	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
0.5	0.02	0.16	0.78	1.16	1.14	0.76	0.38	0.26	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.74
1	-	0.32	1.34	2.60	3.50	3.74	3.62	2.56	1.50	0.44	0.14	0.08	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19.85
1.5	-	0.08	0.68	1.28	1.78	2.04	3.22	3.38	3.84	2.46	1.18	0.38	0.16	0.04	0.02	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.55
2	-	0.08	0.12	0.40	0.50	0.66	0.88	1.26	2.10	3.26	3.42	2.70	1.18	0.30	0.08	0.06	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.03
2.5	-	-	0.14	0.08	0.08	0.12	0.34	0.44	0.66	1.02	2.32	3.26	2.52	1.78	0.80	0.24	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13.93
3	-	-	0.02	-	0.10	0.04	0.04	0.16	0.16	0.18	0.40	1.18	1.52	1.66	1.48	0.86	0.22	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	8.08
3.5	-	-	-	-	0.02	-	-	-	0.06	0.06	0.16	0.24	0.78	1.40	1.42	1.26	0.74	0.38	0.14	-	0.02	-	-	-	-	-	-	-	-	-	-	6.68
4	-	-	-	-	-	-	-	-	0.02	0.04	0.04	0.04	0.18	0.58	0.88	0.62	0.72	0.40	0.16	0.04	-	0.02	-	-	-	-	-	-	-	-	-	3.74
4.5	-	-	-	-	-	-	-	-	-	-	0.02	0.06	0.06	0.12	0.20	0.38	0.36	0.44	0.12	0.14	0.06	0.02	-	-	-	-	-	-	-	-	-	1.98
5	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.02	0.12	0.20	0.46	0.40	0.32	0.04	0.14	0.02	-	-	-	-	0.02	-	-	-	-	1.78
5.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.12	0.20	0.26	0.26	0.18	0.04	0.06	0.02	0.04	-	-	-	-	-	-	-	1.22
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	-	0.02	0.02	0.02	0.04	0.02	0.04	-	0.02	-	-	-	-	-	0.24
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	0.02	-	-	-	-	-	-	-	-	0.04
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.02	0.06	-	0.02	-	-	-	-	-	-	0.14
7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.02	0.64	3.08	5.52	7.12	7.36	8.47	8.06	8.41	7.46	7.68	7.94	6.46	5.90	5.04	3.74	2.96	1.94	1.02	0.44	0.32	0.18	0.12	0.08	0.02	0.02	0.02	-	-	-	-	100.00

Appendix E Bed Shear Stress Analysis

In order to assess the baseline sediment regime and the potential impacts of the proposed development on metocean and coastal processes, the bed shear stresses induced by hydrodynamic and wave processes were determined. These were then assessed against the critical entrainment stress, in order to determine the percentage of time for which this critical shear stress is exceeded.

Both currents and waves (due to the wave orbital velocity) generate a bed shear stress, and these can be calculated individually using well-established equations. The total bed shear stress, i.e. the combined force due to currents and waves, can also be calculated, although it should be noted that this is not simply the sum of the bed shear stresses due to currents and waves separately.

This Appendix provides details of how the bed shear stress and the critical entrainment stress have been calculated. All of the equations used have been taken from Soulsby (1997).

E.1 BED SHEAR STRESS DUE TO CURRENTS

The equation used to determine the bed shear stress due to tidal currents only is Equation 30 in Soulsby (1997):

$$\boldsymbol{\tau_c = \rho * C_D * U^2} \qquad \textbf{Equation 1}$$

where:

τ_c = bed shear stress due to tidal current

U = depth-averaged tidal current

ρ = density of seawater

C_D = drag coefficient applicable to depth-averaged current – from Equation 37 (Soulsby, 1997):

$$C_D = (0.4 / (1 + \mathrm{Ln}(Z_o/d)))^2$$

where:

z_0 = bed roughness length

d = depth

Depth-averaged tidal current speeds were extracted from the Forth and Tay Modelling System (FTMS) hydrodynamic model. In order to determine the range of percentiles of bed shear stress due to currents, as required for the assessment, the 50, 90, 95 and 99-percentiles of depth-averaged current speed (taken from the mean spring and mean neap tides) were calculated for each model element across the model domain.

A spatially varying map of median grain size (d_{50}) was also calculated across the domain (see Appendix C), and from this the required drag coefficient (C_D) was determined. Using the spatially varying percentile values for U (extracted from the FTMS), and the spatially varying values of C_D, the percentiles of bed shear stress due to currents (τ_c) were calculated (using Equation 1 above) at each model element.

E.2 BED SHEAR STRESS DUE TO WAVES

The equation used to determine the bed shear stress due to wave-induced currents only is Equation 57 (in Soulsby, 1997). This is shown below.

$$\tau_w = 0.5 * \rho * f_w * U_w^2 \qquad \textbf{Equation 2}$$

where:

τ_w = bed shear stress due to wave orbital current

ρ = density of seawater

U_w = wave orbital velocity amplitude at the bed

f_w = wave friction factor given by:

f_w = 0.3 for r ≤ 1.57 or $f_w = 0.00251 * \exp(5.21 * r^{-0.19})$ – from Equation 60a and 60b (Soulsby, 1997), where:

$r = A/k_s$ – from Equation 58b (Soulsby, 1997)

$A = U_w T/2\pi$

k_s = Nikuradse equivalent sand grain roughness

T = wave period

The required wave parameters (wave orbital velocity at the bed and wave period) were obtained from the FTMS spectral wave model output. The bed shear stress was then calculated across the model domain for each of the different wave scenarios modelled, and the percentage frequencies of occurrence for different bed shear stress values were determined by summing the probability of occurrence associated with each modelled wave scenario. In this way, an exceedence curve for bed shear stress was generated, from which the 50, 90, 95 and 99-percentiles of wave-induced bed shear stress were determined.

E.3 BED SHEAR STRESS DUE TO COMBINED CURRENTS AND WAVES

The equations used to determine the bed shear stress during a wave cycle under combined currents and waves are Equation 69 (for mean stress), and Equation 70 (for maximum stress) (in Soulsby, 1997). These are shown below:

Mean bed shear-stress:

$$\tau_m = \tau_c \left[1 + 1.2(\tau_w/(\tau_c + \tau_w))^{3.2}\right] \qquad \textbf{Equation 3}$$

where:

τ_c = bed shear stress due to currents only (calculated from Equation 1)

τ_w = (mean) bed shear stress due to waves only (calculated from Equation 2)

Maximum bed shear-stress:

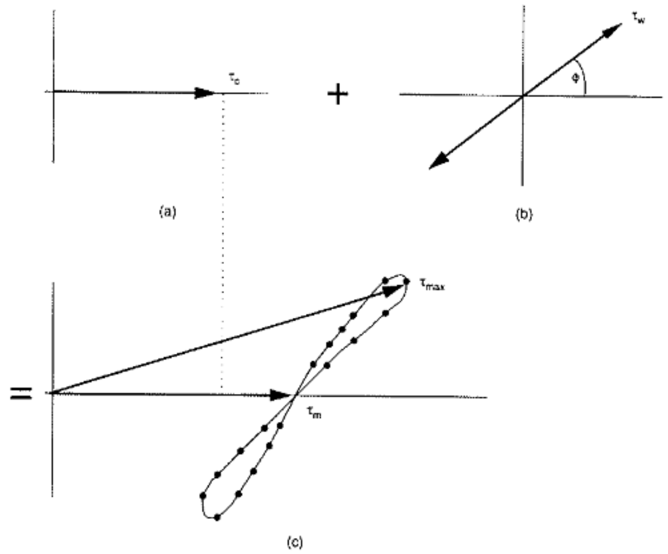
$\tau_{max} = [(\tau_m + \tau_w\cos\Phi)^2 + (\tau_w\sin\Phi)^2]^{1/2}$ **Equation 4**

where:

Φ = angle between tidal current direction and orbital wave direction

Figure E-1 demonstrates the non-linear nature of bed shear stress under the combined influence of currents and waves.

Figure E-1: Schematic diagram of non-linear interaction of wave and current bed shear stresses (from Soulsby, 1997)



E.4 CRITICAL ENTRAINMENT STRESS (THRESHOLD BED SHEAR STRESS)

The equation used to determine the critical (or threshold) shear stress for entrainment of sediment is Equation 77 in Soulsby (1997). This is shown below.

$\Theta_{cr} = 0.30/(1 + 1.2D_*) + 0.055[1 - \exp(-0.020D_*)]$ **Equation 5**

where:

$D_* = [g(s - 1)/v^2]^{1/3}d_{50}$ **Equation 6**

g = acceleration due to gravity

$s = \rho_s/\rho$ = specific density of the sediment (i.e. ratio of densities of sediment and water)

v = kinematic viscosity of water

d_{50} = median sediment grain size

The critical entrainment stress was calculated across the domain using the spatially varying map of d_{50} (as was used to determine the bed shear stress due to currents only). The spatially varying plots of bed shear stress due to combined currents and waves (both the mean and maximum stress) were compared with the critical entrainment stress map, in order to determine the percentage of time the threshold for sediment entrainment was exceeded. The resulting percentage exceedance plots were then used to help assess the baseline sediment regime. Specifically, any modelled changes to these exceedance plots (due to the proposed wind farm developments) allow the magnitude of the effect of the developments on the sediment regime and coastal processes to be quantified and assessed.

E.5 REFERENCES

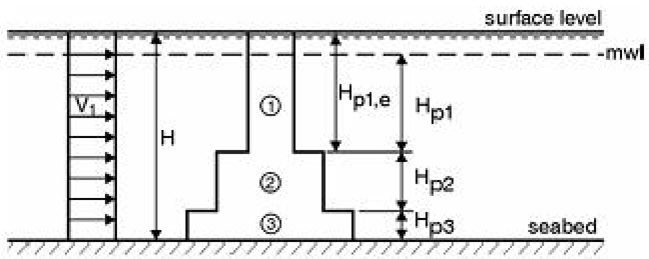
Soulsby, R. 1997. Dynamics of Marine Sands: A Manual for Practical Applications, Thomas Telford.

Appendix F Modelling of Structures

Installing any non-permeable or semi-permeable structure into the marine environment will have a hydraulic effect on the ambient current flow and wave energy by essentially blocking the area it occupies. The tower of a gravity-based structure acts on currents and waves in the same way as piers. Piers introduce a current-induced drag force on the pier itself, increasing the resistance to the flow and thereby altering the flow regime. Calculating the drag force is dependent on the size and geometry of the structure and the magnitude of the current. Piers also dissipate the energy travelling within a wave, initially reducing the wave height on the lee side of the structure.

Within the hydrodynamic model of the Forth and Tay Modelling System (FTMS), gravity bases are modelled using a sub-mesh technique as their size is smaller than that of the mesh elements in which they are located. This technique calculates the flow past the structure by considering the upstream and downstream water levels. Information about the structure is required, including its location, orientation, streamline factor (this is typically 1.02 for piers) and geometry. The gravity base structure is represented in the FTMS hydrodynamic model as a series of stepped sections. For circular structures, each section requires details on its height and diameter – see Figure F-1.

Figure F-1: Schematic of structure in the water column. Source: DHI MIKE21 manuals



Example : Effective height for pier section:

$H_{p1} = \max\{(H - H_{p2} + H_{p3}), 0\}$

$H_{p2} = \max\{(H - H_{p3} - H_{p1e}), 0\}$

$H_{p3} = \min\ (H_{p3}, H)$

The effect of flow around each pier is modelled by calculating the current induced drag force on each individual pier.

The effective drag force, F, is determined from:

$$F = \frac{1}{2}\ \rho_w\ \gamma C_D A_e V^2$$

where ρ_w is the density of water, γ is the streamline factor, C_D is the drag coefficient, A_e is the effective area of the pier exposed to current and V is the current speed. The sign of F is such that a positive force acts against the current.

The FTMS spectral wave model also uses the sub-mesh technique, and applies a source term approach. The source term approach takes the effects of the structures into account by introducing a decay term to reduce the wave energy behind the structure. The FTMS is only capable of representing simple geometry types, so the gravity bases were represented by a circular structure, dimensioned so as to be representative of the proposed gravity base size. Therefore, the information required to model a gravity base structure is its location and representative diameter.

The source term due to the effect of a structure can be written;

$$s = -\frac{c}{A} c_g E(\sigma, \theta)$$

Where A is the area of the cell/element in the mesh in which the structure is located, c is the reflection factor, c_g is the group celerity and $E(\sigma, \theta)$ is the energy density.

The approaches as outlined above for representing marine structures in hydrodynamic and spectral wave models are in line with accepted industry standards best practice guidance, for example as outlined in Lambkin *et al*. (2009).

F.1 REFERENCES

Lambkin, D.O., Harris, J.M., Cooper, W.S. and Coates, T. 2009. Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment: Best Practice Guide. COWRIE.

Appendix G Scour Potential Assessment – Neart Na Gaoithe Offshore Wind Farm Site

G.1 BACKGROUND

Repsol Nuevas Energias UK Limited (RNEUK), on behalf of the Forth and Tay Offshore Wind Developers Group (FTOWDG), has commissioned Intertek METOC to undertake assessments of meteorological/oceanographic (metocean) and coastal processes relating to two Offshore Wind Farms (OWF). The Wind farms in question are the proposed Scottish Territorial Waters (STW) developments at Inch Cape and Neart na Gaoithe. RNEUK is developing the Inch Cape OWF, whereas the Neart na Gaoithe site is being developed by Mainstream Renewable Power Limited (Mainstream).

These developments have the potential to affect both the metocean and coastal processes regimes in and around the development areas. Effects may range from short to long term, and the assessment will consider timescales up to 25 years. The OWF developers require an understanding of the magnitude and significance of these effects, with a view to implementing, where necessary, appropriate mitigation measures to minimise impacts.

The study requires the delivery of a calibrated and validated coastal hydrodynamic (HD) and spectral wave (SW) model, and the delivery of a coastal processes assessment using the models and available information. The assessments will provide the developers and other stakeholders with the regional and site-specific characterisation of the metocean and physical geomarine environment. This will enable baseline environmental conditions to be determined, against which the effects of each individual development, and the cumulative and in-combination effects of all developments can be assessed. The study results will provide input into the Technical Report and the required Environmental Impact Assessment (EIA) for each development.

The technical issue of the potential for scour must be addressed for the sites. Scour frequently occurs around the foundations of marine structures in tidal and wave-exposed environments due to flow accelerations. Because scour gives rise to resuspension of sediment which might not ordinarily occur, there is the potential for change to the sediment regime. Therefore this aspect needs to be quantified.

G.1.1 Scope of Work

The scope of this report is to deliver an assessment of the likelihood of scour at the Neart na Gaoithe OWF site, together with an overview of anticipated scour dimensions. The analysis has been performed for a single jacket-type structure at a ‘representative’ location within the site boundaries. A preliminary overview scour assessment has been undertaken for prospective export cable routes. A review of the principal scour protection/mitigation approaches has also been performed.

G.2 INTRODUCTION

The present distribution of sediments on the continental shelf reflects the balance between the supply of different grades of sediment (clay–silt–sand–gravel) and the reworking over millennia by the prevailing hydrodynamic conditions. When a wind turbine foundation is installed the hydrodynamic field will be increased locally (Whitehouse, 1998) producing an associated increase in sediment transport and erosion. This is referred to as 'scour'.

Marine scour is a complex phenomenon and the scour potential at a given location is a function of water depth (bathymetry), the wave-tide climate, the geological properties of the surface and sub-surface seabed sediment, and the type of foundation. In a typical offshore situation, differences in scour may arise due to differing water depths, variable waves and/or currents across the site, and spatially variable sediment type. An analysis of scour risk draws together the above elements into an integrated assessment process.

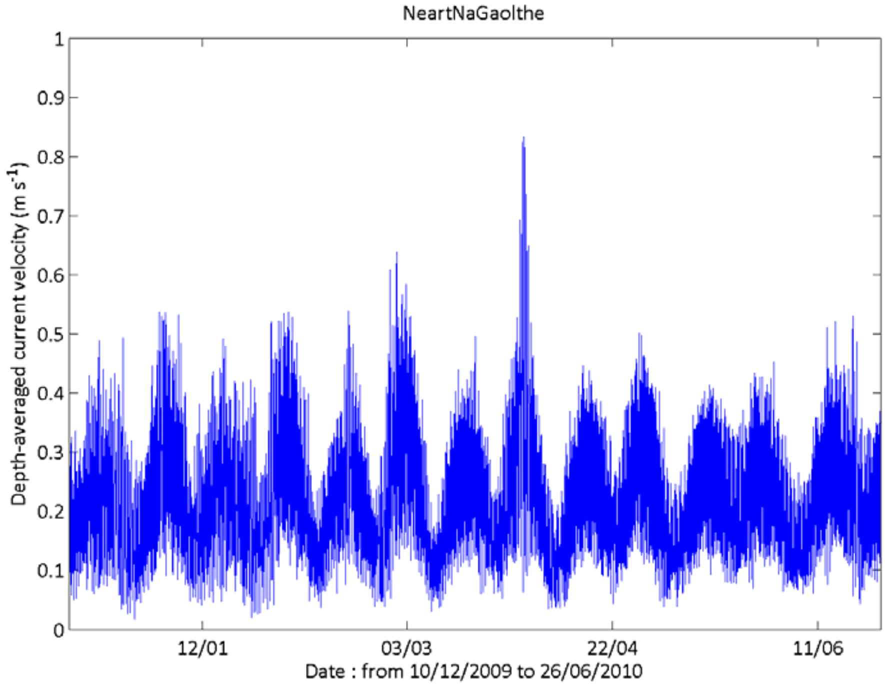
G.3 INPUT DATA

Detailed information on the site conditions which govern scour potential (tidal range, water depth, wave-tide climate, geological properties of the surface and sub-surface seabed sediments) is provided in the Regional Baseline Assessment for the outer Forth and Tay area and the Site Specific Baseline Assessment for the Neart na Gaoithe development.

Figure G- 1 shows the current velocity data measured at the site during the oceanographic monitoring campaign. Likely geometric and dimensional data have been provided by Mainstream for the jacket foundation structures.

Table G- 1 provides a summary of the principal input data used in the scour analysis.

Figure G- 1 : Time series of depth averaged current speed (upper panel) and current rose of velocity magnitude (m s^{-1}) & direction (º). Source: Neart na Gaoithe Metocean Campaign



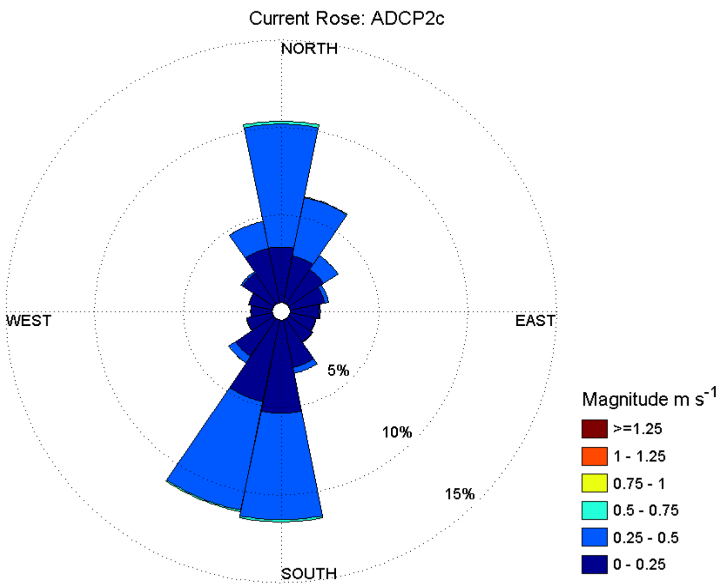
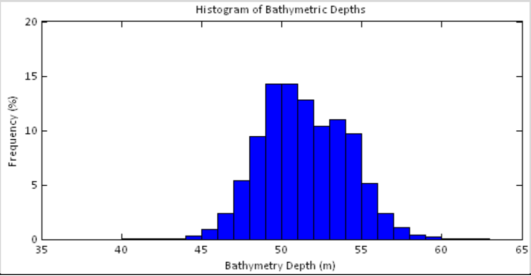


Table G- 1 : Input data for the scour assessment specific to the Neart na Gaoithe OWF site

<table>
<tr><th>Metric</th><th colspan="3">Data</th></tr>
<tr><td>Location</td><td colspan="3">Representative (not on hummocks or mounds)</td></tr>
<tr><td>Tide range</td><td colspan="3">~ 4.5 m</td></tr>
<tr><td rowspan="5">Water depth

</td><td>Mean depth (h)</td><td colspan="2">51.43 m</td></tr>
<tr><td>Minimum depth</td><td colspan="2">40.44 m</td></tr>
<tr><td>Maximum depth</td><td colspan="2">57.70 m</td></tr>
<tr><td>Modal depth</td><td colspan="2">50.13 m</td></tr>
<tr><td>Median depth</td><td colspan="2">51.21 m</td></tr>
<tr><td>Surficial grain size data</td><td colspan="3">Largely very fine to fine sand (0.063 to 0.250 mm). Gravel present generally very fine to fine (2 – 8 mm), isolated pockets ~20 – 30 mm.</td></tr>
<tr><td>Sediment Vertical Profile</td><td colspan="3">Generally soft-sediments range from 0 to 15 m thick with a mean of 3.4 m. Composition as above.</td></tr>
<tr><td>Critical entrainment stress/Shields value (medium sand; d_{50}= 0.250 mm used)</td><td colspan="3">τ_{0crit} = 0.209 N m^{-2}; θ_{crit}=0.053</td></tr>
<tr><td>Wave data</td><td colspan="3">Mean annual Hm0* = 1.13 m, T_z typically ~4 s
Maximum Hm0 = 6.03 m, T_z typically 6 – 8 s
Modal direction NNE</td></tr>
<tr><td>Extreme wave data</td><td colspan="3">1:1 year return wave Hm0 = 4.53 m; T_z = 7.31 s
1:10 year return wave Hm0 = 5.94 m; T_z = 8.55 s
1:25 year return wave Hm0 = 7.35 m; T_z =9.74 s
1:50 year return wave Hm0 = 8.42 m; T_z = 10.63 s</td></tr>
<tr><td>Current data</td><td colspan="3">Mean peak neap current 0.25 m s^{-1} (depth-averaged)
Mean peak spring current 0.52 m s^{-1} (depth-averaged)
1:1 year return current 0.61 m s^{-1}
1:10 year return current 0.81 m s^{-1}
1:25 year return current 0.96 m s^{-1}
1:50 year return current 1.11 m s^{-1}
Principal current axis N/S-SSW (rectilinear)</td></tr>
<tr><td>Bed stress data (from metocean campaign)</td><td colspan="3">Mean peak neaps = 0.04 N m^{-2}
Mean peak springs = 0.21 N m^{-2}
Mean annual wave (Hm0 = 1.13 m) 0 N m^{-2}
Maximum Hm0 (Hm0 = 6.03 m) = 0.003 N m^{-2}
1:1 year return wave = 0.100 N m^{-2}
1:10 year return wave = 0.327 N m^{-2}
1:25 year return wave = 0.841 N m^{-2}
1:50 year return wave = 0.923 N m^{-2}</td></tr>
<tr><td rowspan="3">Foundation geometry information</td><td>Small
(3.6 MW)</td><td>Demonstrator
(5MW)</td><td>Large
(6 or 7 MW)</td></tr>
<tr><td colspan="3">Jacket Leg Diameter; D (m)</td></tr>
<tr><td>1.7 m</td><td>1.9 m</td><td>2.5 m</td></tr>
<tr><td>Maximum Number of Turbines</td><td>125</td><td>110</td><td>75</td></tr>
<tr><td>Distance between jacket legs (m)</td><td>15 - 21</td><td>15 - 21</td><td>17 - 34</td></tr>
</table>

*Hm0 is significant wave height (also referred to as Hs)

G.4 PRELIMINARY CONSIDERATIONS

G.4.1 Introduction

Prior to undertaking a scour risk assessment, some characteristics of the site require definition and some procedural issues require mention. The following sections briefly address these.

G.4.2 Clear Water versus Live Bed

Seabed areas exposed to tidal currents can be classified as either 'clear water' or 'live-bed'. Clear water scour is where sediment transport occurs only in the vicinity of the structure following acceleration of flow around the piling base. Live-bed scour is where flow everywhere on the bed is sufficient to mobilise and transport sediment at all times. The regional and site specific (baseline) assessments indicate that the tidal currents are not capable of mobilising sand (and thus also gravel) at the Neart na Gaoithe site under normal tidal conditions and therefore the site can be classified as 'clear water'. The importance of this is related principally to backfilling; if the local bed material is not mobile under native currents, post-scour backfilling of the scour pit is unlikely to occur and thus the computed equilibrium value is unlikely to vary. This may also have a bearing on the design and implementation of any dynamic scour protection.

G.4.3 Foundation Dimensions and Layout

Jacket structures may be regarded as a pile cluster. These are complex structures in comparison to cylindrical monopiles, and effects such as flow blockage, wake flow interference and turbulence generation between legs, or sheltering of piles, may occur. Further, the presence of a horizontal cross brace between the jacket legs (used in some jackets) may potentially generate scour depending on the brace width (vertically), the flow velocity, the nature of the bed material (sand, gravel etc.) and the distance to the bed. Diagonal braces will also block the flow and create turbulence but since they angle upward and away from the bed (see Section G.7) their impact on scour generation over and above that due to flow contraction at the bed surface due to the leg base is considered to be minimal.

Three jacket types with differing leg dimensions have been considered. The jacket bases comprise four legs of diameter *D* (m) equidistant with a spacing (*G* [m]) of either 15 – 21 m (for 3.6 or 5 MW WT) or 17 – 34 m (for a 6 or 7 MW WT), and without a cross brace in either case[1]. Conventionally the minimum separation distance for jacket legs that is considered as non-interfering with adjacent legs is $G/D > 2 – 3$ (according to Sumer and Fredsoe, 2002) and > 6 (according to Whitehouse, 1998). G/D is, respectively, 8 – 12 (3.6 MW, D = 1.7 m); 7 – 11 (5 MW, D = 1.9 m); and 7 – 14 (6 or 7 MW, D = 2.5 m). Hence, herein each leg can be considered for present purposes as a discrete cylindrical structure around which scour may develop fully and independently. This approach is consistent with that applied within the Ormonde OWF EIA (33 jackets), and follows the general approach taken for similar oil and gas jacket scour problems (Allen, pers. comm.). It is based, in part, on the logic that if scour is predicted to occur for a discrete cylindrical structure, then it would in reality also be expected for a jacket. The analysis will, in addition, present any

[1] This is the same configuration of jacket structures as used at the Beatrice OWF site.

cumulative effects of the four legs and consider the generation of global scour as a consequence.

The ratio of pile diameter (*D*) to water depth (*h*) defines to an extent which equations should be used in any analysis. Clearly for the Neart na Gaoithe site $D/h < 0.5$ (see Table G- 1), which indicates that the legs must be treated as a 'slender' cluster rather than 'wide' pile cluster (Whitehouse, 1998).

G.4.4 Structure Orientation

With jacket type structures comprising symmetric but multiple legs, the orientation of the structure to the principal tidal axis should not lead to differences in scour extent around each leg. Since the current is rectilinear it is anticipated that scour will develop equally at and around each leg during both the flood and ebb tide phases. No wake interactions between legs are anticipated based upon the inter-leg spacing (see above).

G.4.5 Seabed Datum

Scour around foundations produces a vertical excavation of the sediment to generate a scour pit. The depth of this pit is conventionally referenced to the datum of the surrounding seabed level, which itself is known to change in coastal regions. Surrounding bed level changes are not anticipated to be significant at Neart na Gaoithe as the seabed sediments are generally stable (except during extreme storms). This issue is discussed more fully in the site-specific Baseline Coastal Processes report.

G.4.6 Scour Pit Alignment and Symmetry

Tidally generated scour pits are usually aligned with the principal tidal axis for rectilinear currents. This is the case at the Neart na Gaoithe site and the axis is aligned N/S-SSW. Asymmetries in the tidal currents can also drive asymmetries in the scour pit dimensions. Flood currents at the site are stronger than the ebb currents, with the difference being slightly more pronounced for neap tides. The ratio of spring flood to ebb tide current magnitude is 1.1 whereas that for the neap tide is 1.3. Some degree of asymmetry is therefore expected but it is not anticipated to be pronounced.

G.4.7 Stress Amplification

Scour occurs due to the amplification of bottom frictional stresses adjacent to structures. For a slender cylinder in deep water the usually accepted stress amplification magnitude is 4 (Whitehouse, 1998), although amplification factors up to 10 have been reported (Hjorth, 1975).

G.4.8 Influence of Waves

It is necessary to consider if waves impact the bottom, and if they do whether they have the potential to mobilise sediments. The sediment transport analysis in the Neart na Gaoithe baseline summary description broadly indicates that during the summer months waves do not or only very marginally impact the seafloor, but that winter waves may generate sediment suspension.

G.4.9 Sediment Size Influence

There are potential controls on scour through the ratio of structure geometry and size to sediment size. Melville and Sutherland (1988) showed that the effect of sediment size on the scour depth disappears when $D/d_{50} \geq 50$. Therefore, for the present study (sand), sediment size is not considered to be an important factor as this inequality is satisfied for the values of D and d_{50} (see Table G- 1).

G.4.10 Methodology

The quantitative assessment of scour is not an exact science and should not be regarded as such. Despite research over many years, and two prior rounds of offshore wind farm development in the UK, there remains a high level of uncertainty as to the potential depth and extent of scour at offshore foundations (Whitehouse *et al*., 2011). Further, there is at present no accepted method of assessing scour around multi-leg structures, apart from physical modelling (Wallingford, 2005). The range of uncertainties is, to an extent, reflected in the range of technical approaches. This analysis is based upon the methodology of Whitehouse (1998) for clear water scour and a quad pile cluster with non-interfering vortex streets (Equation 1). This method embodies research data from a range of studies and is based upon the ratio of bed stress to critical bed stress.

$$S_e/D = 1.3\ [2(\theta/\theta_{cr})^{0.5} - 1] \text{ when } 0.25 \leq \theta/\theta_{cr} < 1 \qquad 1$$

and when $\theta < \theta_{cr}/M$ (with $M = 4$ for single pile situations). Here, S_e is the equilibrium scour depth, D is the jacket leg diameter, M is the stress amplification factor, and θ is the Shields parameter given by:

$$\theta_{\infty} = \tau_0 / [(\rho_s - \rho)gd_{50}] \qquad 2$$

where τ_0 is the bed shear stress, ρ_s and ρ are the density (specific gravity) of sediment and water (respectively), g is the acceleration due to gravity, and d_{50} is the median grain size. θ_{cr} is the value of θ at the threshold of sediment motion.

Medium sand, rather than fine sand, is used as a worst case scenario, and this sand grade is found extensively across the site. The effects of ambient currents (spring and neap tides) and extreme currents are investigated. Although the consensus which exists indicates that waves are of less importance in contributing to scour development, this is also explored. The principal scour metrics reported are the equilibrium scour depth (S_e), the horizontal extent or length-scale of scour (X_s), the scour volume (V_s) and scour footprint (α) for a single foundation. X_s is computed using a constant angle of repose (30°) which is only an approximation to the real-world situation. Cumulative scour volumes have not been computed and presented. However, these can be generated using the total number of turbines expected for each jacket size (see Table G- 1).

G.4.11 Representative Location

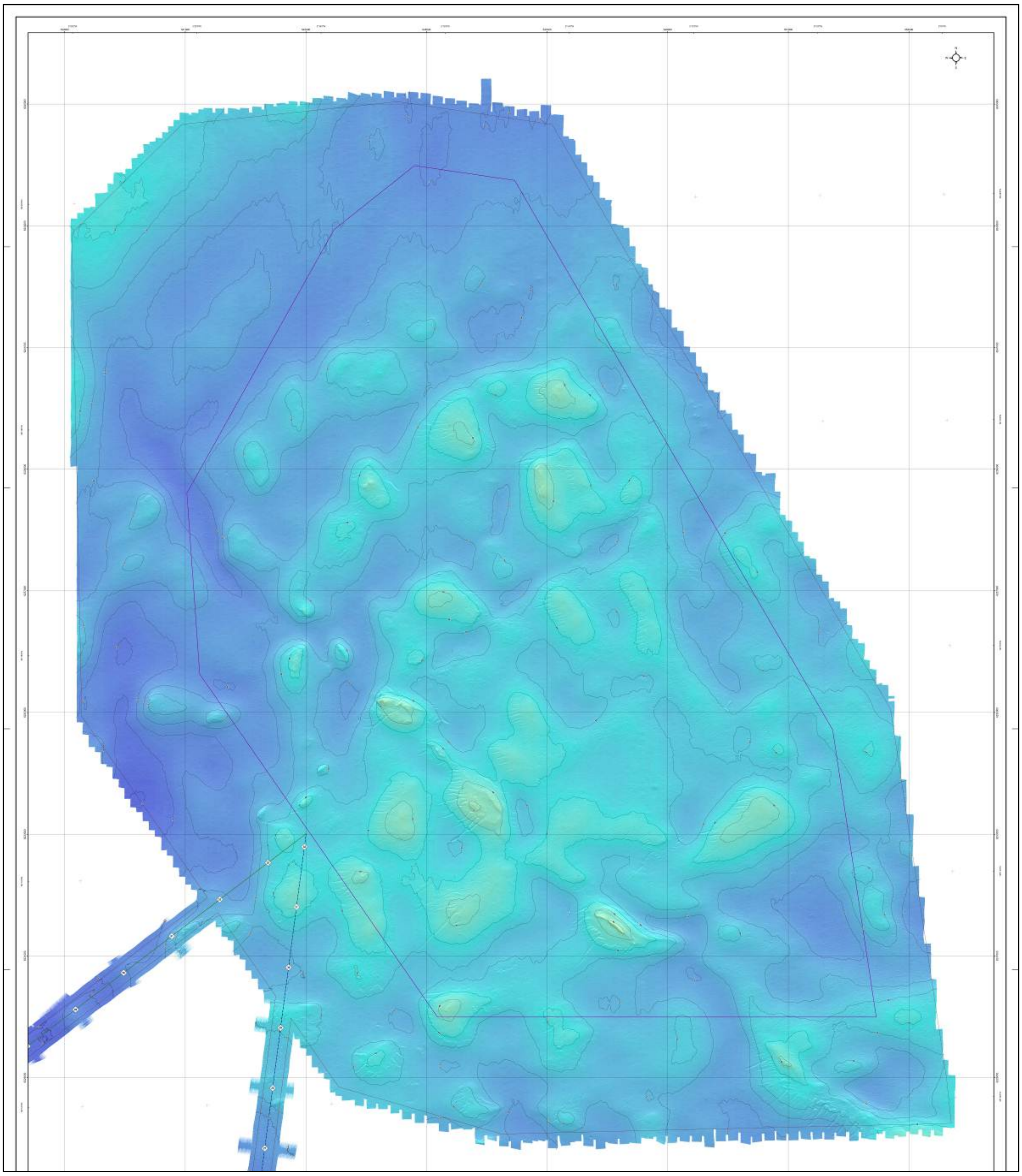
The requirement of this study is for a generic scour risk analysis for a 'representative' location at the site. For this a hypothetical site has been chosen. This is on a dominantly sandy area of the seabed (>80% sand, the case for >75% of the site – see Table G- 2), away from the numerous low amplitude hummocks and mounds (over 25 mounds are present within the survey area – (see Figure G-2) in the central and southern regions of the site, with a zero or very minor fines/gravel fraction (see Table G-2), and at average depth (~51 m). The sand present is fine to medium in size, and in order to provide a conservative estimate of scour a critical entrainment stress for medium sand has been used (see Table G- 1) (if medium sand is entrained then the fine sand will also be mobilised).

The analysis assumes a local depth of surficial sediment to 10 m; however, the importance of any limiting sub-surface geological conditions across the site is discussed in the result.

Table G- 2: Summary of particle size distribution data. Orange shading indicates samples where percentage of sand is >80%. Source: Environmental Survey

Sample	% Gravel	% Sand	% Silt	Mean Grain Size (mm)	Sorting[1]	Folk Sediment Classification (Folk, 1954)
6	0.17	89.13	10.70	0.125	0.81	Slightly Gravelly Muddy Sand
7	0.03	91.27	8.70	0.141	0.91	Slightly Gravelly Sand
	0.03	94.21	5.76	0.152	0.79	Slightly Gravelly Sand
12	33.66	60.53	5.81	0.909	3.29	Sandy Gravel
13	0.21	91.92	7.87	0.185	1.12	Slightly Gravelly Sand
14	2.53	84.89	12.57	0.164	1.329	Slightly Gravelly Muddy Sand
18	7.29	79.00	13.72	0.174	1.68	Gravelly Muddy Sand
19	0.19	93.13	6.68	0.194	1.00	Slightly Gravelly Sand
20	0.05	89.93	10.02	0.134	0.89	Slightly Gravelly Muddy Sand
21	0.17	94.39	5.44	0.175	0.92	Slightly Gravelly Sand
22	51.94	38.10	9.96	2.593	3.89	Muddy Sandy Gravel
24	2.79	90.95	6.26	0.151	0.86	Slightly Gravelly Sand
25	16.06	75.80	8.14	0.341	2.64	Gravelly Sand
26	5.60	86.64	7.76	0.219	1.69	Gravelly Sand
27	1.09	89.89	9.02	0.188	1.25	Slightly Gravelly Sand
28	0.24	88.10	11.66	0.119	0.88	Slightly Gravelly Muddy Sand
31	0.04	88.01	11.94	0.118	0.80	Slightly Gravelly Muddy Sand
32	2.36	92.62	5.03	0.192	1.04	Slightly Gravelly Sand
33	0.00	95.65	4.35	0.194	0.83	Sand
35	41.63	54.39	3.98	1.145	2.71	Sandy Gravel
36	6.75	88.98	4.27	0.215	1.35	Gravelly Sand
37	0.00	94.98	5.02	0.157	0.75	Slightly Gravelly Sand
38	11.34	88.49	0.17	0.553	1.56	Gravelly Sand
39	0.10	99.29	0.61	0.253	0.77	Slightly Gravelly Sand
40	0.00	92.21	7.79	0.143	0.79	Sand
44	0.02	89.89	10.09	0.137	0.84	Slightly Gravelly Muddy Sand
45	0.62	94.28	5.11	0.176	0.87	Slightly Gravelly Sand
46	25.74	66.64	7.62	0.677	3.00	Gravelly Muddy Sand
47	0.01	94.25	5.74	0.141	0.69	Slightly Gravelly Sand

Figure G- 2 : Distribution of water depths (bathymetry) across the Neart na Gaoithe site. Source: Geophysical Survey



G.5 SCOUR ASSESSMENT

G.5.1 Scour Assessment under Tidal Currents

Inspection of the input data indicates that bed stresses during neap tides (even when amplified adjacent to the jacket foundation) will not generate scour. Scour is thus dominantly due to spring tidal currents. Low scour rates are expected simply on the basis that the duration of scour is reduced by 50% through the year. Higher currents, such as those resulting from additional meteorological forcing (surges), will also generate scour. Currents with up to 1:25 year return periods are assessed, and this is a timeframe which approximates the initial lease term for the site and assessment period for the study. Table G- 3 summarises the anticipated equilibrium scour depth (S_e) and the horizontal extent or length-scale of scour (X_s) under the above tidal conditions (computed using Equation 1). In addition, the volume of sediment (V_s) liberated by scouring per leg and for the entire (single turbine) foundation (V_{TOT}), and the total scour footprint (α) are presented. Values of V_s are inherently conservative due to assumptions made on the scour pit shape.

Cumulative scour volumes have not been computed and presented. However, these can be generated using the total number of turbines expected for each jacket size (see Table G- 1).

Table G- 3 : Summary of predicted equilibrium scour depth, lateral extent, volume of sediment per leg and per foundation, and the total scour footprint

Forcing	Scour Depth (S_e) m			Lateral extent X_S (m)			Volume of Scoured Sediment Per Leg, V_S (m^3)			Volume of Scoured Sediment Per Foundation, V_{TOT} (m^3)			Total Scour Footprint, α (m^2)		
	Leg Diameter (m)														
	1.7	1.9	2.5	1.7	1.9	2.5	1.7	1.9	2.5	1.7	1.9	2.5	1.7	1.9	2.5
Peak Spring Tide	2.22	2.48	3.26	3.98	4.45	7.99	49	69	275	196	276	1100	284	357	1063
Peak Neap Tide	No scour														
Return Period Currents (Yrs)															
1:1	3.47	3.88	5.11	6.23	6.97	12.51	169	244	987	676	976	3948	621	779	2369
1:10	6.48	7.25	9.53	11.64	13.01	23.36	1043	1458	5994	4172	5832	23976	1950	2439	7598
1:25	7.25	8.11	10.67	13.02	14.56	26.13	1443	2019	8319	5772	8076	33276	2407	3012	9407

Note that if coarser sediments e.g. gravelly sediments are used in the analysis then the time period within each spring tide during which scour can occur is less and therefore the rate of scour will be slower, but that the same equilibrium scour depth will eventually be attained.

Many previous scour (computation) studies have worked on the premise that the dimensions of the scour pits generally scale geometrically with the diameter *D* of the pile, and expressed the equilibrium (maximum) scour (S_e) depth as a multiple of the monopile diameter (*D*). Similarly, the ratio of the horizontal extent of the scour pit (X_s) to *D* has received attention and generally the relation is found[2]: $X_s \cong 2.25D$ (measured from the pile wall not the centre). For the above analysis S_e/D = 1.3 – 1.31 and X_s = 2.3 – 3.2*D* (assuming an unconstrained sediment thickness). These estimates are in generally good agreement with those reported in the literature:

- Sumer and Fredsoe (2002) found Se/D ≅1.3 (±0.7)
- Clark et al., (1982) quote values for Se/D ranging from 1.0 to 2.3
- den Boon et al., (2004) found Se/D ≅1.75

In an examination of 115 datasets, Whitehouse *et al.*, (2011) report only six of these were greater or equal to S_e/D = 1.3. The maximum value for S_e/D found anywhere on the UK continental shelf since the inception of the development of offshore wind farms (i.e. encompassing the range of inshore water depths, tidal and wave conditions) is 1.77 (Carroll *et al*., 2010). This is reported at Robin Rigg, which is a far higher energy environment than that at the Neart na Gaoithe site. It is essential to note the data of Sumer and Fredsoe (2002), which form the basis of the DNV Guidance (2007), have a standard error term (0.7) due to variability in their results. Closer inspection of the Whitehouse (1998) approach for a clear water scour also shows scatter and variation in the estimate of S_e/D ranging from ~0.7 – 1.8 (due principally to uncertainties in bed stress values). Whilst it is judged that the Neart na Gaoithe site is a relatively low current, deeper water environment in which scour depths would be lower, a judicious and conservative approach would be to assume a worst case scenario of e.g. S_e/D = 1.5. Adoption of this value would provide a margin, for instance, in relation to the design of scour protection.

G.5.2 Scour Footprint

The values of X_s (Table G- 3) can be used to judge whether scour pits merge to form part of a larger region of scour beneath and around the structure (so-called 'global' scour) or whether pits remain local to each leg. Table G- 4 presents results for regular (peak) spring tides and for a worst case situation (largest leg diameter, smallest gap) for a set of extreme tides. These show that for the jackets with *D* = 1.7 m or 1.9 m, scour is anticipated local to each leg only for regular spring tides. This is also true for *D* = 2.5 m and a larger jacket structure (6 or 7 MW) where *G* (leg spacing) = 34 m; however, global scour i.e. a general lowering of the seabed within and around the structure, is expected during regular spring tides where an alternative (smaller, *G* = 17 m) 6 or 7 MW WT structure is used. It follows that all extreme tides would also therefore generate global scour.

[2] DNV 2007. Design of Offshore Wind Turbine Structures. Offshore Standard DNV-OS-J101. 142pp.

This analysis assumes that there are no horizontal cross-brace beams that are close to the bed on jackets. The presence of these would modify the scour process and may promote global scour at lower current velocities and smaller values of *G*.

Table G- 4 : Comparison of predicted lateral scour extent with leg separation distance

Forcing	Leg Diameter *D* (m)	Leg Separation Distance *G* (m)		Lateral Scour Extent X_s (m)	Scour Pit Interaction?
		Min (m)	Max (m)		
Peak Spring Tide	1.7	15	21	3.98	No
	1.9	15	21	4.45	No
	2.5	17	34	7.99	Possibly just (for min *G*)
Return Period Currents (Yrs)					
1:1	2.5	15		12.51	Yes
1:10	2.5	15		23.36	Yes
1:25	2.5	17		26.13	Yes

The values of X_s also indicate the footprint region outwith the foundation structure that is affected by scour. These show that a typical spring tide impacts an area extending ~4 – 8 m from the foundation (variable according to leg diameter), whereas the 1:25 year storm surge current impacts a length scale of just over three times this. Given that the marine scour conditions at Neart na Gaoithe are clear water, there are no effects (such as sediment wakes) anticipated beyond these distances.

G.5.3 Scour Timescales

The timescale over which scour occurs can be derived, although these are very approximate as no analytical solutions are available to predict scour timescale in reversing tidal environments with great accuracy. For a given set of environmental conditions the scouring of sediments at structures initially occurs rapidly but then approaches its ultimate (equilibrium) value. Scour at the Neart na Gaoithe site would be expected to begin during the first spring tides following jacket installation, but to cease during neap tides. Scour would thus develop recurrently but in an alternating fashion.

Scour pit evolution through time is given by the expression:

$$S(t) = S_e[1 - \exp(-t/T)^p] \qquad 3$$

where $S(t)$ is the scour depth after time t, S_e is the equilibrium scour depth, T is the characteristic timescale for the scour and p is a fitting coefficient usually taken as unity. T is defined as the time after which the scour depth has developed to 68% of the equilibrium value. T is obtained from:

$$T^* = T[g(s – 1)d_{50}^3]D^{-2} \qquad 4$$

where g is the gravitational acceleration, s the sediment mineral specific gravity ρ_s/ρ (where ρ_s is normally 2650 kg m^{-3} for sand), and d_{50} the median grain size of the sediment. This equation requires:

$T^* = A\theta_\infty^{\ B}$ 5

where:

$\theta_\infty = \tau_0 / [(\rho_s - \rho)gd_{50}]$ 6

A is 0.005 and B is -2.2 (these are constants for a given geometry), τ_0 is the bed stress, and θ_∞ is the Shields parameter related to the ambient flow i.e. away from the structure.

For the Neart na Gaoithe site T = 29 days i.e. roughly a month. Since active scour occurs for only ~ 50% of the time this value can be doubled; i.e. 58 days. Corresponding values for 1.9 m and 2.5 m diameter foundations are, respectively, 66 and 86 days.

It is of interest to note that static scour protection, if required, could be placed during neap tides i.e. when there is no scour.

G.5.4 Scour Assessment under Waves

The energy associated with mean annual wave conditions (H_{m0} = 1.3 m; T_z ~ 4 s) does not penetrate to the seabed and therefore is not able to generate scour. The observed peak significant wave observed during the oceanographic monitoring campaign (H_{m0} = 6.03 m) only barely induces sediment transport (typical bed stress τ_0 = 0.003 N m^{-2}; Table G- 1) and this is due to limiting wave periods, which are mostly < 8 s. Longer wave periods possess a greater propensity to generate sediment transport, but occur only very infrequently. Similarly, extreme wave events (see Table 1) where T_z > ~9 s will impact the seabed but these are also highly infrequent with statistical return values greater than 1:25 i.e. longer than the initial site lease term. Moreover, rare storm events are of relatively short duration (i.e. days) and therefore the severity of sediment transport events is limited. On this basis waves can effectively be ignored as an important scour-generating mechanism at the Neart na Gaoithe site, and the site can be classified as *tidally dominated*.

G.5.5 Limiting Sub-Surface Conditions

Scour involves the amplification of near-bed flow velocity by the presence of a fixed structure and vertical excavation of the sediment mass. In unconstrained, non-cohesive and unconsolidated sediments scour is able to continue for as long as the amplified flow around the structure base is capable of transporting sediments. Whether scour can progress unabated depends essentially on the vertical down-core profile of grain size/sediment type to the equilibrium scour depth (S_e). If there are sub-surface horizons where substantially different[3] grain sizes occur, or if there is a highly limiting condition such as bedrock, then the actual scour depth will be less than that predicted. Limiting sub-surface issues are known from other UK OWF sites and Whitehouse *et al*., (2011) present case studies from these with a range of differing limiting conditions.

The foregoing analysis was undertaken using the assumption that the structure would be sited on at least 4 m thickness of medium sand. Across the northern and western extents of the site, sand deposits up to 8 m thick are found and therefore scour depths may approach S_e. However, although sand is the

[3] i.e. different to the surficial grain sizes.

pervasive sediment type across the site, the above assumption is not satisfied everywhere across the site.

Generally soft-sediments across the proposed offshore wind farm survey area (including site and buffer) range from 0 to 15 m thick with a mean of 3.4 m. Across large areas of the site, upon Wee Bankie Formation exposures and occasionally where bedrock outcrops near the surface, the soft-sediment cover is a ~0.2 to 1 m thick veneer. The Wee Bankie Formation is described as a stiff, variably matrix-dominated polymictic (multiple grain sizes) diamicton[4] with some interbeds of sand, pebbly sand and silty clay with boulders (Gatliff et al., 1994). It was formed during the Quaternary period as a result of glacial processes. Whilst the veneer sediments are likely to be unconsolidated sands and thus potentially mobile under currents, the presence of the Wee Bankie Formation both at the surface or sub-cropping will offer significantly greater resistance to hydrodynamic (erosional) forces at the seabed thereby limiting scour to values less than predicted i.e. lower than S_e. A comparable situation exists, particularly in the centre and east of the wind farm site, where a similar thin veneer of sediment (less than 0.3 m thick) is present over bedrock. The bedrock, of course, will limit scour entirely.

A full analysis of the scour potential for the site would integrate build layout/turbine location information with more detailed geological data from the site investigation geotechnical core log data. This approach would indicate at which turbine locations fully developed scour would be expected, and those for which scour might be depth-limited.

G.5.6 Backfilling

Backfilling is where the scour pit accumulates sediments during periods in the tidal cycle when scouring is not well developed. Backfilling results in differences between the actual scour depth and the predicted scour depth. Since the Neart na Gaoithe site is a 'clear water' situation with scouring prevalent only during spring tides and in the presence of a structure, backfilling rates will be extremely low or non-existent. This means that the maximum scour extent (S_e), once generated, is likely to remain largely unchanging, except potentially following major storm events when higher levels of suspended sediment are able to settle back to the bed and infill the pit. These events, however, are rare and of comparatively short duration.

G.5.7 Bedforms

Migration of bedforms e.g. megaripples, dunes etc. through a scour pit can modify the scour depth through time. This issue is not generally important here as bedforms are not present at the site (except in the vicinity of hummocks and mounds). If turbines are built in areas where bedforms are observed then this issue may rise in importance.

G.5.8 Comparison with Other Similar UK and International Sites and Studies

Marine scour is a complex phenomenon, and not entirely understood by engineers and scientists (Sumer and Fredsoe, 2002; Sumer, *et al*., 2001). Even for the simple case of a monopile foundation, normalised scour depths

[4] A diamicton is a very poorly sorted sediment comprising large sedimentary grains set in a stiff matrix of fine grains.

may vary by more than a factor of four according to the computational assessment method used (e.g. Riechwien and Lesney; 2004), and intercomparisons between field data and predictive methods indicate both over and under-prediction (e.g. Noormets *et al.*, 2006). For this reason a precautionary approach is required where predictions are made regarding the scour depth, the timescales for scour etc., particularly where the data may be used to inform scour protection placement. The value of observations and data from similar projects in similar environments cannot be over-estimated.

Although jacket structures have been widely used in the oil and gas industry for many decades, these have not been the foundation of choice for offshore wind turbines to date. However, as the industry moves into deeper water and more powerful turbines become available additional structural strength is required, and jackets are increasingly being selected as a suitable foundation. Jacket type foundations are more complex structures with different flow blockage areas close to the bed. The interaction with near-bed flows, and the potential for generation of sediment scour, is correspondingly more complicated. Since there are no accepted, universal methods available to predict scour around jackets (Wallingford, 2005), examination of experience elsewhere where jackets have been used may be useful.

Within the UK jacket structures have been used only at the Beatrice Offshore Wind demonstrator in the Moray Firth and at the Ormonde Irish Sea development. Elsewhere jackets have been used at the Alpha Ventus development.

European Offshore Wind Development

Vattenfall, Technip and Aberdeen Renewable Energy Group (AREG) are the joint venture (JV) partners behind a Wind Deployment Centre in Scottish waters – the 11-turbine European Offshore Wind Deployment Centre (EOWDC) off Aberdeen Bay. The project has been developed following extensive consultation with stakeholders and studies which have seen the project significantly evolve over the last six years from an offshore wind farm into a deployment centre to test and demonstrate up to eleven next generation offshore wind turbines, support infrastructure and other related technology.

The *Coastal Processes Assessment Report* for the EOWDC provides predictions for the principal scour metrics for a range of foundation types, including jackets, for a situation where only currents have been used in the analyses. Although there are no details on the jacket type/structure it may reasonably be assumed not to differ substantially from other UK sites. The sediments of the EOWDC site are very similar to those at Neart na Gaoithe. The data are as follows: S_e is 3.25 m; X_s is 5 m; and V_s is 749 m^3. Since D is not known, no value for S_e/D is available.

Both S_e and X_s are very similar to the predicted values reported here, notably for the larger leg diameters (1.9 m and 2.5 m) (Table G- 3). The volume scoured value (V_s) falls mid-point between that for a 1.9 m and 2.5 m structure. The quantitative similarity between the scour metrics data for EOWDC and this study provide a level of reassurance that the predictions presented herein are meaningful, and that jackets on sandy seabed sediments possess a generally similar impact envelope.

Beatrice OWF

Beatrice Wind Farm Demonstrator Project was a joint venture between Scottish and Southern Energy and Talisman Energy (UK) to build and operate an evaluation wind farm in the deep water close to the Beatrice Oil field in the North Sea. Built in 2007, with two turbines and a total capacity of 10 MW, it was designed to examine the feasibility of creating a commercial wind farm in deep water and a reasonable distance from the shore. The project was the first OWF development to use a jacket type structure (Figure G- 3) This was designed and developed by the Norwegian company OWEC Tower, and fabricated in Scotland by Burntisland Fabrications. The site is 22 km from the Scottish coast and in 45 m of water. The water depths, bottom sediments and hydrodynamic conditions are highly similar to the Neart na Gaoithe site.

In spite of its position in the market as the first jacket structure to be used in UK waters, an environmental-engineering decision was made not to implement any scour protection i.e. to provide for a design scour allowance. This would appear to be on the basis that scour at similar, earlier structures and pipelines/cables in the Moray Firth has not presented any serious concern. The *Environmental Statement* mentions use of ROVs to provide scour surveys but to our knowledge this has not been performed. Moreover, no obligations to collect data on the scour magnitudes were emplaced by the Scottish regulator. Although there would appear to be no major concerns there is, therefore, virtually no information on the presence and magnitude of scour at the Beatrice site that can be utilised for comparative purposes.

Figure G- 3: The jacket structure used at the Beatrice OWF demonstrator site, Moray Firth

Ormonde OWF

The Ormonde Offshore Wind Farm is located 10 km off Barrow-In-Furness, in the Irish Sea. It is located in 17 to 21 m water depth, mean spring currents are ~0.5 m s^{-1} and the seabed is predominantly muddy sand. The highest anticipated waves are 4.7 m. These conditions are similar to Neart na Gaoithe but the water is shallower and the sediments rather finer. 31 jacket foundation structures have been built and Ormonde is the first large-scale commercial wind farm in European waters to use jackets for both the turbine foundations as well as the substation foundations.

The *Coastal Processes Scoping Report* provides predictions for the principal scour metrics for jacket foundations, for a situation where only currents have been used in the analyses. The scour hole due to tidal currents alone was predicted to extend about 3 x D horizontally from the pile and up to about 1.5 x D vertically, where D is the monopile diameter (5 m at the Ormonde site). These estimates, which are at present unsubstantiated at the site by survey data, compare well with estimates for the Neart na Gaoithe site (S_e/D = 1.3 – 1.31 and X_s = 2.3 – 3.2D (assuming an unconstrained sediment thickness).

Alpha Ventus OWF

The Alpha Ventus OWF is Germany's first offshore wind farm, and was built by a consortium consisting of the utilities EWE, E.ON and Vattenfall. The project is located some 45 km from the coast of Borkum and comprises twelve 5 MW class wind power turbines: six AREVA Wind M5000 turbines and six REpower 5M turbines, resting on two different foundation types. Whereas the AREVA wind turbines stand on tripods, the REpower turbines are mounted on jacket foundations in a water depth of 30 m.

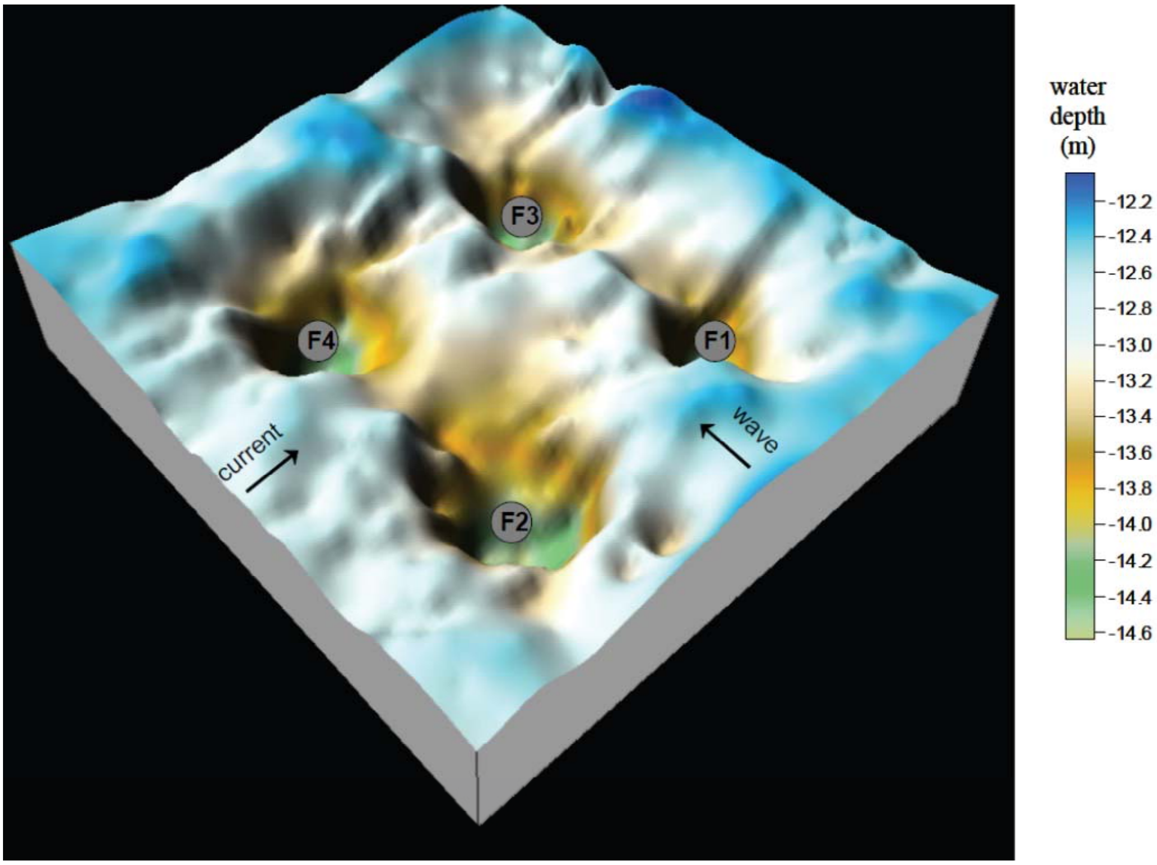
To date we have not been able to obtain relevant information on the jacket foundations at Alpha Ventus.

Scale Model Studies

Engineering scale models studies are commonly undertaken to examine the interaction of maritime structures with hydrodynamic forcing over mobile beds. Yang *et al*., (2010) provides a useful example (the only one in the literature) for a jacket foundation in a wave-current climate. 1:36 scale model studies were undertaken in a wave basin to examine local and global scour around the foundations of a typical jacket structure, (See Figure G-4) with Froude scaling being applied to both the hydrodynamics and to sediment density. Each jacket leg was 2.08 m in diameter. Two different water depths were investigated (12 m and 16 m) and the wave field and current fields were applied orthogonally to one another Figure G- 4 shows a 3D plot of bed bathymetry around the foundation. The principal findings of this work are:

- $0.46 < S_e/D < 1.07$
- generally $0.5 < X_s < 2.5D$
- S_e is, in the presence of waves, a weak function of water depth
- scour occurs quickly, with >70% of the depth to S_e occurring within 20 minutes
- more serious scour is induced at the up-current side of the foundation
- scour beneath the leg – leg cross braces occurs but is less excessive than around the legs

Figure G- 4 : Three dimensional bathymetry around the foundation following scouring during ‘worst case’ (i.e. most severe) hydrodynamic conditions. Note the currents and waves approach at 90°. Scour beneath the leg to leg cross members is evident. From Yang et al.



The jacket structure is very similar to that under consideration in this study. However, these studies represent a hydrodynamic situation which is, in comparison to marine conditions at Neart na Gaoithe, far more energetic (although the sediment types are comparable). The water depth is about one third that at Neart na Gaoithe, applied currents ~40% greater in magnitude and wave heights approximately half the water depth. A comparison with anticipated scour at Neart na Gaoithe is thus only partially valid. Nonetheless, if the values of scour depth (S_e) and lateral extent (X_s) reported by Yang et al. (*op. cit.*) are treated as worst case values and inclusive of energetic wave scour, then these could be used either to constrain the estimates for the same metrics for Neart na Gaoithe, or to provide a general guide.

G.5.9 Summary

The following are the chief conclusions from the scour analysis:

1) The Neart na Gaoithe site can be considered a deep water tidally dominated site, with wave action highly limited in its impact upon the seabed.

2) The site is a clear water site, meaning that scour only occurs in the vicinity of a structure.

3) Only spring tides give rise to scour (neap tides are too weak) and therefore scour has the potential to occur for only 50% of the time.

4) The tidal current is rectilinear and it is anticipated that scour will develop equally at and around each leg during both the flood and ebb tide phases.

5) Tidally generated scour pits are likely to be aligned with the principal tidal axis (N/S-SSW at Neart na Gaoithe).

6) Scour depth (S_e) scales geometrically with leg diameter (D), S_e/D = 1.3 – 1.31.

7) The lateral extent of scour (X_s) varies within the range X_s = 2.3 – 3.2D.

8) Scour is localised to the foundation area around individual jacket legs for most scenarios (jacket leg diameters; current conditions), but global scour is expected for all extreme current events.

9) The timescales for scour to develop to 68% of S_e is between 58 and 86 days, depending on leg diameter.

10) Backfilling is not expected to occur as a result of the clear water characteristic of the site.

11) Bedform migration within and around scour pits is not an important factor, except where jackets may be sited in bedform fields associated with resistant Quaternary hummock features.

12) For many locations across the site the presence of only a thin surface sediment veneer over resistant horizons (rock; Quaternary formations e.g. Wee Bankie) will limit the vertical extent of scour.

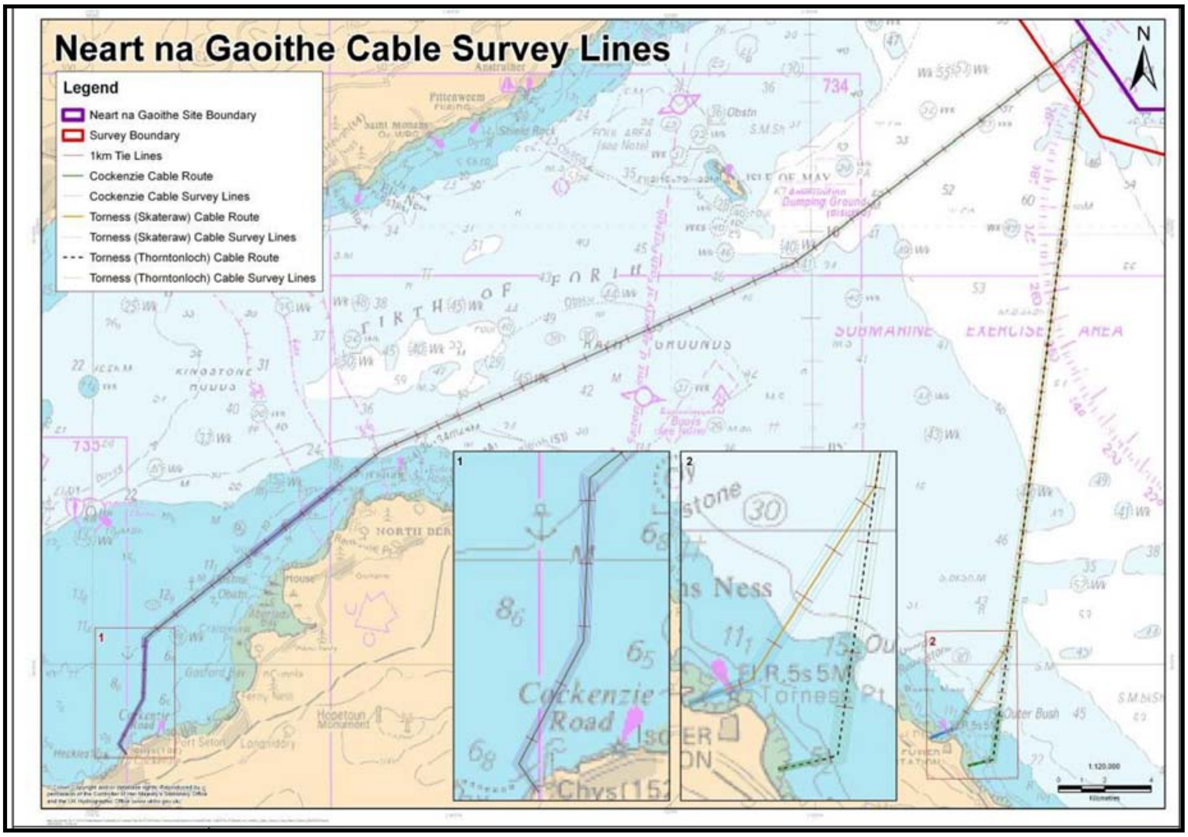
13) There is generally reasonable agreement with the limited available scour information and data from other sites where jacket foundations have been used.

G.5.10 Overview Scour Assessment for Proposed Cable Routes

Two potential export cable routes were initially identified for the Neart na Gaoithe site development (Figure G- 5)The northern route, termed the ‘Cockenzie’ route, exits the site boundary at its south western boundary and follows a south western bearing to landfall at Cockenzie on the northern East Lothian coast. The route is ~54 km long. The southern route (the ‘Torness’ route) leaves the site at the same point but follows an approximately southern bearing to landfall at one of two proposed locations in the vicinity of the Torness headland (where there is a nuclear power station). The route is ~32 km long. It is assumed in both cases that the export cable would be buried, to a depth of up to 2.0 m, to provide a level of protection from vessel anchoring, trawling and sediment transport. The principal marine environmental impact for this situation is the generation of sediment plumes during burial, during any necessary removal for repair, and during eventual decommissioning.

Subsequent to the initial export cable route studies, the Cockenzie route was dropped as a development option. The scour assessment for this route has been retained in this report to provide comparison to the Torness route.

Figure G- 5 : Candidate export cable routes for the Neart na Gaoithe site with three different landfall locations. Source Geophysical Survey



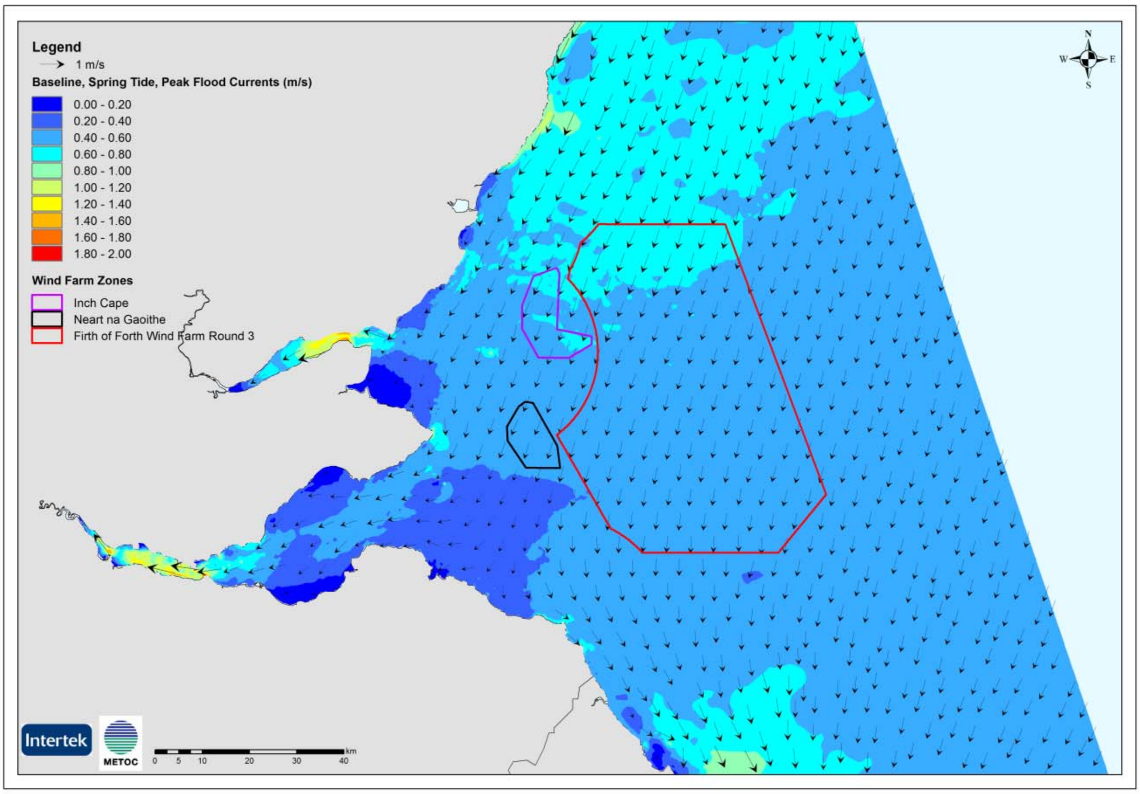
Cable burial is achieved using a variety of mechanical approaches, including jetting, mechanical trenching and ploughing. Modern technologies are now developed to the point where loss of sediment is substantially minimised; however, some material is unavoidably and permanently disturbed both through sediment removal and direct trenching vehicle impact. Typical cable burial depths for OWFs are 0.7 to 1.0 m, with trench widths of ~ 0.3 to 0.7 m, but burial depths up to 2.0 m may be considered. The rate at which burial operations are performed is also important in terms of the fate of sediment plumes because the ambient current magnitudes vary throughout the tide; average rates of progress for OWF cable installation are of the order 300 – 400 m per hour, which gives 1800 – 2400 m per half tide (CTC, pers. comm.). A realistic worst case scenario would arise for a 2 m burial depth and trench width of 1 m. Table G- 4 provides the volumes and mass of sediment (using a porosity value for the upper layer sediments of 0.4; Soulsby, 1997) introduced into the water column assuming 100% liberation during trenching. These data can be used within the regional hydrodynamic model to assess the subsequent degree of transport of the plume; plume fate can be projected for every hour of the tide or for an entire half tide. This work is not reported here.

An example of the model is provided in Figure G- 6 : Example of hydrodynamic model output: peak spring tidal flood current vectors (speed, direction).

Table G- 5 : Summary of predicted realistic worst case volumes and corresponding masses of sediment resuspended by trenching per hour

	Time (hours)/Linear Metre of Trench (m)				
	1	2	3	4	5
	400	800	1200	1600	2000
Cumulative Sediment Volume Removed (m^3)	480	960	1,440	1,920	2,400
Cumulative Dry Mass Removed (kg)	1,272,000	2,544,000	3,816,000	5,088,000	6,360,000

Figure G- 6 : Example of hydrodynamic model output: peak spring tidal flood current vectors (speed, direction)



G.5.11 Changes in Sediment Characteristics Along Export Cable

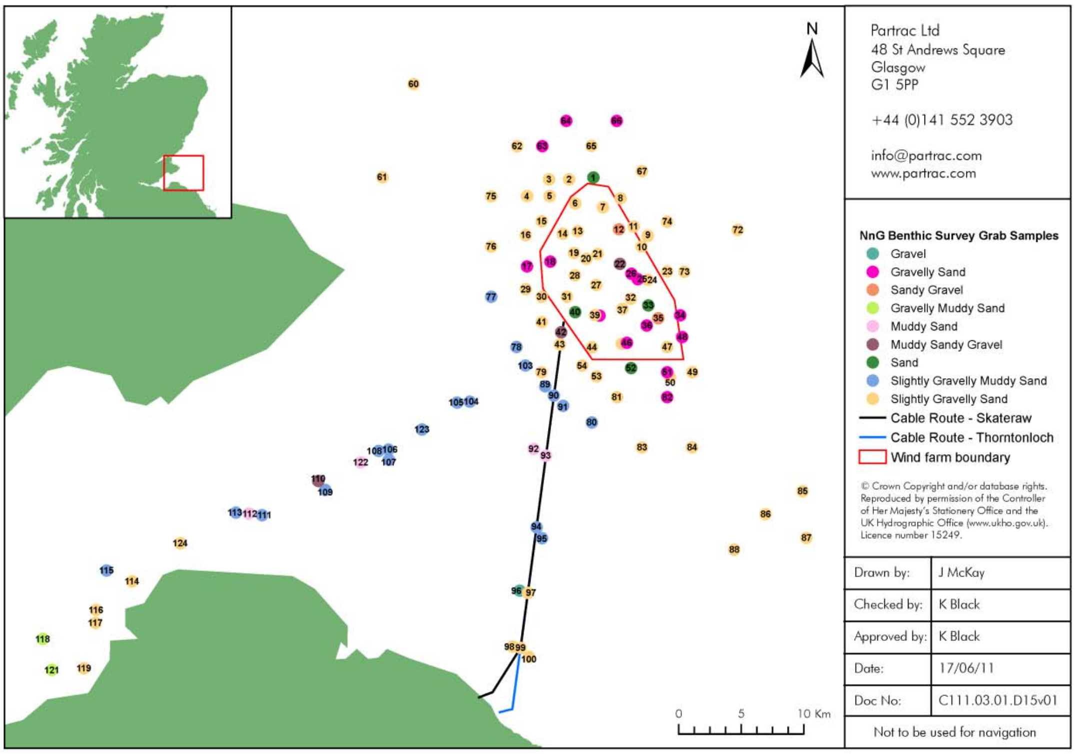
The main sediment types along both the Cockenzie and Torness cable routes are slightly gravelly muddy SAND. However, there is some local variability, especially around the inshore region on the Cockenzie route (where sediments are coarser). The plume transport modelling is sensitive to the distribution of particle size. Table G- 6 summarises grain size metrics for samples collected along the cable route within the Environmental Survey and Figure G- 7 shows these on a map. These data can be used in conjunction with the data in

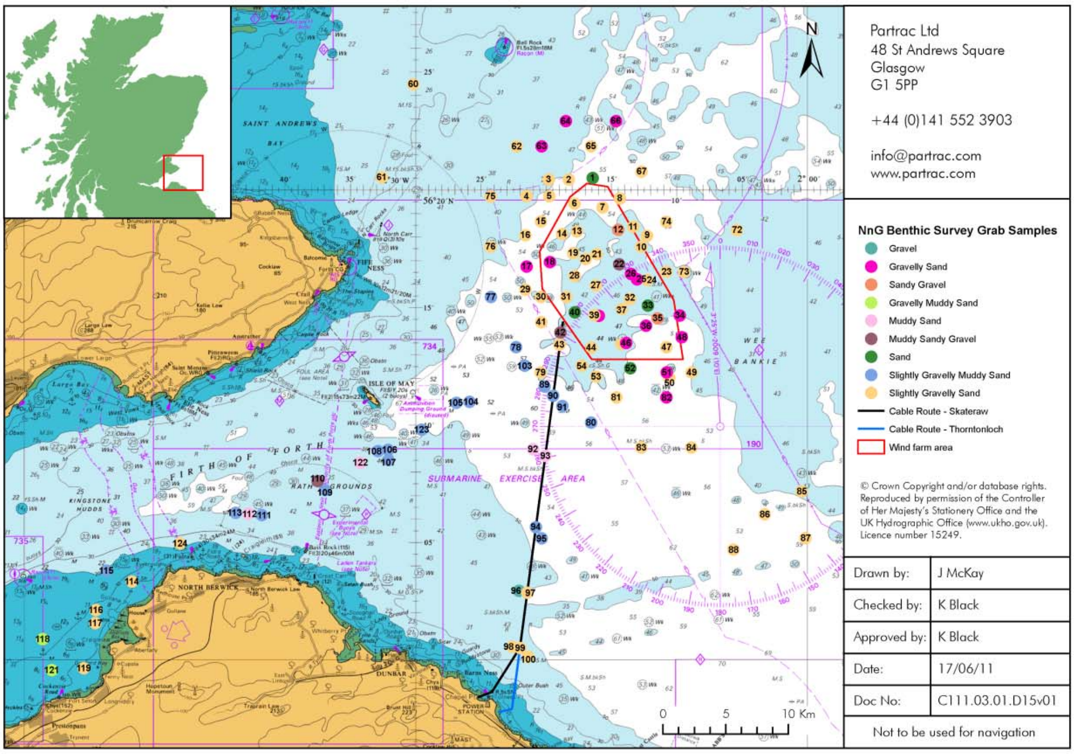
Table G- 5 to inform the plume fate modelling at different sections along the route. A worst case scenario would be created by using the finest sediments observed (e.g. sample number 118) and assuming 100% liberation into suspension.

Table G- 6:Grain size statistics from samples along the Cockenzie and Torness proposed cable routes. Source: Environmental Survey

Route	Sample #	UTM30N_E	UTM30N_N	% Gravel	% Sand	% Mud
Torness Cable Route	43	542705.53	6231216.81	0.10	86.79	13.11
	90	542204.42	6227132.66	0.08	75.37	24.55
	91	542947.53	6226312.90	0.18	73.47	26.35
	92	540604.84	6222893.56	0.00	55.19	44.81
	93	541579.32	6222346.29	0.00	54.03	45.97
	94	540828.41	6216658.42	0.09	68.43	31.48
	95	541279.50	6215785.03	0.20	76.21	23.58
	96	539488.01	6211602.22	80.60	11.43	7.97
	97	540146.72	6211436.36	1.18	82.02	16.81
	98	538918.17	6207146.86	0.76	86.44	12.80
	99	539571.63	6207055.53	0.49	85.72	13.79
	100	540216.42	6206337.48	0.31	87.42	12.27
Cockenzie Cable Route	103	539941.71	6229516.88	0.28	77.68	22.04
	104	535526.16	6226649.75	0.01	42.92	57.07
	105	534489.89	6226570.38	0.01	46.05	53.94
	106	529032.52	6222840.36	0.63	72.62	26.75
	107	529055.66	6222026.21	0.29	70.01	29.70
	108	528231.60	6222722.74	0.27	67.00	32.73
	109	523996.46	6219624.24	0.04	58.72	41.24
	110	523422.88	6220339.77	56.20	29.68	14.11
	111	518945.28	6217625.62	0.06	51.23	48.71
	112	517874.24	6217731.64	0.00	48.22	51.78
	113	516858.88	6217814.53	0.11	53.50	46.39
	114	508593.68	6212343.95	0.23	99.56	0.20
	115	506555.33	6213212.74	0.35	44.86	54.79
	116	505705.59	6210074.96	0.74	88.52	10.74
	117	505668.00	6209032.75	4.16	88.06	7.78
	118	501452.43	6207752.71	10.92	29.51	59.57
	119	504739.23	6205434.75	1.68	88.77	9.55
	121	502200.24	6205288.38	18.89	51.27	29.84
	122	526814.15	6221810.91	0.00	56.94	43.06
	123	531700.26	6224444.25	0.27	76.79	22.94
	124	512443.47	6215372.54	0.29	81.67	18.04
	78	539245.70	6230994.61	0.07	71.77	28.17

Figure G- 7 : Distribution of samples along the prospective export cables (with and without Admiralty Chart). Colour is used to indicate sediment type. Source: Environmental Survey





G.5.12 Overview of Scour Mitigation

Construction industry codes specify that an adequate assessment of scour be included at the design stage and, if necessary, that appropriate preventive measures be provided. The notes appropriate to offshore structures (e.g. DoE/HSE, 1992/93) indicate methods for consideration at certain types of installation. There are a variety of approaches that can be taken to prevent or mitigate against scour around OWF foundations. Whitehouse (1998) provides a review of scour protection options. Included within this review are the following:

- Anti-scour collars (monopoles only);
- Rock armour placed on the seabed around the foundation (static scour);
- Rock armour placed in the scour hole around the structure (dynamic scour);
- Rock armour placed on the seabed prior to foundation installation (gravity bases only);
- Sandbags/geotextile bags placed on the seabed around the foundation;
- Concrete mattresses placed on the seabed around the foundation (usually only for cable protection); and
- Frond mats placed on top of concrete mattresses or anchored directly to the seabed around the foundation.

A detailed overview of these various scour protection/mitigation measures is beyond the scope of this report, and ordinarily a specific application would require a formal scour protection assessment in relation to the structure, foundation type, site specific oceanographic conditions and bottom sediment type. The following provides a brief description of those methodologies suitable for jackets and highlights the chief considerations for application.

Rock Armouring

Rock armouring is the most common approach to provision of scour protection in the UK OWF industry. This involves placement of a layer of rip-rap (stone or gravel) around a structure (Figure G- 8). The material is commonly quarry run stone of blasted rock (usually limestone or granitic rocks). An initial assessment is required to a) provide a scour potential assessment and b) generate an estimate of the stable rock size for the site oceanographic conditions (including the extreme events). Standard procedural methods exist for this (e.g. Whitehouse, 1998). Commonly, and in order to avoid winnowing of the native bottom sediments through spaces in between the rocks by flows, one or more finer filter layers are first spread over the bed across the anticipated (calculated) scour footprint. Larger rocks are then placed on top of this layer. In some instances a geotextile map may overlie directly the filter layer but care is required to avoid this becoming clogged by mobile sediments which reduces dissipation of pore pressures. Occasionally widely graded rocks are dumped directly into already formed scour pits.

Figure G- 8 : Underwater photograph of rock armour at the base of a structure. Source: Whitehouse et al., (2011)

Rock armour can be either placed into an already formed scour pit (dynamic protection) or it can be laid as soon as possible after jacket installation on the level surrounding seabed (static protection).

Several methods exist to place rocks from surface vessels and these are reviewed by Herbich *et al*., 1984). These include:

- From a side dumping barge or vessel with individual stones falling to the sea bed
- From a split hopper barge as one mass
- From a barge through a pipe to reduce the fall velocity of rock and improve placement accuracy

De Wolf (1994) describe the use of rock armouring as a method of scour protection for a structure off the Belgian coast.

Sandbags/geotextile bags

Sandbags, or as they are also termed, 'geotextile' bags are modern, synthetic bags/tubes which contain clean sand. The geotextile material is inert, has a very high resistance to tearing and puncturing, and is porous to permit water exchange and dissipation of pore pressures. The geotextile fibre is versatile and can be formed into various containers, including bags and tubes (ranging from hand-filled 40 kg containers to 400 tonne sand mega-containers and tubes). These can be infilled with either dry sand or hydraulically pumped wet sand, and then sealed to form stable, but mechanically flexible, structures for use in a range of engineering applications.

These include:

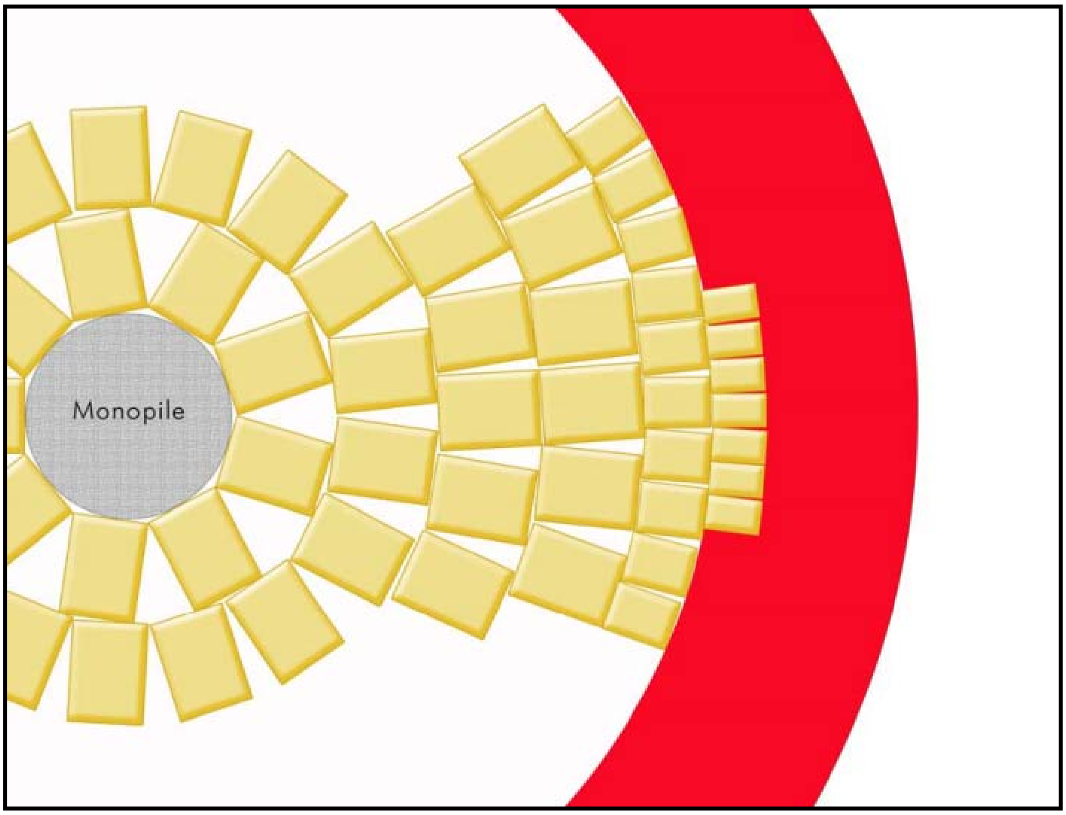
- sea walls;
- groynes;
- artificial reefs;
- channel and bank protection;
- shore protection works;
- containment structures; and
- coffer dams.

Figure G- 9 shows an example of a geotextile bag. They have been used for over 40 years in a range of ('soft') coastal engineering situations, particularly to offer stabilisation to shorefront and river bank sections. Recently, there has been interest in the potential use of geotextile bags as a means of providing protection against scour for OWF structures.

Figure G- 9 : Close-up photograph of a modern woven geotextile fabric. Courtesy of Elcomax™

For square jacket structures geotextile bags (rather than tubes) would be used. Bags can be made in a variety of sizes. Each bag can be carefully emplaced and stacked vertically one by one around a structure (see Figure G- 10), perhaps in a squat pyramidal configuration. Geotextile bags would provide adequate scour protection and are suited to both the dynamic scour and static scour situations. Since they are filled with clean sand rupture of a bag e.g. during placement would not present any serious environmental issue. What limited data exist indicate that whilst geotextile bags used in this way do work, they are susceptible to undermining and displacement by peripheral flow acceleration (Watson, 1979).

Figure G- 10 : Plan view (bed layer bags only) of the scour protection arrangement for the case of static scour around a monopile. The red strip is a ballasted nylon matt aimed at reducing secondary scour. Source: Partrac Consulting/OMM Ltd.



Maidl and Schiller (1979) provide an example of the use of geotextile bags for scour protection for offshore environments.

Frond mats ('artificial seaweed')

Frond mats are a form of flow energy dissipation device, and are an attractive option for scour protection since they actually tackle the source of the scour itself. Modern frond mats comprise continuous lines of overlapping buoyant polypropylene fronds that when activated create a viscous drag barrier that significantly reduces current velocity. The frond lines are secured to a polyester webbing mesh base that is itself secured to the seabed by anchors pre-attached to the mesh base by polyester webbing lines. The action of reducing current velocity immediately prevents seabed sediment in the immediate area of the fronds from being transported i.e. 'scoured out', and causes sediment transported across the fronded area to fall into, and collect, within the fronds. Through time, a bank of sediment can form. The reduction in the speed of the water flow through the fronds can be as much as 80% (Hindmarsh, 1980). Figure G- 11 shows a set of time-lapse photographs illustrating the mode of action of the fronds and the gradual entrapment and build-up of sediment.

The principal practical issues associated with the use of frond mats is to ensure the fronds are fully open, otherwise they have minimal effect, and to ensure the foundation anchors and strops have adequate strength and are themselves immobile.

The use of frond mats as scour protection to date is more widespread in the offshore oil and gas industry, but is equally applicable to offshore wind applications.

Figure G- 11 : Series of photographs illustrating the action of frond mat technique

INITIAL SEDIMENT BUILD-UP COVERING MAT BASE AND THE FOOT OF THE FRONDS

CONTINUED SEDIMENT BUILD-UP IN CENTRE OF THE MAT AND SLOPING TO AND BEYOND THE MAT EDGES.

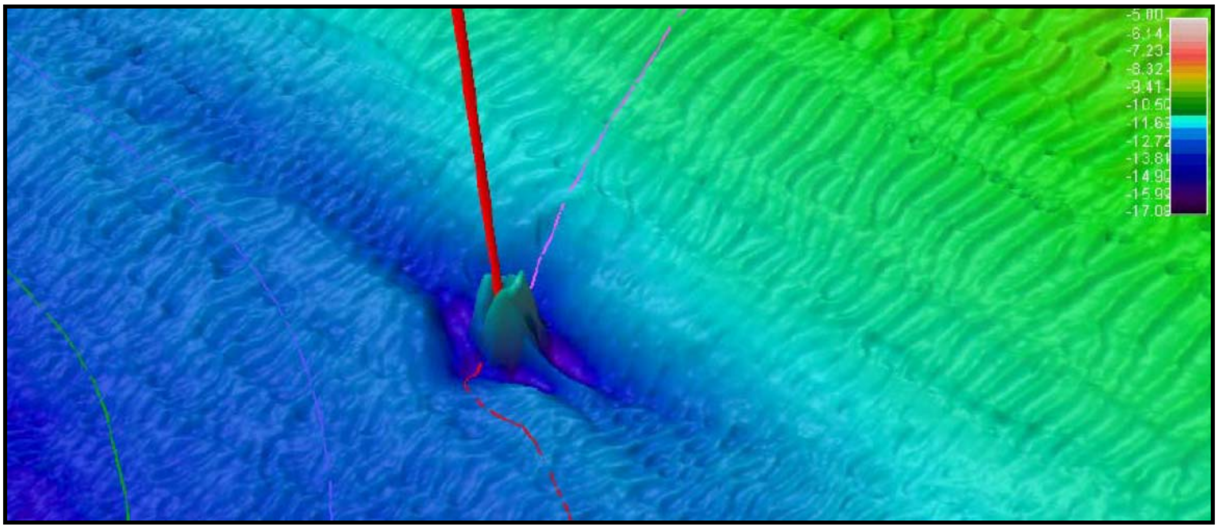
RE-INFORCED SEDIMENT BANK NEAR FULL DEVELOPMENT WITH A FEW SHORT LENGTHS OF FRONDS EXPOSED

DIVER INSPECTING FULLY DEVELOPED SEDIMENT BANK WITH SHORT RANDOM FRONDS SHOWING AND A TYPICAL "RIPPLE" PATTERN APPEARING ON SEDIMENT SURFACE

Secondary Scour

Secondary scour is defined as scour at the edges and along the periphery of the scour protection. Some degree of secondary scour inevitably occurs for all remedial approaches, but it is more prevalent at higher (wave and tidal) current sites (Figure G- 12) It is often associated in its most extreme form with badly positioned rock dump projects, which occurred, for example, at the Scroby Sands OWF. Secondary scour results in a lowering of the seabed around the periphery of the protection, the so-called ‘falling apron’. Displaced rocks were observed in the falling apron area at Scroby Sands. Secondary scour is of little concern as long as it is fulfilling its primary function of preventing scour at the foundation, and any scour wakes do not extend laterally and unbury interconnector cabling or interact with adjacent turbine structures. Rarely is this the case, even at more energetic sites. A simple practical tenet is to taper any scour protection radially so that the height at the seabed interface is very low.

Figure G- 12 : Seabed MBES image showing acute secondary scour around the scour protection (dumped rock) around the base of the monopile (red cylinder) for the Scroby Sands wind farm



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G.7 EXAMPLE JACKET STRUCTURE FROM BEATRICE OWF

Figure G- 13 shows the jacket structure used at the Beatrice OWF site. The scour analysis has been performed on the basis that a very similar foundation will be used at Neart na Gaoithe.

Figure G- 13 : Photographs of the jacket structure used the Beatrice OWF site

Appendix H Modelled Impact Assessment Plots

This appendix includes the results of the assessment of the effect of the proposed developments on the metocean and sediment regimes.

The appendix is divided into the following sections:

- The effects due to the Neart na Gaoithe development only (H.1);
- The cumulative impacts from Inch Cape and the Firth of Forth Round 3 developments, in addition to those from the Neart na Gaoithe OWF (H.2); and
- The effects from the potential climate change (H.3).

The effects from the developments are shown as differences, or changes, to key metocean and sediment regime parameters, including water level, current speed, wave height and ultimately the exceedance of the critical shear stress. It is the change in the percentage of time that the critical shear stress is exceeded which most clearly demonstrates the impact of the development(s) on the sediment regime. An additional set of plots (Figures H.139 to H.142) shows any changes to the far-field suspended sediment transport pathways.

Differences are calculated by subtracting the results from the baseline model runs from the same results obtained from the impact assessment model runs. Therefore positive values (shown in the orange/brown colour range) indicate an increase (in the parameter) due to the development(s), and negative differences (shown in the pink/purple colour range) indicate a decrease in the presented parameter.

Finally, where possible the same contour banding has been used for the set of plots for each parameter (i.e. for the differences to 50, 90, 95 and 99%ile significant wave height), to allow easy comparison. This means that on some plots only one or two contour colours are presented.

H.1 EFFECTS DUE TO THE NEART NA GAOITHE DEVELOPMENT

This section shows the effects of just the Neart na Gaoithe development. It is divided into separate sections which show changes to: the hydrodynamic regime (H1.1); the wave climate (H1.2); and the sediment regime (H1.3). Near-field changes are shown first for each regime, followed by the regional, or far-field impacts.

H.1.1 CHANGES TO THE HYDRODYNAMIC REGIME – NEART NA GAOITHE AREA (NEAR-FIELD)

Figure H-1 : Difference in mean spring tide high water (HW) level (m) – near-field

Figure H-2 : Difference in mean spring tide low water (LW) level (m) – near-field

Figure H-3 : Difference in mean neap tide high water (LW) level (m) – near-field

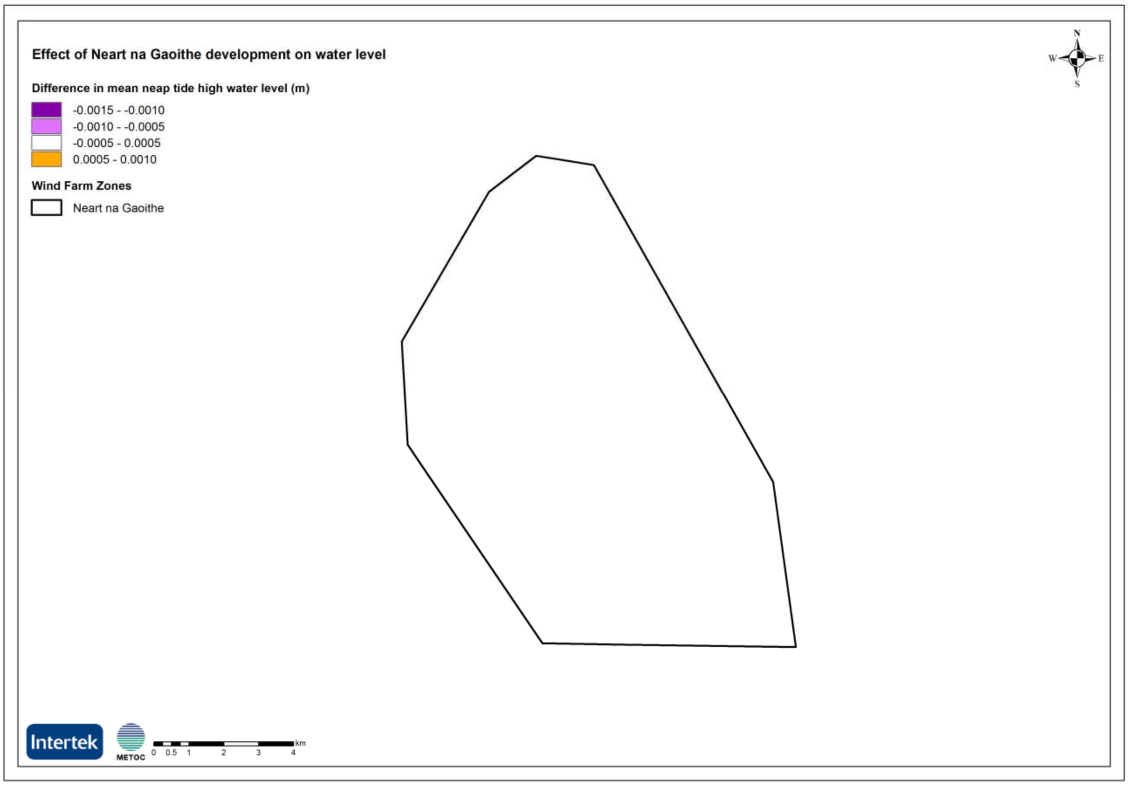


Figure H-4 : Difference in mean neap tide low water (LW) level (m) – near-field

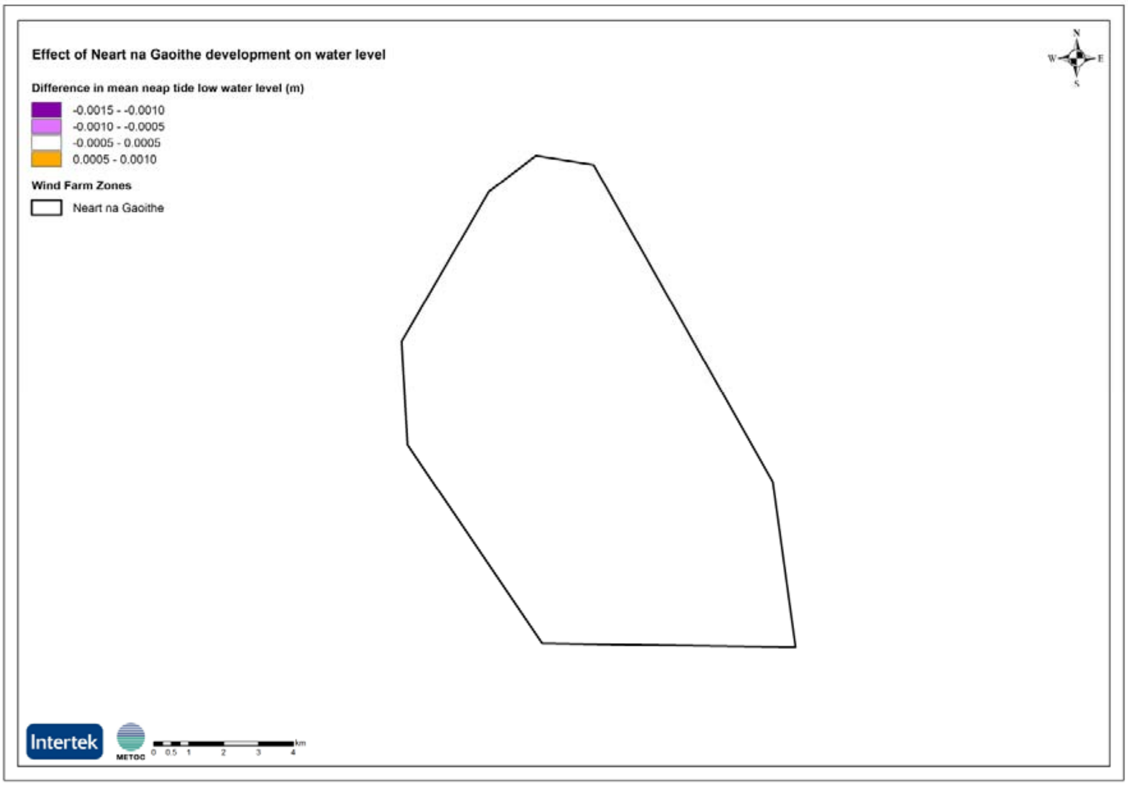


Figure H-5 : Difference in mean spring tide peak flood current speed (m/s) – near-field

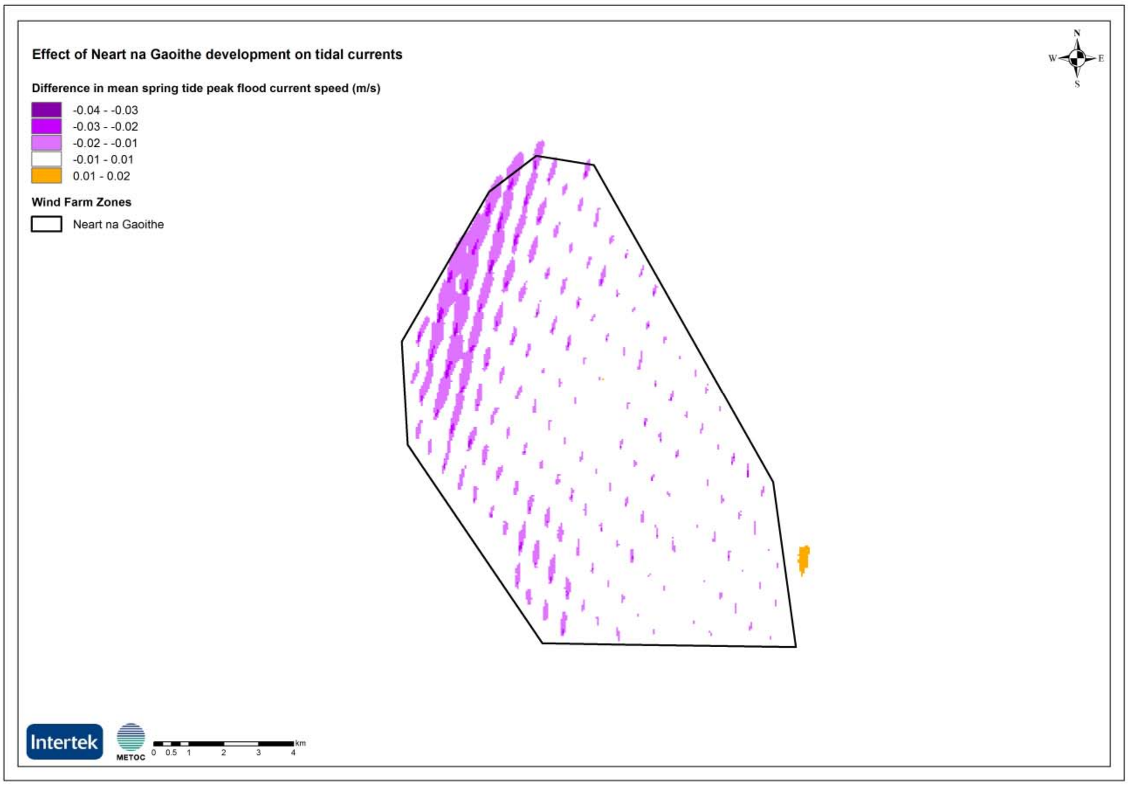


Figure H-6 : Difference in mean spring tide peak ebb current speed (m/s) – near-field

Figure H-7 : Difference in mean neap tide peak flood current speed (m/s) – near-field

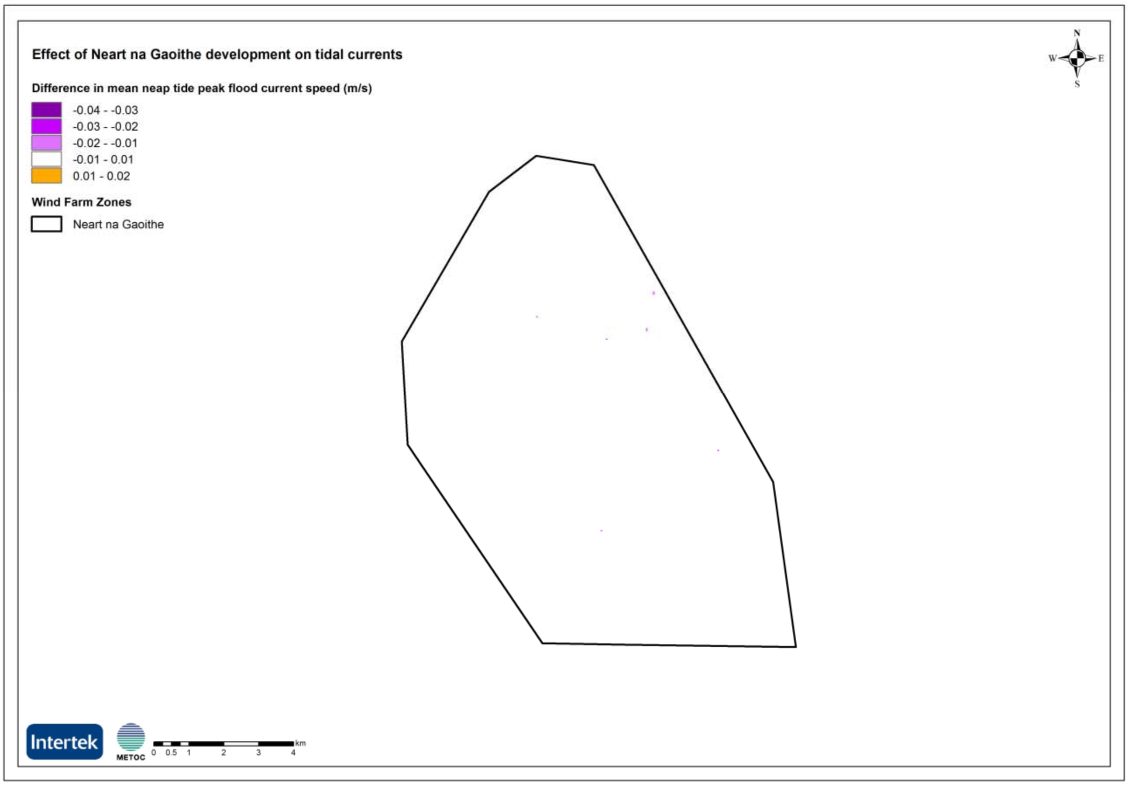


Figure H-8 : Difference in mean neap tide peak ebb current speed (m/s) – near-field

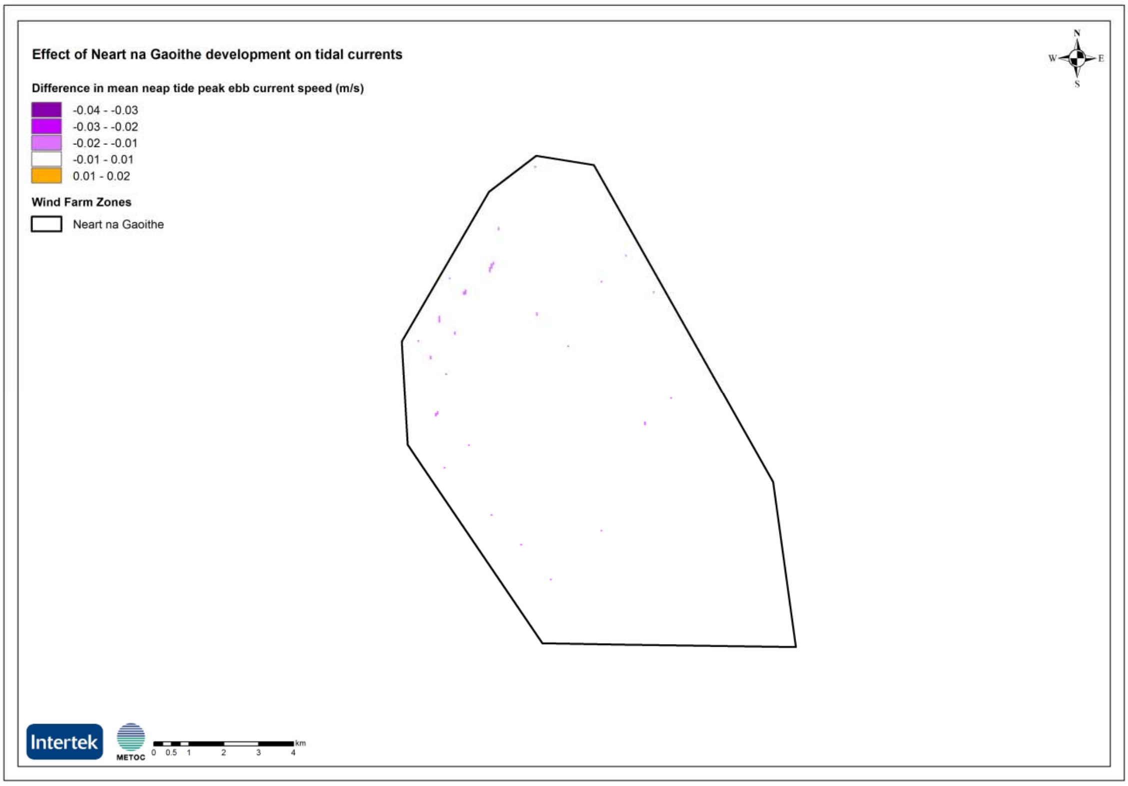


Figure H-9 : Difference in the 50-percentile current speed (m/s) – near-field

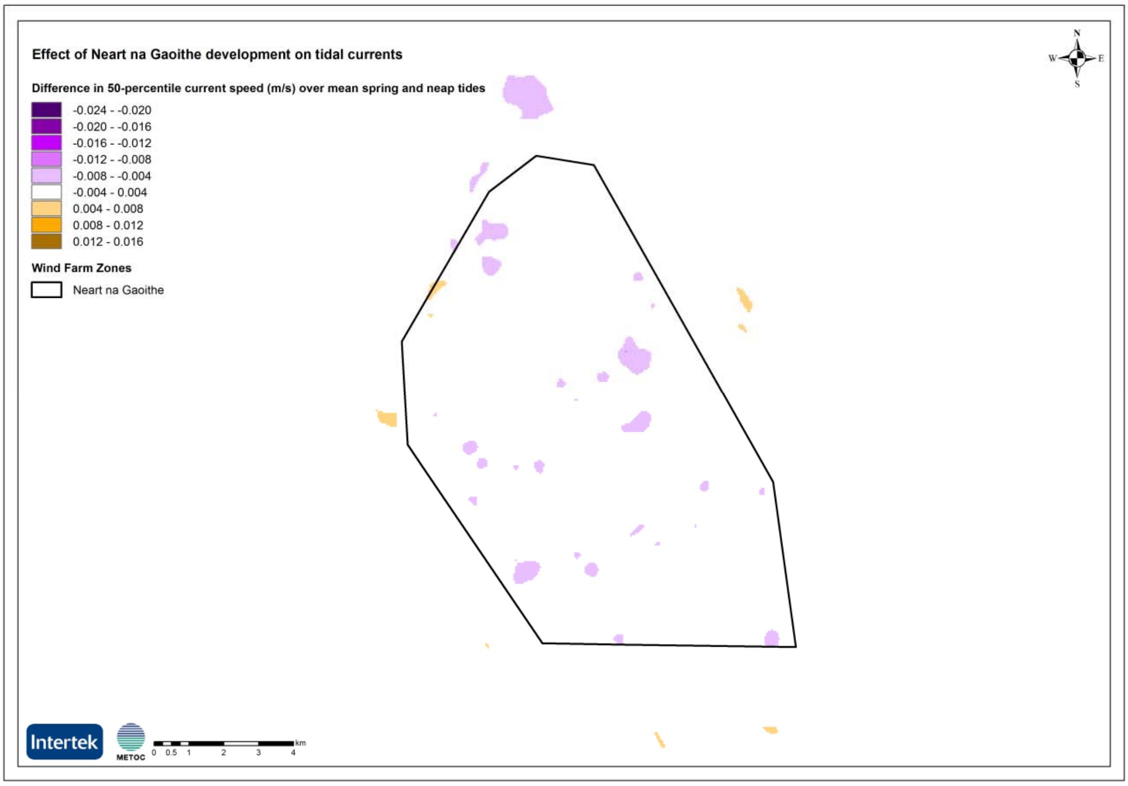


Figure H-10 : Difference in the 90-percentile current speed (m/s) – near-field

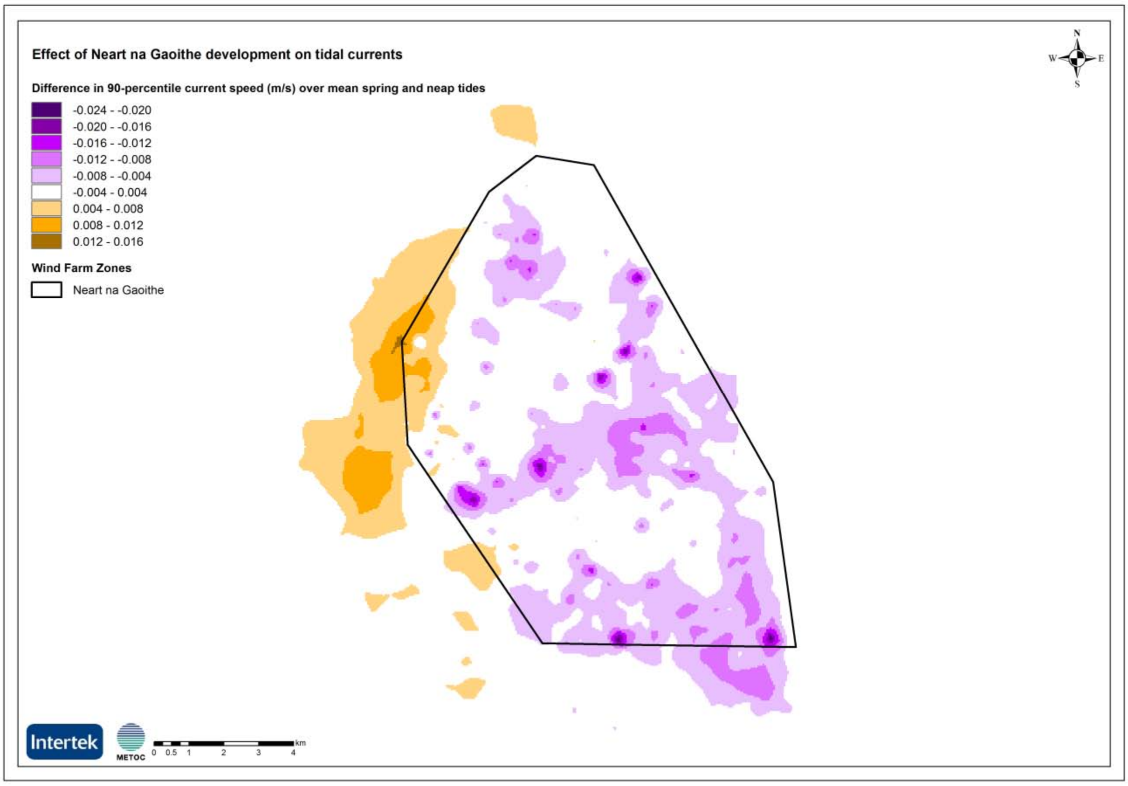


Figure H-11 : Difference in the 95-percentile current speed (m/s) – near-field

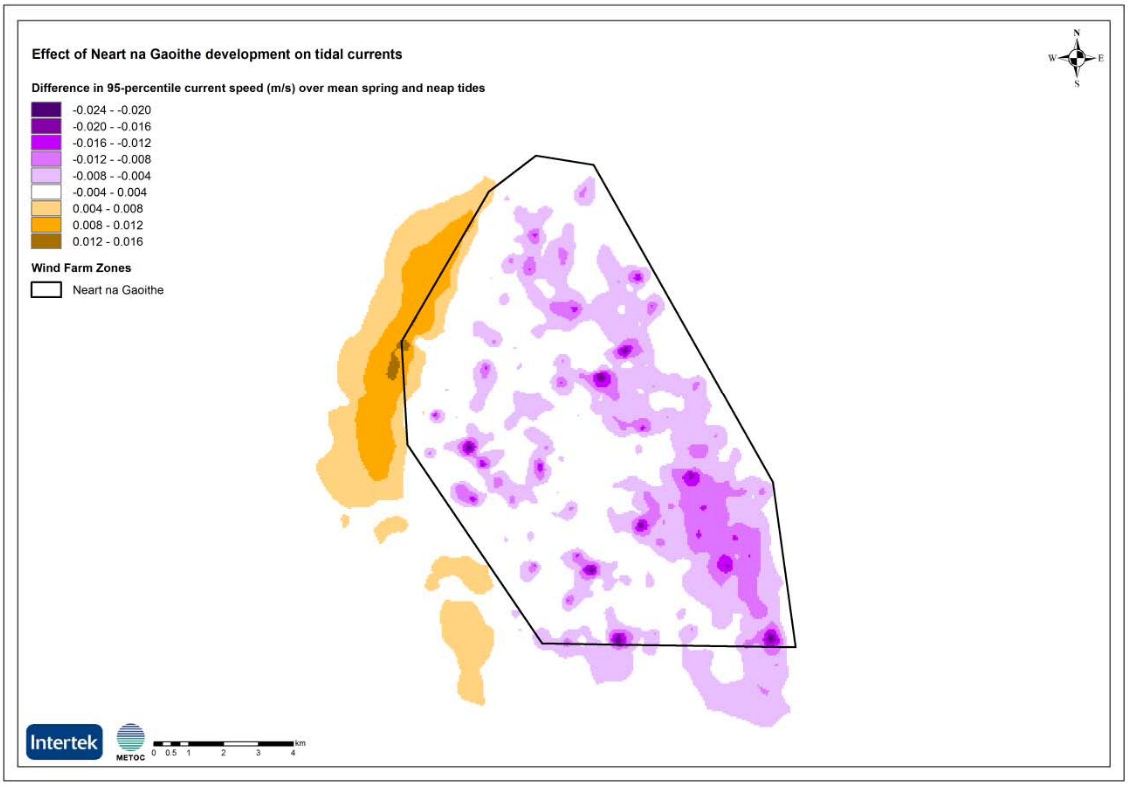
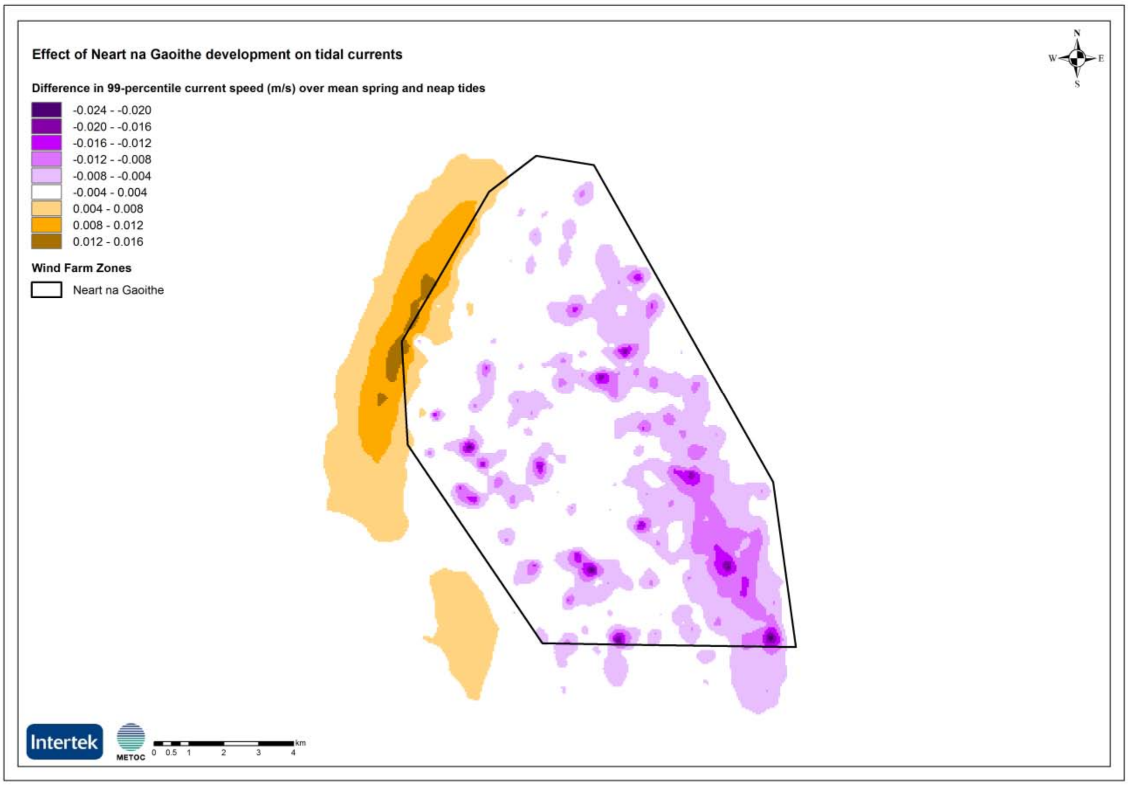


Figure H-12 : Difference in the 99-percentile current speed (m/s) – near-field



H.1.2 CHANGES TO THE HYDRODYNAMIC REGIME – REGIONAL AREA (FAR-FIELD)

Figure H-13: Difference in mean spring tide high water (HW) level (m) – far-field

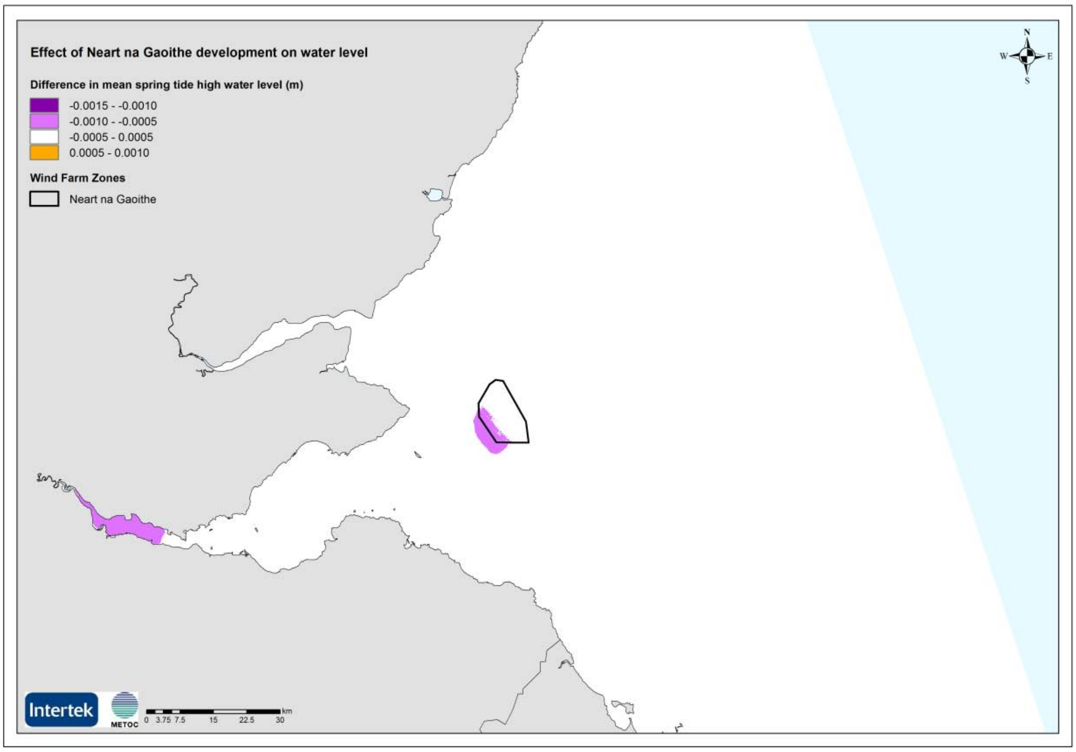


Figure H-14 : Difference in mean spring tide low water (LW) level (m) – far-field

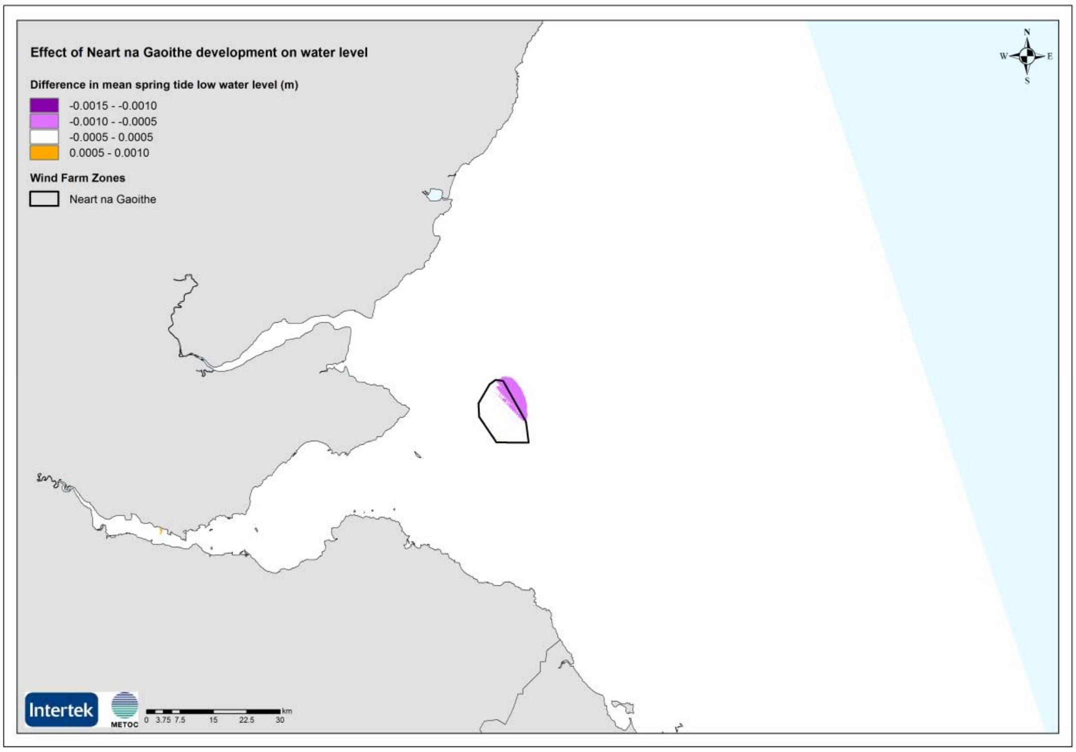


Figure H-15 : Difference in mean neap tide high water (HW) level (m) – far-field

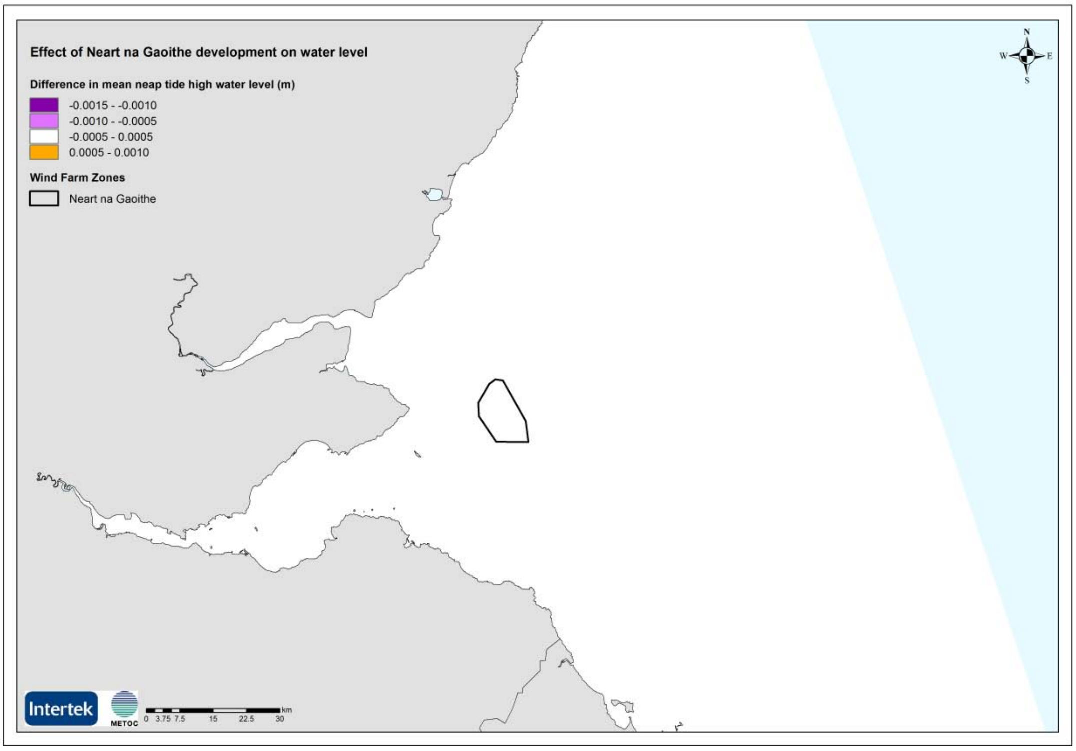


Figure H-16 Difference in mean neap tide low water (LW) level (m) – far-field

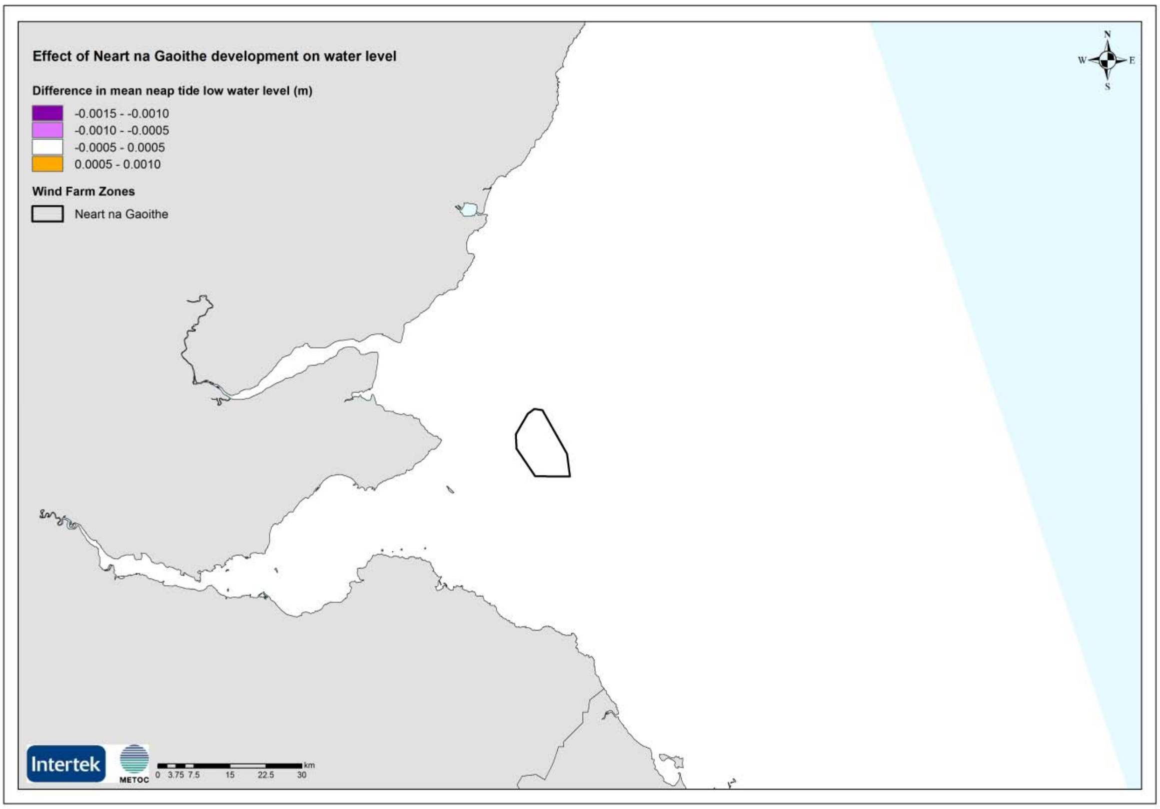


Figure H-17 : Difference in mean spring tide peak flood current speed (m/s) – far-field

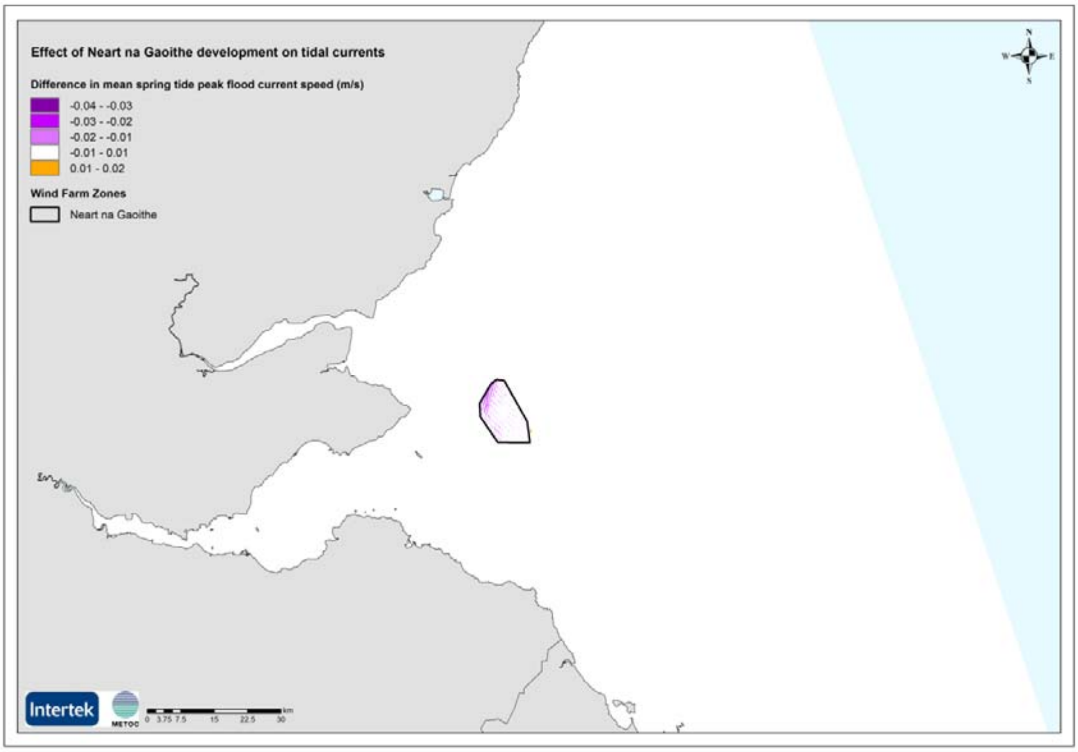


Figure H-18 : Difference in mean spring tide peak ebb current speed (m/s) – far-field

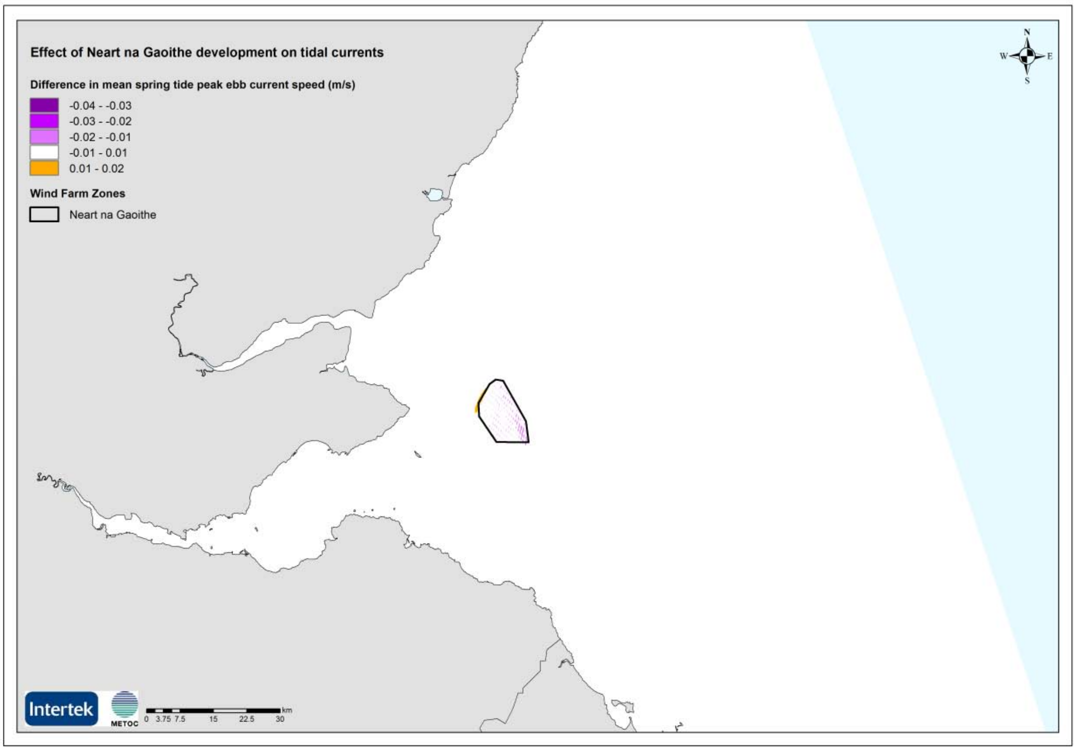


Figure H-19 : Difference in mean neap tide peak flood current speed (m/s) – far-field

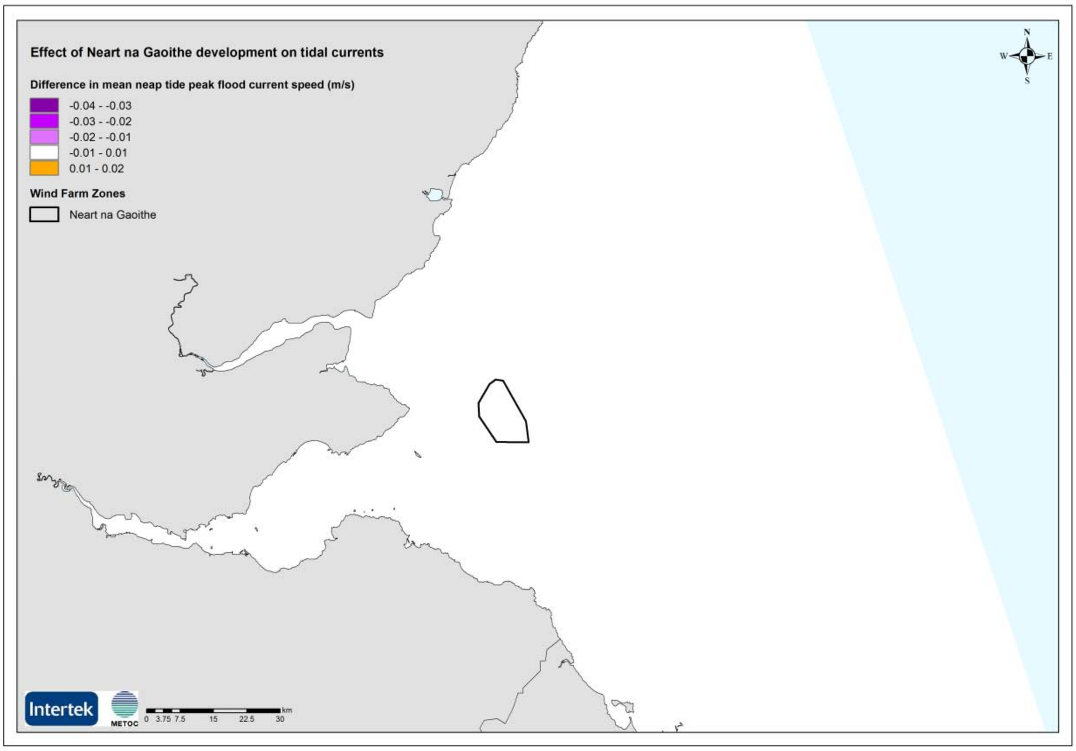


Figure H-20 : Difference in mean neap tide peak ebb current speed (m/s) – far-field

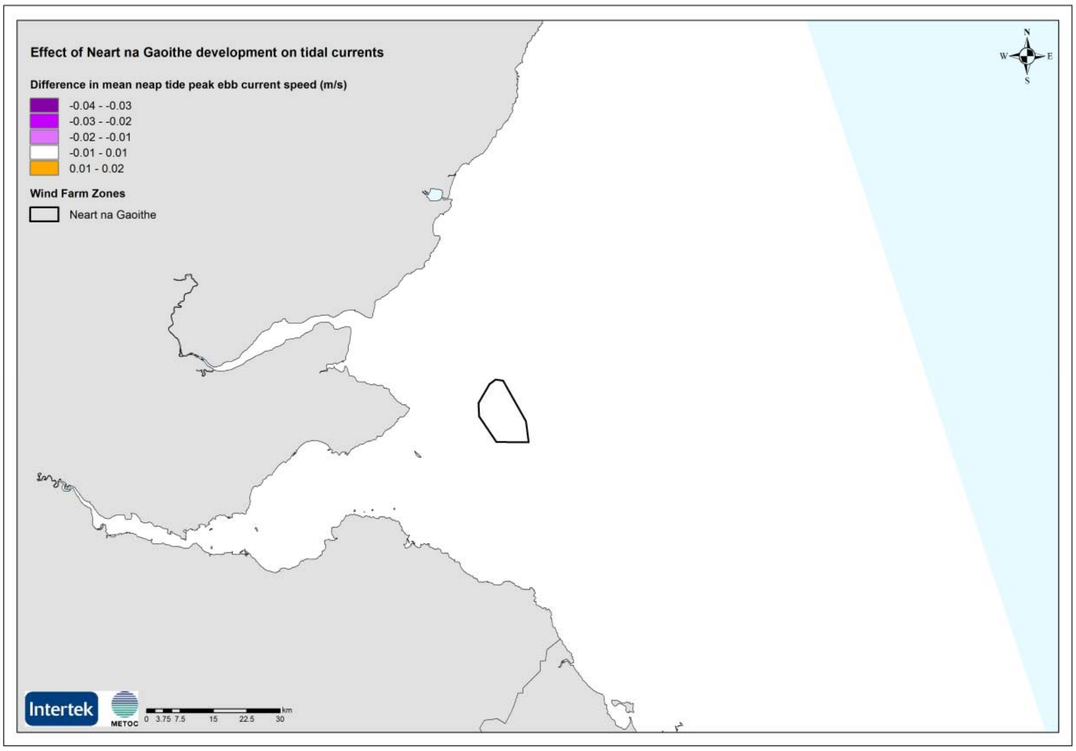


Figure H-21 : Difference in 50-percentile current speed (m/s) – far-field

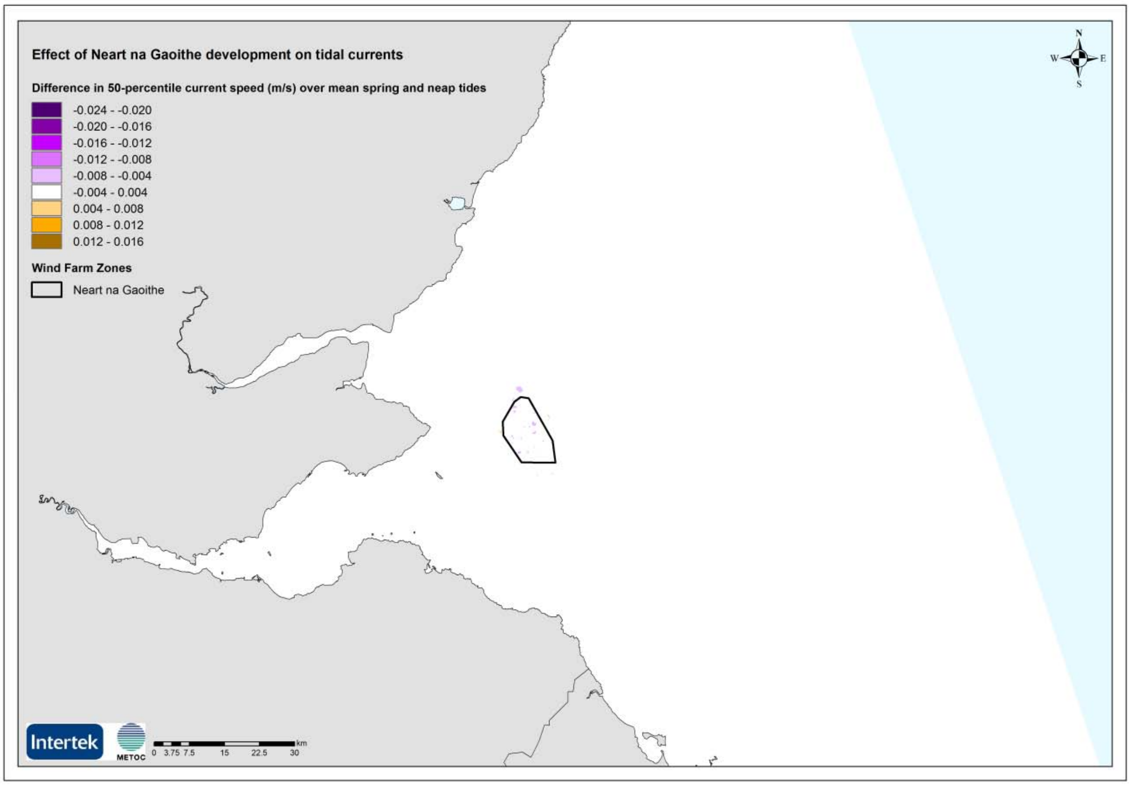


Figure H-22 : Difference in 90-percentile current speed (m/s) – far-field

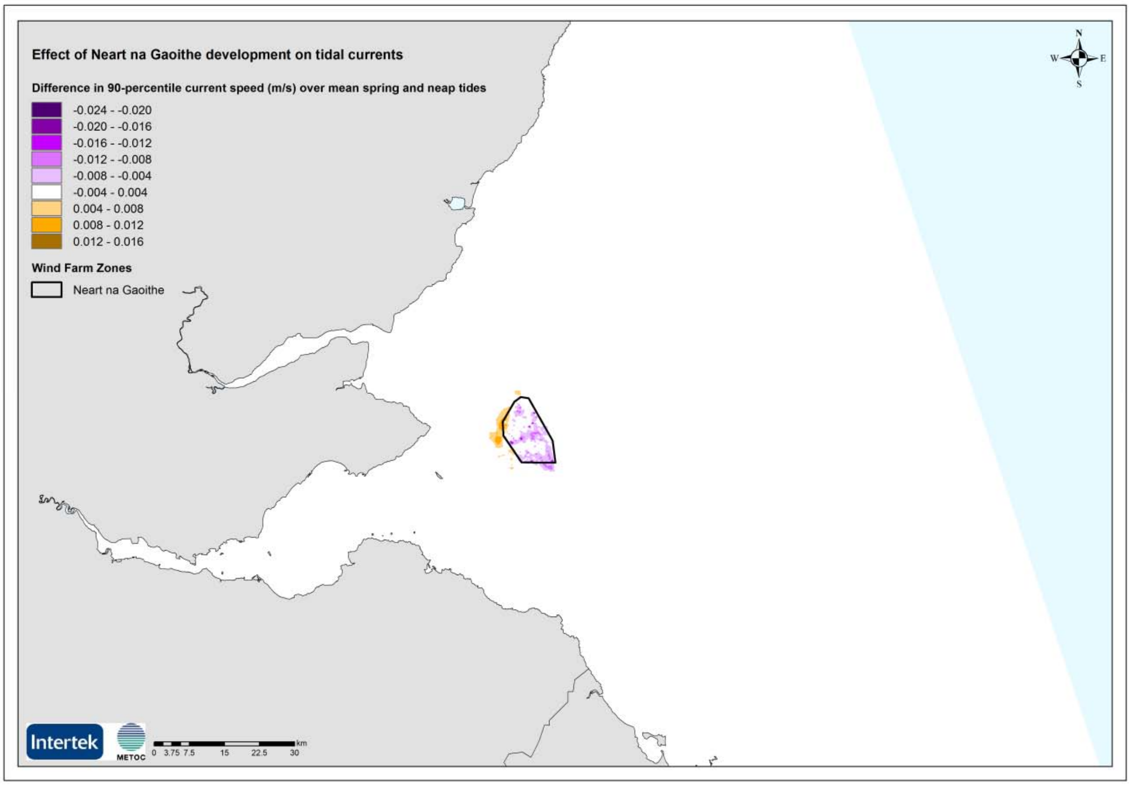


Figure H-23 : Difference in 95-percentile current speed (m/s) – far-field

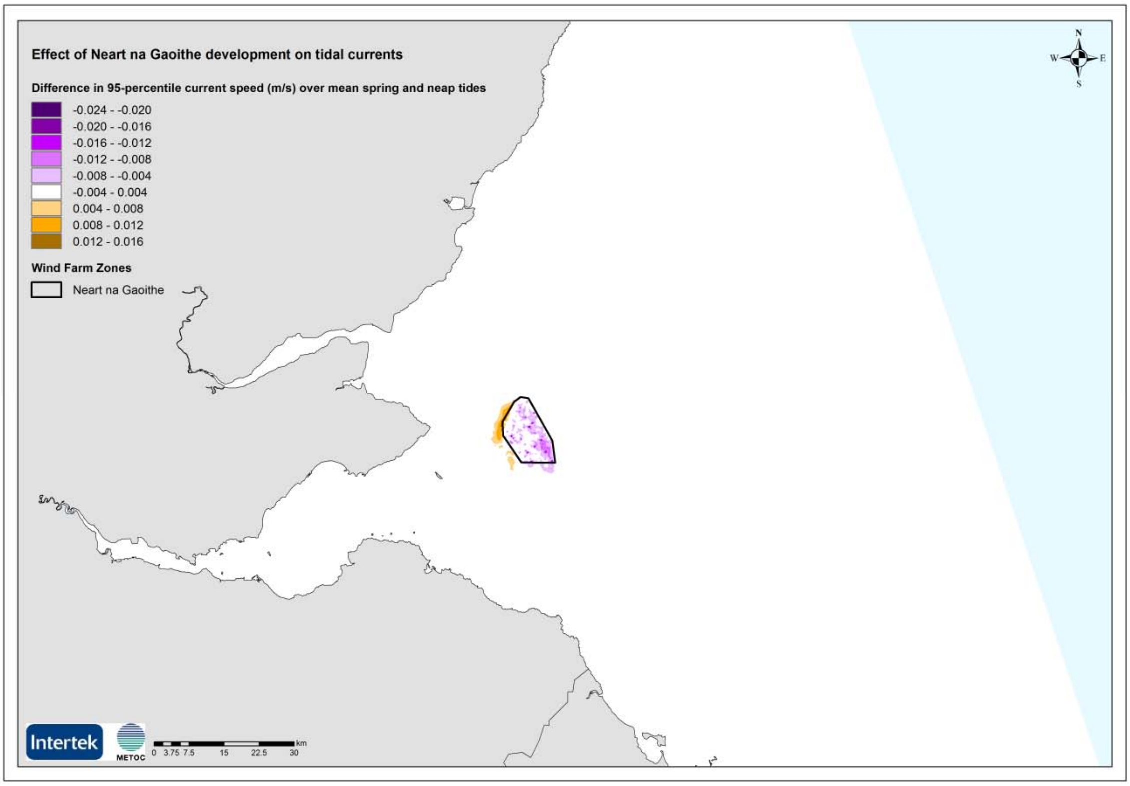
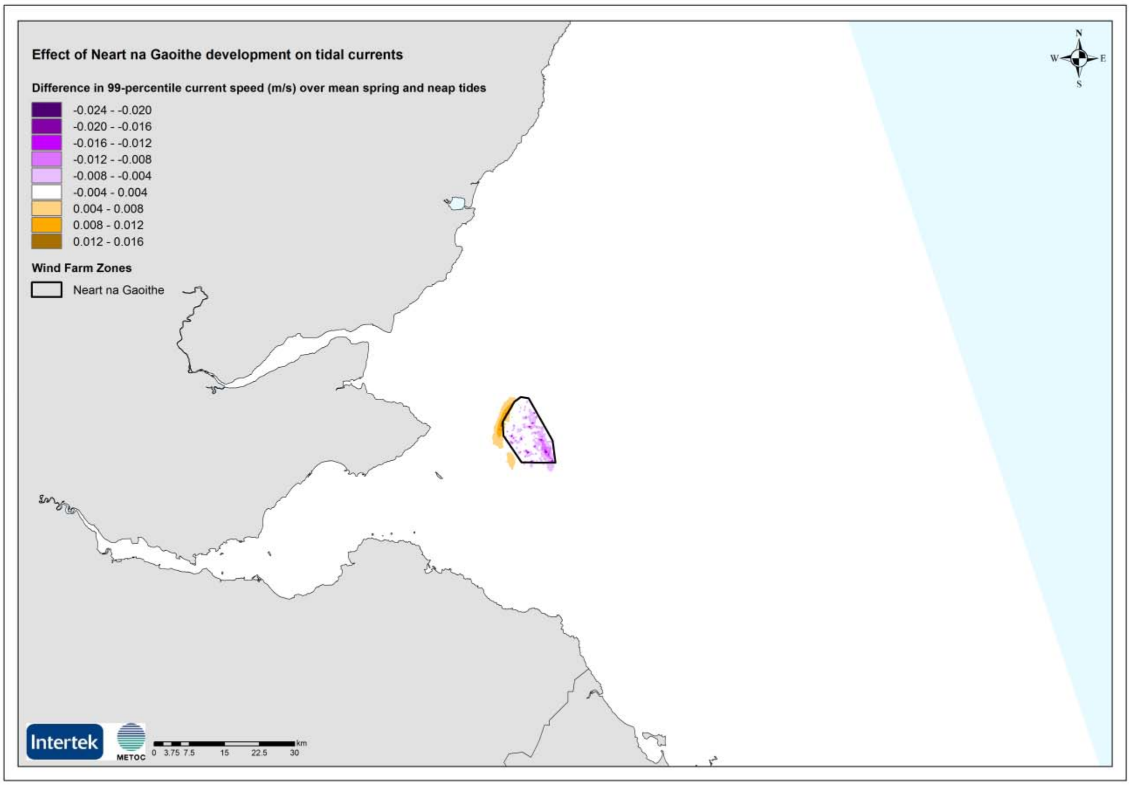


Figure H-24 : Difference in 99-percentile current speed (m/s) – far-field



H.1.3 CHANGES TO THE WAVE CLIMATE – NEART NA GAOITHE AREA (NEAR-FIELD)

Figure H-25 : Difference in 50-percentile significant wave height (m) – near-field

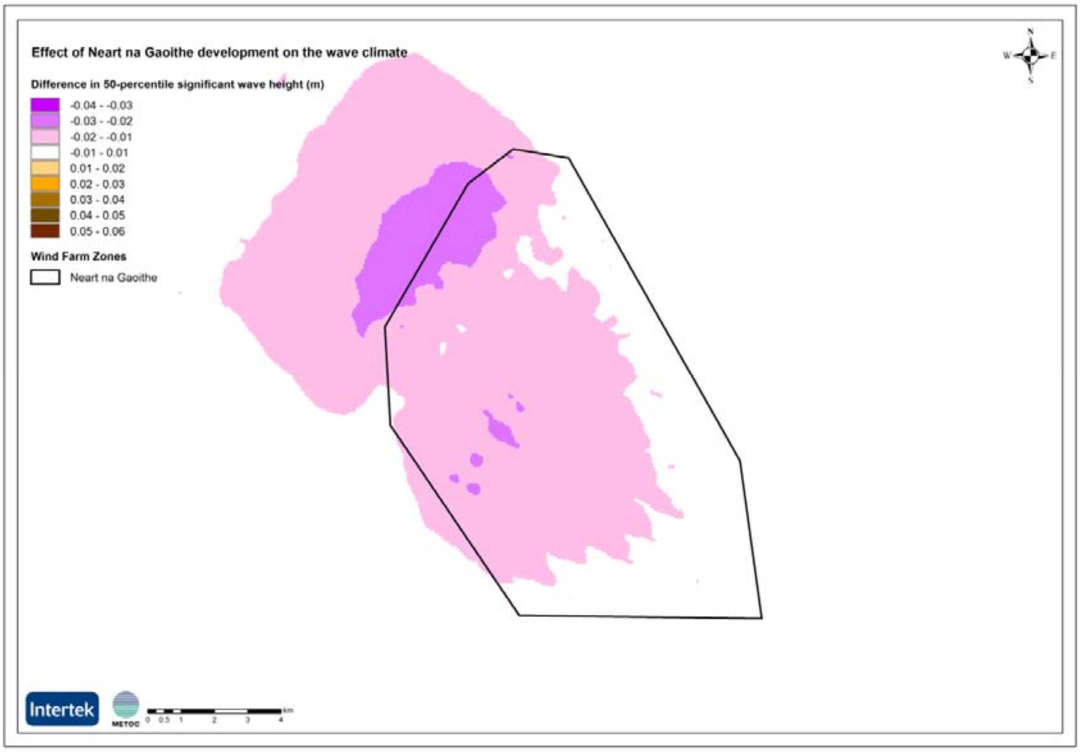


Figure H-26: Difference in 90-percentile significant wave height (m) – near-field

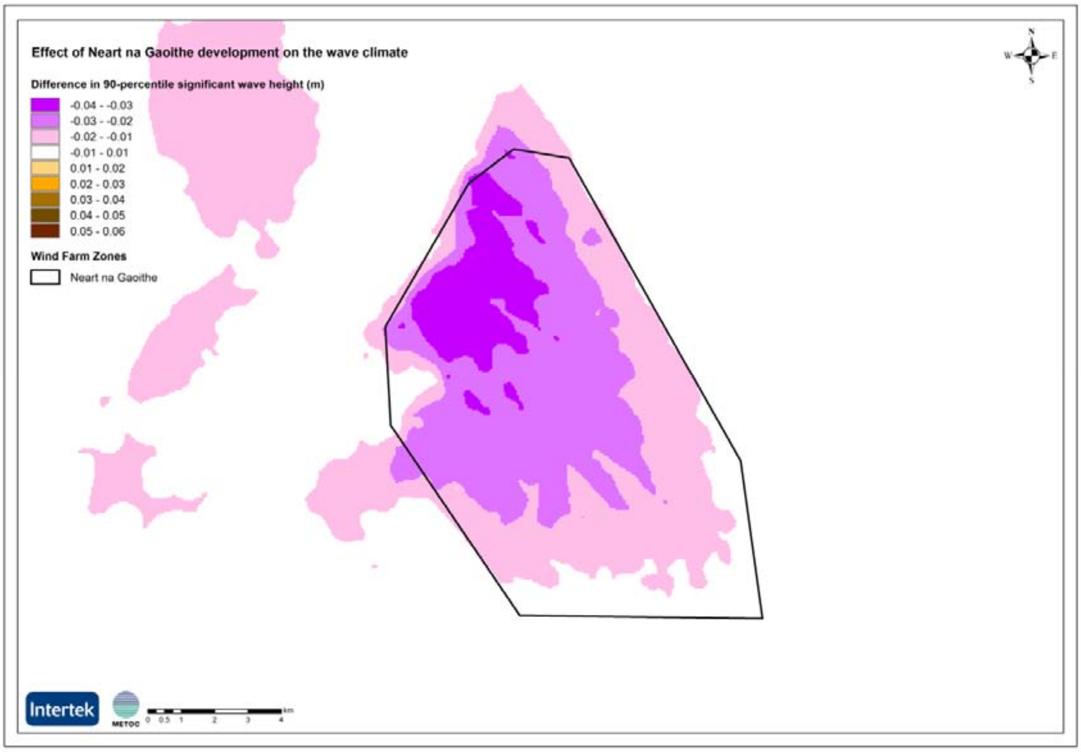


Figure H-27 : Difference in 95-percentile significant wave height (m) – near-field

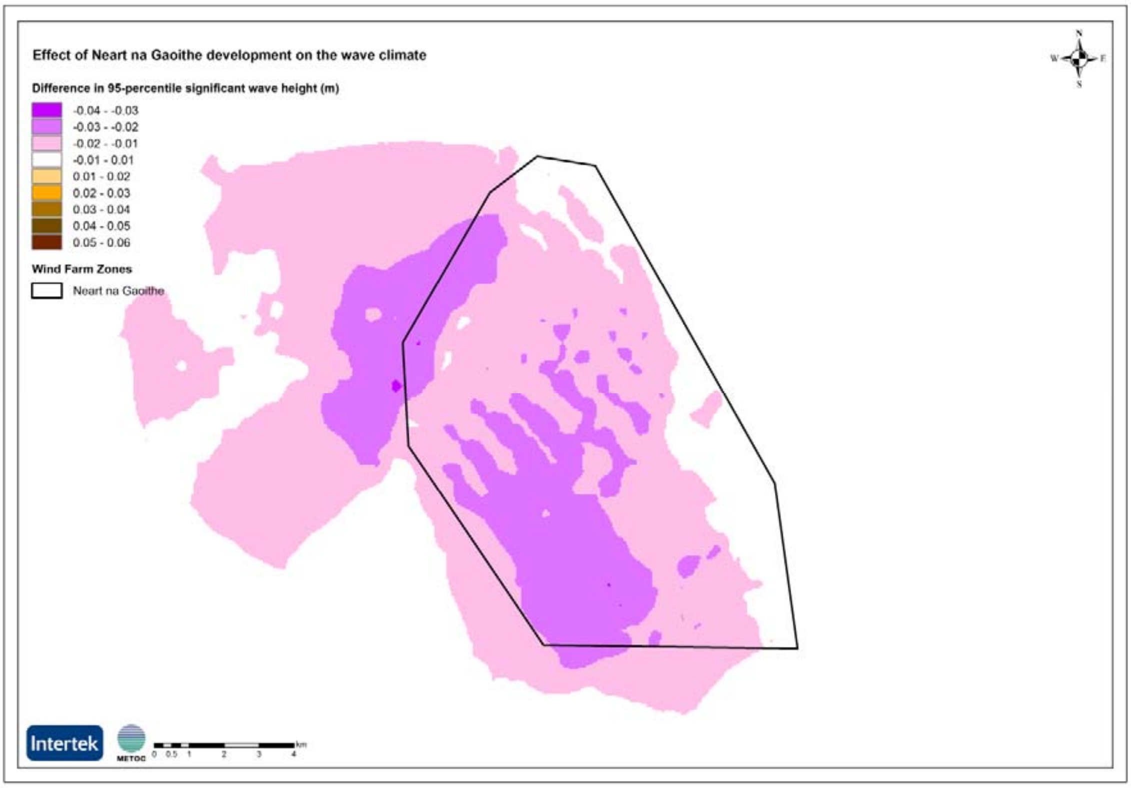
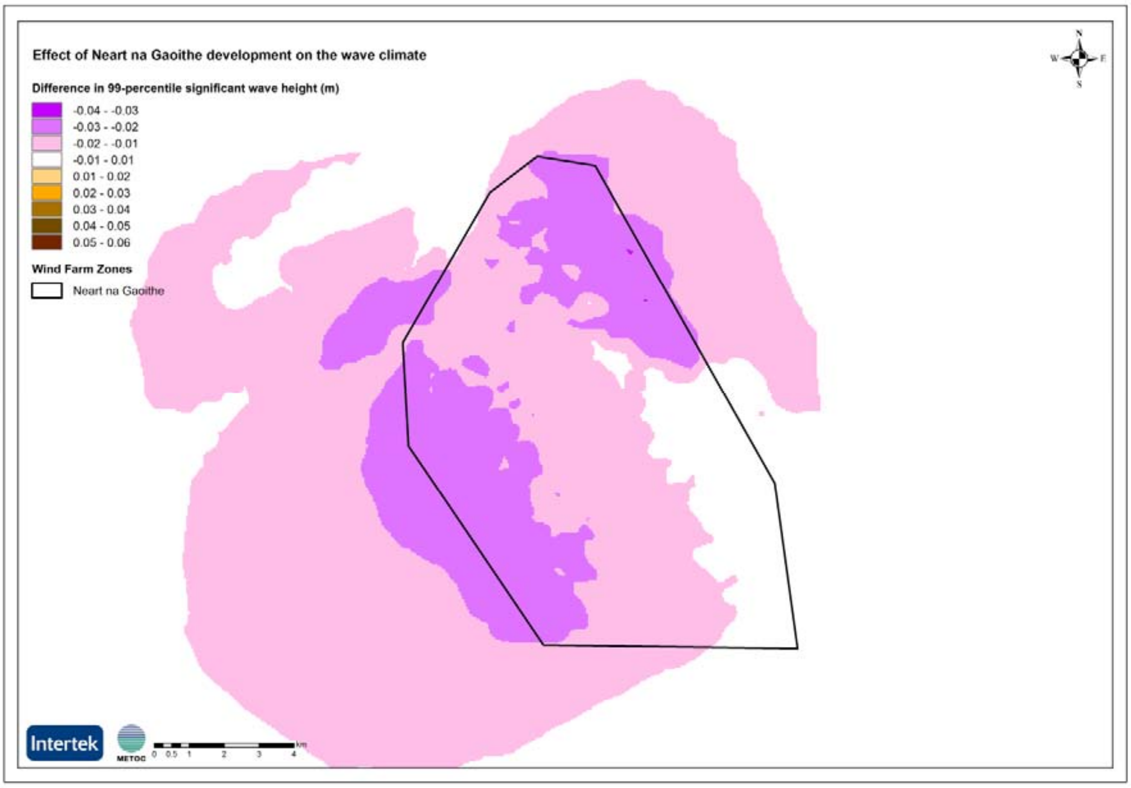


Figure H-28 : Difference in 99-percentile significant wave height (m) – near-field



H.1.4 CHANGES TO THE WAVE CLIMATE – REGIONAL AREA (FAR-FIELD)

Figure H-29 : Difference in 50-percentile significant wave height (m) – far-field

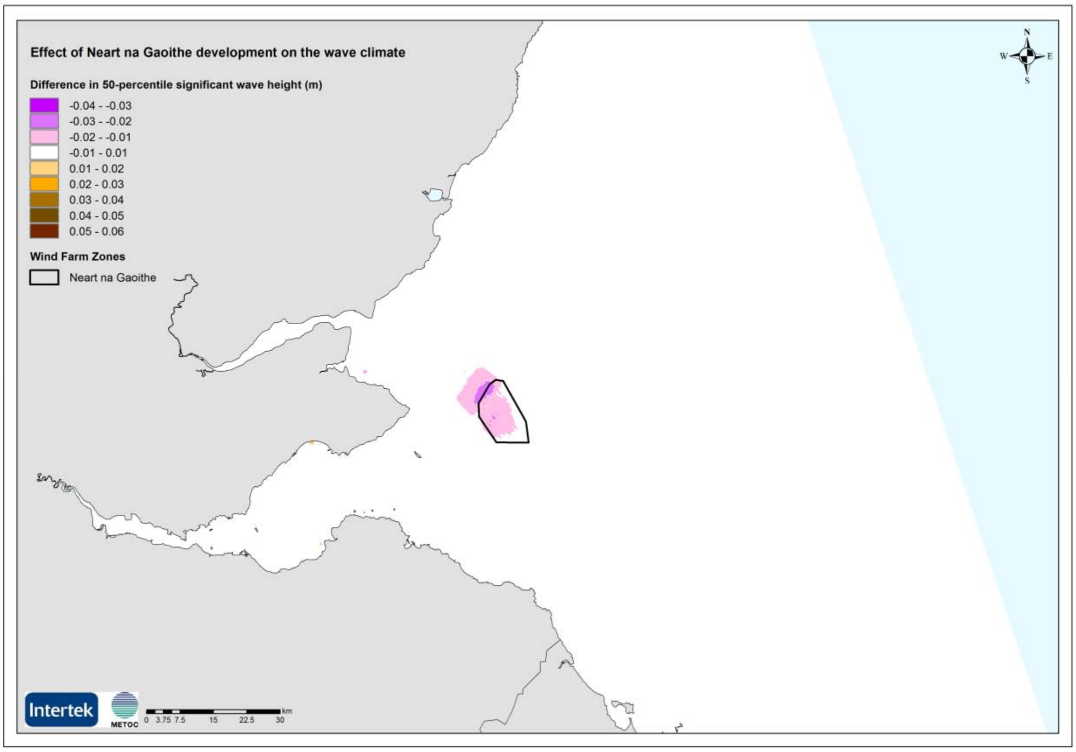


Figure H-30 : Difference in 90-percentile significant wave height (m) – far-field

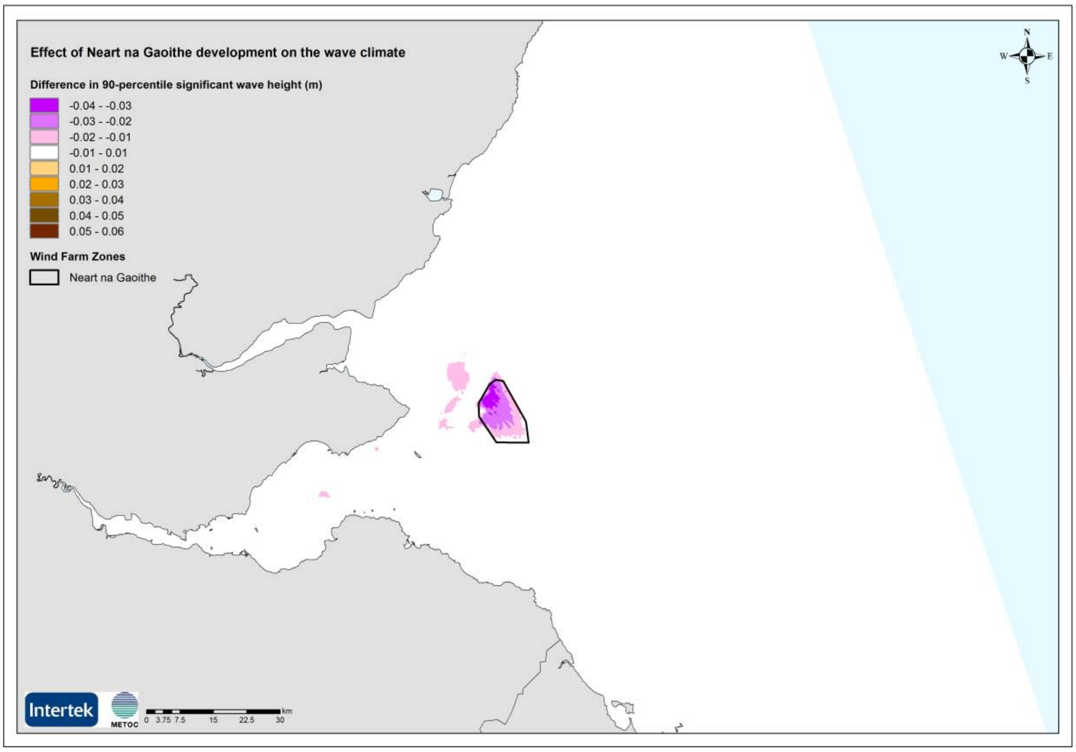


Figure H-31 : Difference in 95-percentile significant wave height (m) – far-field

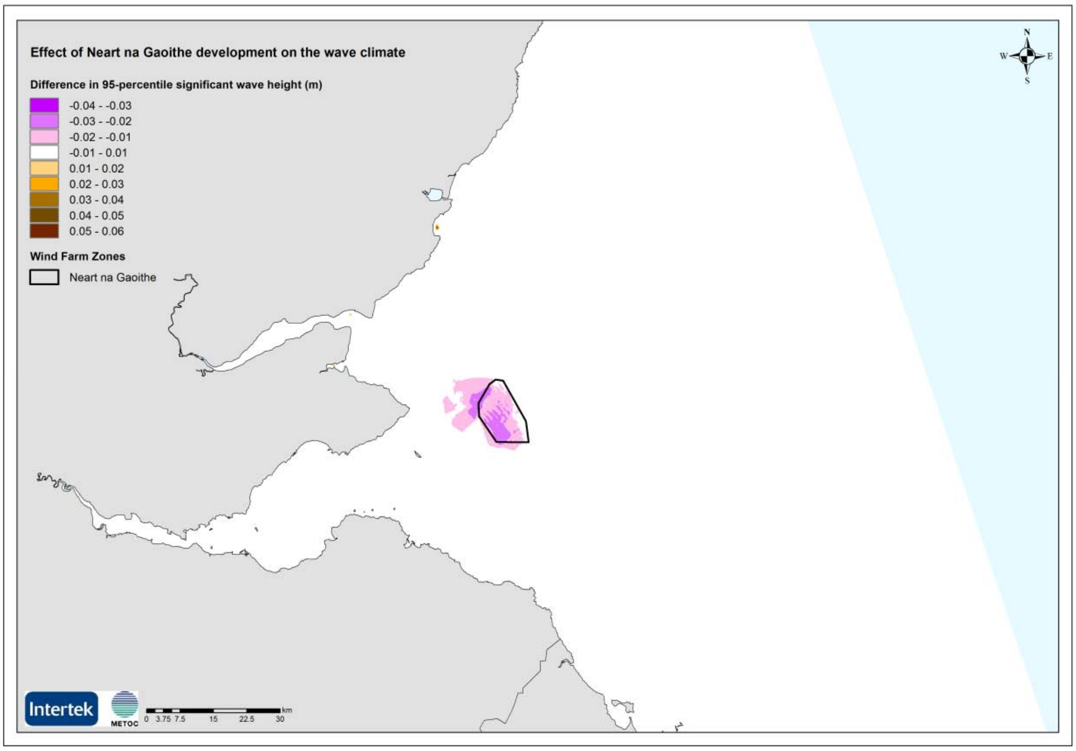
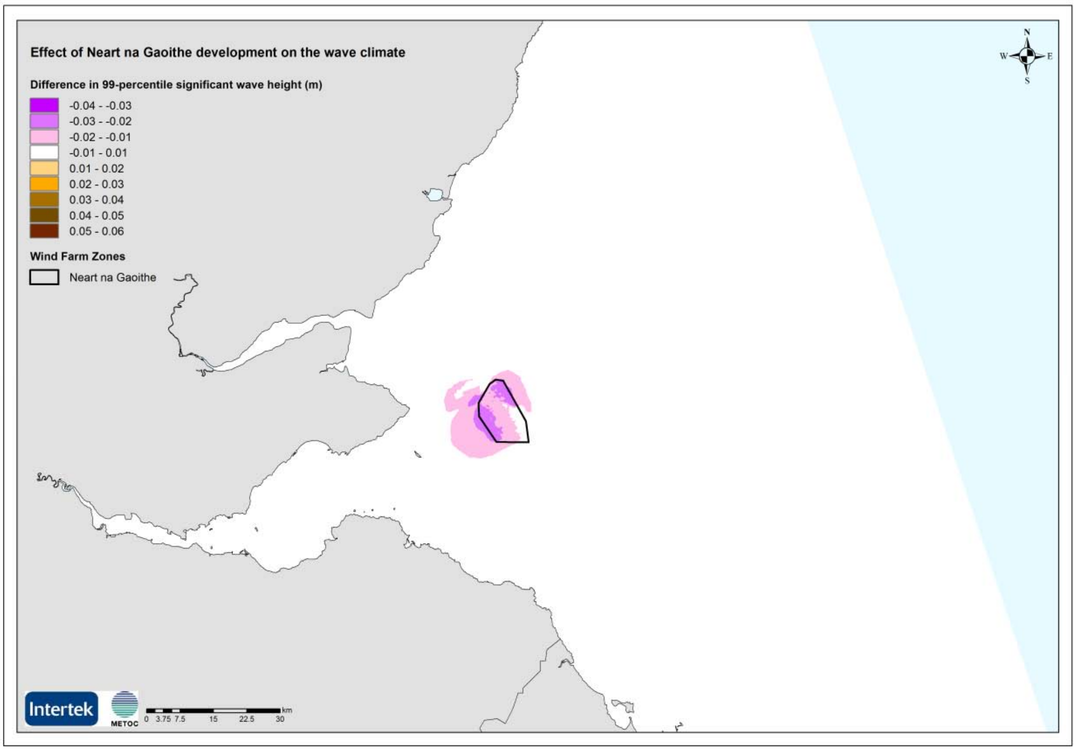


Figure H-32 : Difference in 99-percentile significant wave height (m) – far-field



H.1.5 CHANGES TO THE SEDIMENT REGIME – NEART NA GAOITHE AREA (NEAR-FIELD)

Figure H-33: Difference in the exceedance of critical shear stress (N/m²) – based on the combined (currents plus waves) maximum bed shear stress – near-field

Figure H-34 : Difference in the exceedance of critical shear stress (N/m²) – based on the combined (currents plus waves) mean bed shear stress – near-field

H.1.6 CHANGES TO THE SEDIMENT REGIME – REGIONAL AREA (FAR-FIELD)

Figure H-35 : Difference in the exceedance of critical shear stress (N/m²) – based on the combined (currents plus waves) maximum bed shear stress – far-field

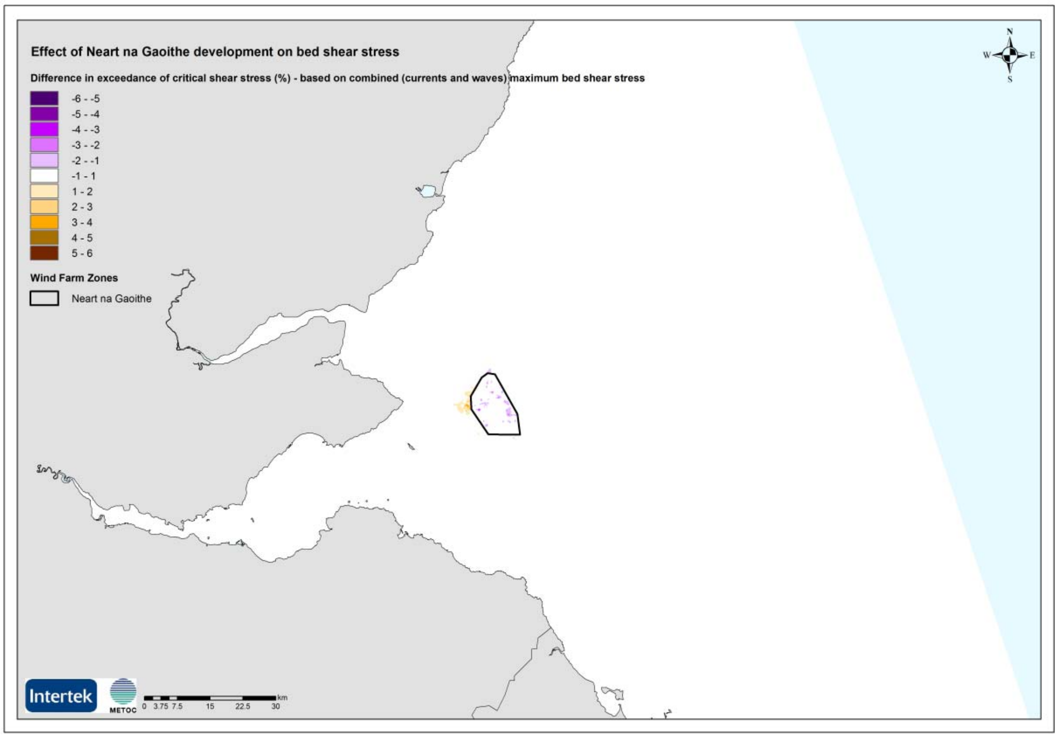
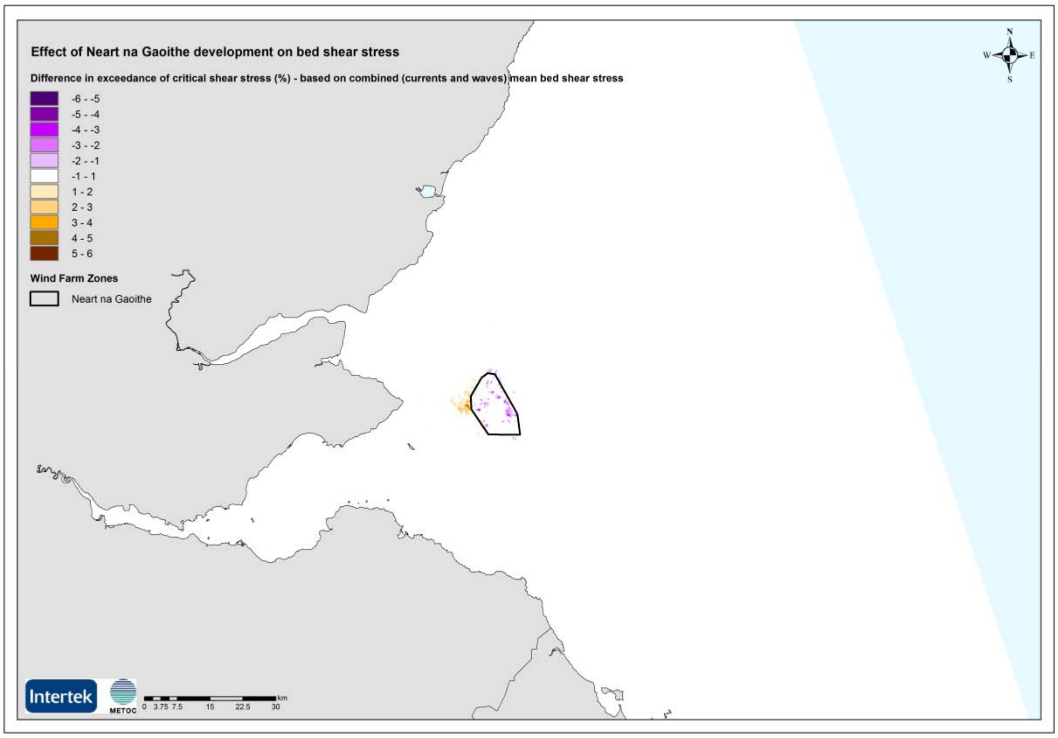


Figure H-36 : Difference in the exceedance of critical shear stress (N/m²) – based on the combined (currents plus waves) mean bed shear stress – far-field



H.1.7 CONSTRUCTION PHASE IMPACTS

Impacts due to the preparation of gravity base foundation (dredging) – sea surface release

Figure H-37 : Suspended sediment concentrations due to dredging – sea-surface release: 6 hours after commencement

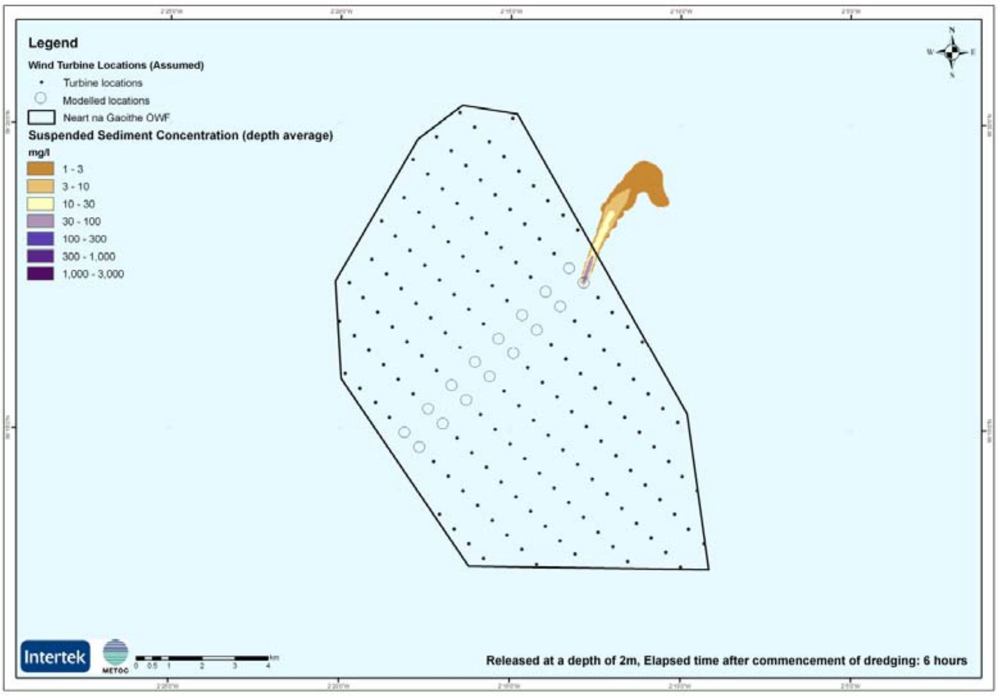


Figure H-38: Suspended sediment concentrations due to dredging - sea-surface release: 12 hours after commencement

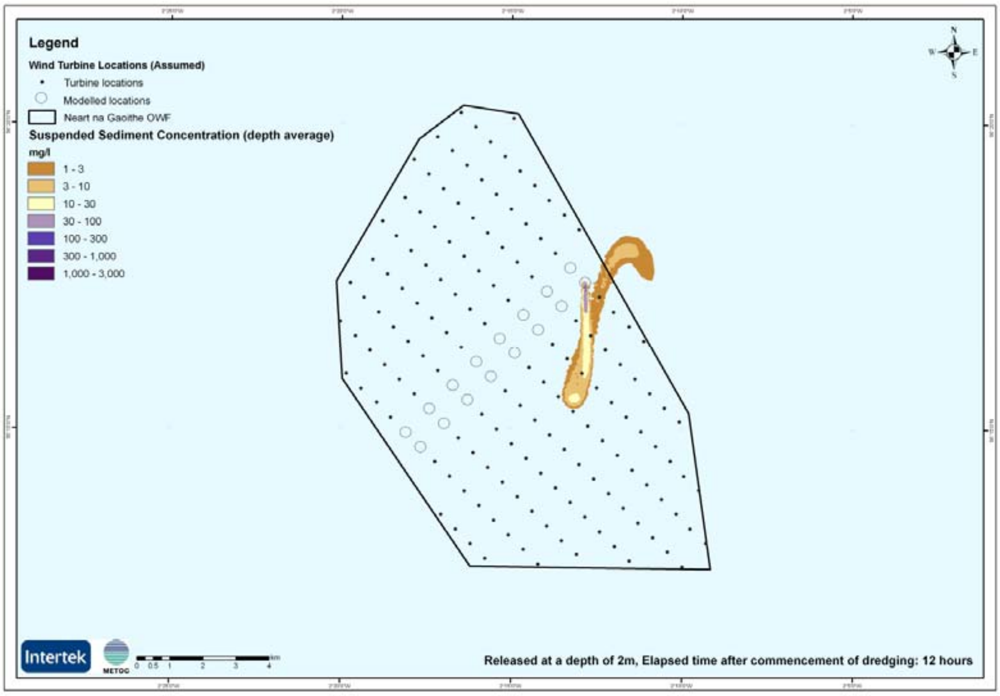


Figure H-39: Suspended sediment concentrations due to dredging – sea-surface release: 1 day after commencement

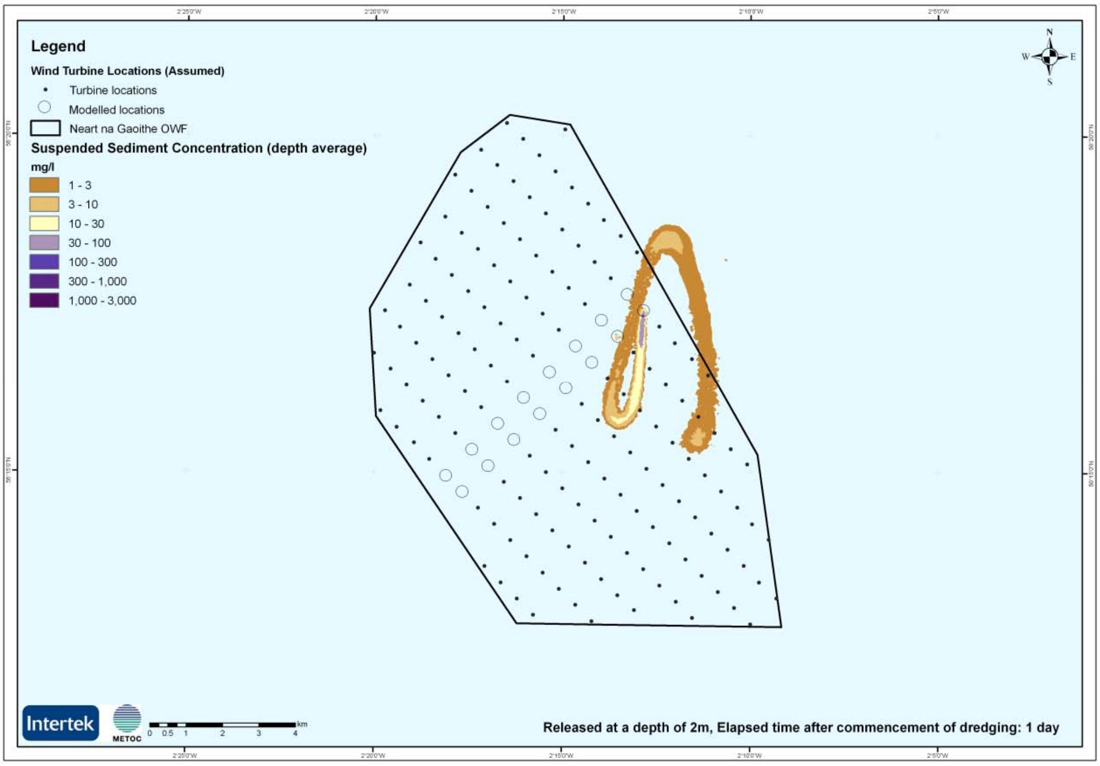


Figure H-40: Suspended sediment concentrations due to dredging – sea-surface release: 2 days after commencement

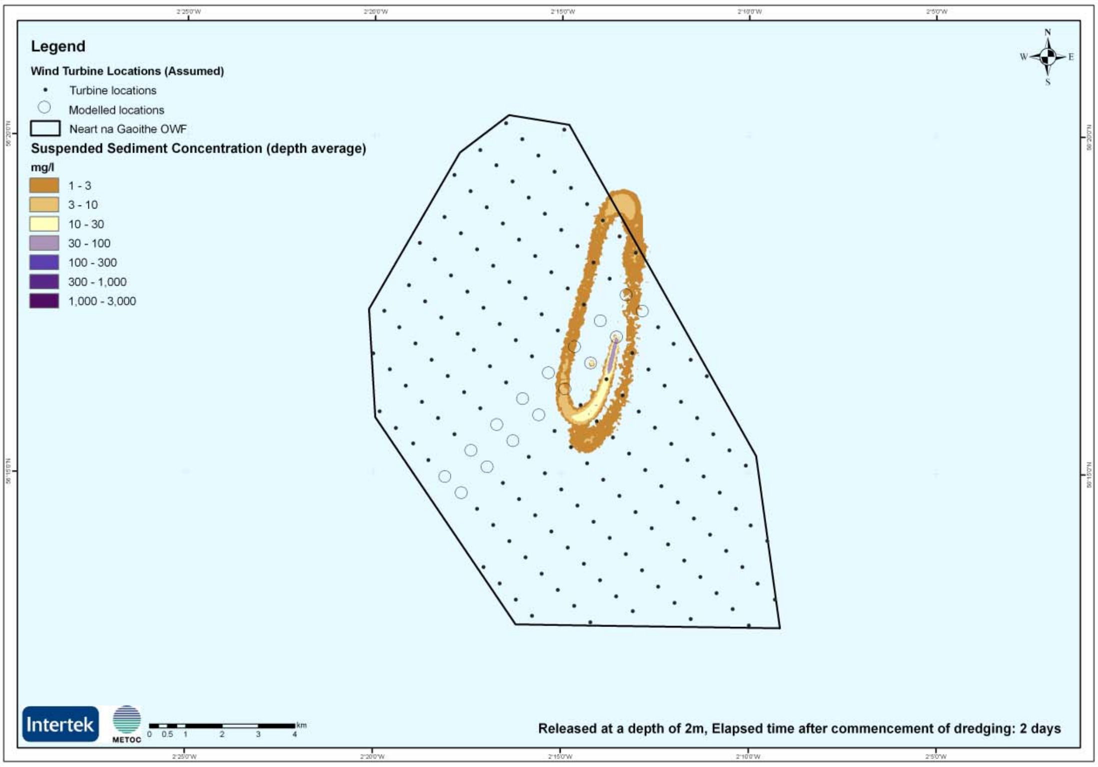


Figure H-41 Suspended sediment concentrations due to dredging – sea-surface release: 3 days after commencement

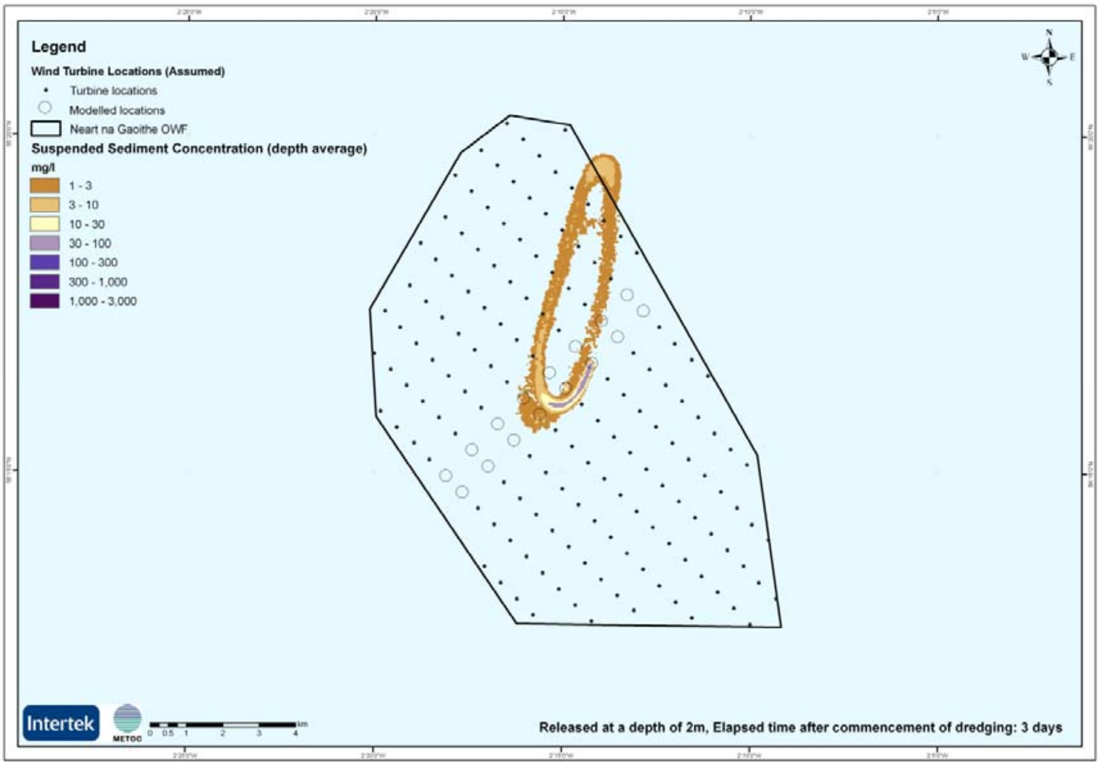


Figure H-42 Suspended sediment concentrations due to dredging – sea-surface release: 4 days after commencement

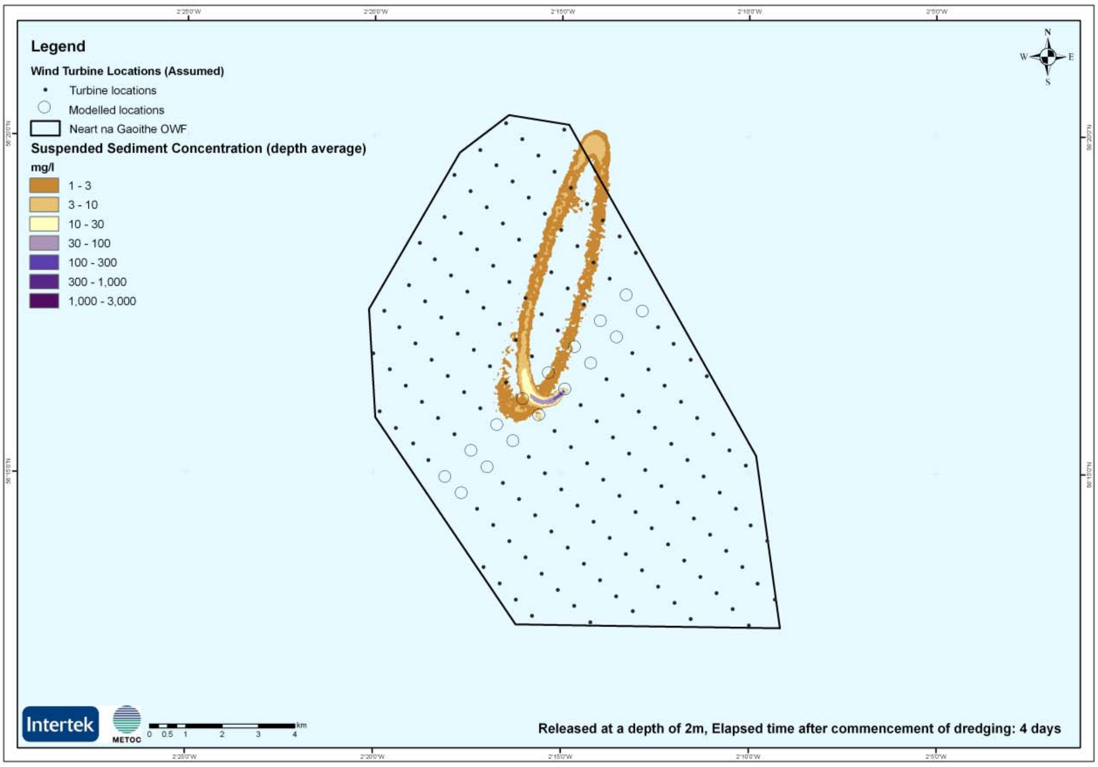


Figure H-43 Suspended sediment concentrations due to dredging – sea-surface release: 5 days after commencement

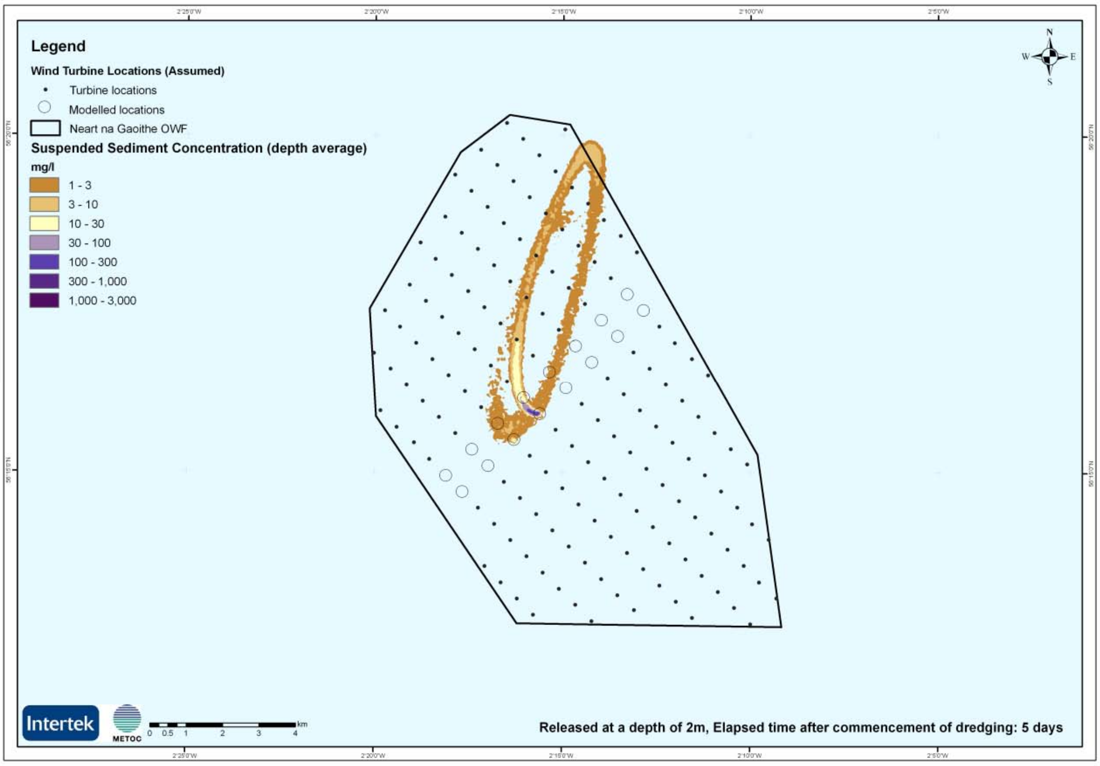


Figure H-44 Suspended sediment concentrations due to dredging – sea-surface release: 6 days after commencement

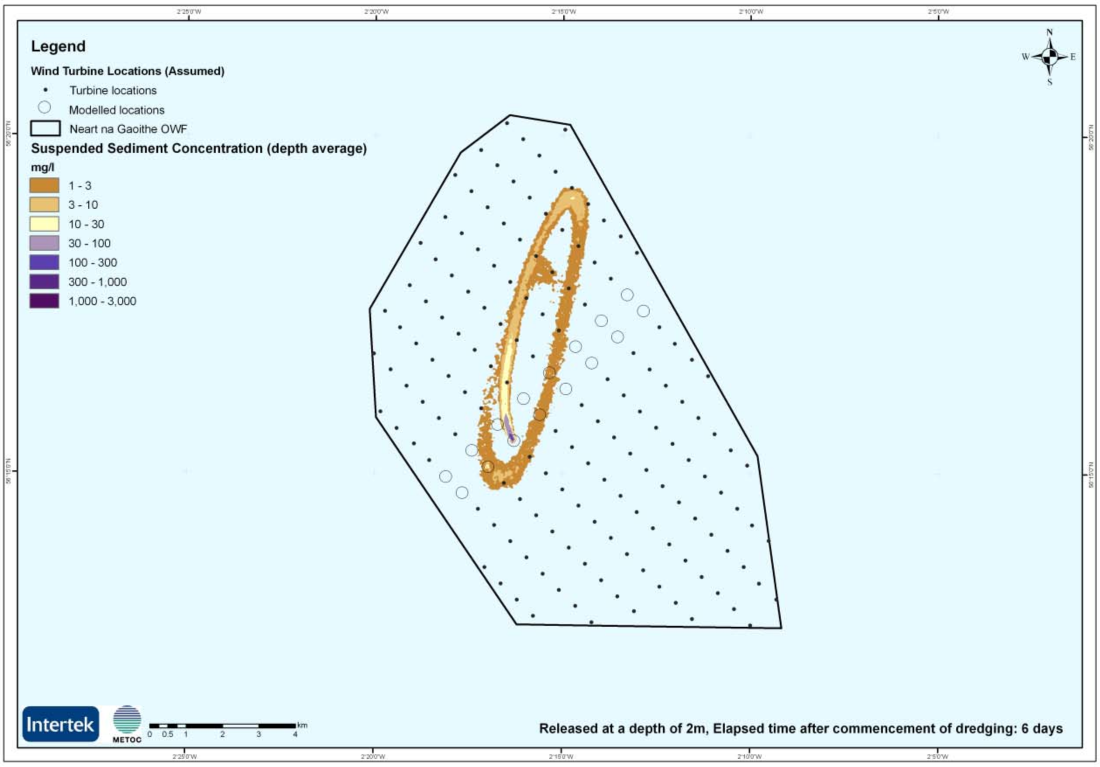


Figure H-45 Suspended sediment concentrations due to dredging – sea-surface release: 7 days after commencement

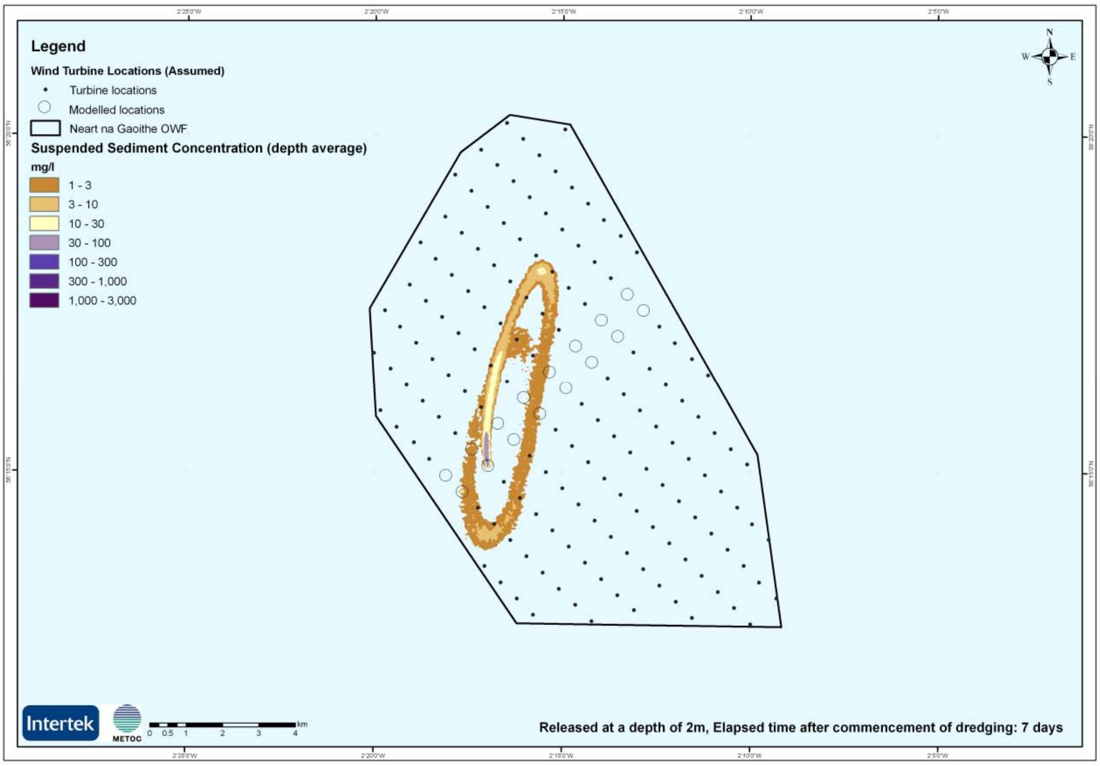


Figure H-46 Suspended sediment concentrations due to dredging – sea-surface release: 8 days after commencement

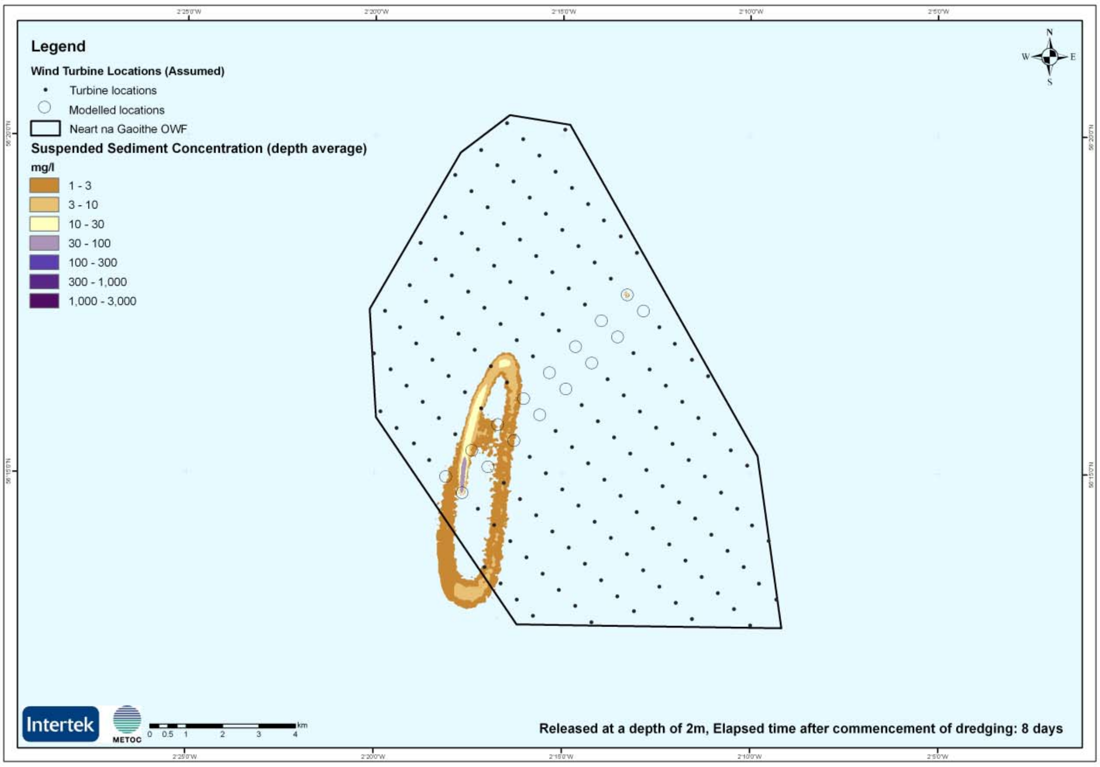


Figure H-47 Suspended sediment concentrations due to dredging – sea-surface release: 9 days after commencement

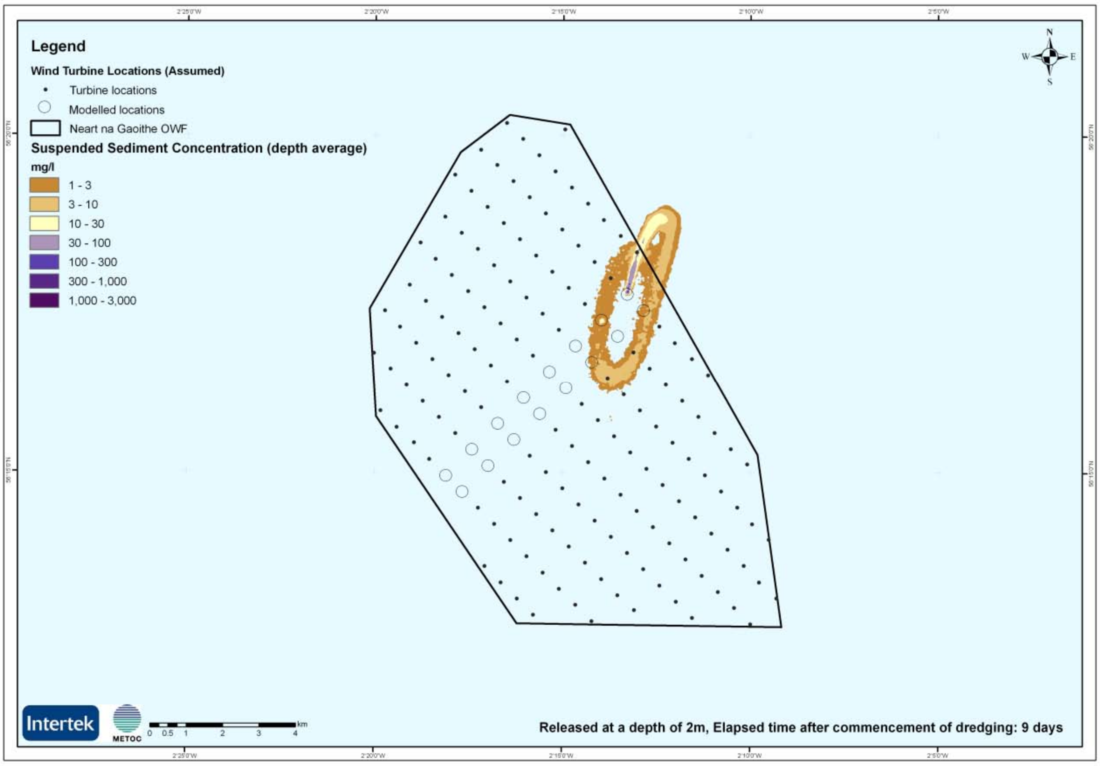


Figure H-48 Suspended sediment concentrations due to dredging – sea-surface release: 10 days after commencement

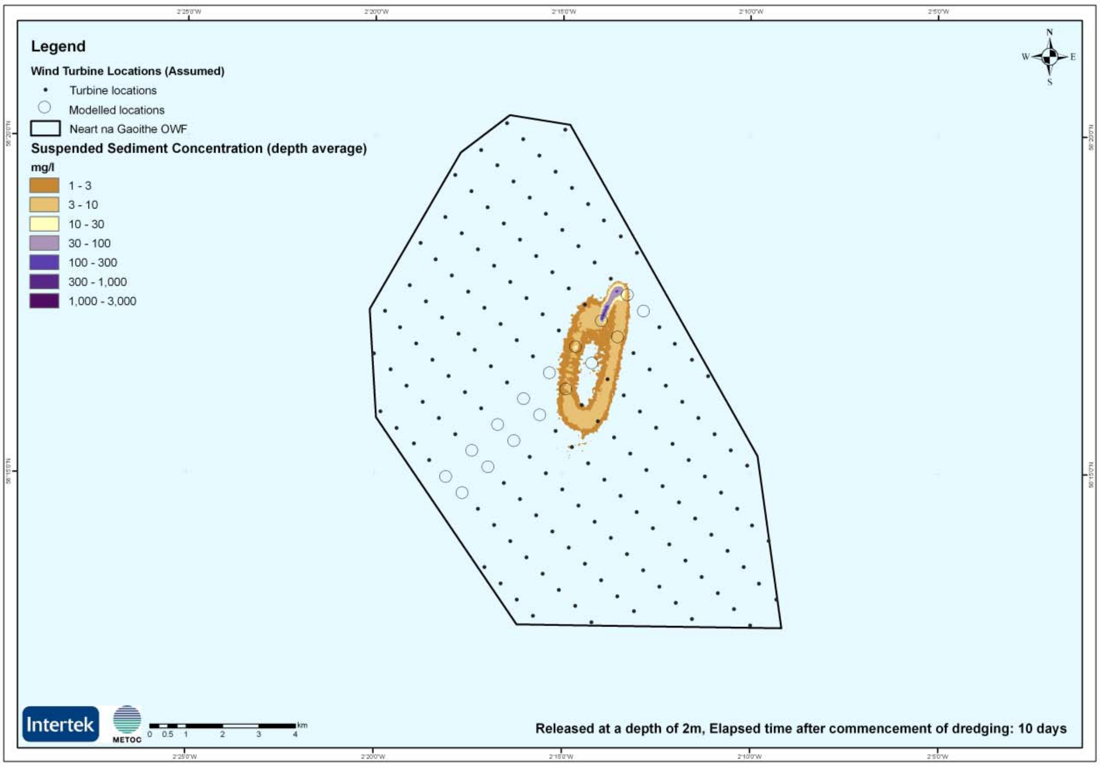


Figure H-49 Suspended sediment concentrations due to dredging – sea-surface release: 11 days after commencement

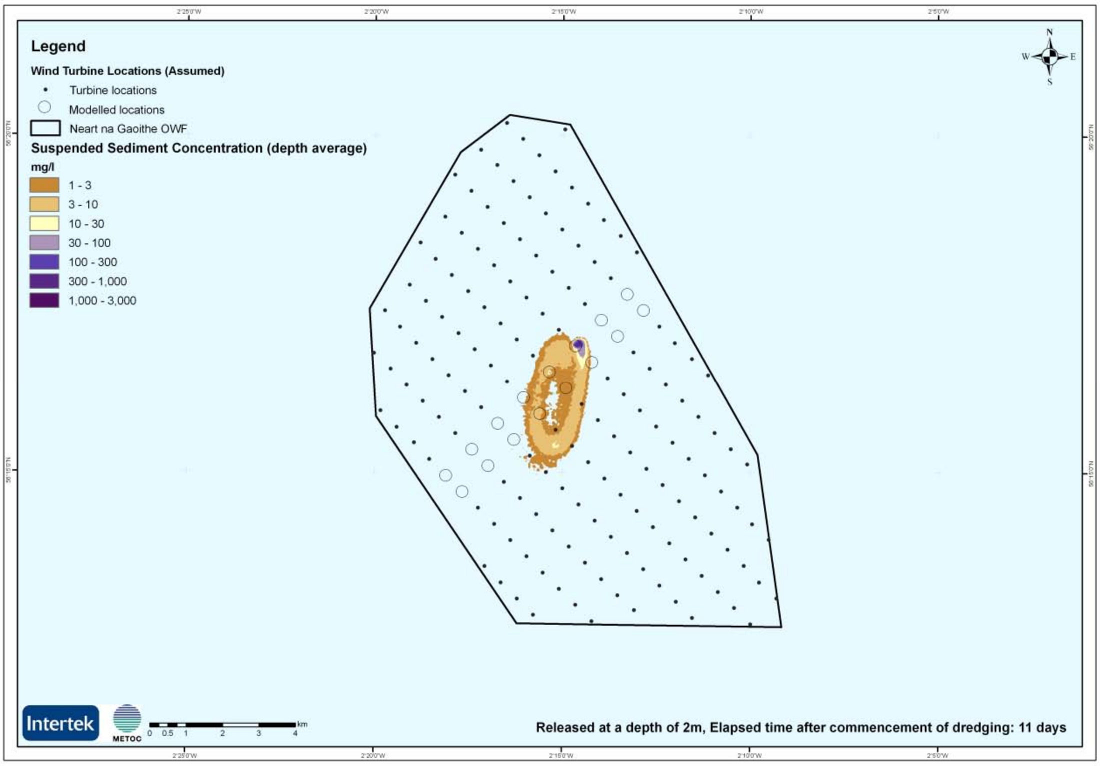


Figure H-50 Suspended sediment concentrations due to dredging – sea-surface release: 12 days after commencement

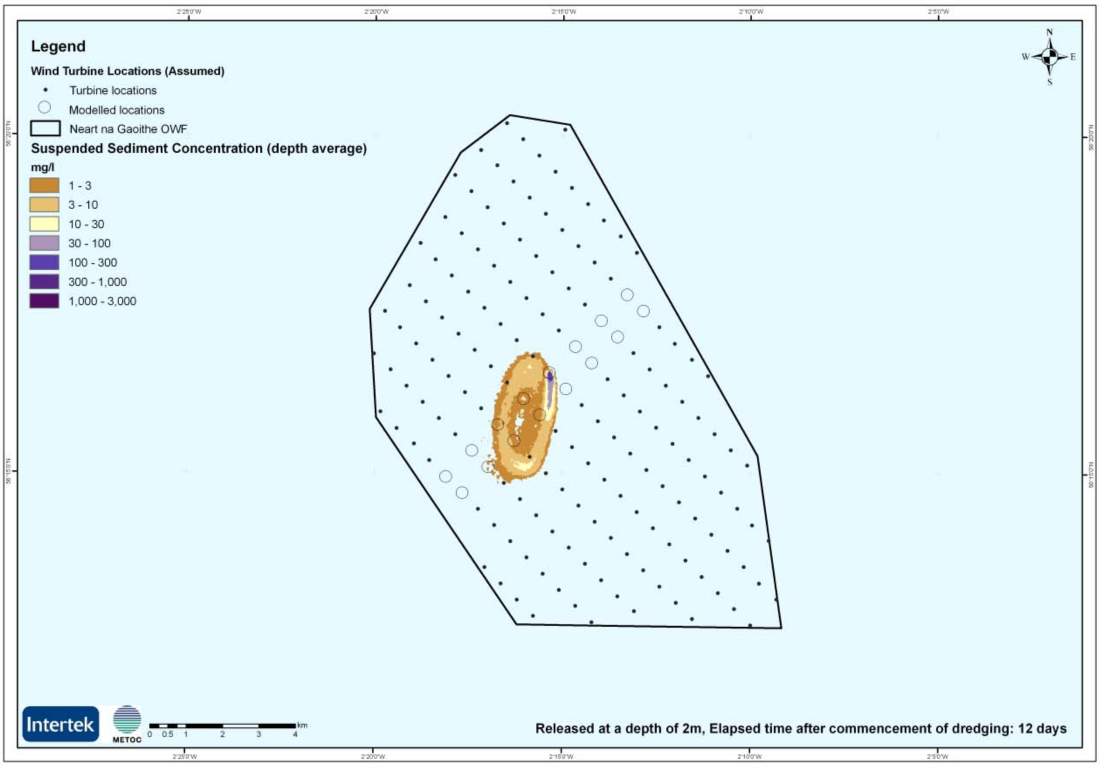


Figure H-51 Suspended sediment concentrations due to dredging – sea-surface release: 13 days after commencement

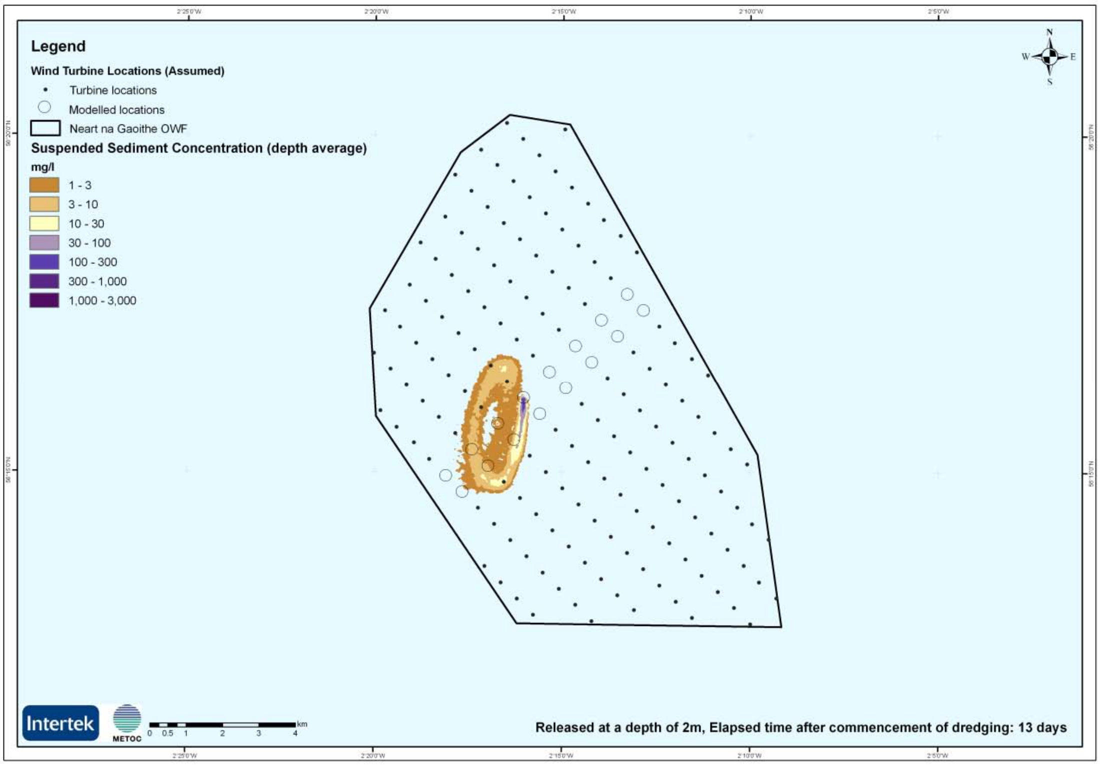


Figure H-52 Suspended sediment concentrations due to dredging – sea-surface release: 14 days after commencement

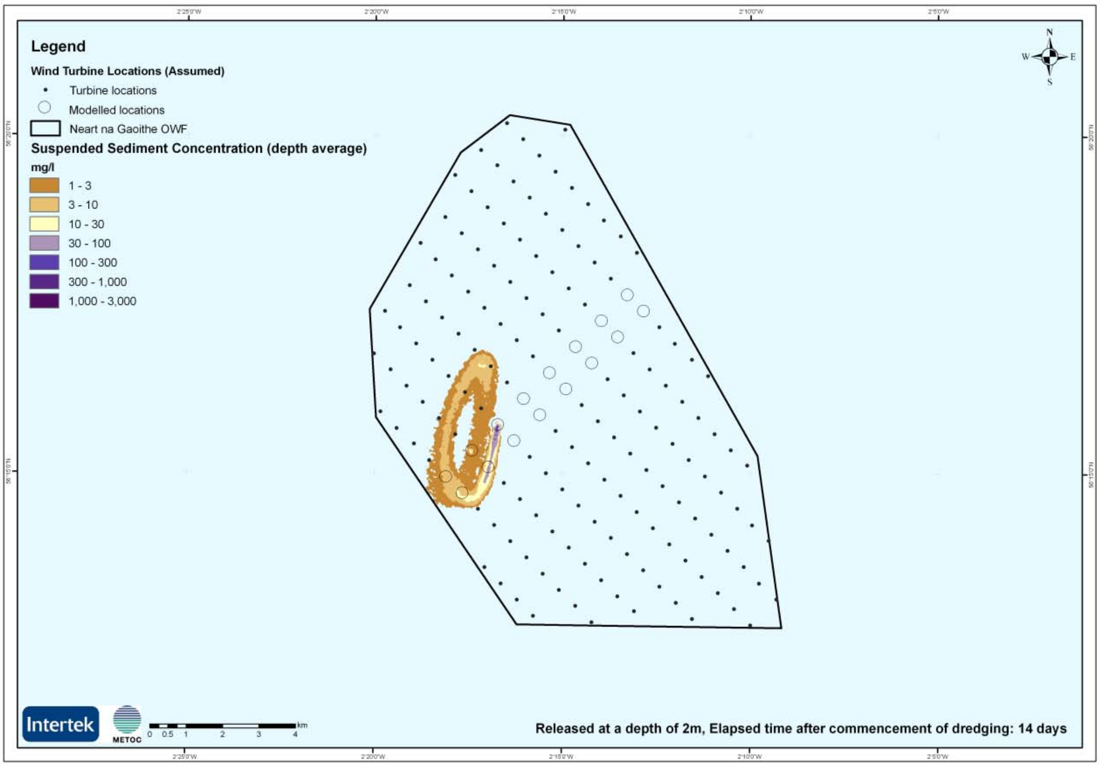


Figure H-53 Suspended sediment concentrations due to dredging – sea-surface release: 15 days after commencement

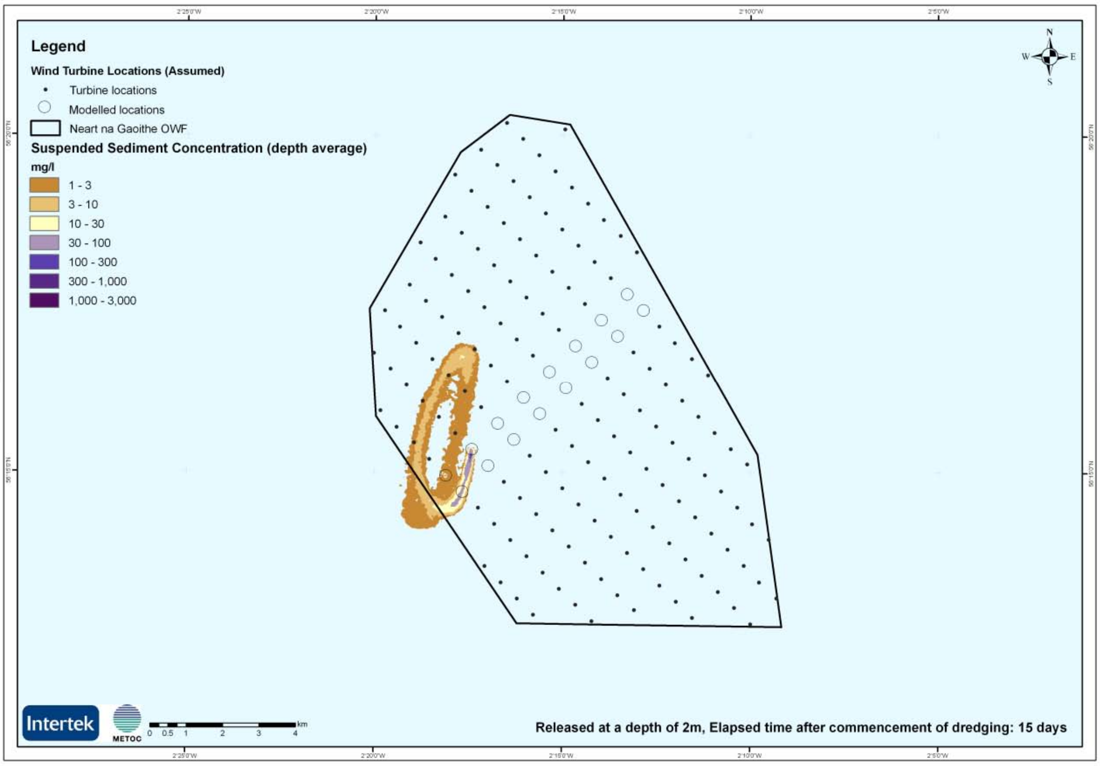


Figure H-54 Suspended sediment concentrations due to dredging – sea-surface release: 16 days after commencement

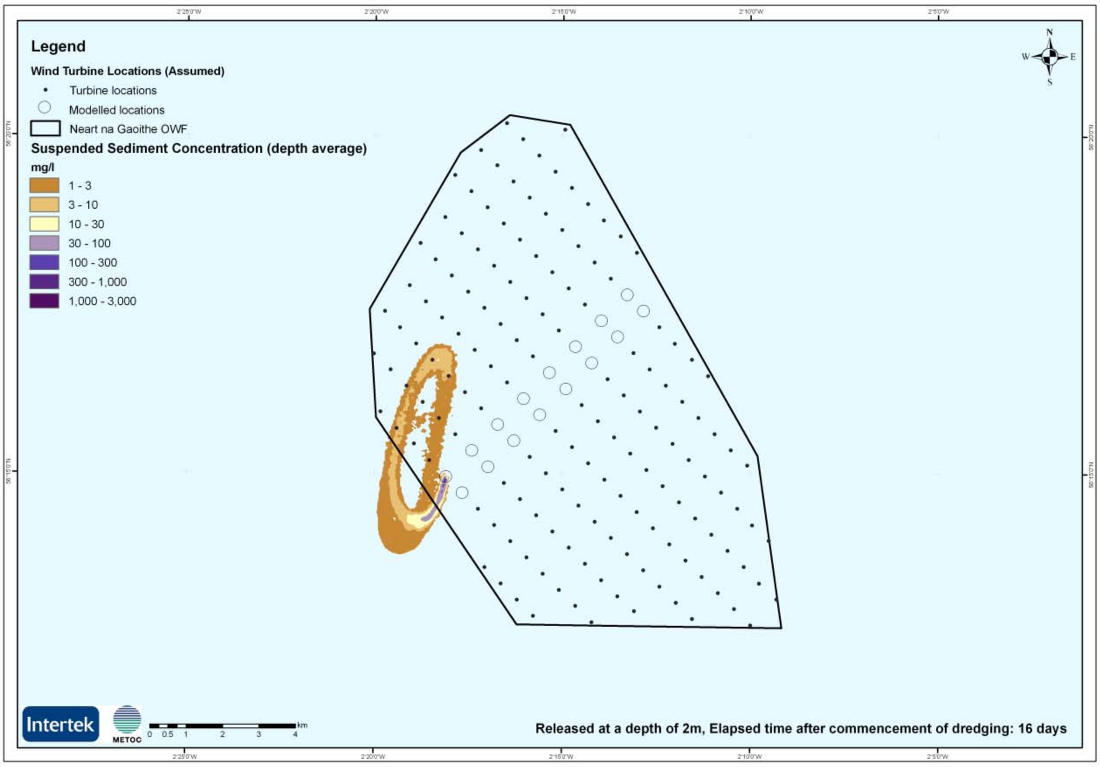
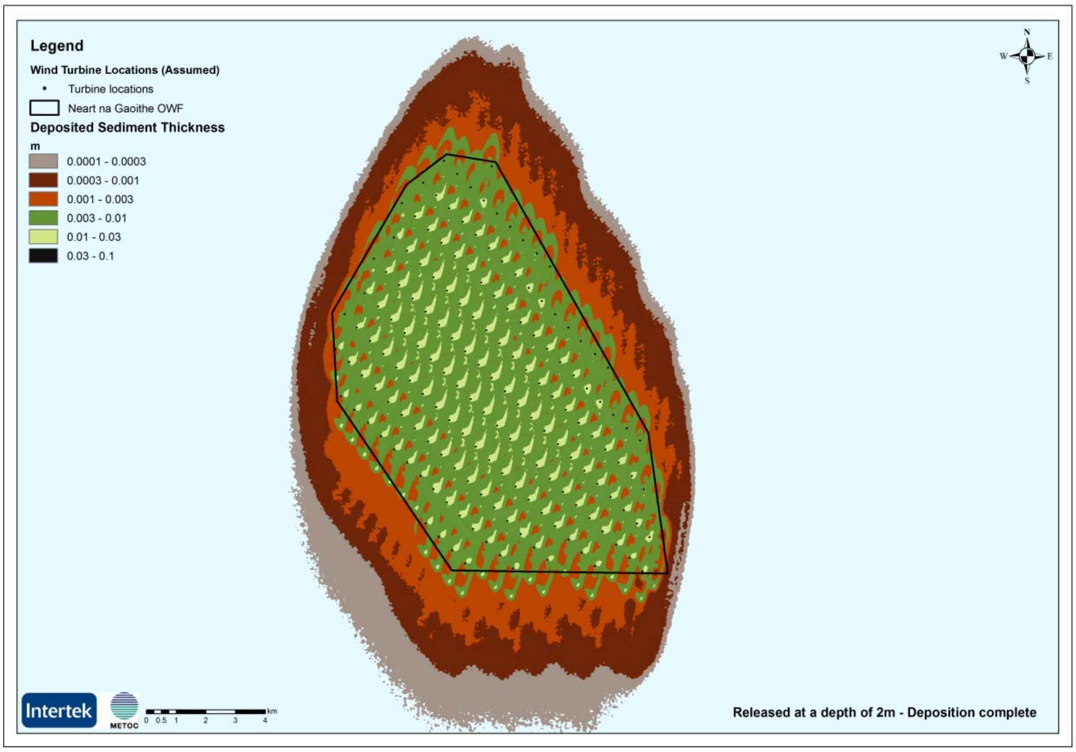


Figure H-55: Deposition thickness due to dredging – sea surface release – after all material has settled



Impacts due to the preparation of gravity base foundation (dredging) – near bed release

Figure H-56 : Suspended sediment concentrations due to dredging – near-bed release: 6 hours after commencement

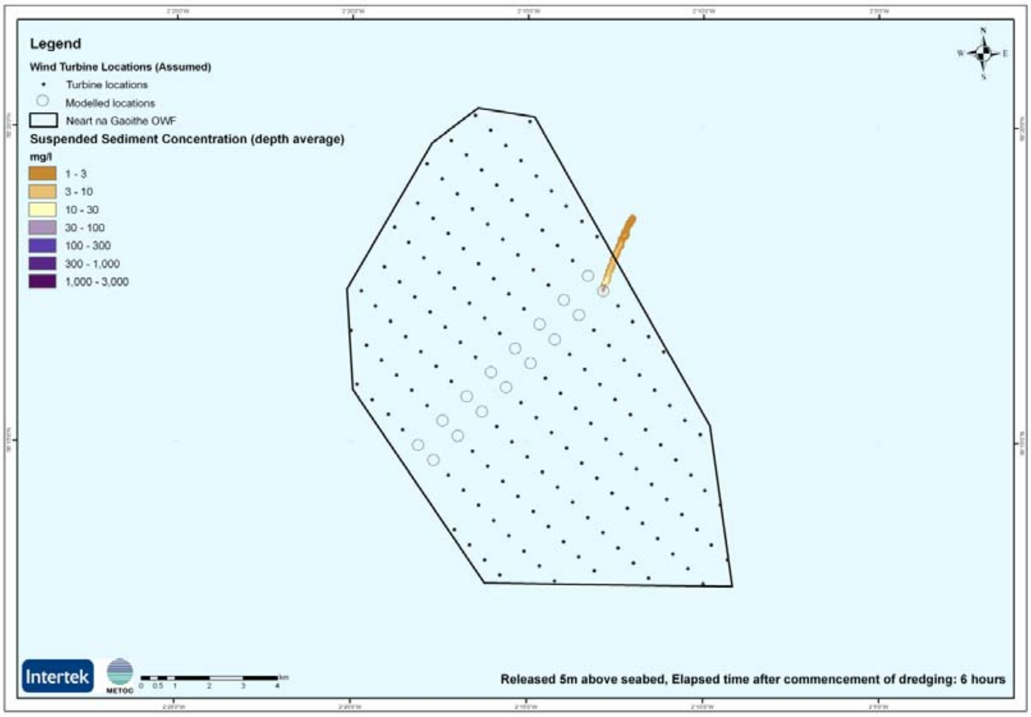


Figure H-57: Suspended sediment concentrations due to dredging – near-bed release: 12 hours after commencement

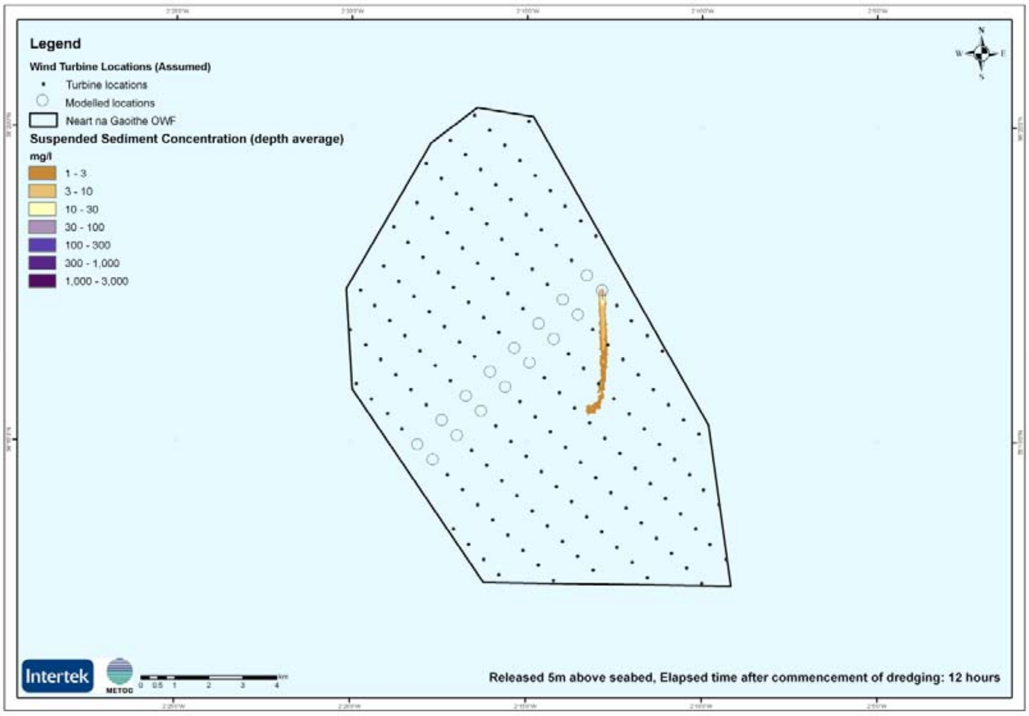


Figure H-58: Suspended sediment concentrations due to dredging – near-bed release: 1 day after commencement

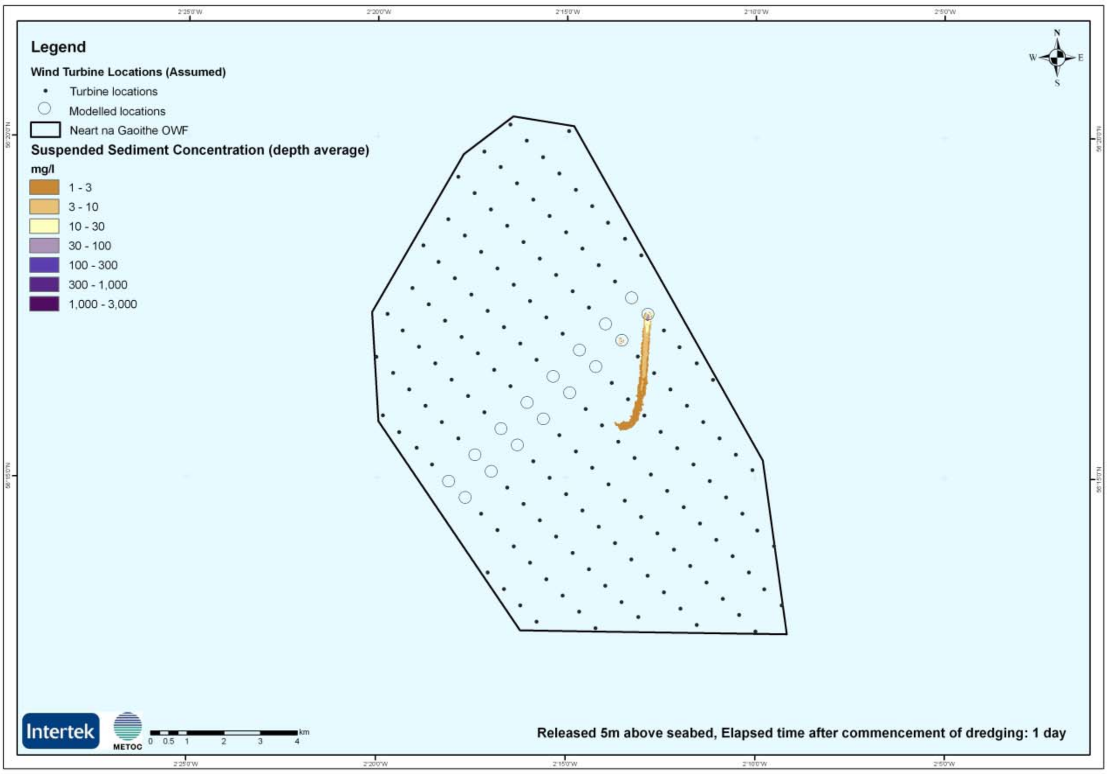


Figure H-59: Suspended sediment concentrations due to dredging – near-bed release: 2 days after commencement

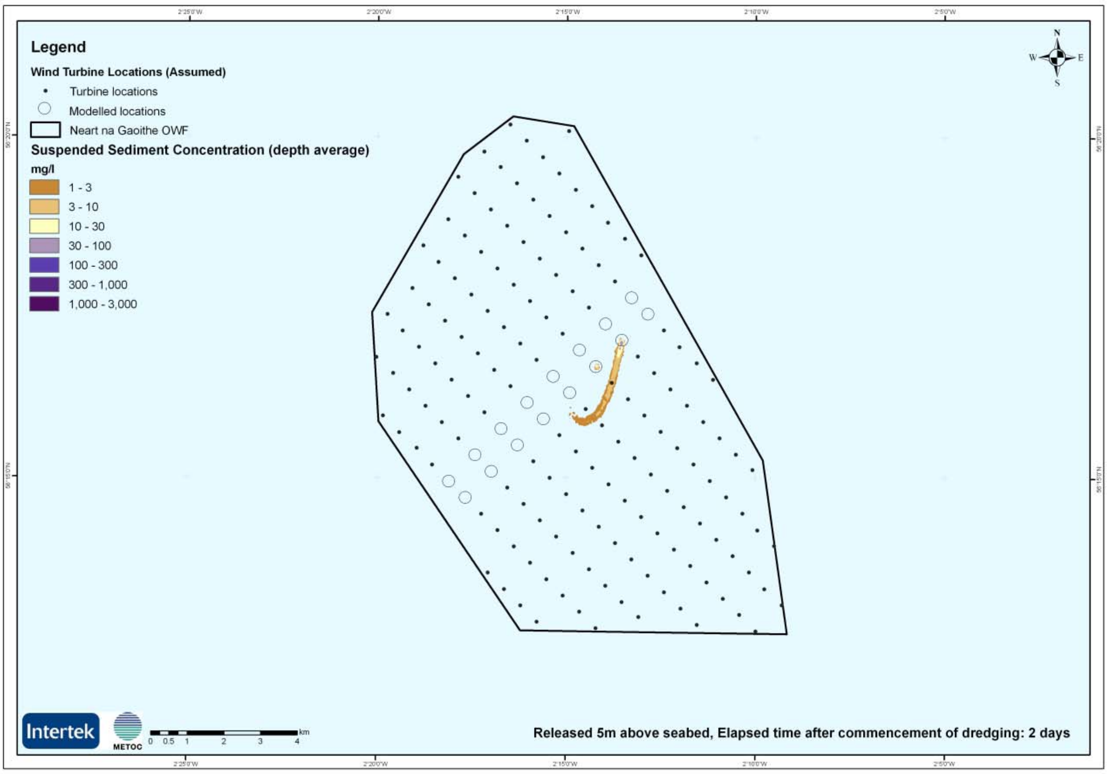


Figure H-60: Suspended sediment concentrations due to dredging – near-bed release: 3 days after commencement

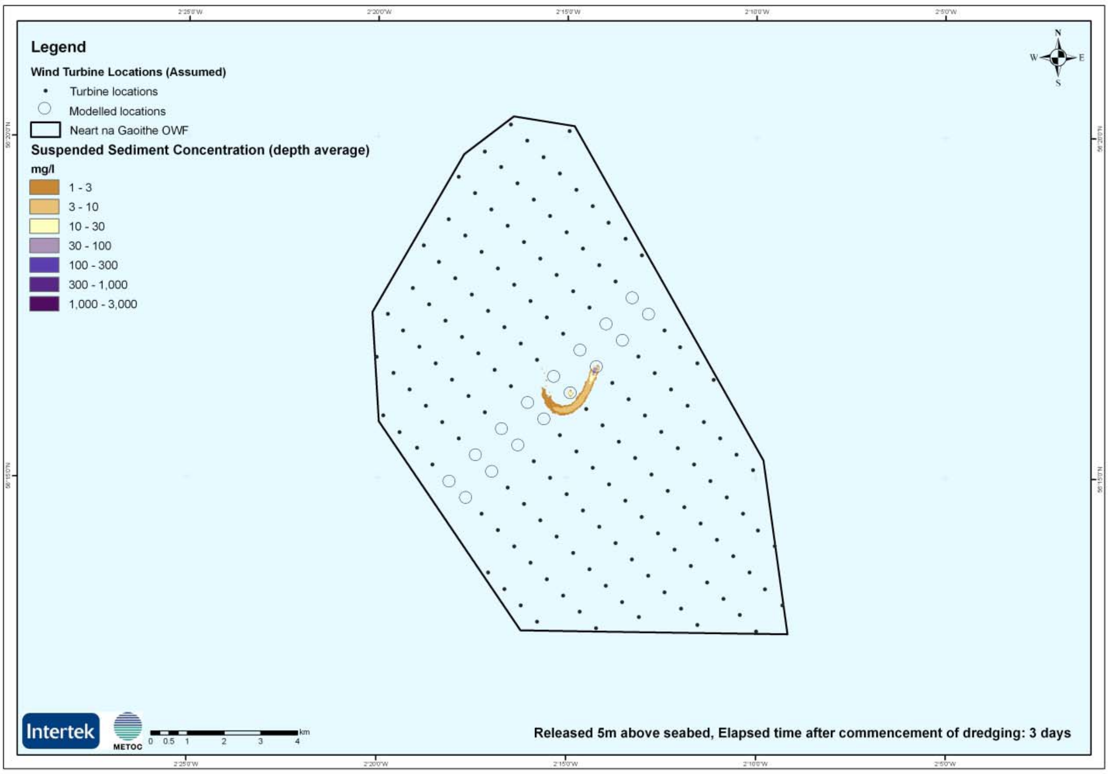


Figure H-61: Suspended sediment concentrations due to dredging – near-bed release: 4 days after commencement

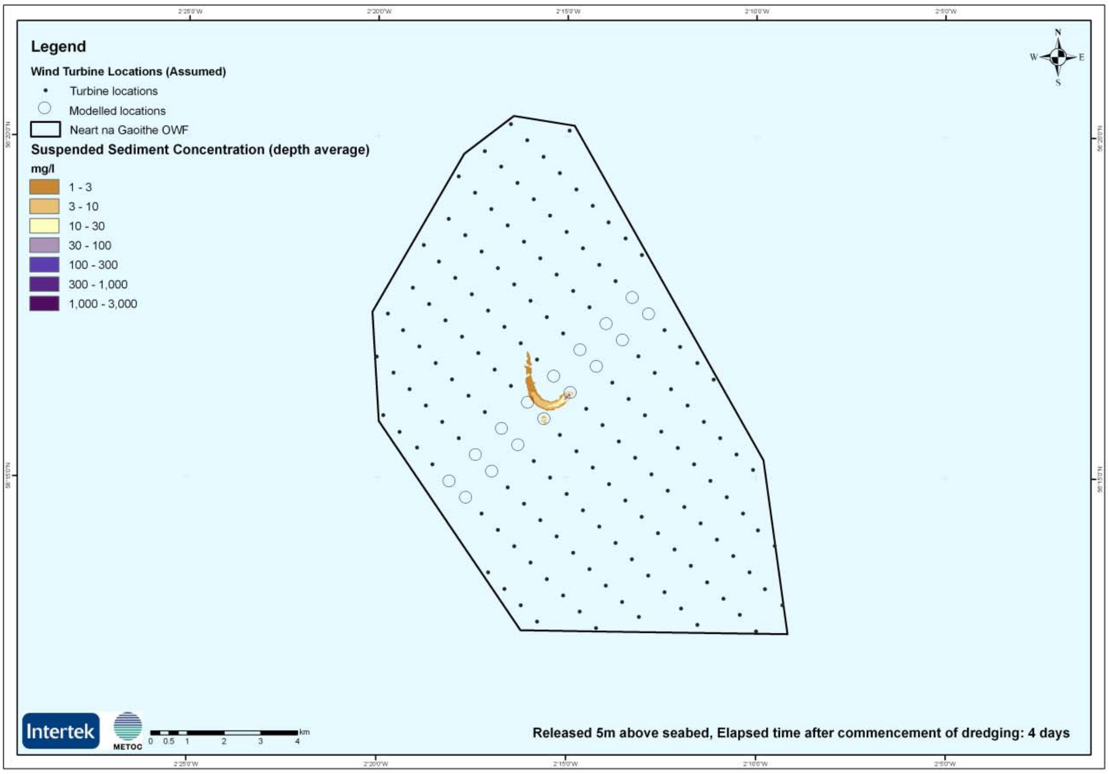


Figure H-62: Suspended sediment concentrations due to dredging – near-bed release: 5 days after commencement

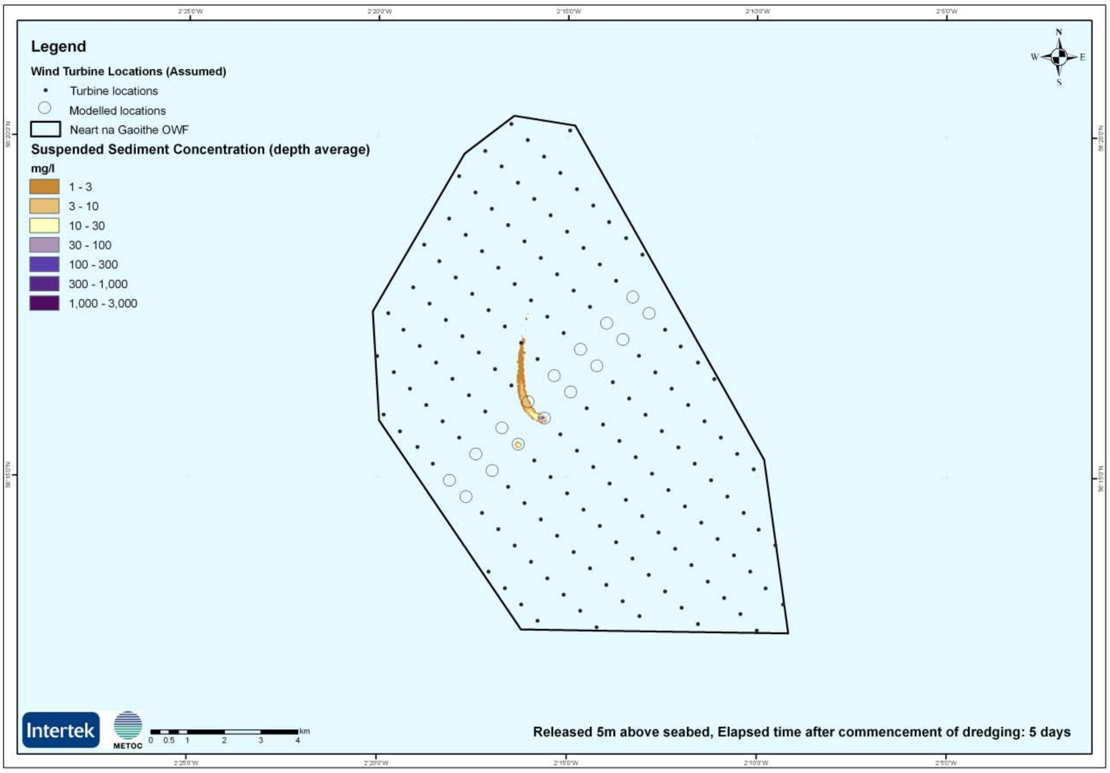


Figure H-63: Suspended sediment concentrations due to dredging – near-bed release: 6 days after commencement

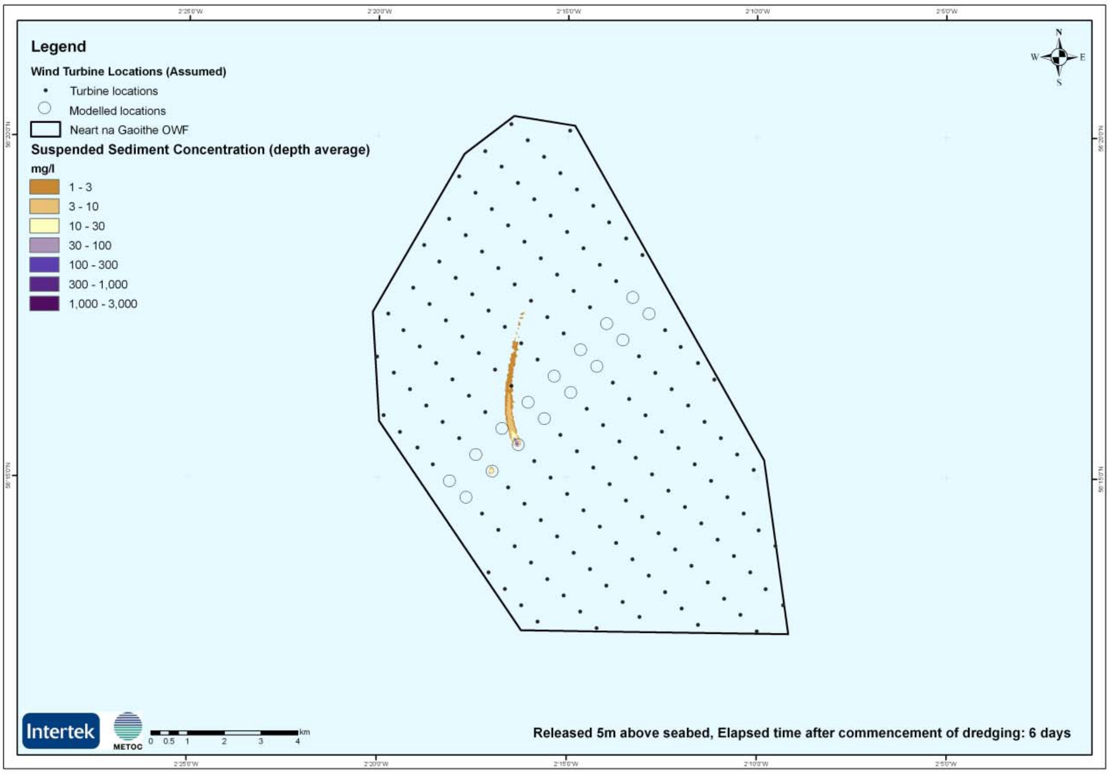


Figure H-64: Suspended sediment concentrations due to dredging – near-bed release: 7 days after commencement

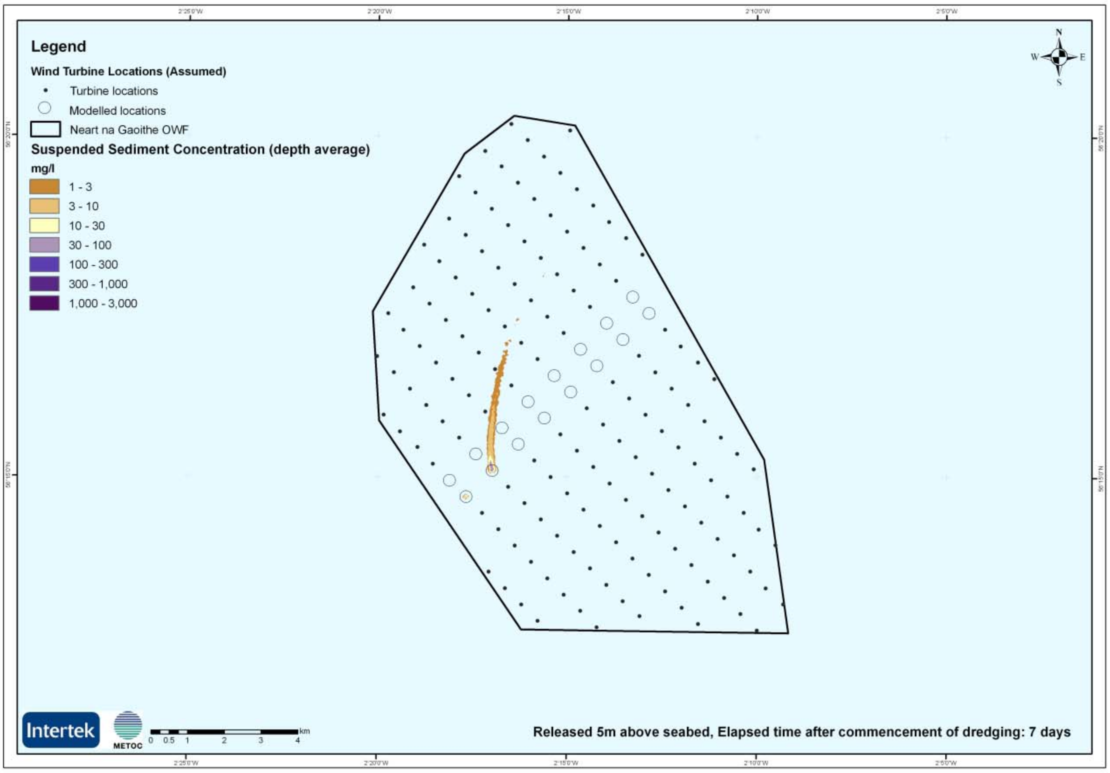


Figure H-65: Suspended sediment concentrations due to dredging – near-bed release: 8 days after commencement

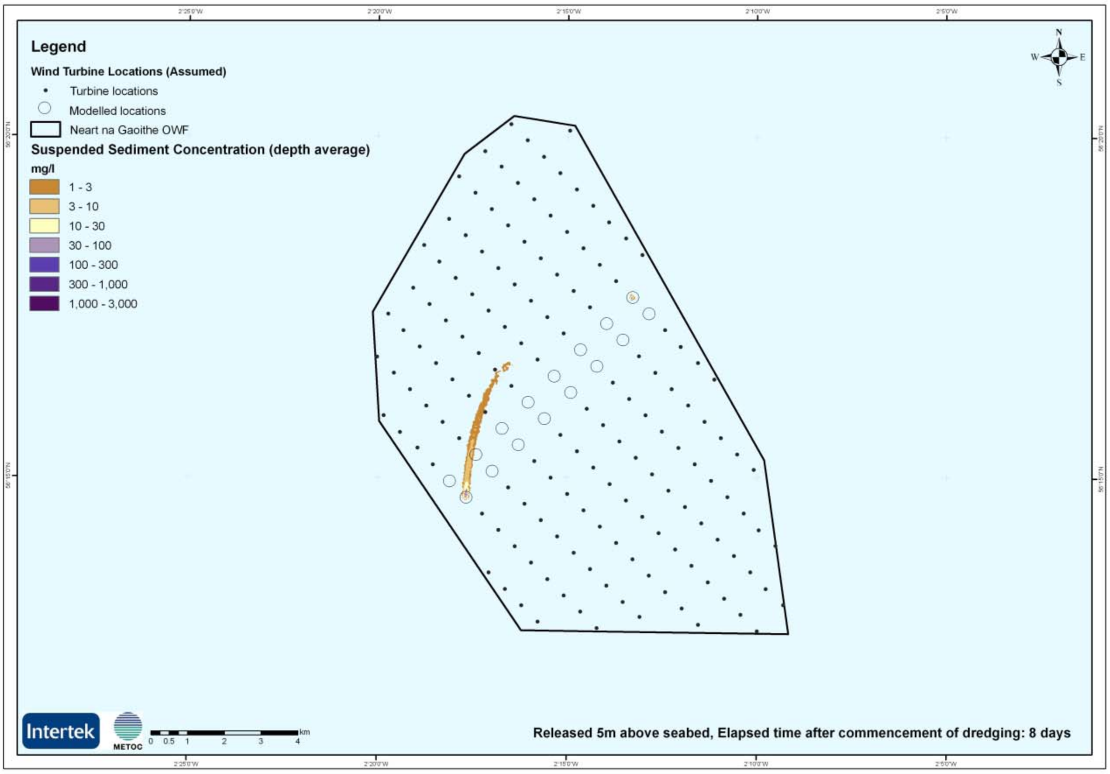


Figure H-66: Suspended sediment concentrations due to dredging – near-bed release: 9 days after commencement

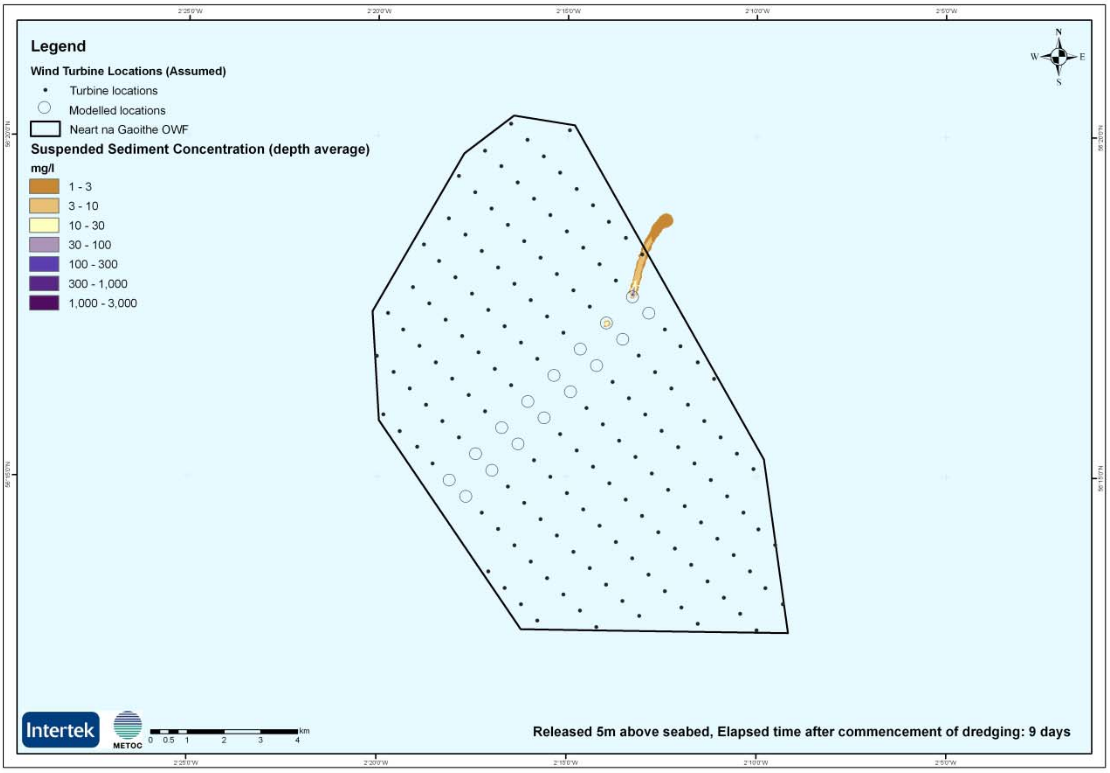


Figure H-67: Suspended sediment concentrations due to dredging – near-bed release: 10 days after commencement

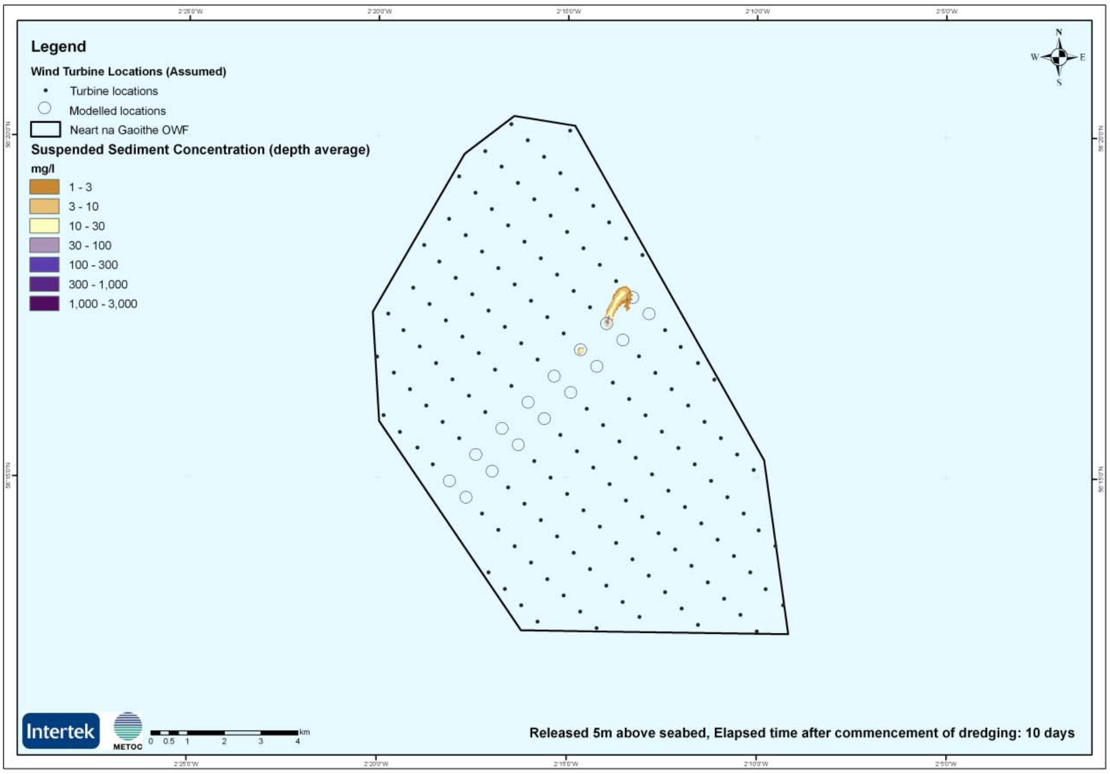


Figure H-68: Suspended sediment concentrations due to dredging – near-bed release: 11 days after commencement

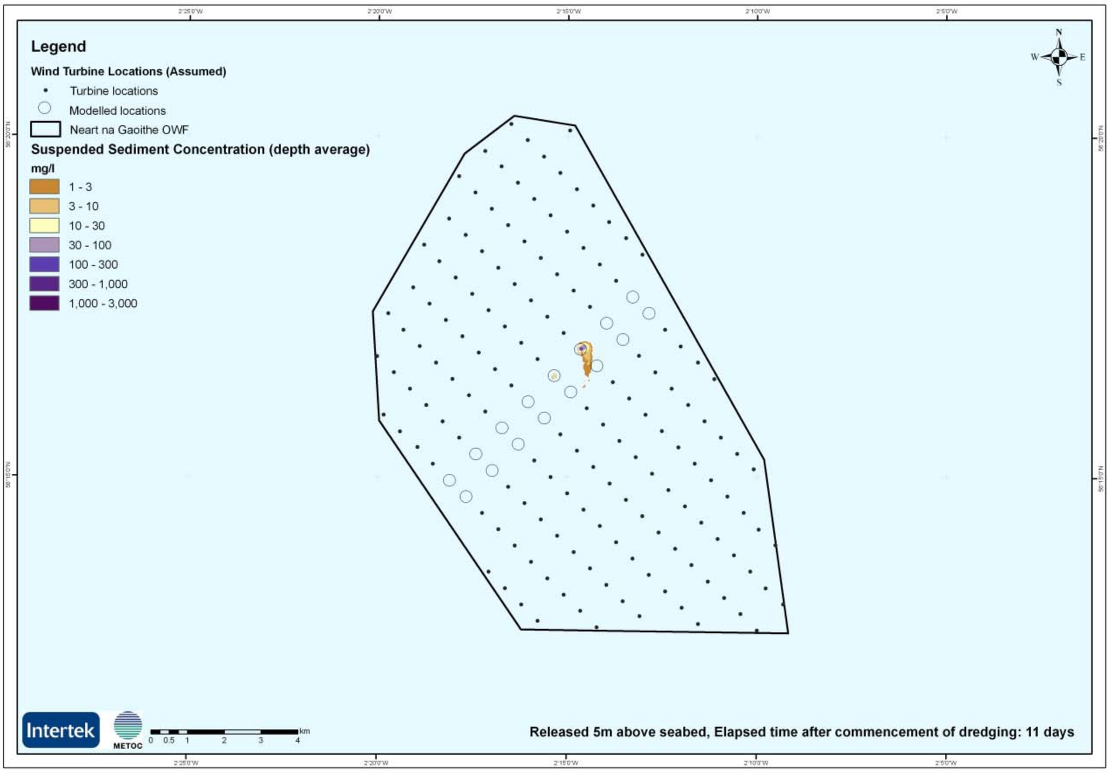


Figure H-69: Suspended sediment concentrations due to dredging – near-bed release: 12 days after commencement

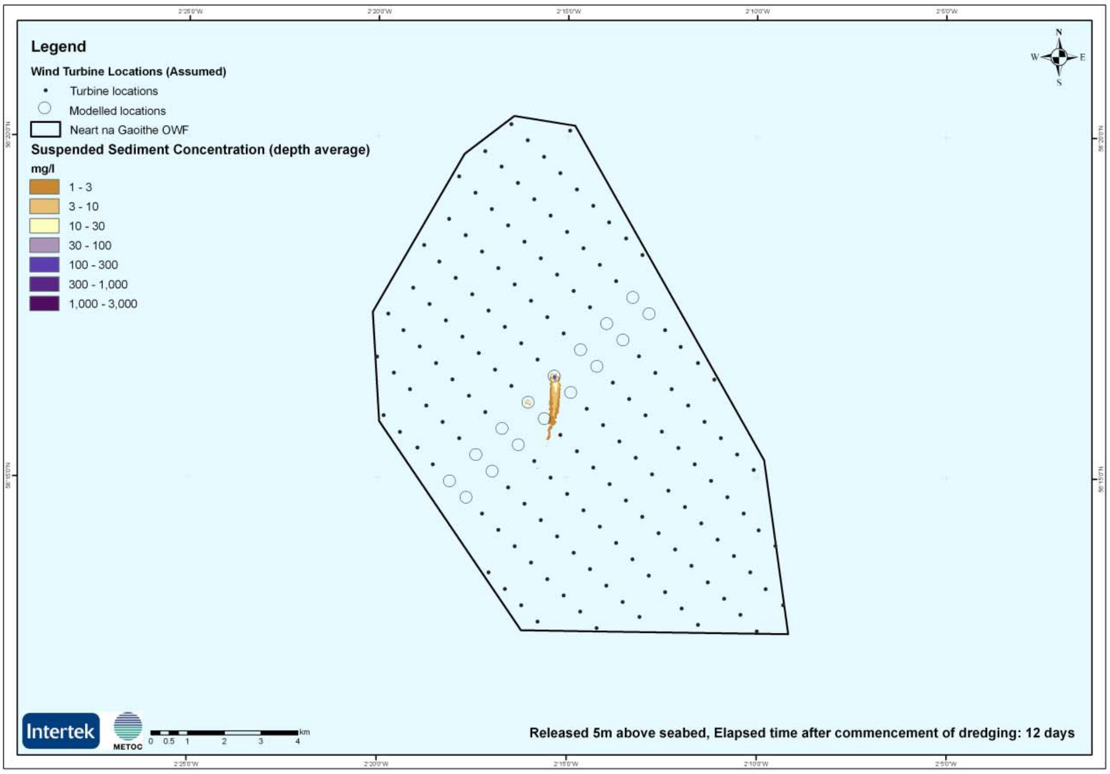


Figure H-70: Suspended sediment concentrations due to dredging – near-bed release: 13 days after commencement

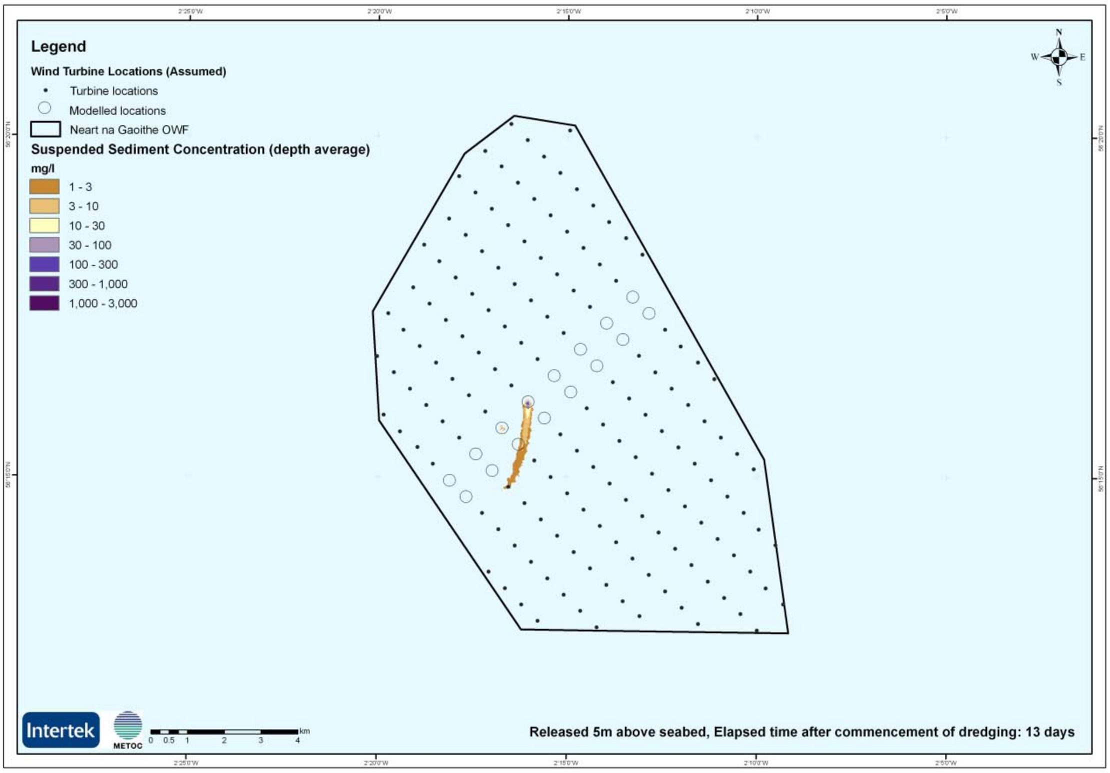


Figure H-71: Suspended sediment concentrations due to dredging – near-bed release: 14 days after commencement

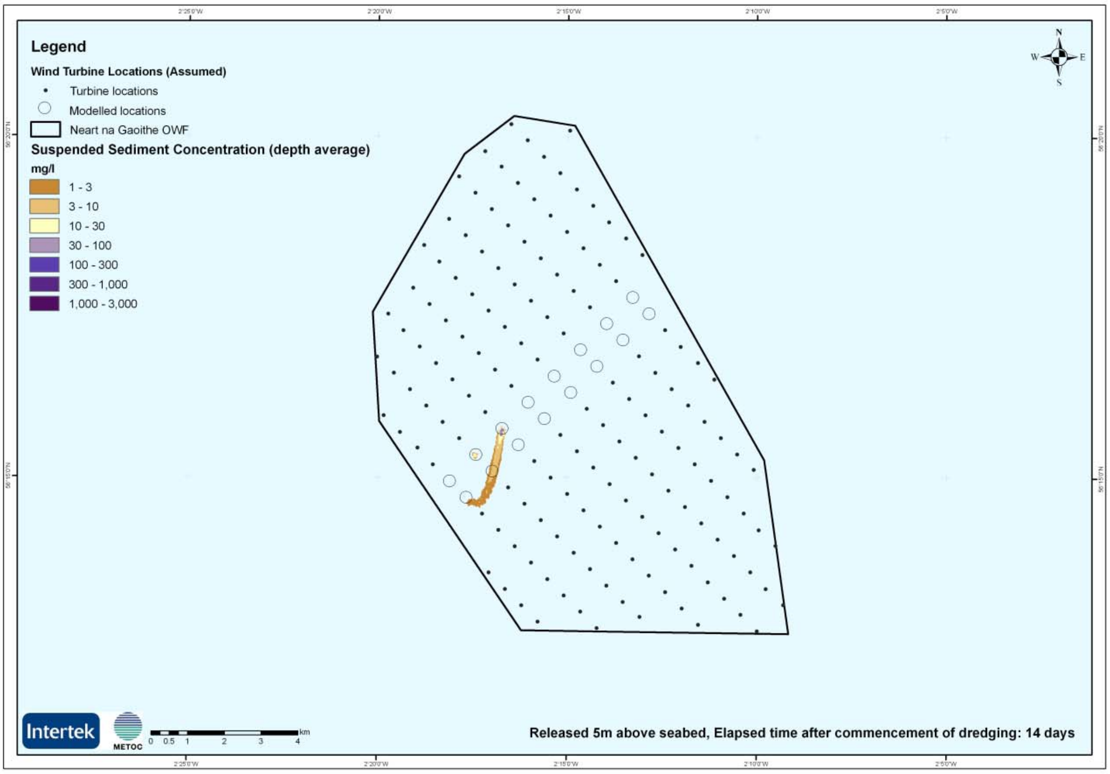


Figure H-72: Suspended sediment concentrations due to dredging – near-bed release: 15 days after commencement

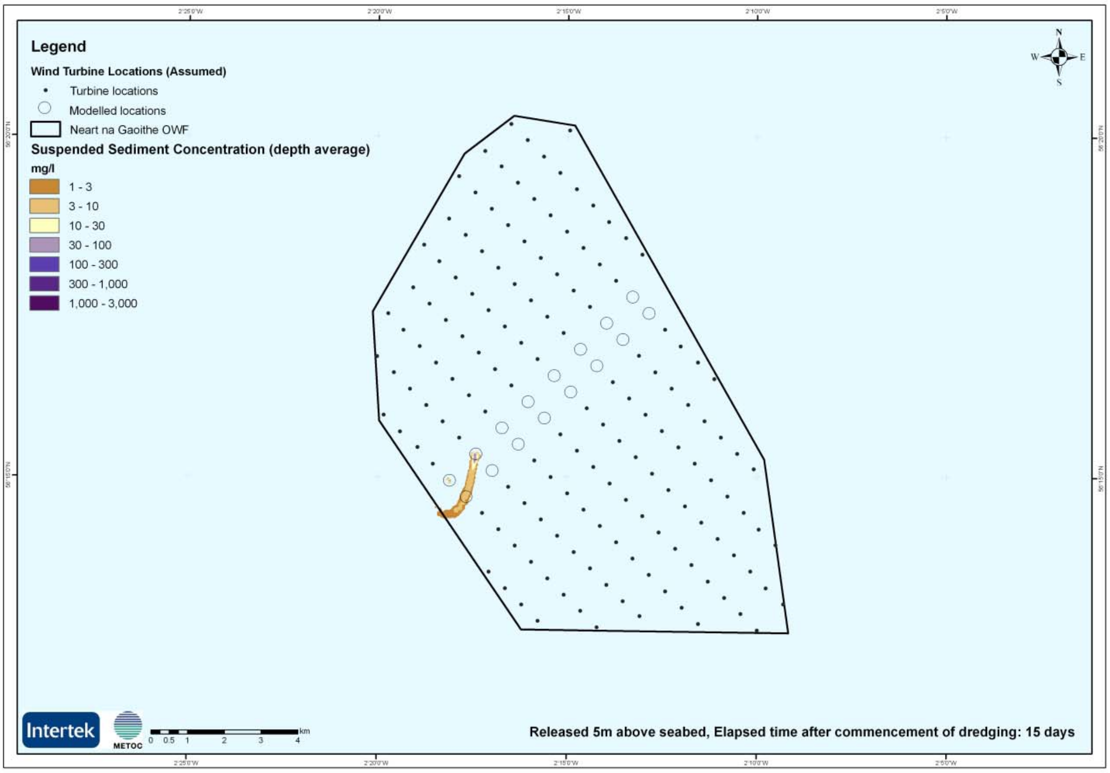


Figure H-73: Suspended sediment concentrations due to dredging – near-bed release: 16 days after commencement

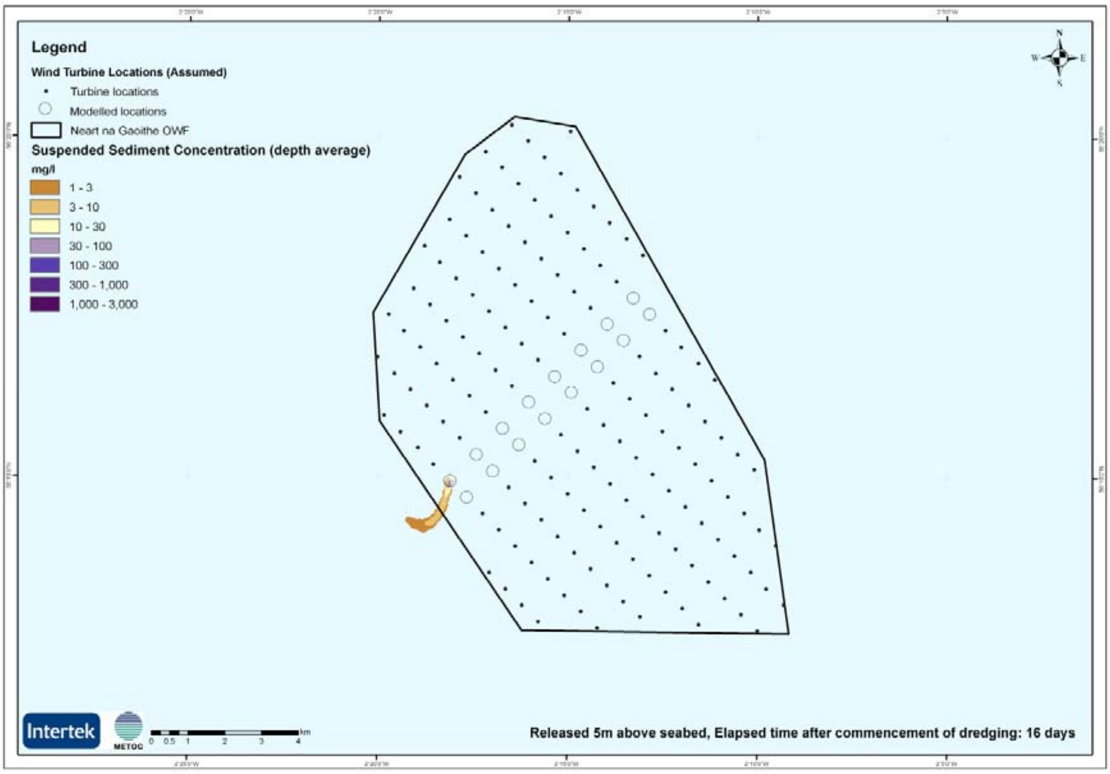
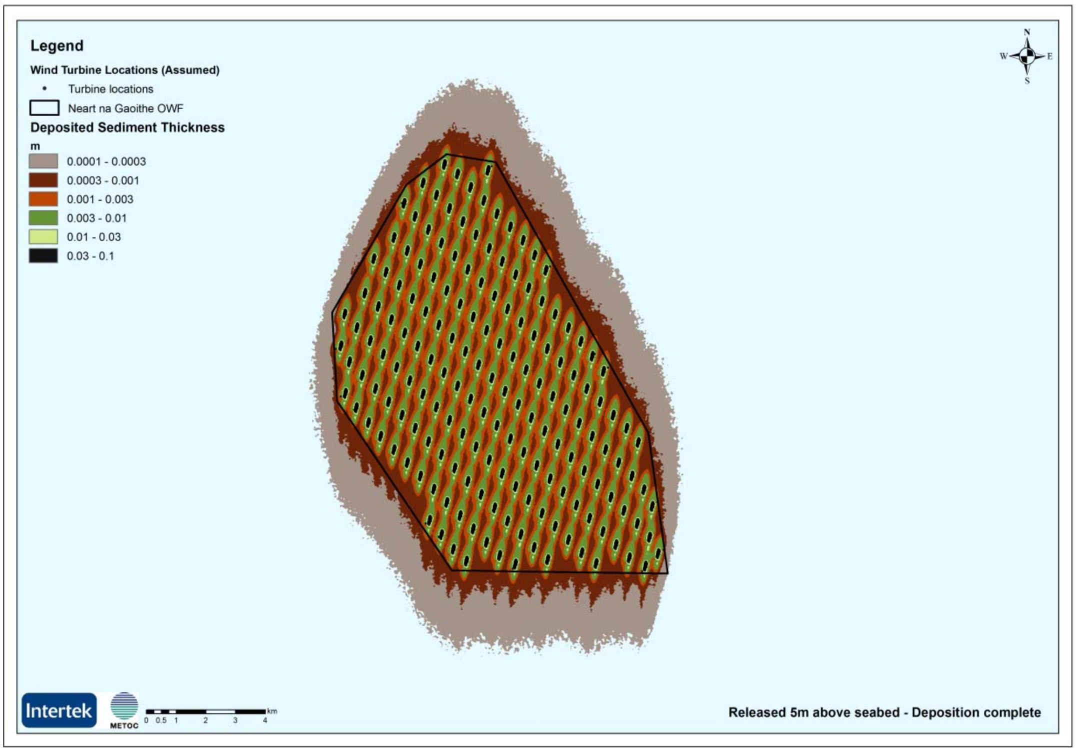


Figure H-74: Deposition thickness due to dredging – near-bed release: after all material has settled



Impacts due to cable burial trenching methods – offshore area Torness Route

Figure H-75: Suspended sediment concentration due to cable trenching – Torness route offshore area: 2 hours after commencement

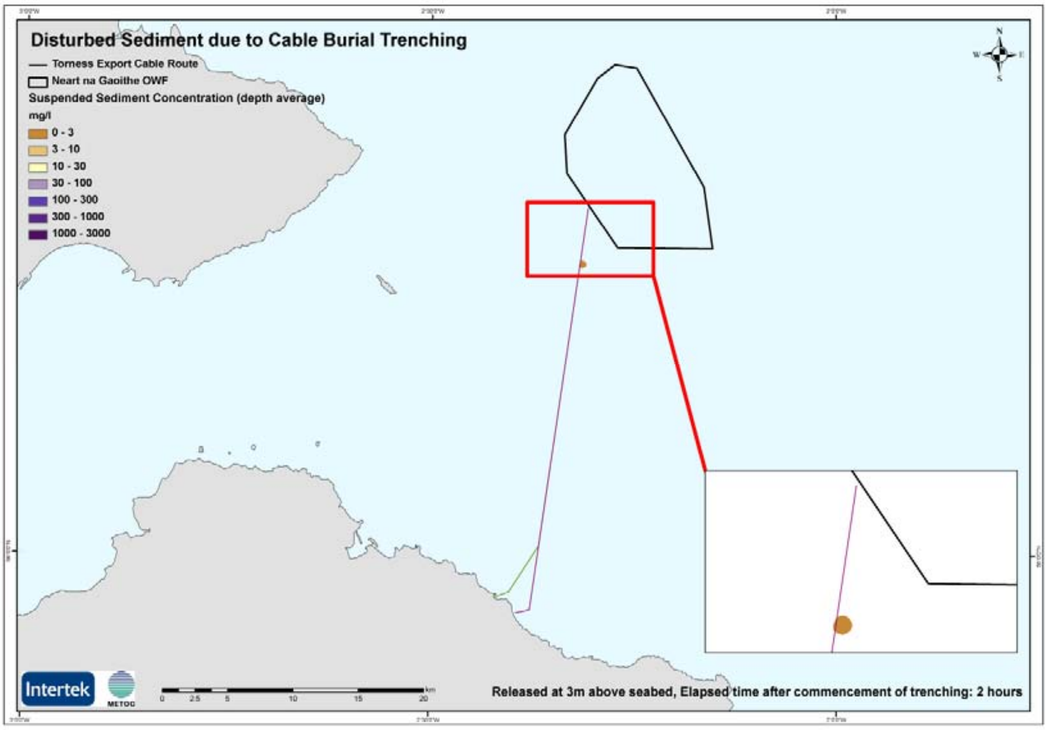


Figure H-76: Suspended sediment concentration due to cable trenching – Torness route offshore area: 4 hours after commencement

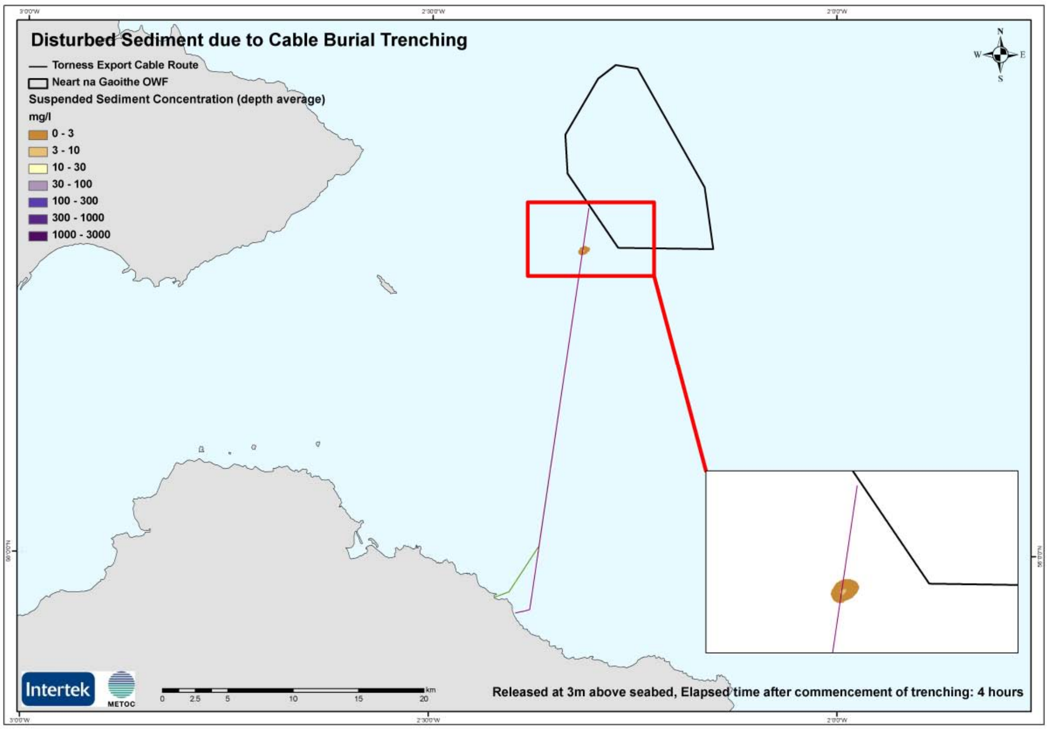


Figure H-77: Suspended sediment concentration due to cable trenching – Torness route offshore area: 6 hours after commencement

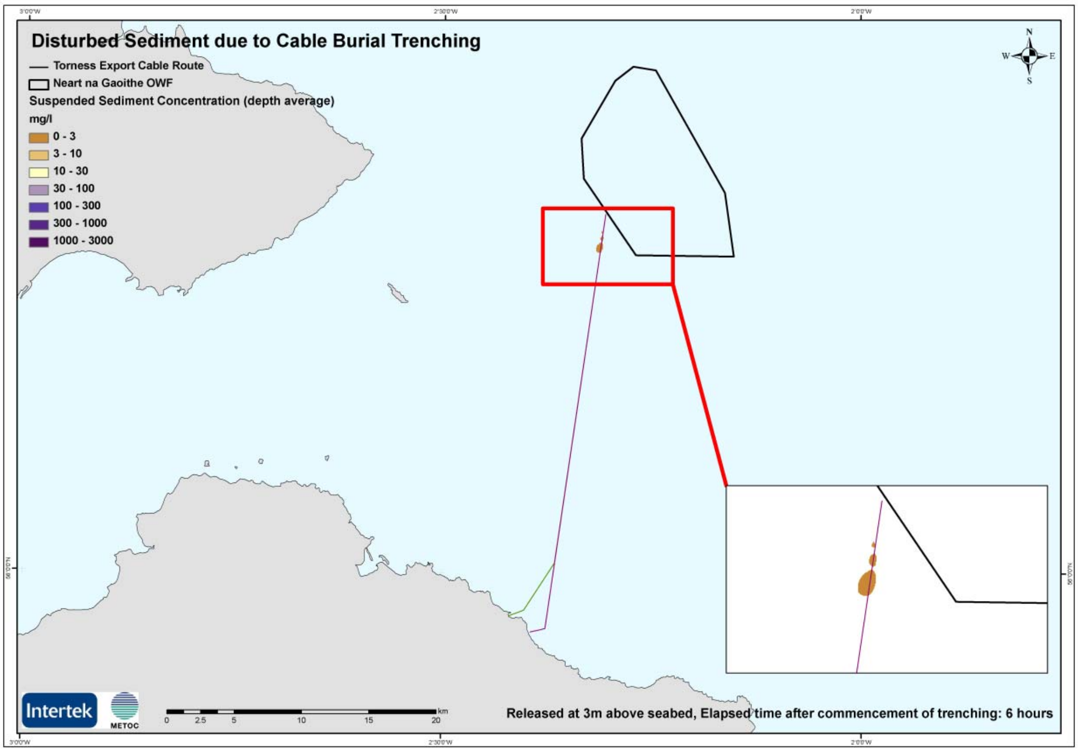


Figure H-78: Suspended sediment concentration due to cable trenching – Torness route offshore area: 8 hours after commencement

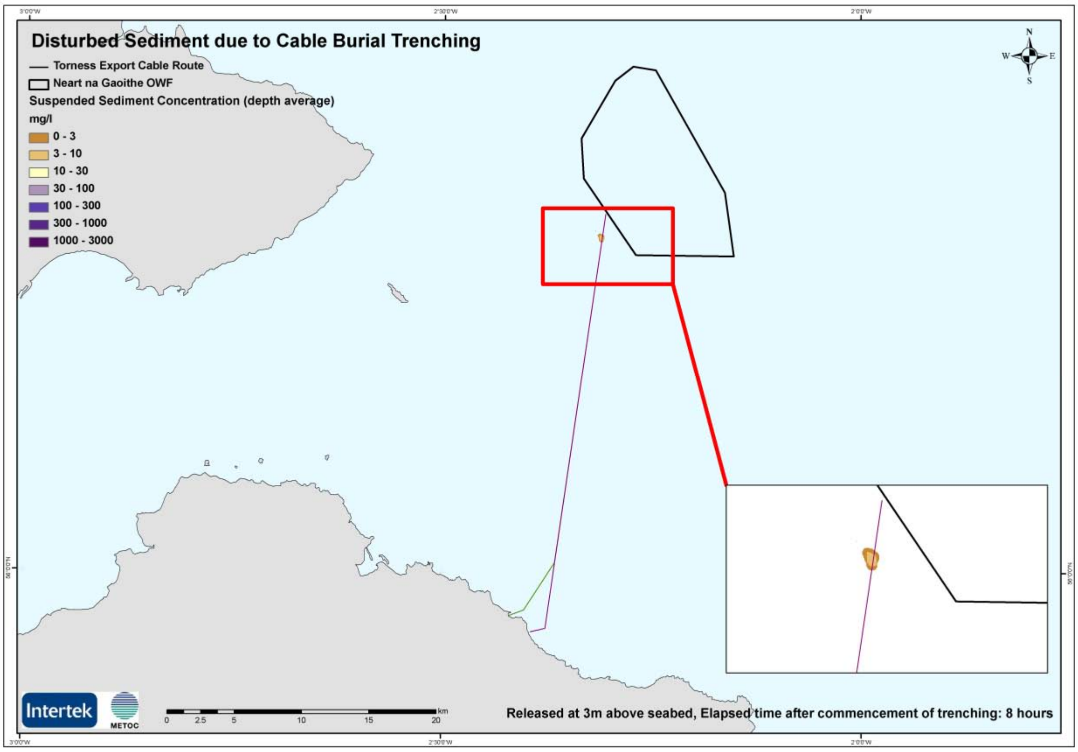


Figure H-79: Suspended sediment concentration due to cable trenching – Torness route offshore area: 10 hours after commencement

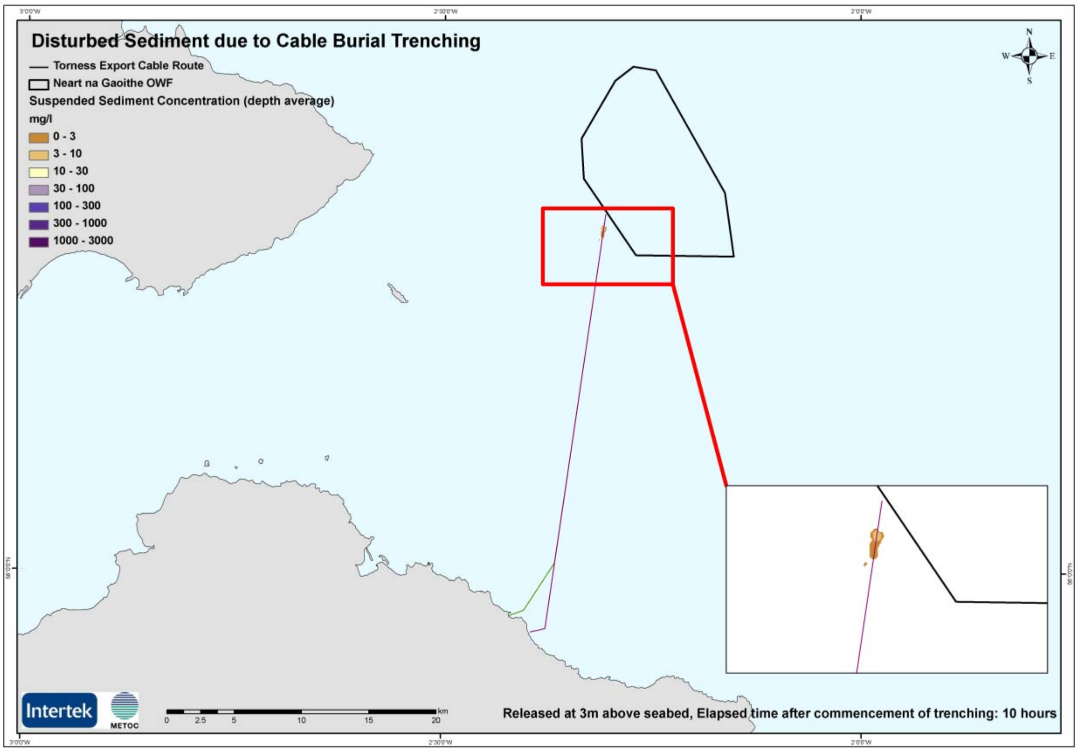


Figure H-80: Suspended sediment concentration due to cable trenching – Torness route offshore area: 12 hours after commencement

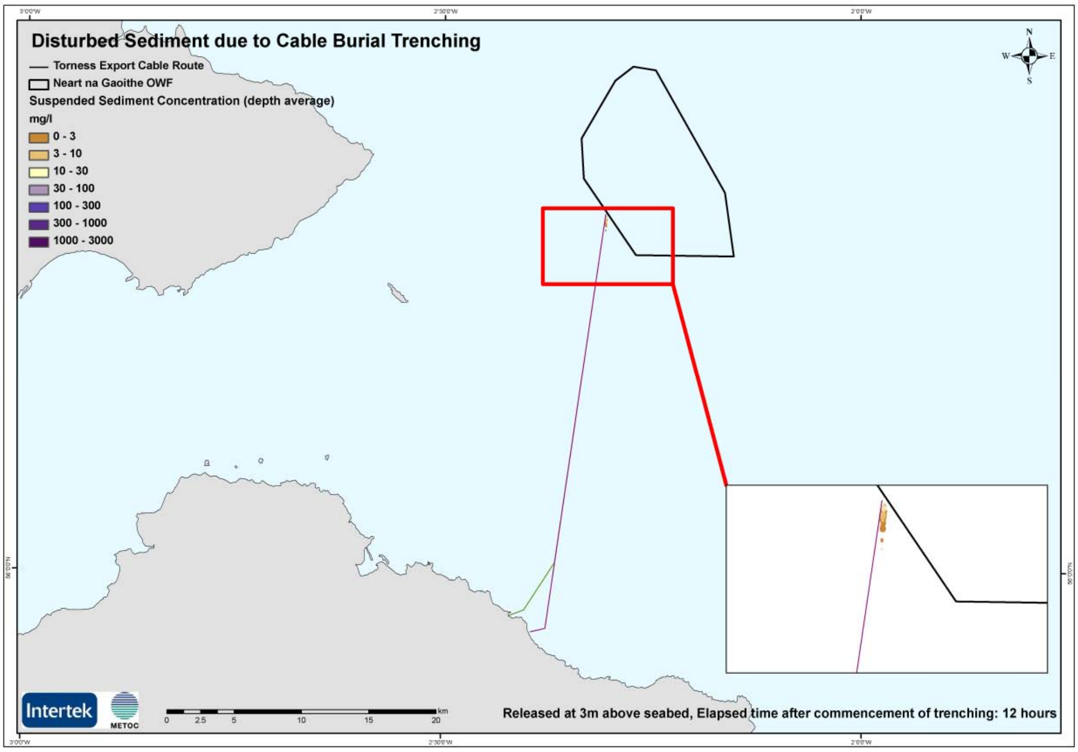


Figure H-81: Suspended sediment concentration due to cable trenching – Torness route offshore area: 2 hours after cessation of trenching

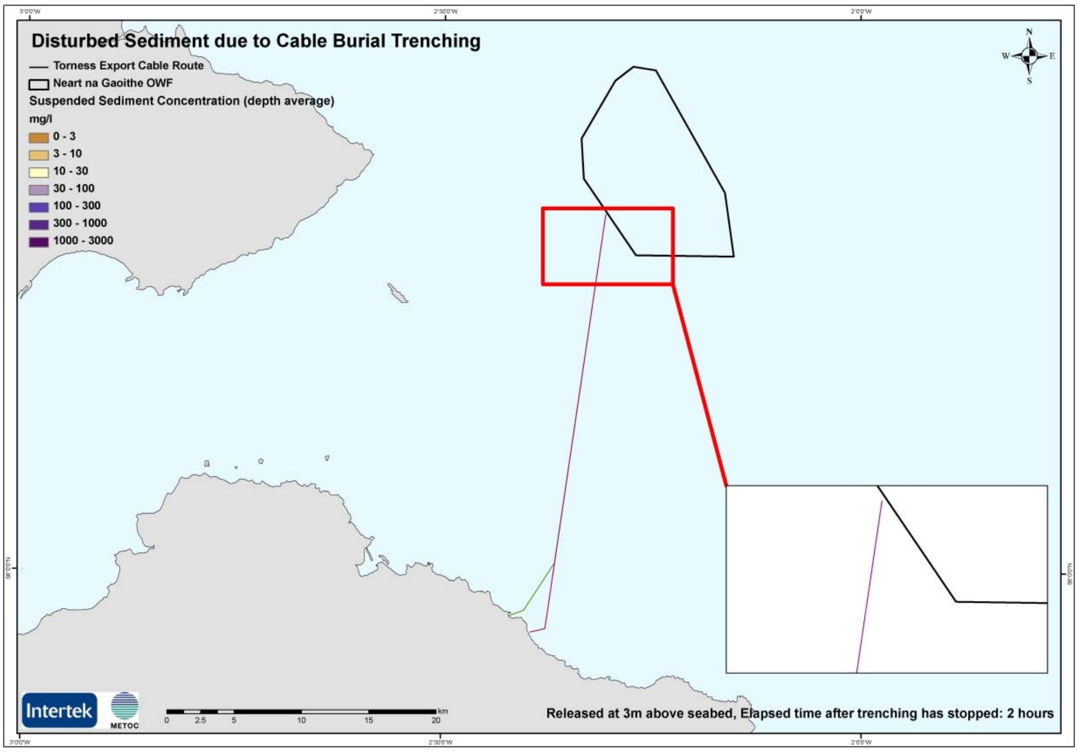
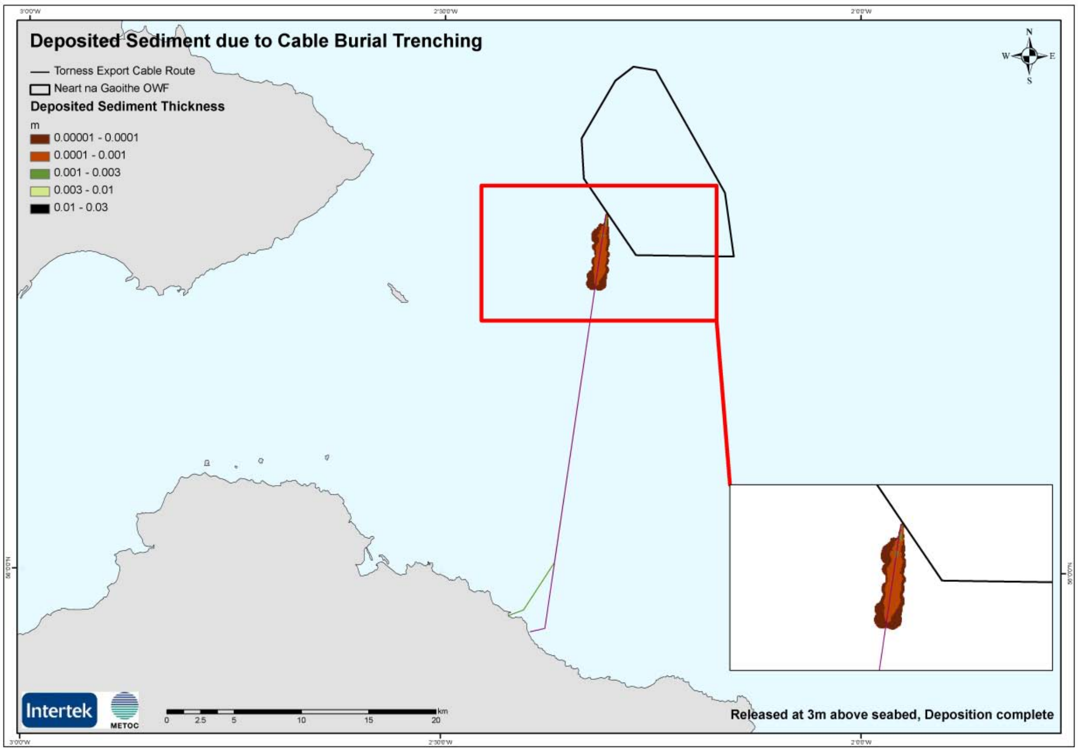


Figure H-82: Deposition thickness due to cable trenching – Torness route offshore area: after all disturbed material has settled



Impacts due to cable burial trenching methods – mid-point area Cockenzie Route

Figure H-83: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 2 hours after commencement

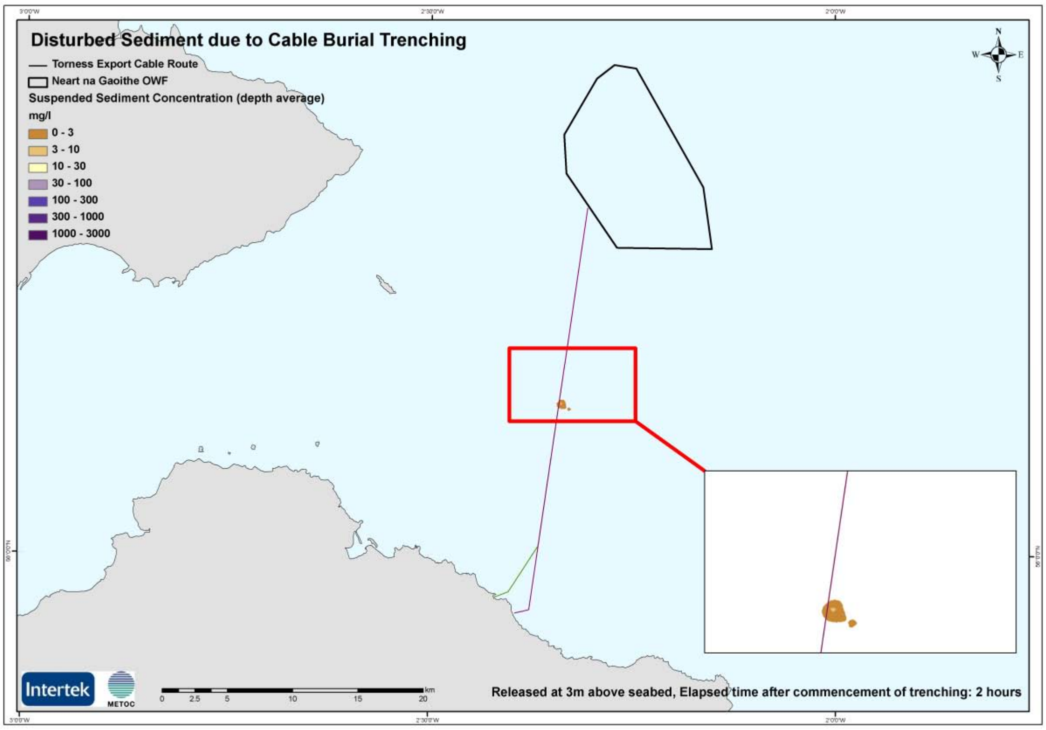


Figure H-84: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 4 hours after commencement

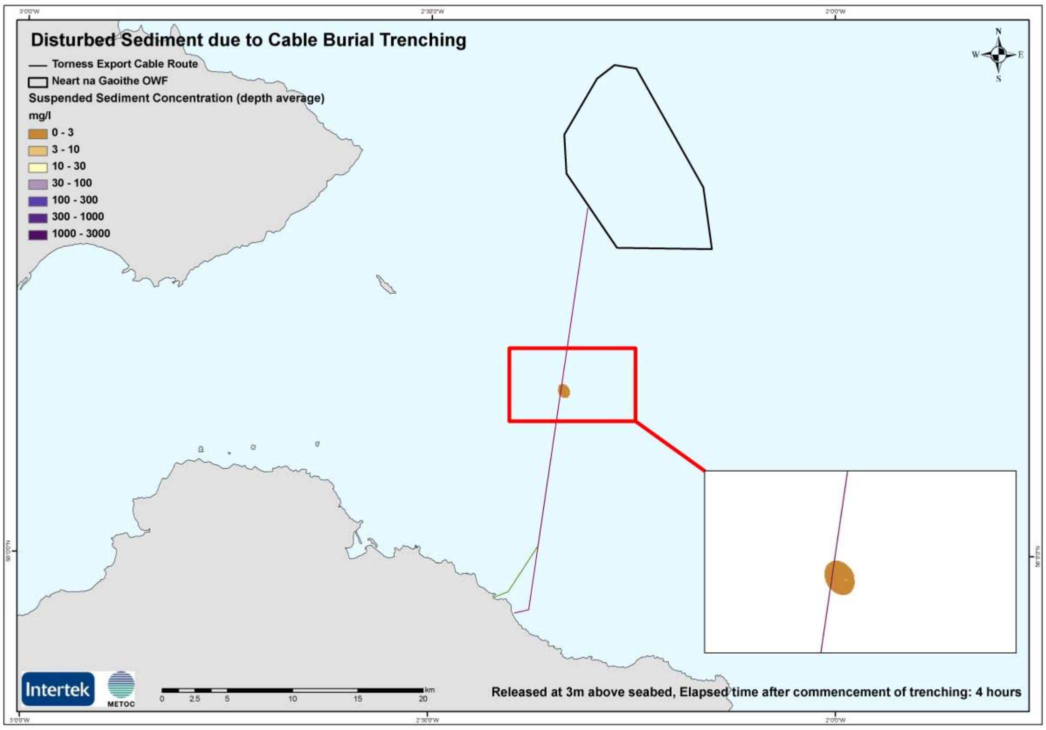


Figure H-85: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 6 hours after commencement

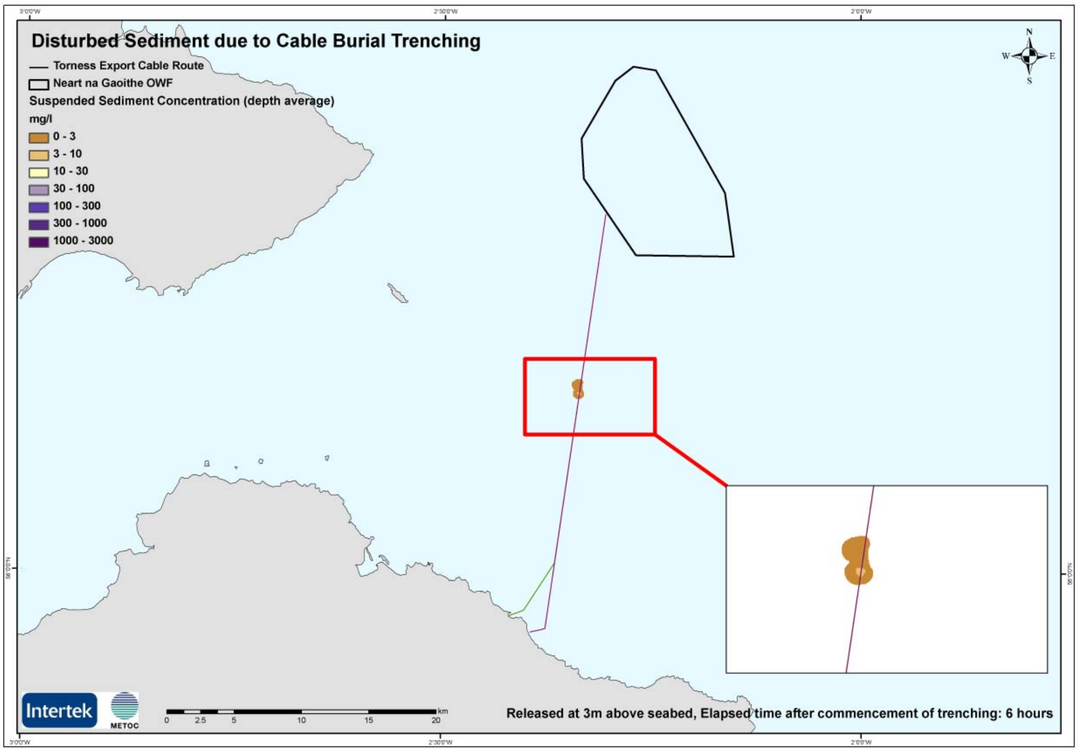


Figure H-86: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 8 hours after commencement

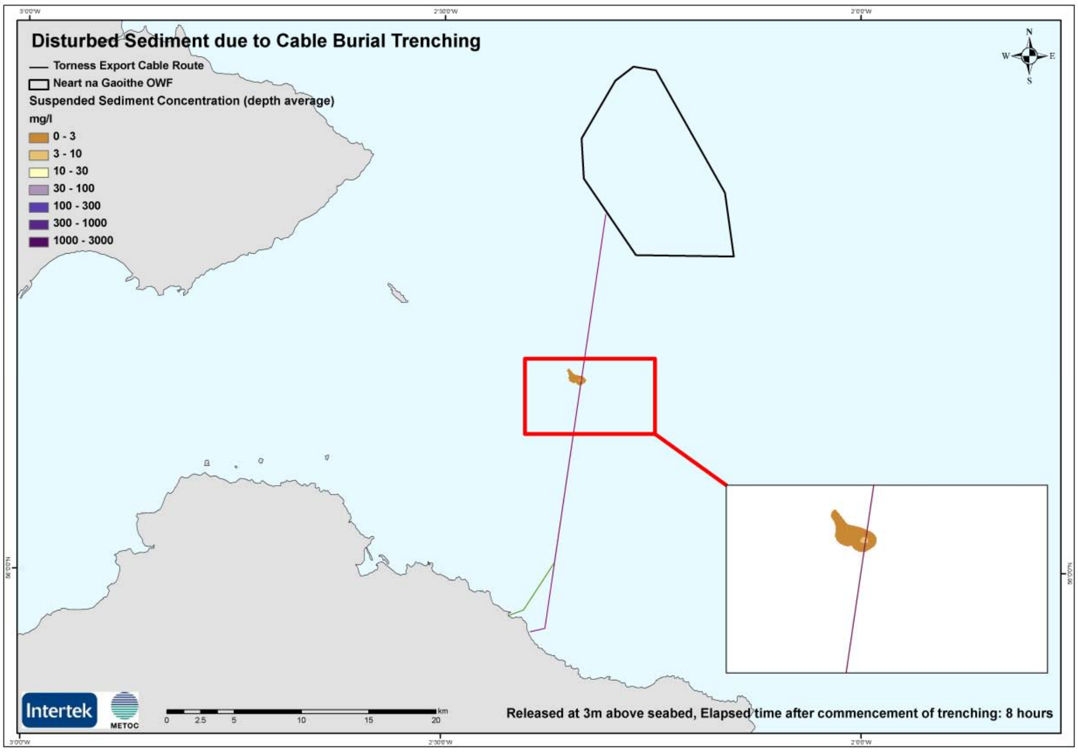


Figure H-87: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 10 hours after commencement

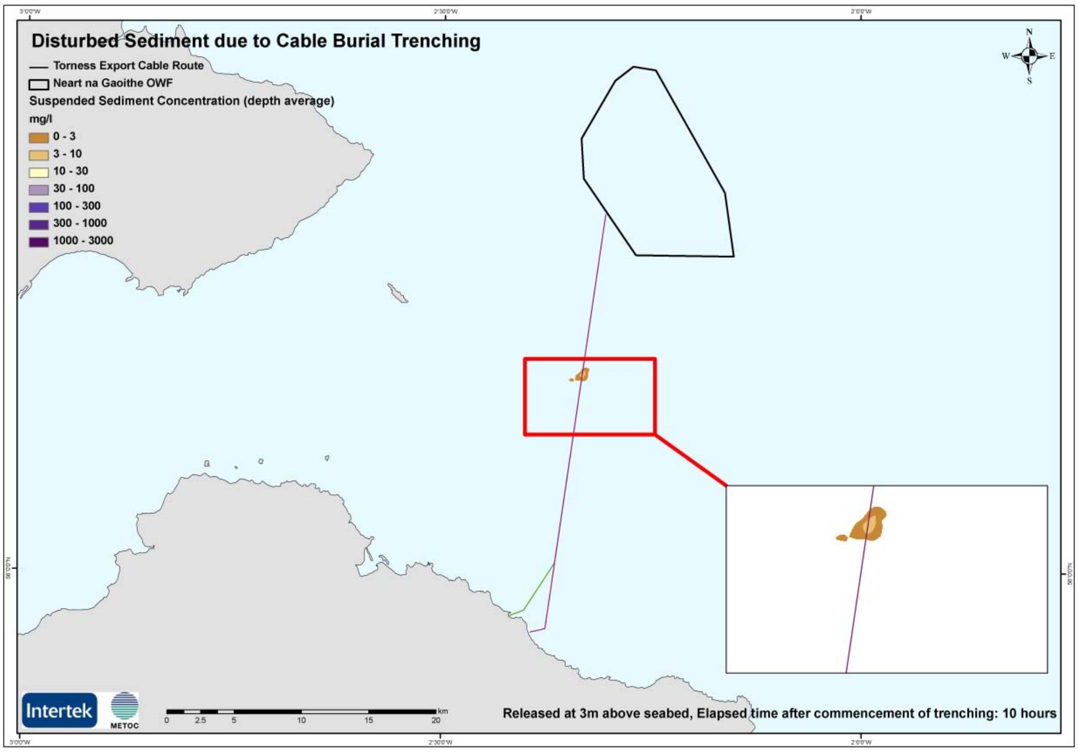


Figure H-88: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 12 hours after commencement

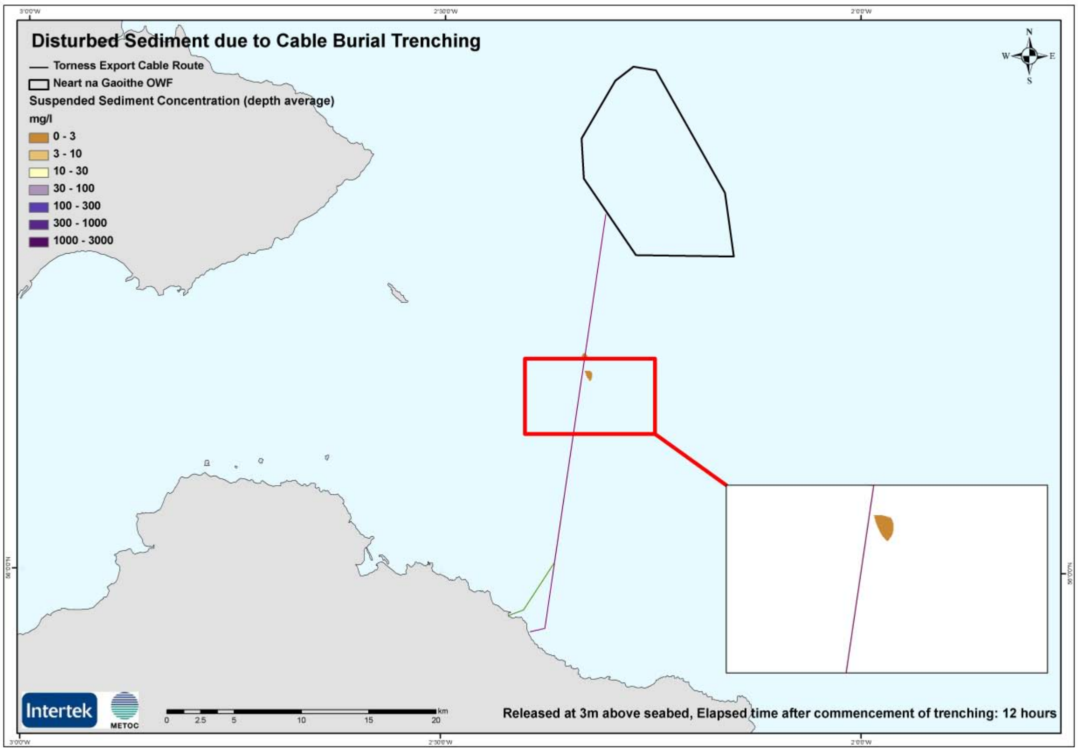


Figure H-89: Suspended sediment concentration due to cable trenching – Torness route midpoint area: 2 hours after cessation of trenching

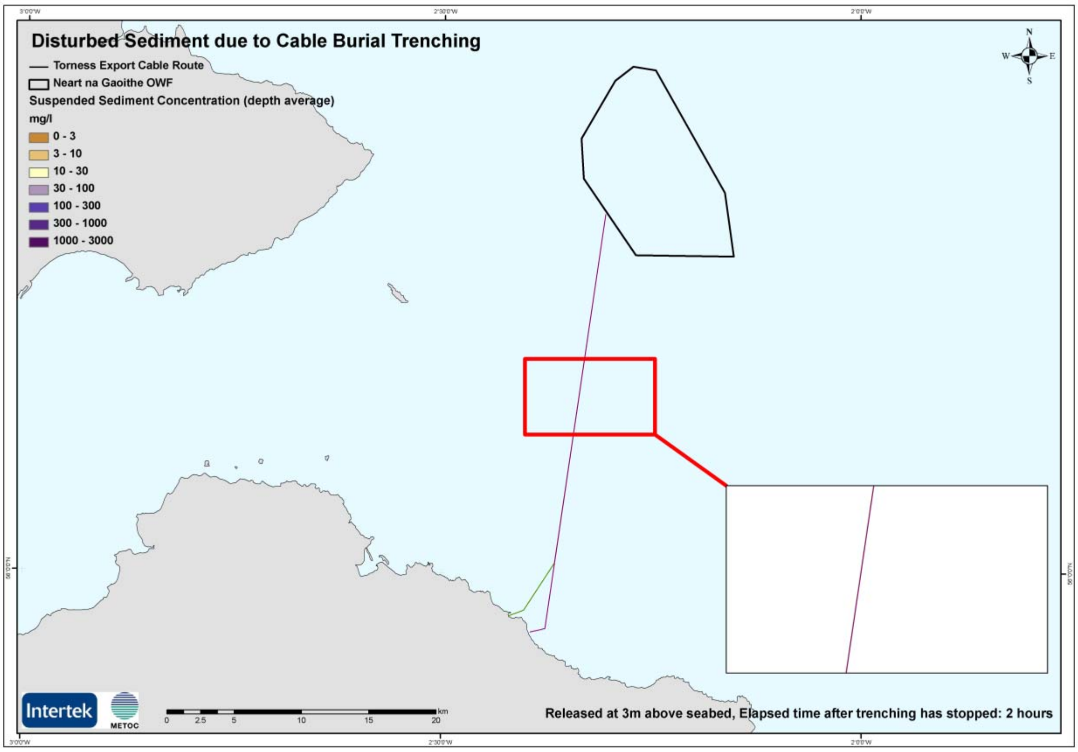
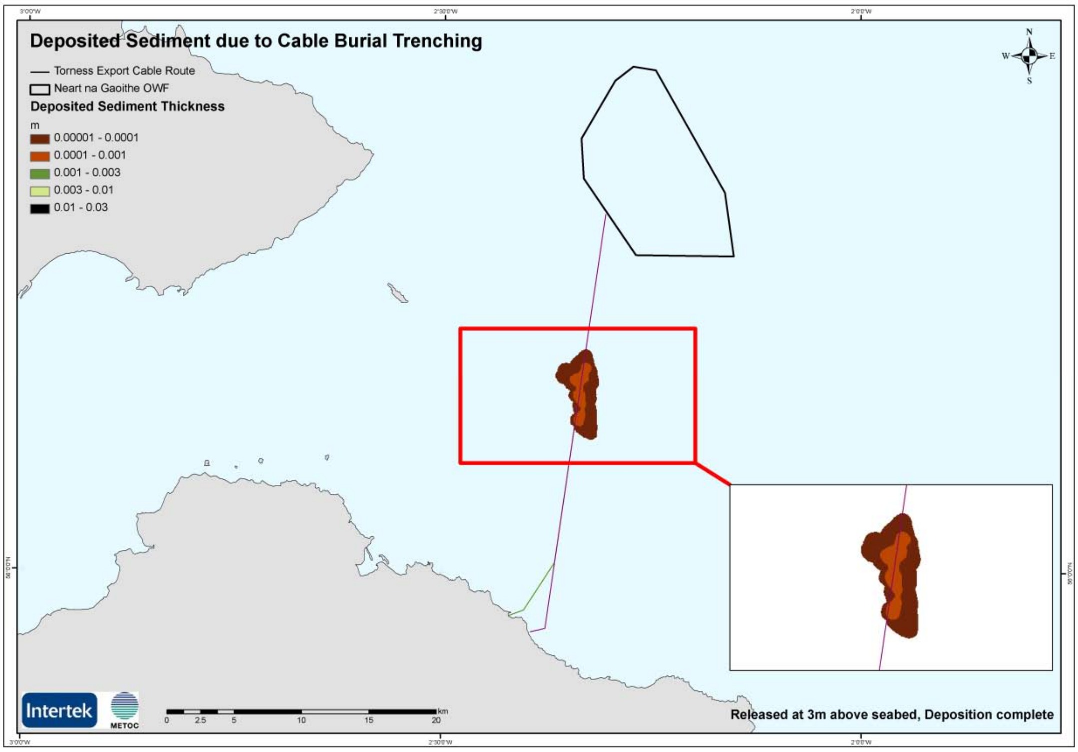


Figure H-90 : Deposition thickness due to cable trenching – Torness route midpoint area: after all disturbed material has settled



Impacts due to cable burial trenching methods – inshore area Torness Route

Figure H-91: Suspended sediment concentration due to cable trenching – Torness route inshore area: 2 hours after commencement

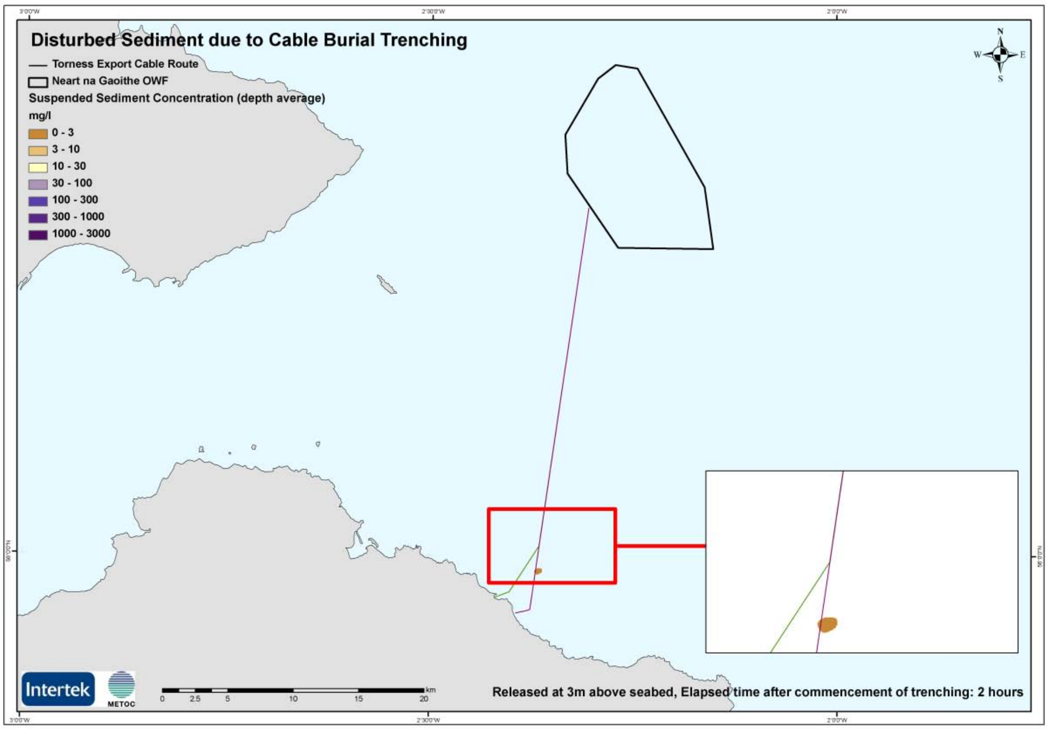


Figure H-92: Suspended sediment concentration due to cable trenching – Torness route inshore area: 4 hours after commencement

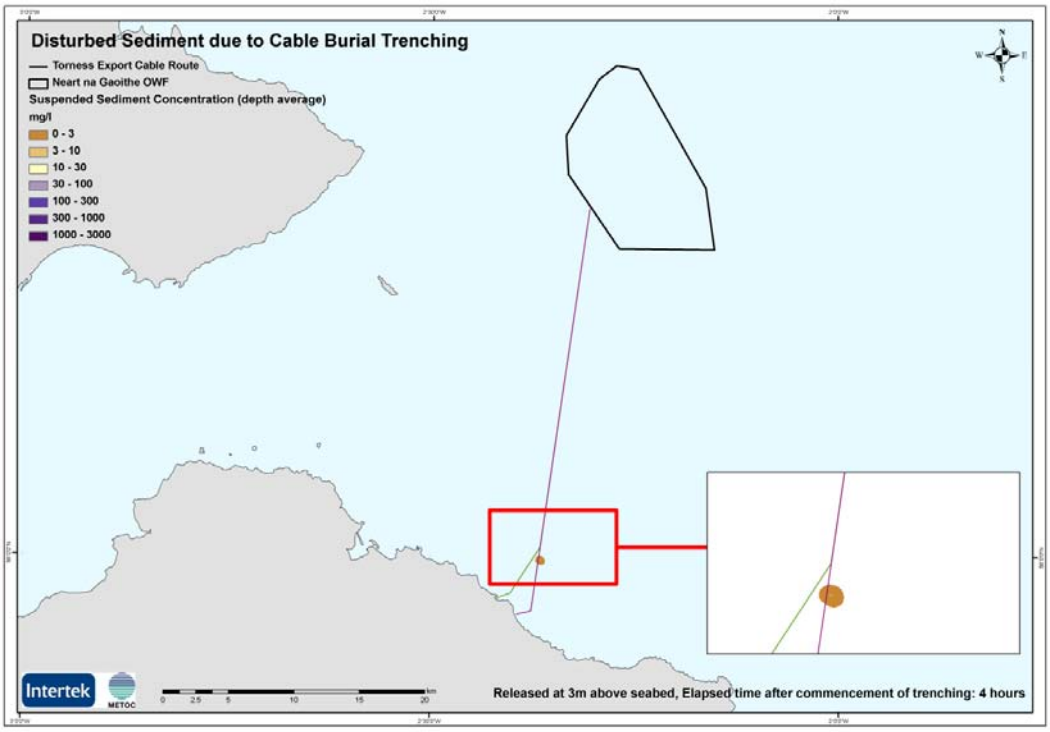


Figure H-93: Suspended sediment concentration due to cable trenching – Torness route inshore area: 6 hours after commencement

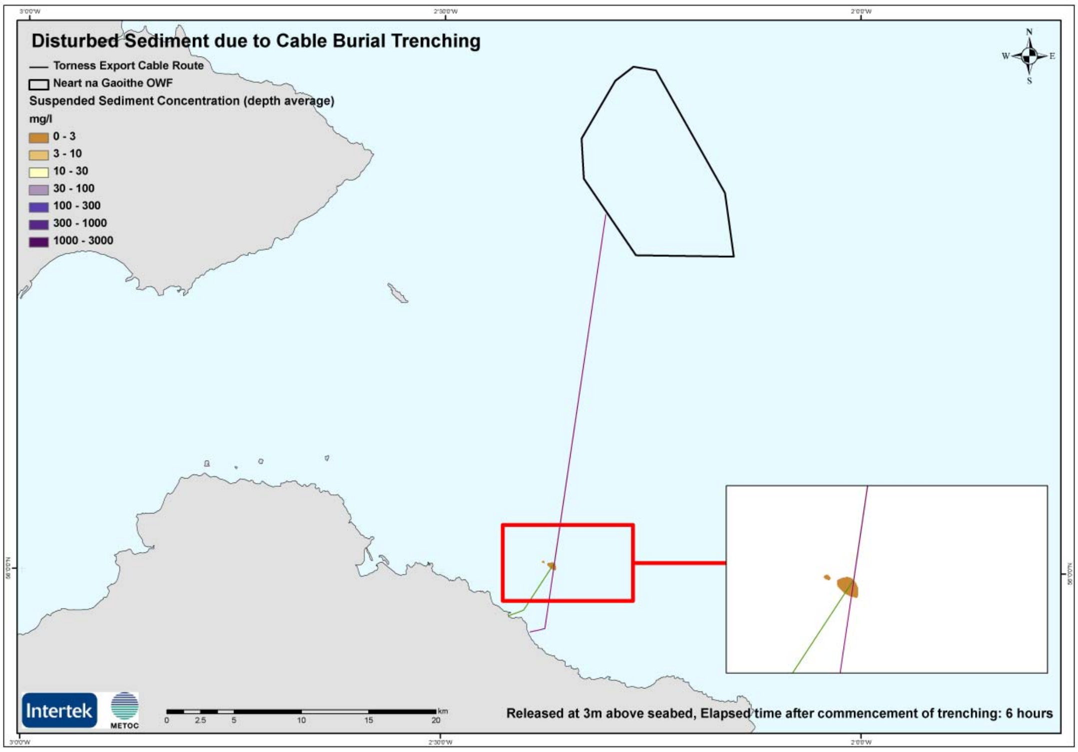


Figure H-94: Suspended sediment concentration due to cable trenching – Torness route inshore area: 8 hours after commencement

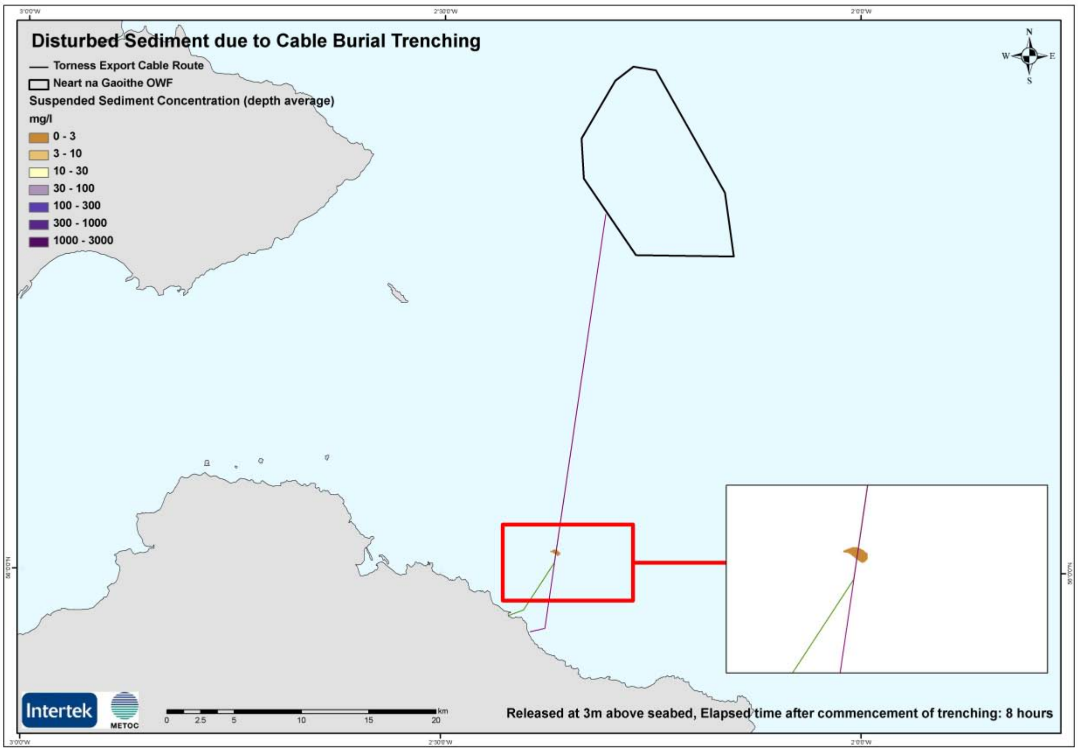


Figure H-95: Suspended sediment concentration due to cable trenching – Torness route inshore area: 10 hours after commencement

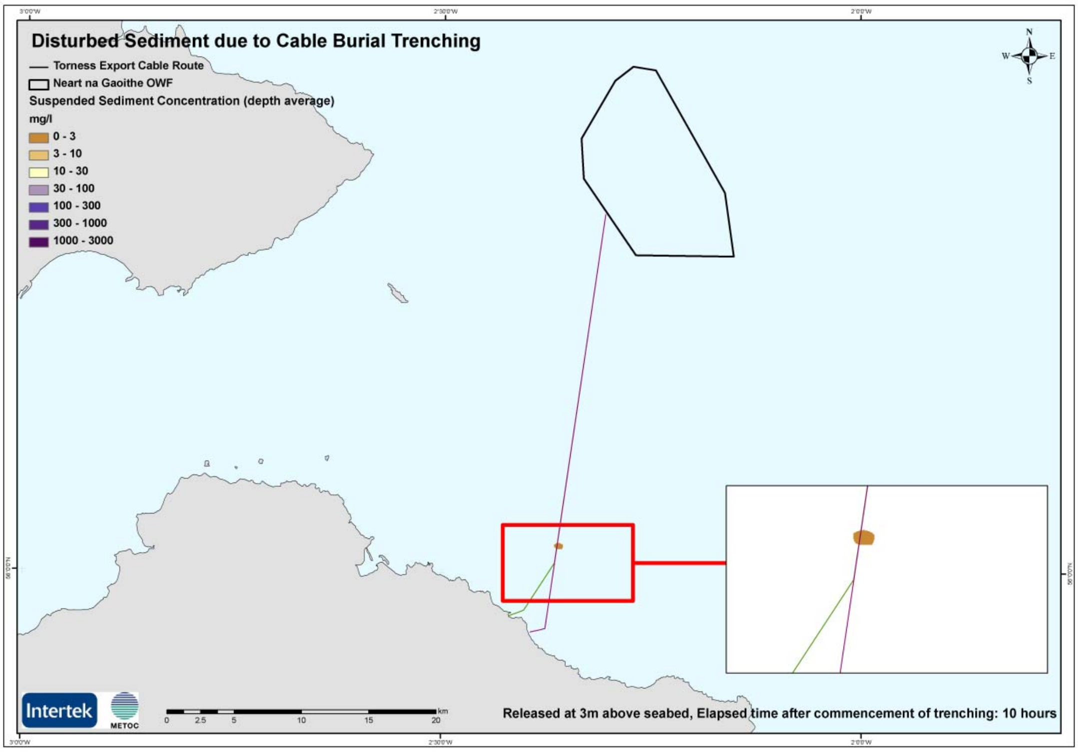


Figure H-96: Suspended sediment concentration due to cable trenching – Torness route inshore area: 12 hours after commencement

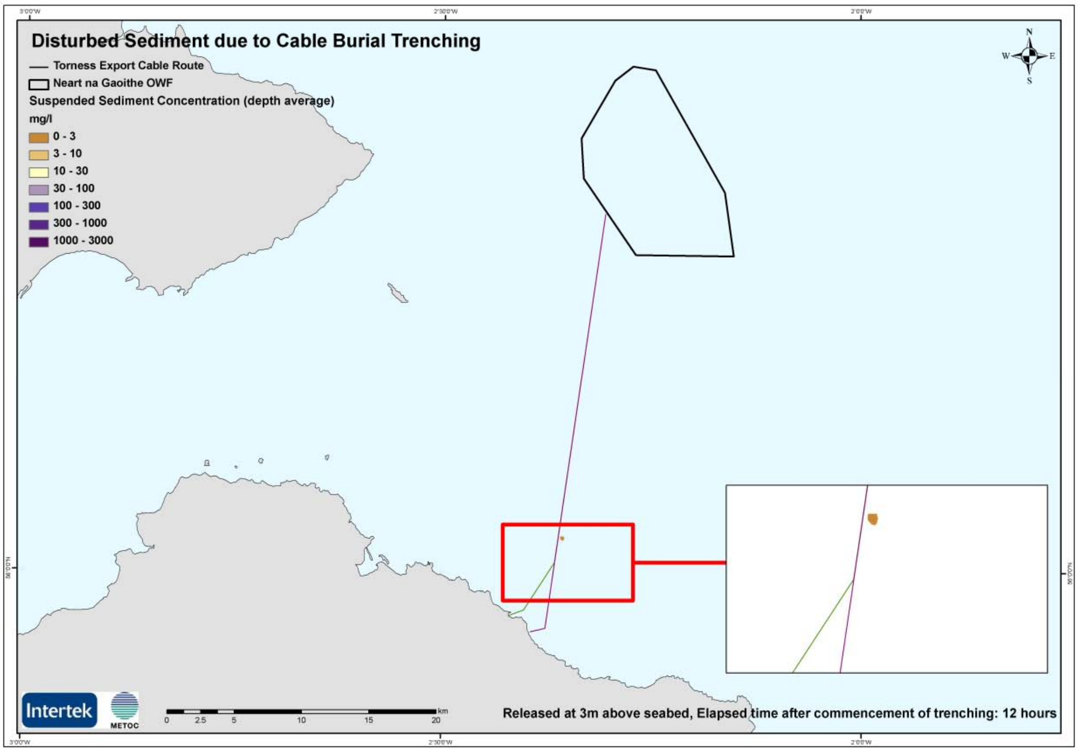


Figure H-97: Suspended sediment concentration due to cable trenching – Torness route inshore area: 2 hours after cessation of trenching

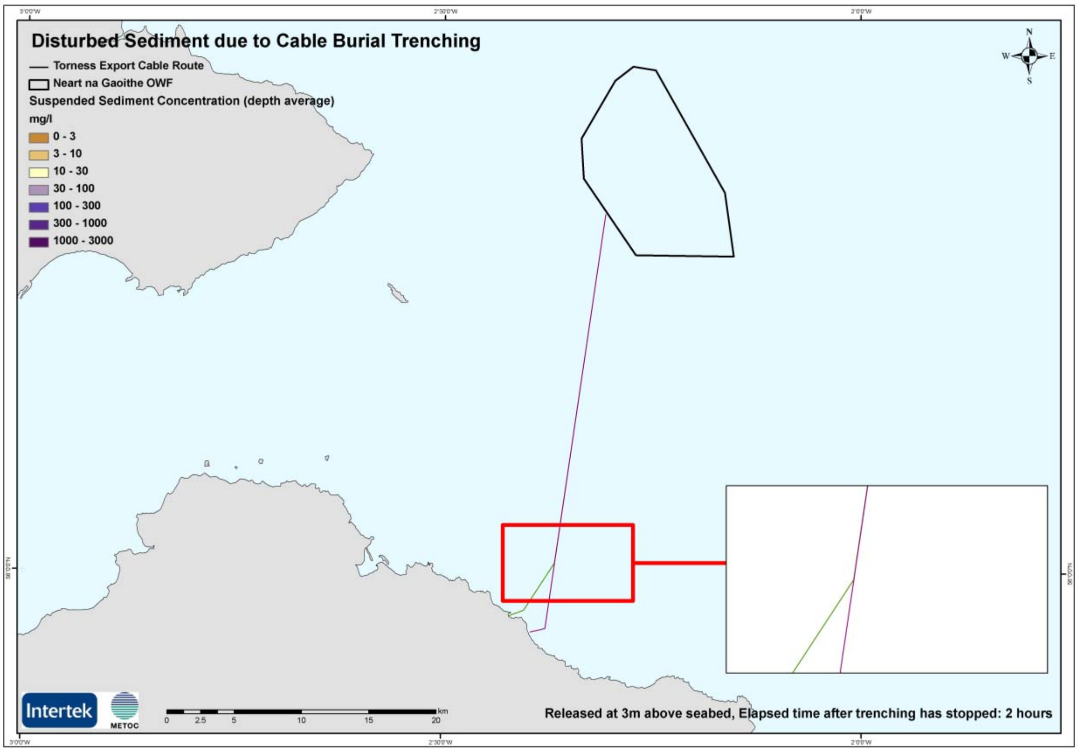
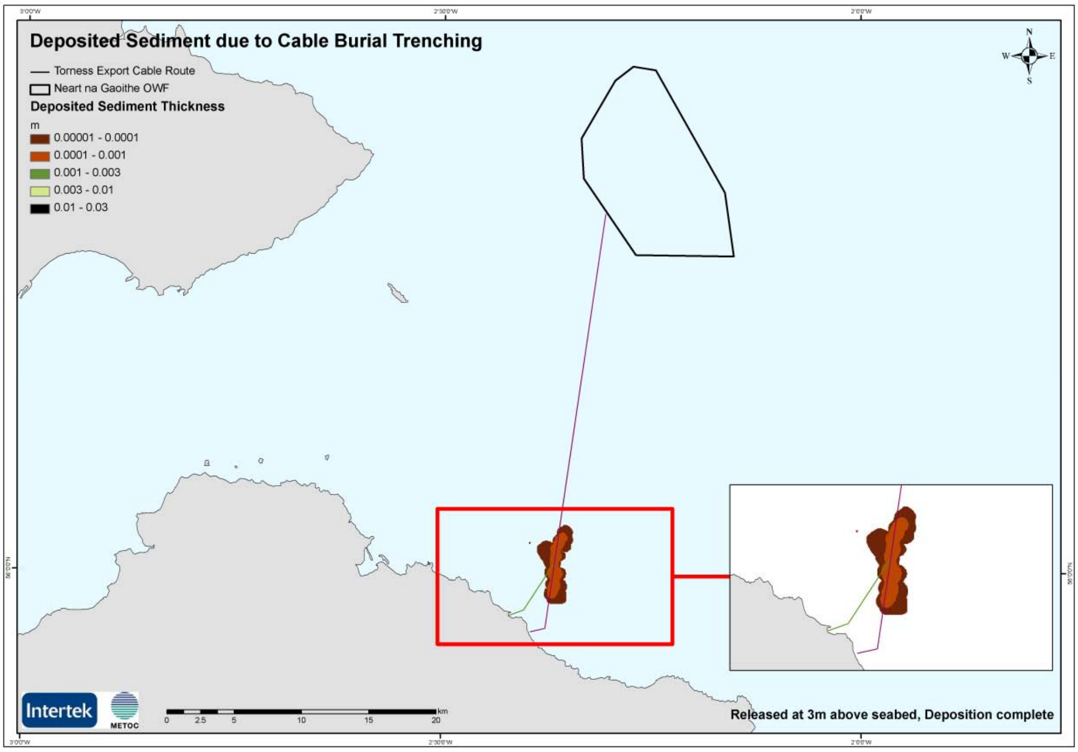


Figure H-98: Deposition thickness due to cable trenching – Torness route inshore area: after all disturbed material has settled



H.1.8 IMPACTS FROM SCOURED MATERIAL

Figure H-99: Suspended sediment concentration due to scouring around gravity bases – 6 hours after ‘commencement’

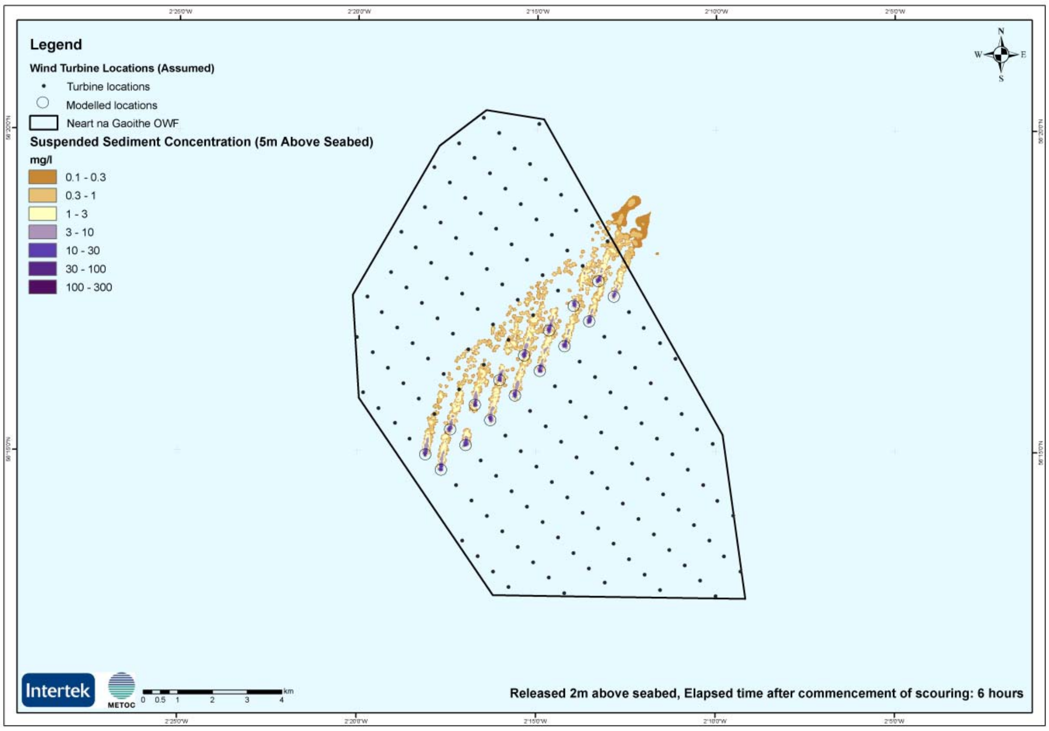


Figure H-100: Suspended sediment concentration due to scouring around gravity bases – 12 hours after ‘commencement’

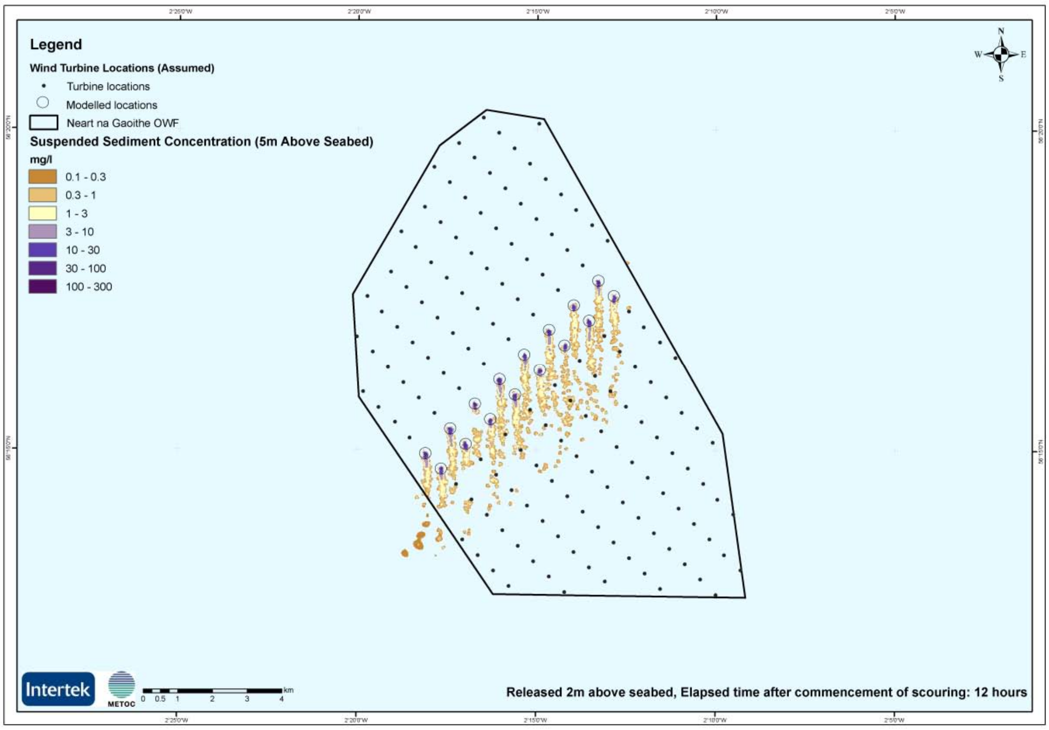


Figure H-101: Suspended sediment concentration due to scouring around gravity bases – 1 day after ‘commencement’

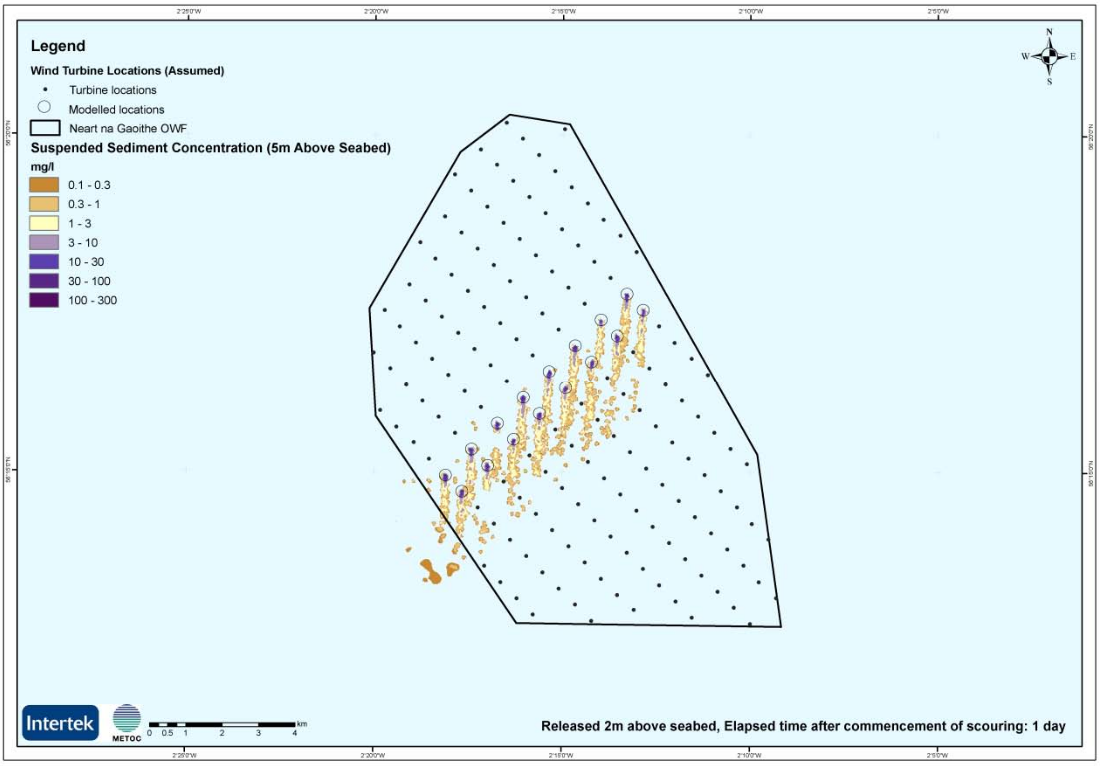


Figure H-102: Suspended sediment concentration due to scouring around gravity bases – 2 days after ‘commencement’

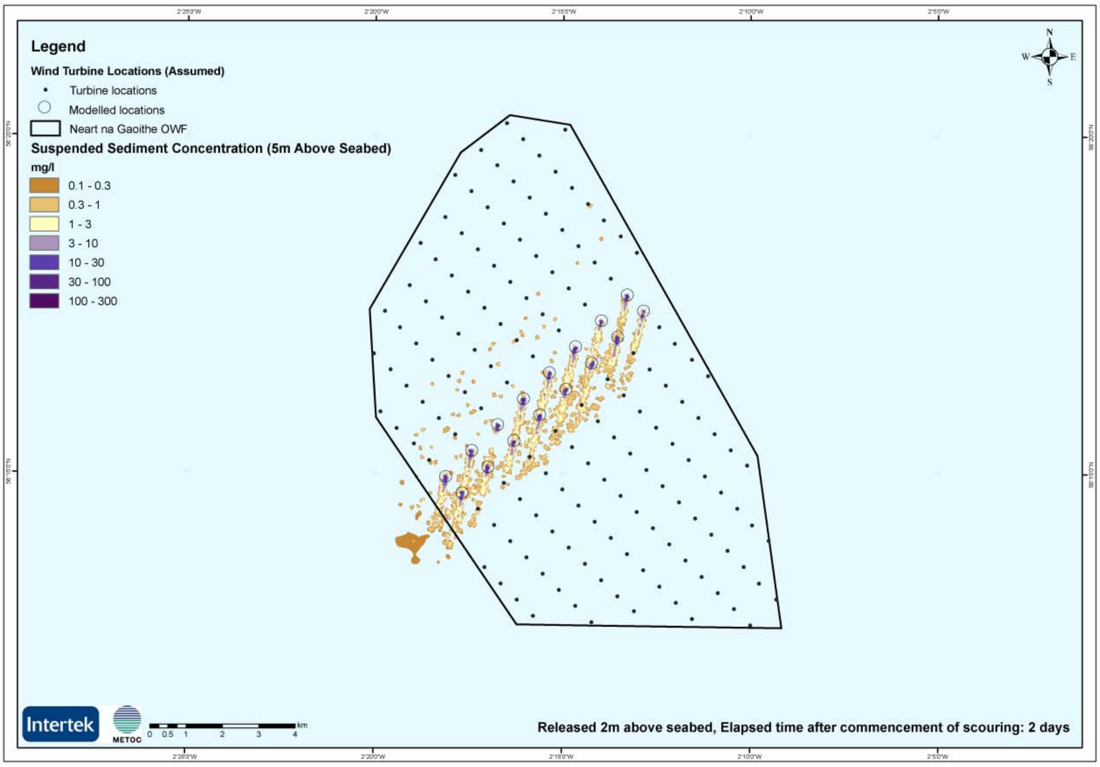


Figure H-103 : Suspended sediment concentration due to scouring around gravity bases – 3 days after 'commencement'

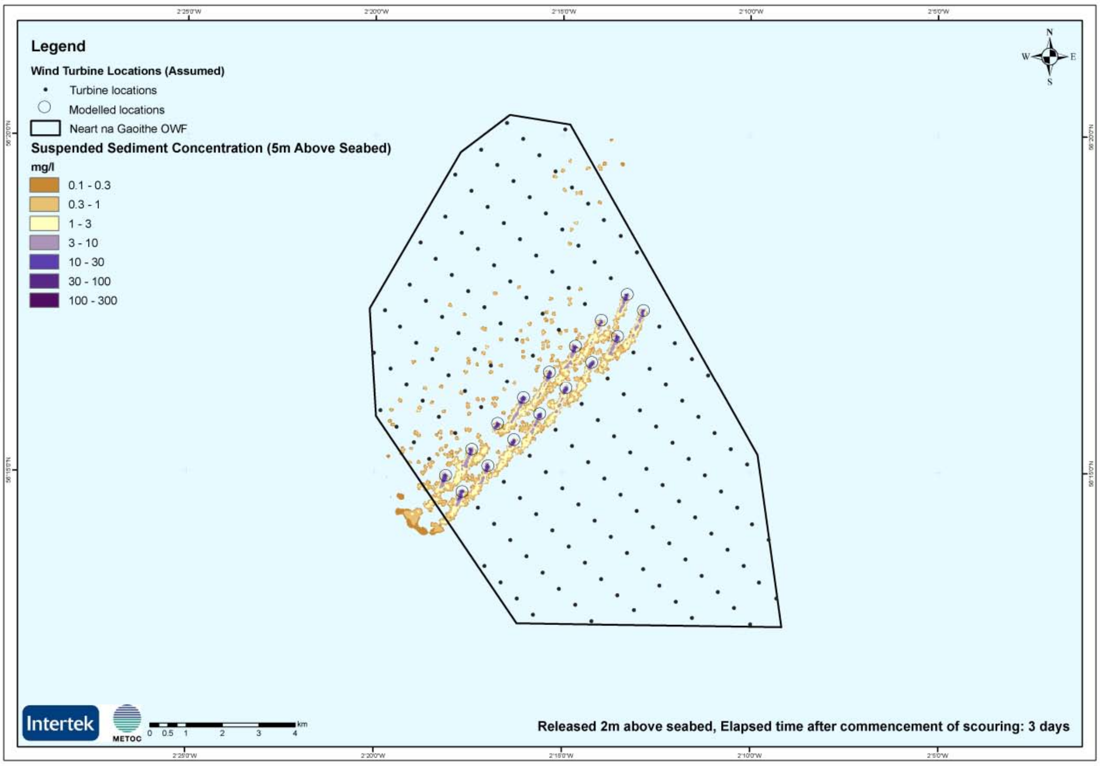


Figure H-104: Suspended sediment concentration due to scouring around gravity bases – 4 days after 'commencement'

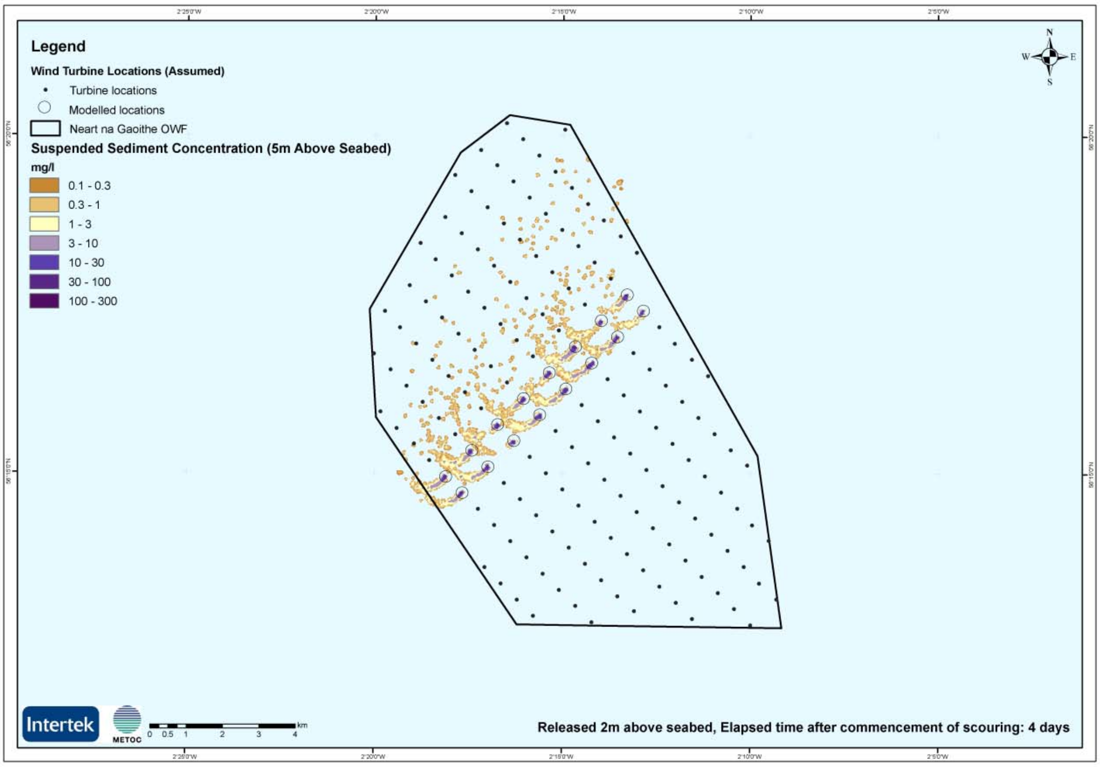


Figure H-105: Suspended sediment concentration due to scouring around gravity bases – 5 days after 'commencement'

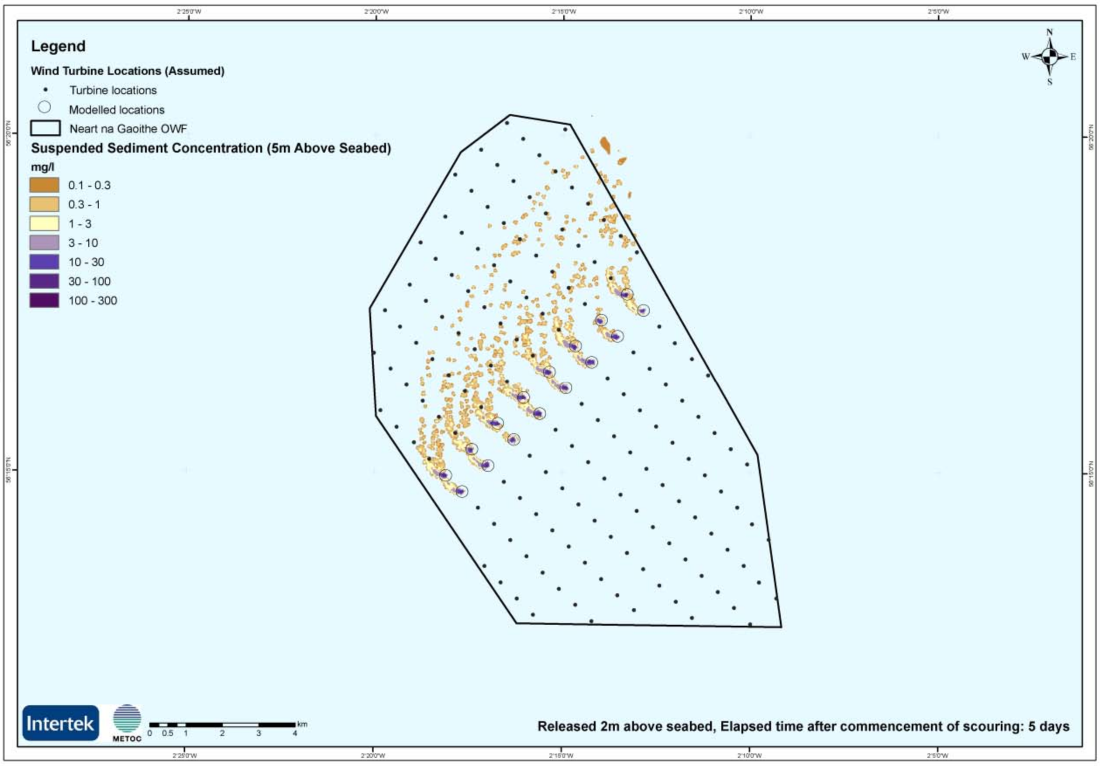


Figure H-106: Suspended sediment concentration due to scouring around gravity bases – 6 days after 'commencement'

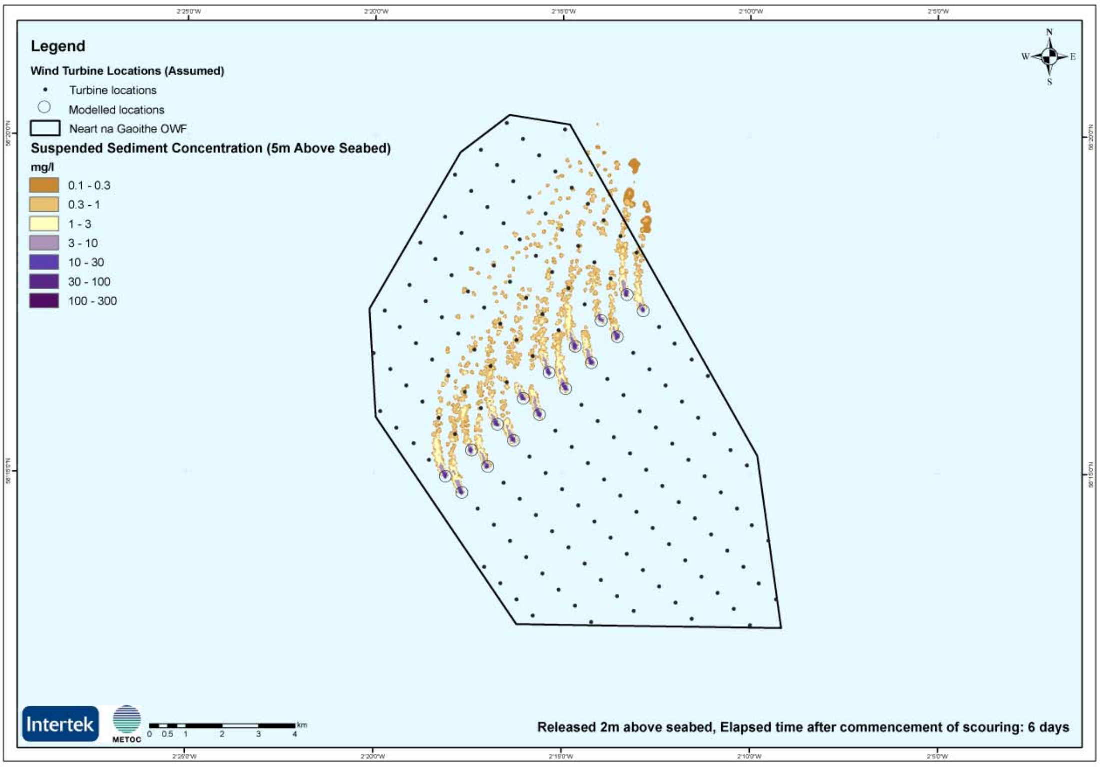


Figure H-107: Suspended sediment concentration due to scouring around gravity bases – 7 days after 'commencement'

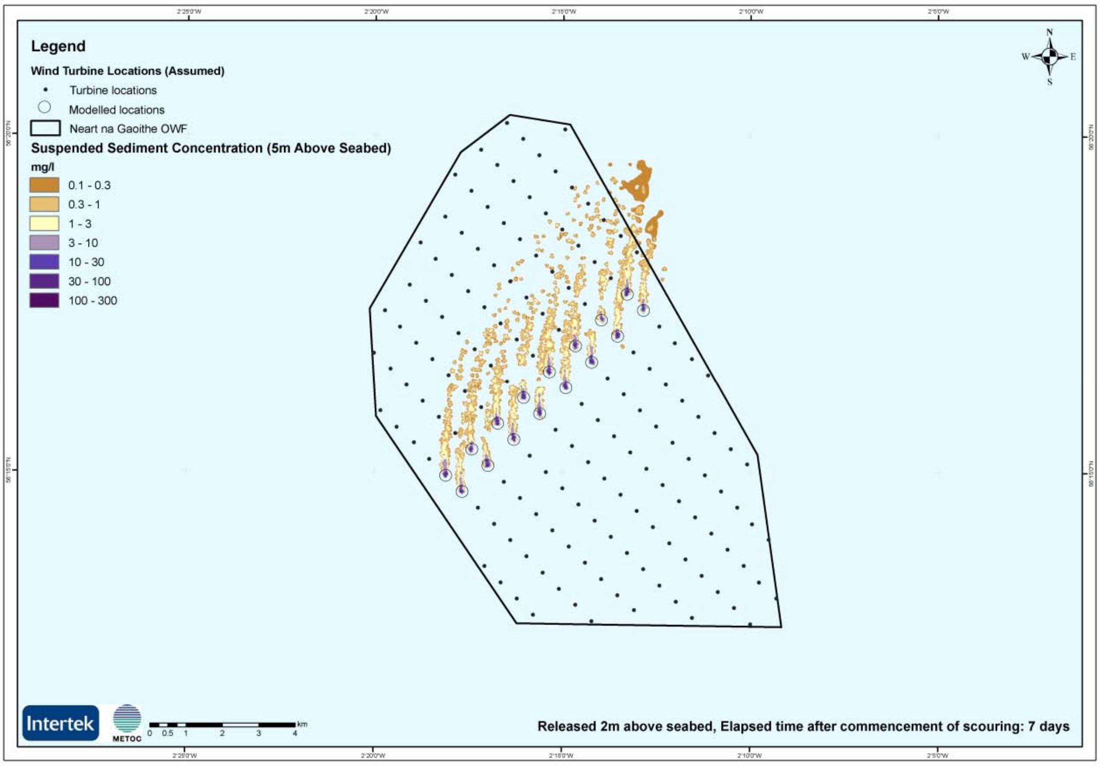


Figure H-108: Suspended sediment concentration due to scouring around gravity bases – 8 days after 'commencement'

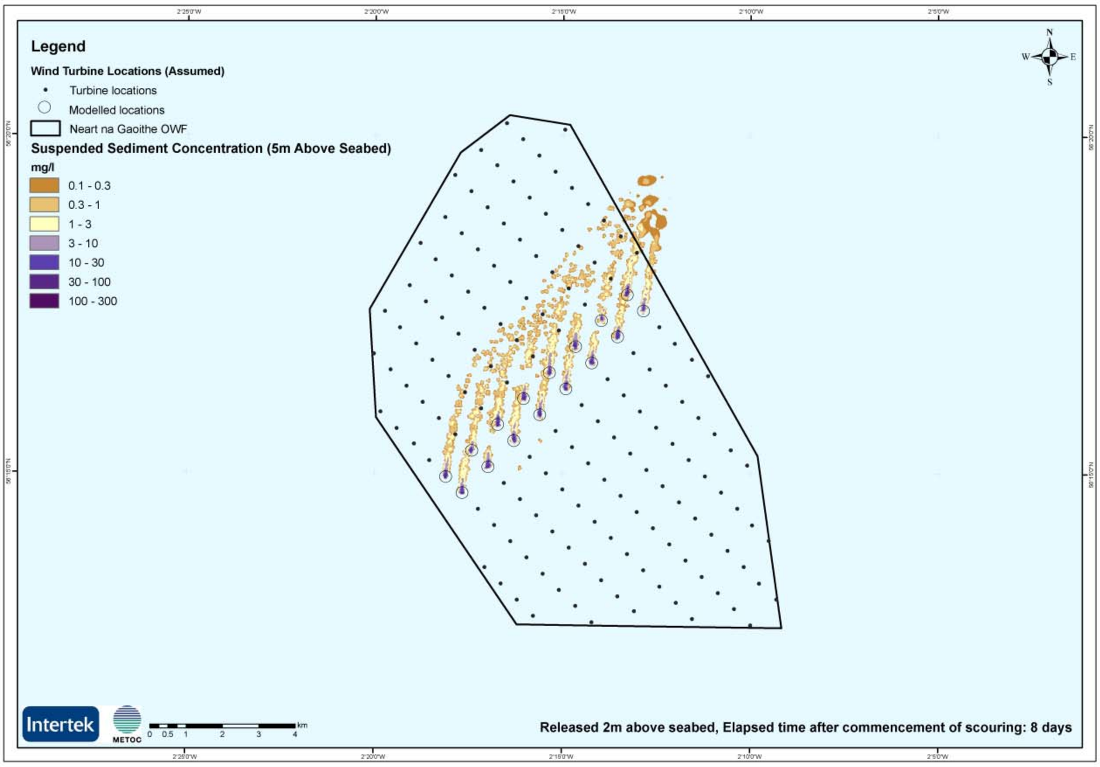


Figure H-109: Suspended sediment concentration due to scouring around gravity bases – 9 days after 'commencement'

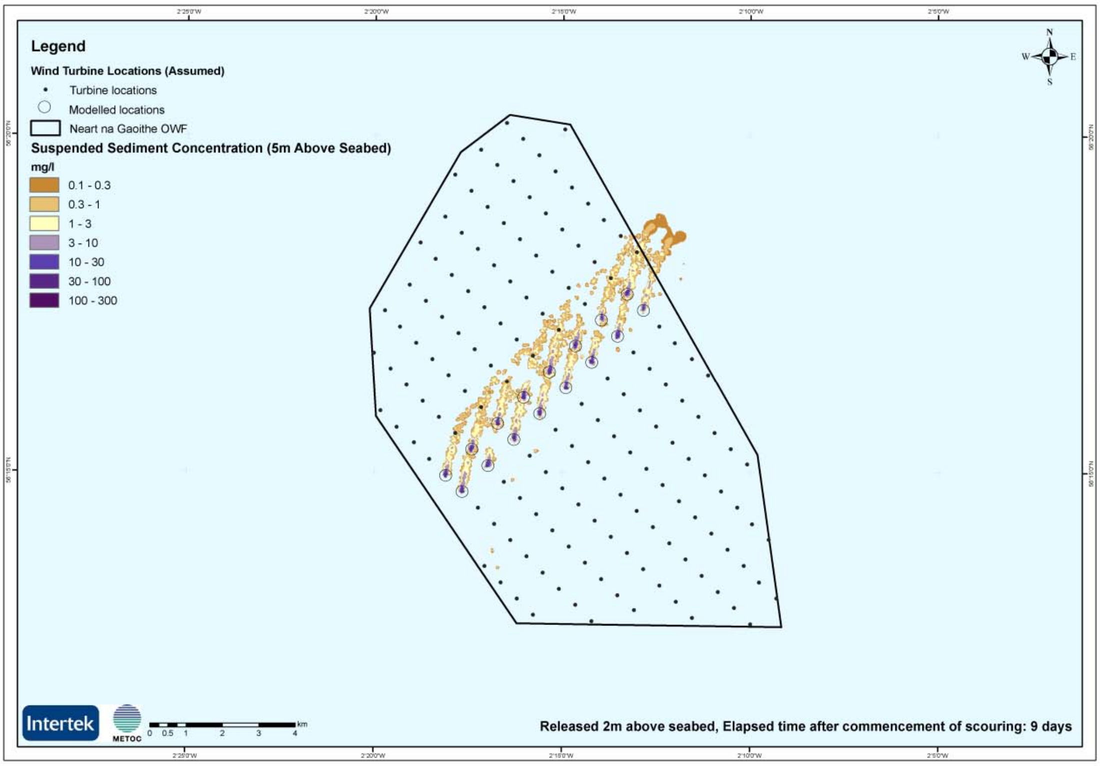


Figure H-110: Suspended sediment concentration due to scouring around gravity bases – 10 days after 'commencement'

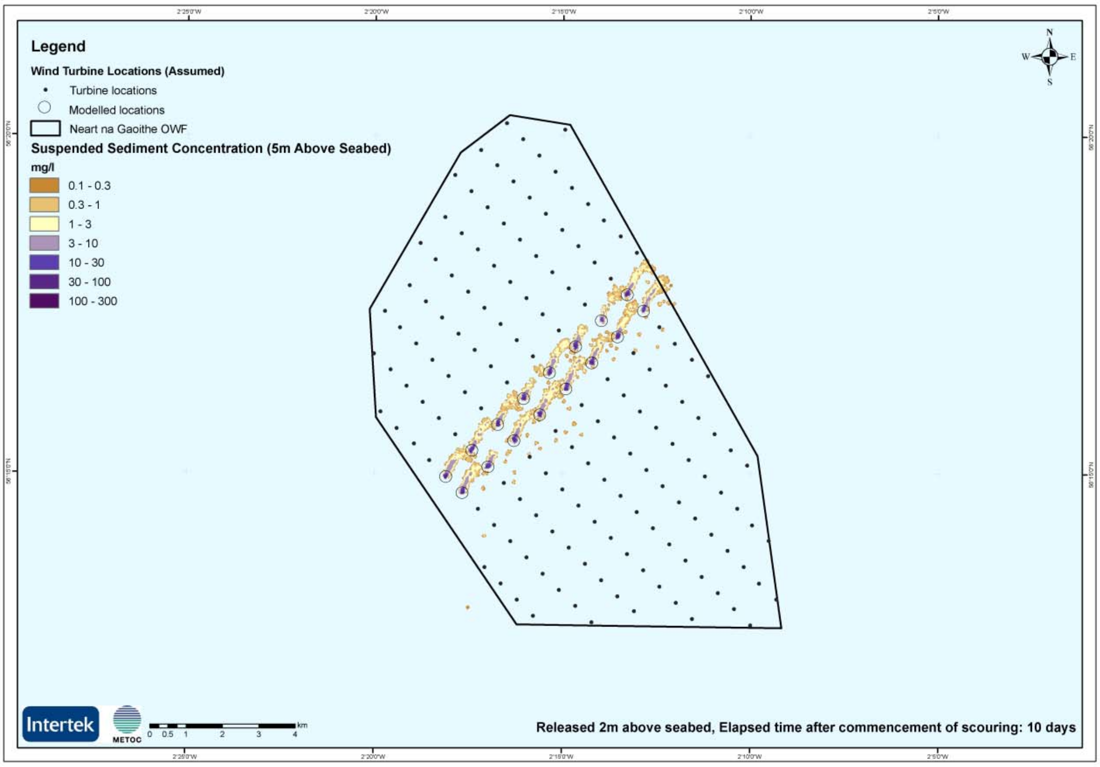


Figure H-111: Suspended sediment concentration due to scouring around gravity bases – 11 days after 'commencement'

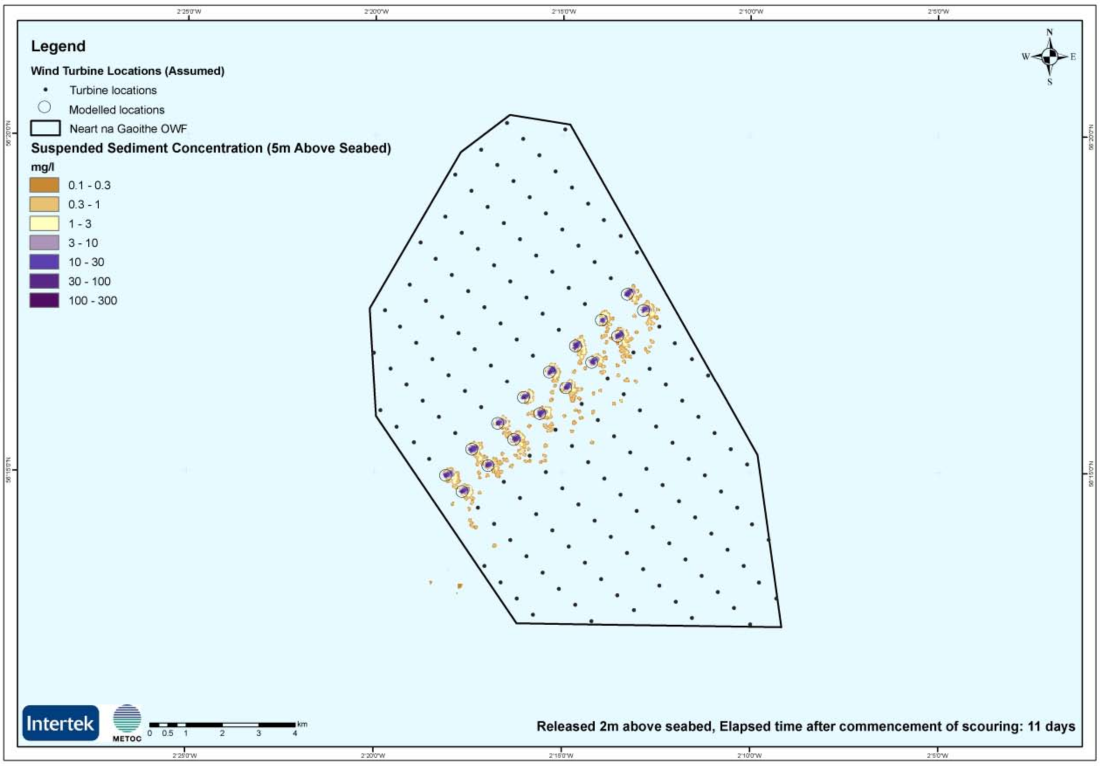


Figure H-112: Suspended sediment concentration due to scouring around gravity bases – 12 days after 'commencement'

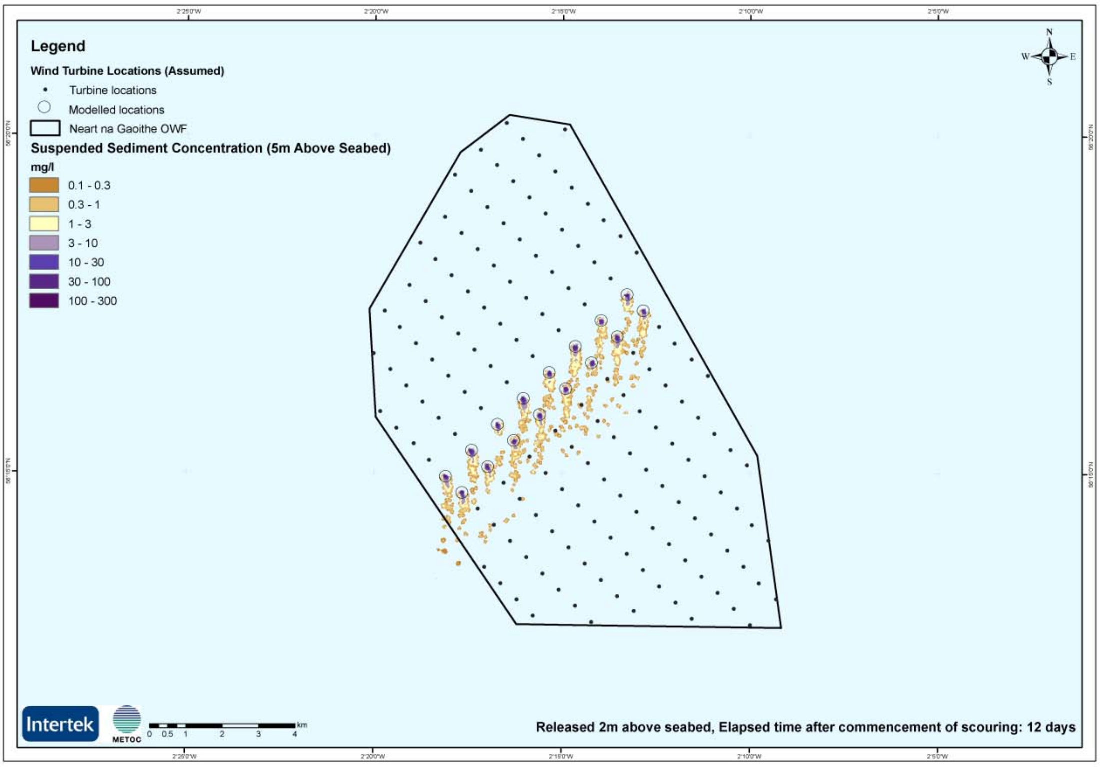


Figure H-113: Suspended sediment concentration due to scouring around gravity bases – 13 days after 'commencement'

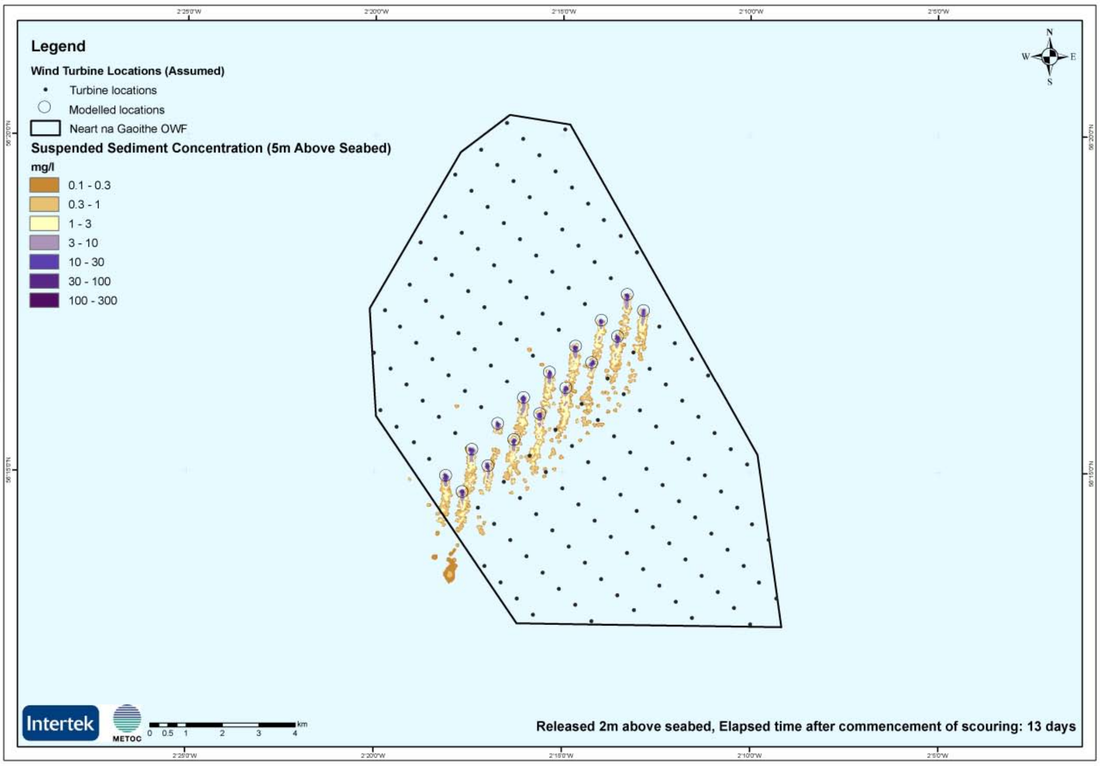


Figure H-114: Suspended sediment concentration due to scouring around gravity bases – 14 days after 'commencement'

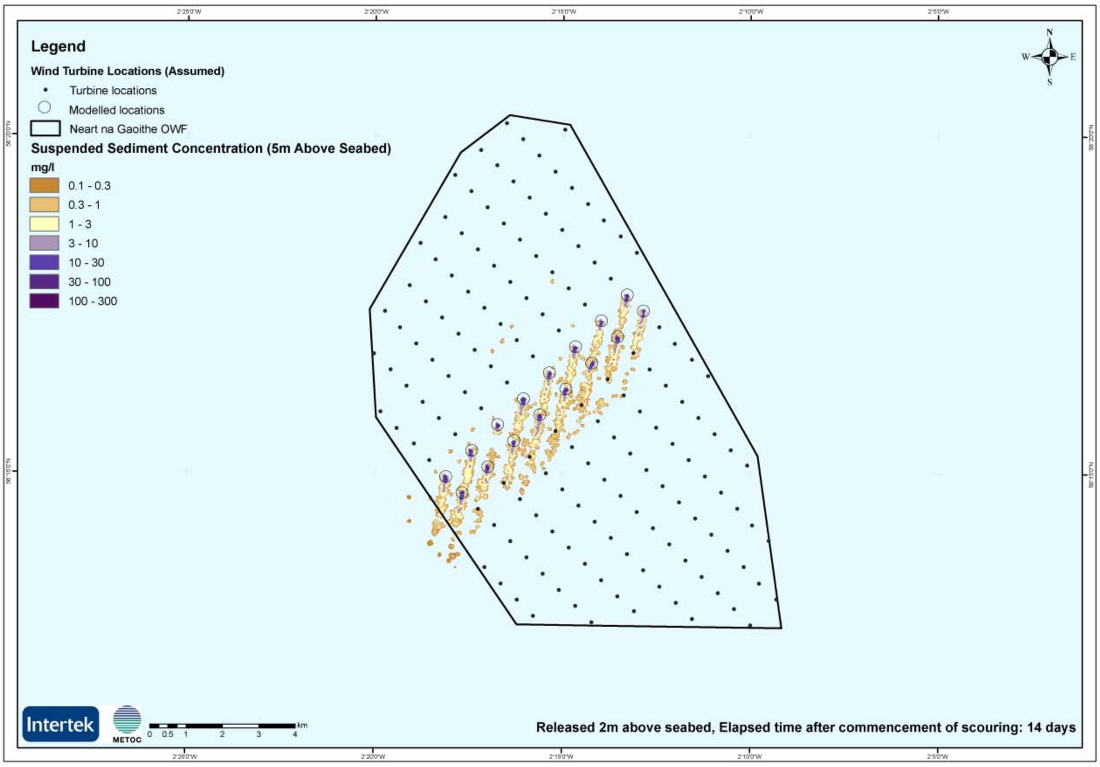


Figure H-115: Suspended sediment concentration due to scouring around gravity bases – 15 days after 'commencement'

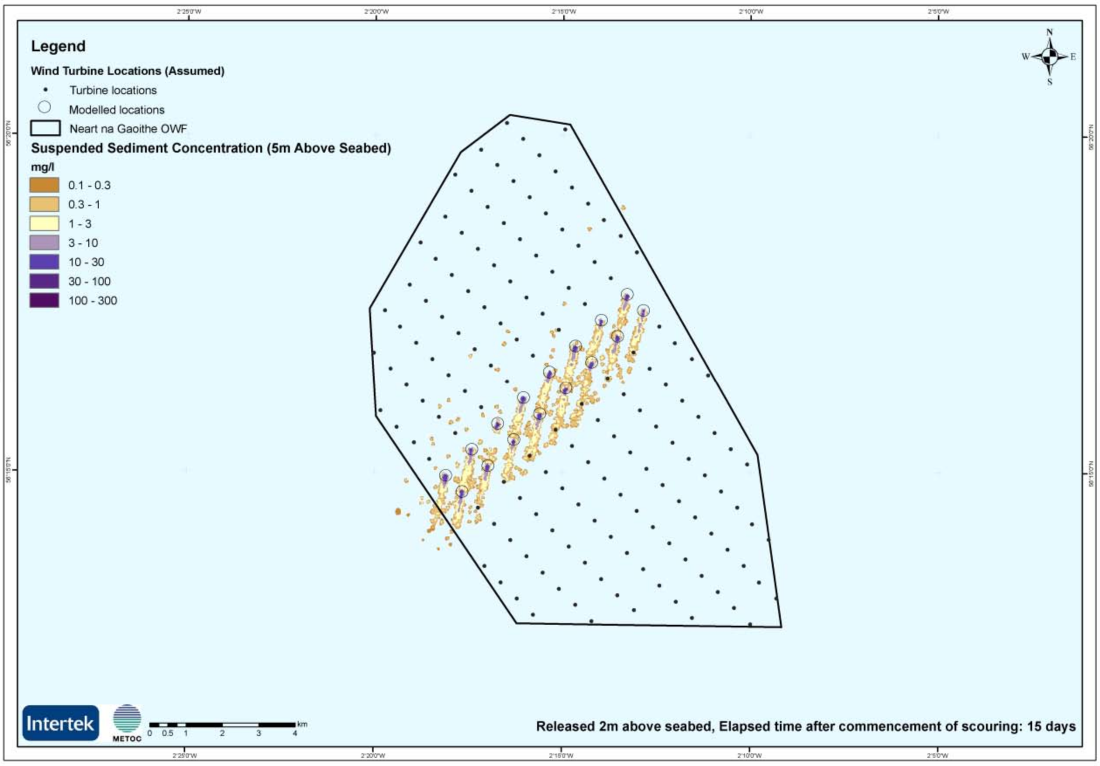


Figure H-116: Suspended sediment concentration due to scouring around gravity bases – 16 days after 'commencement'

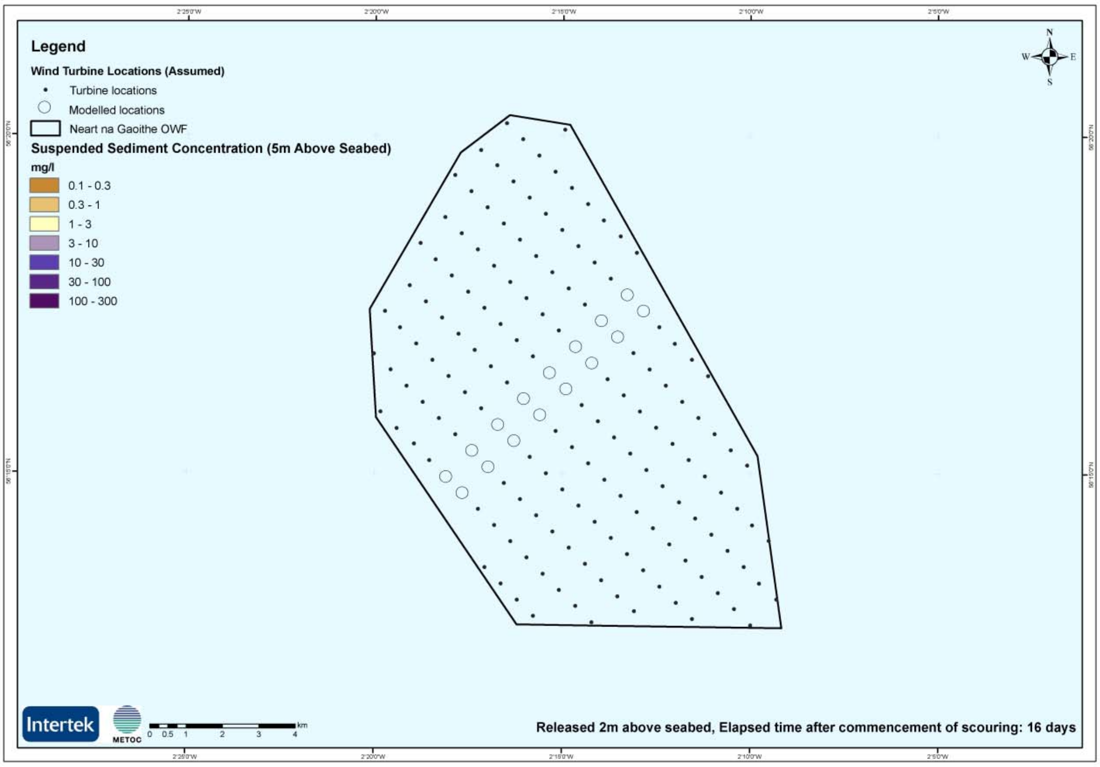
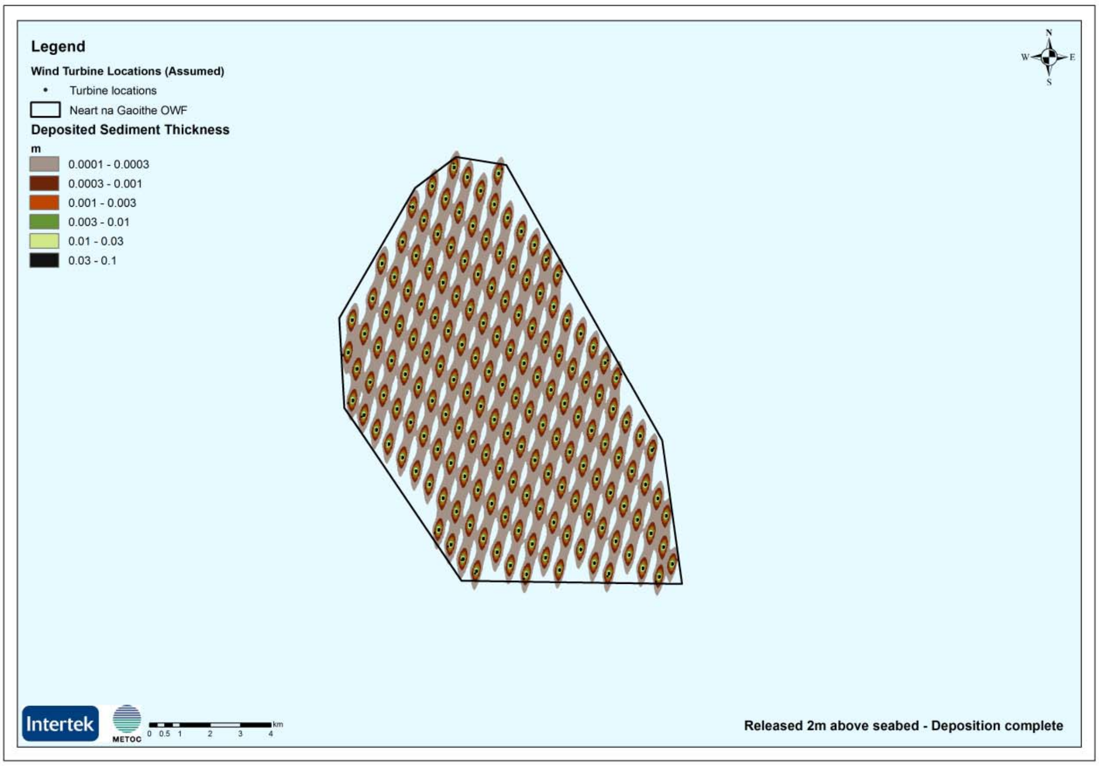


Figure H-117: Deposition thickness due to scouring around gravity bases – after all scoured material has settled



H.2 CUMULATIVE EFFECTS DUE TO THE NEART NA GAOITHE, INCH CAPE AND THE FIRTH OF FORTH (ROUND 3) OWF

H.2.1 CUMULATIVE CHANGES TO THE HYDRODYNAMIC REGIME

Figure H-118: Cumulative difference to mean spring tide high water level (m)

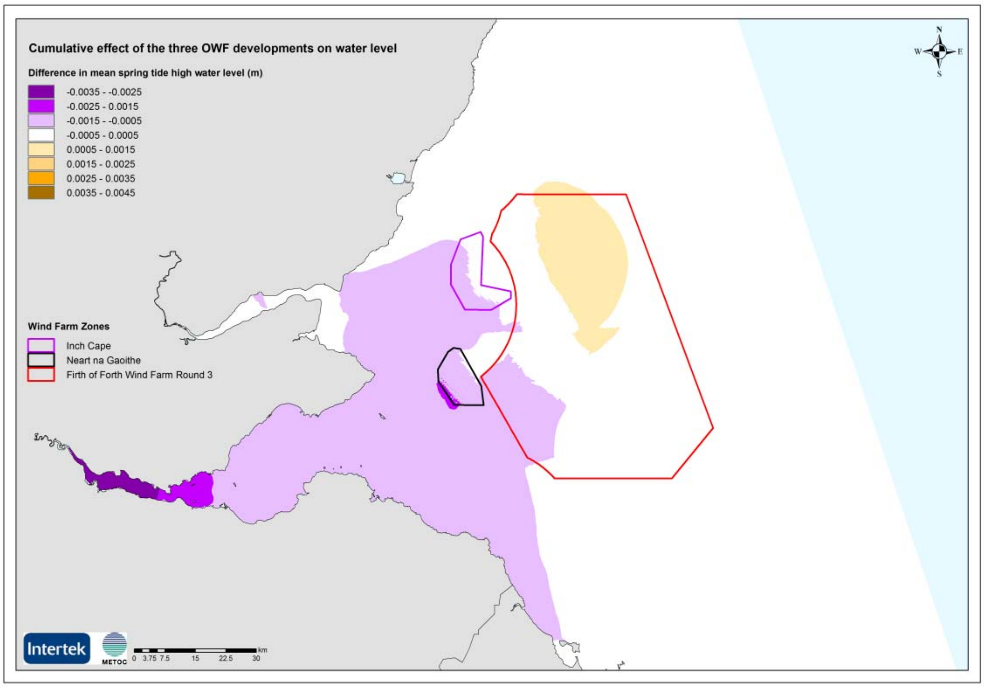


Figure H-118b: Cumulative difference to mean spring tide high water level (m) – zoom

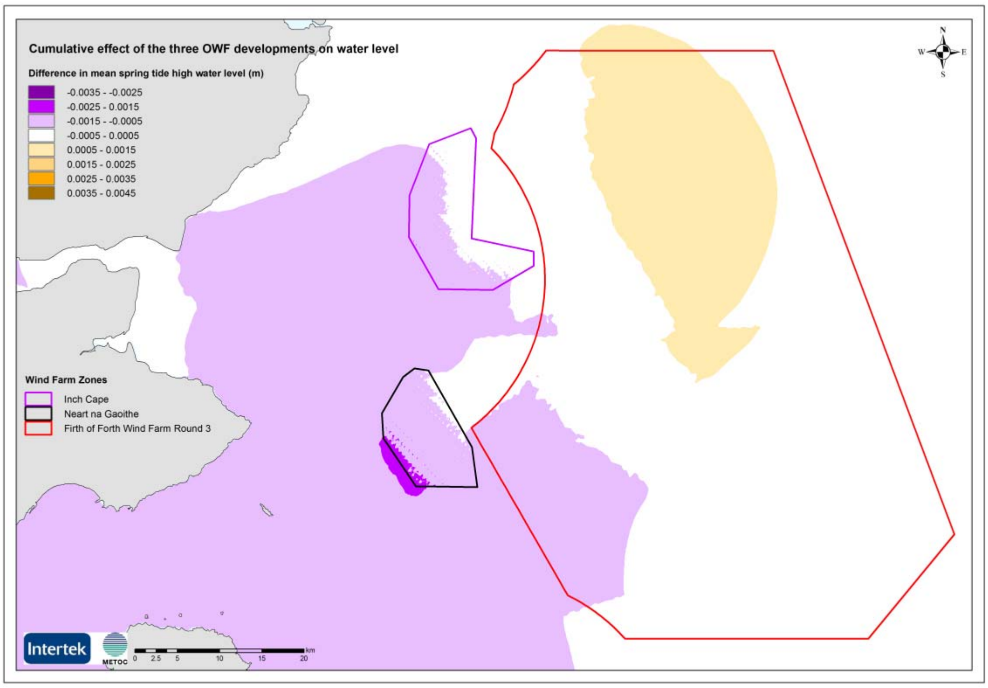


Figure H-119: Cumulative difference to mean spring tide low water level (m)

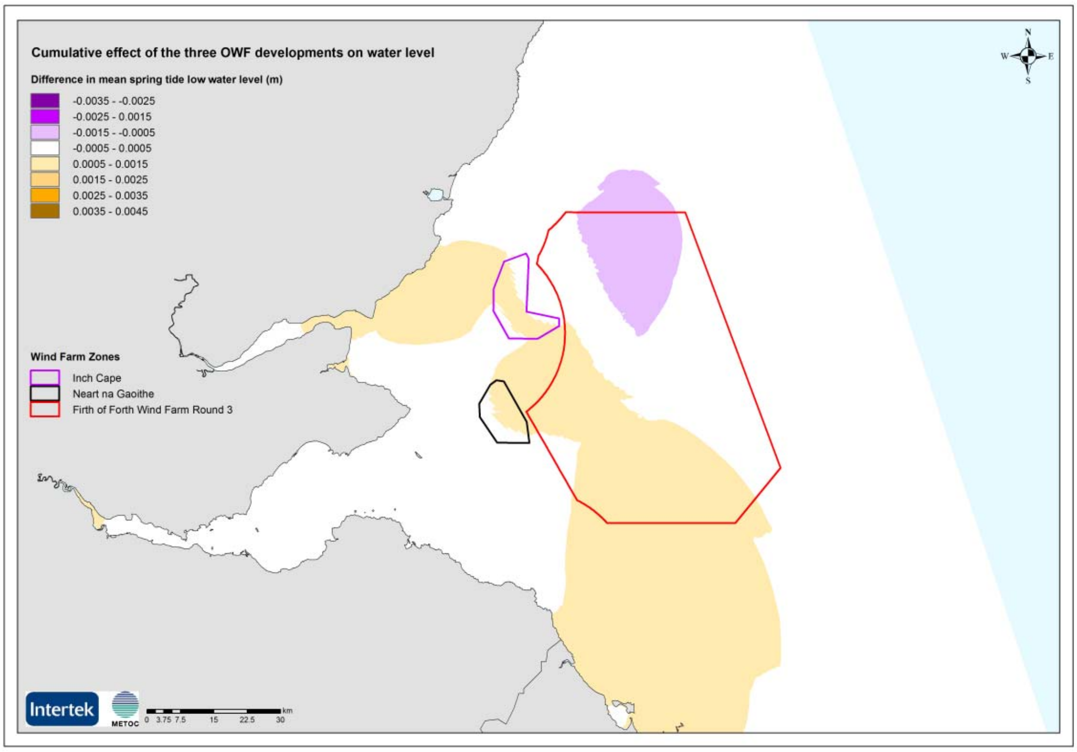


Figure 119b: Cumulative difference to mean spring tide low water level (m) – zoom

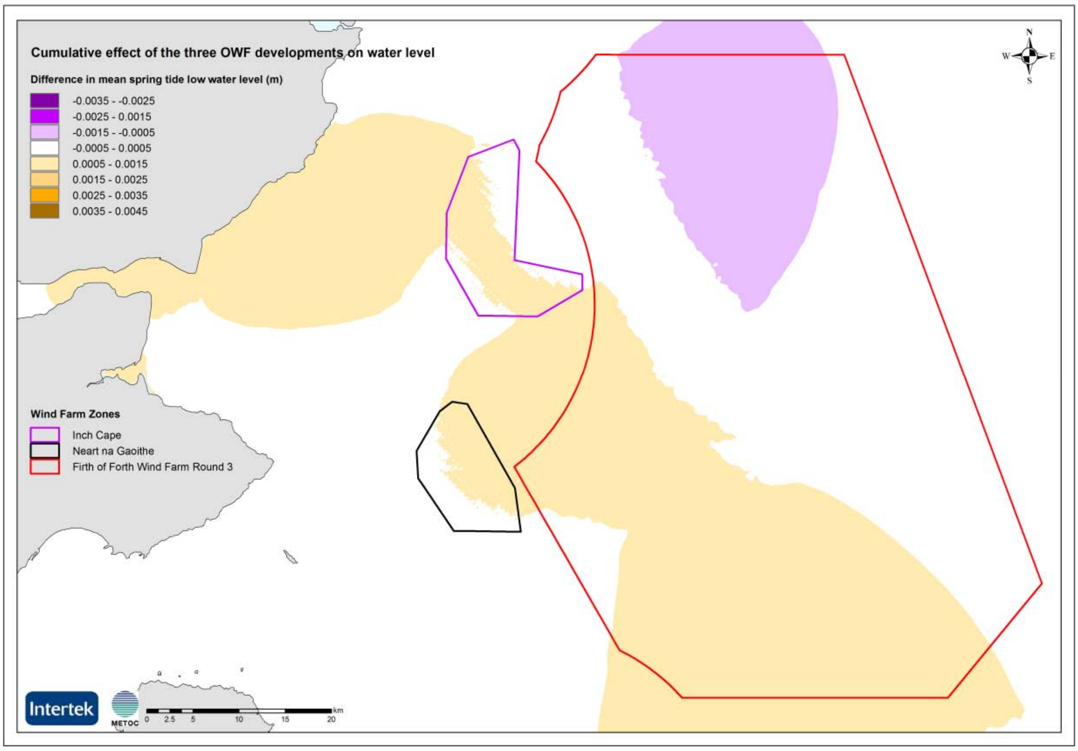


Figure H-120: Cumulative difference to mean neap tide high water level (m)

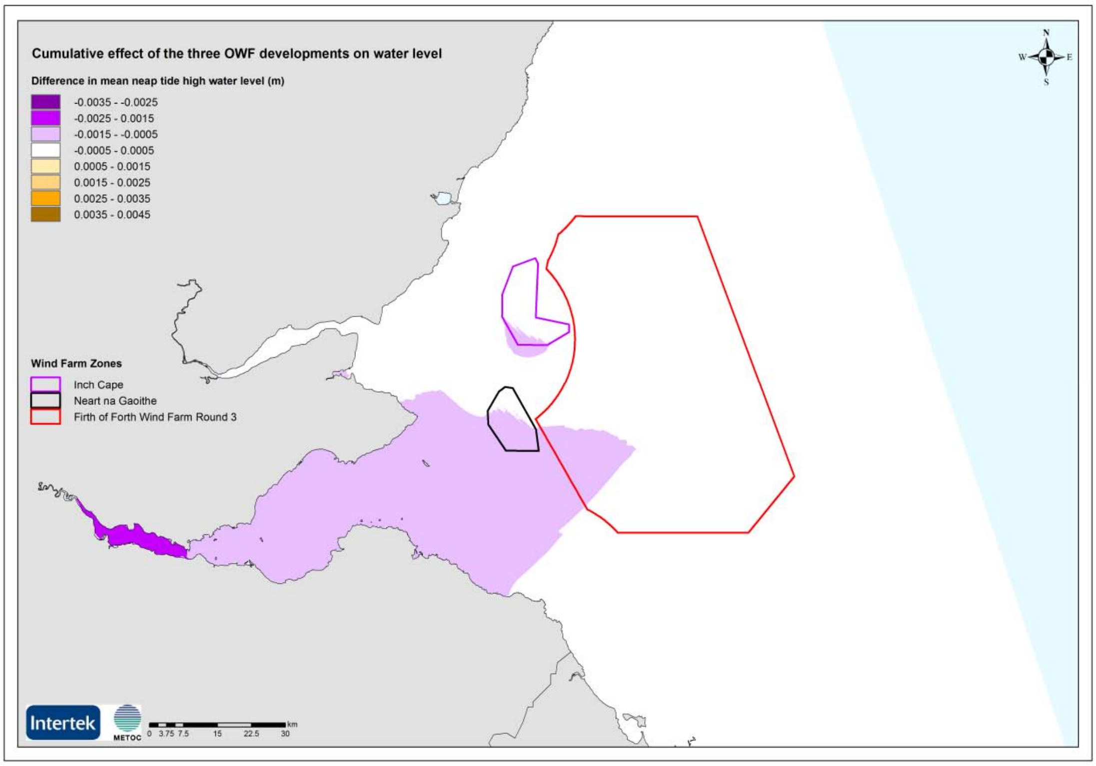


Figure H-120b: Cumulative difference to mean neap tide high water level (m) – zoom

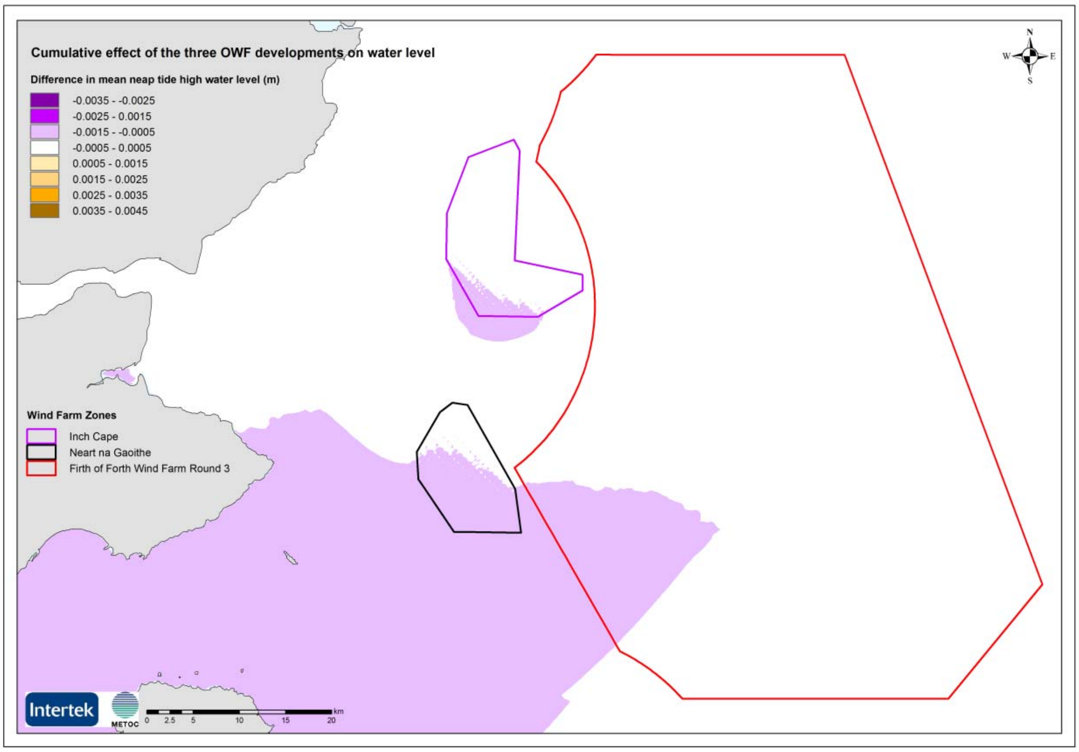


Figure H-121: Cumulative difference to mean neap tide low water level (m)

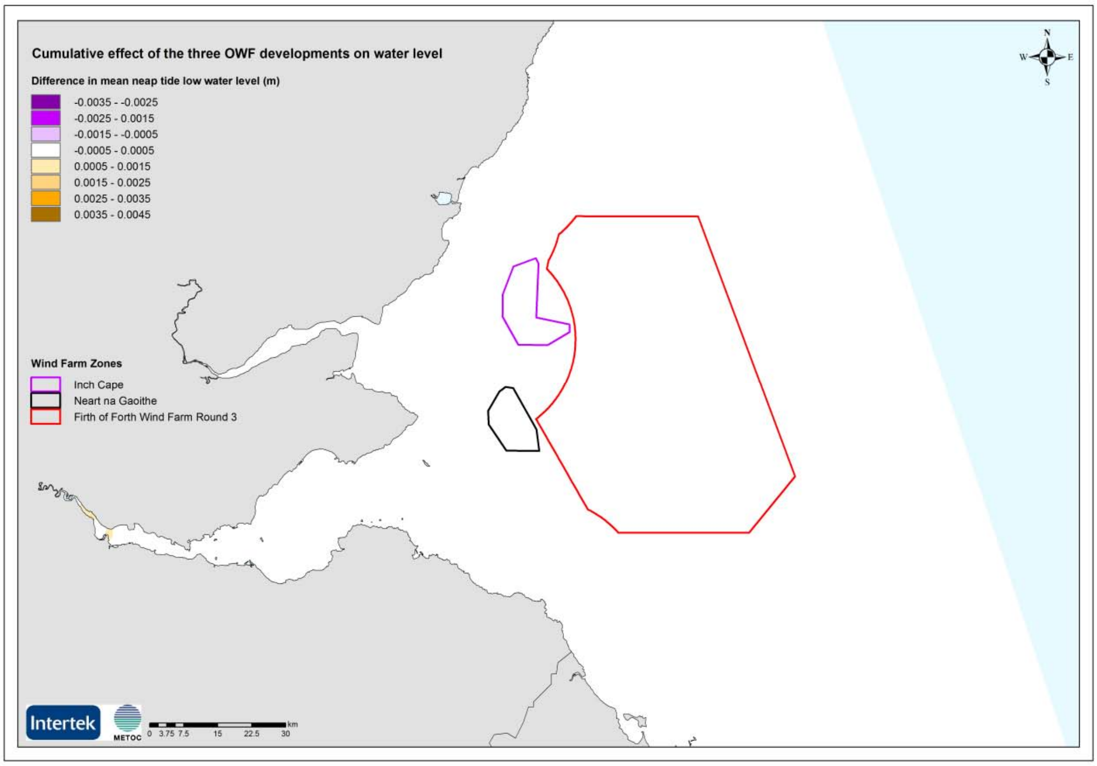


Figure H-121b: Cumulative difference to mean neap tide low water level (m) – zoom

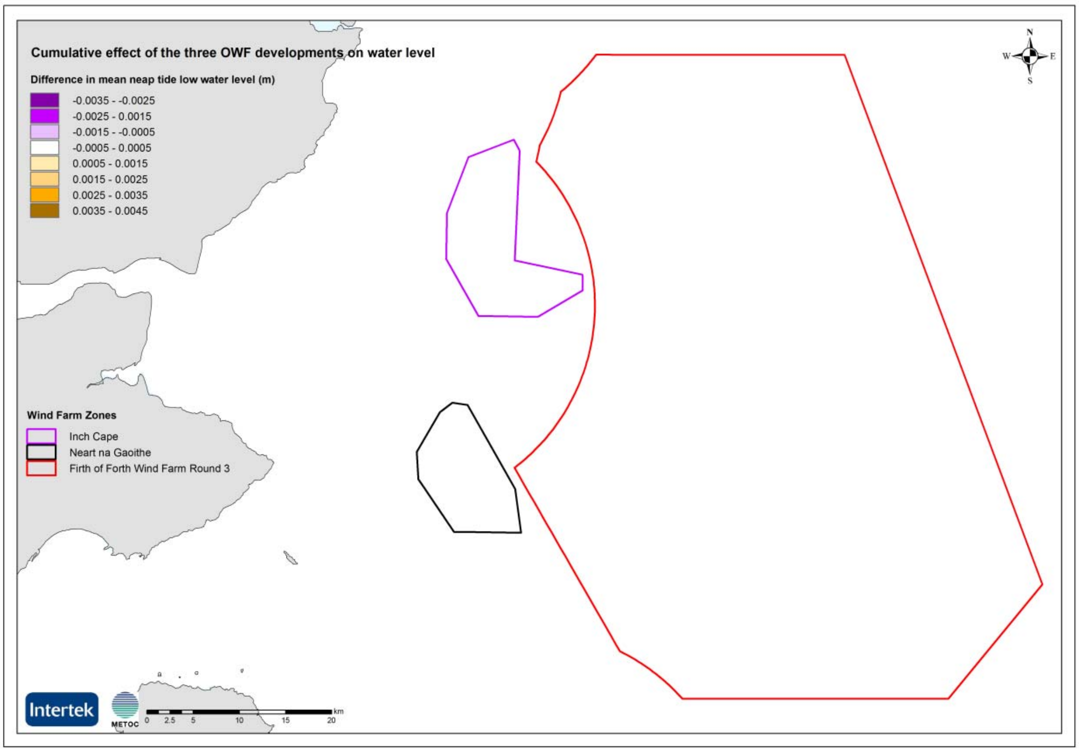


Figure H-122: Cumulative difference to mean spring tide peak flood current speed (m/s)

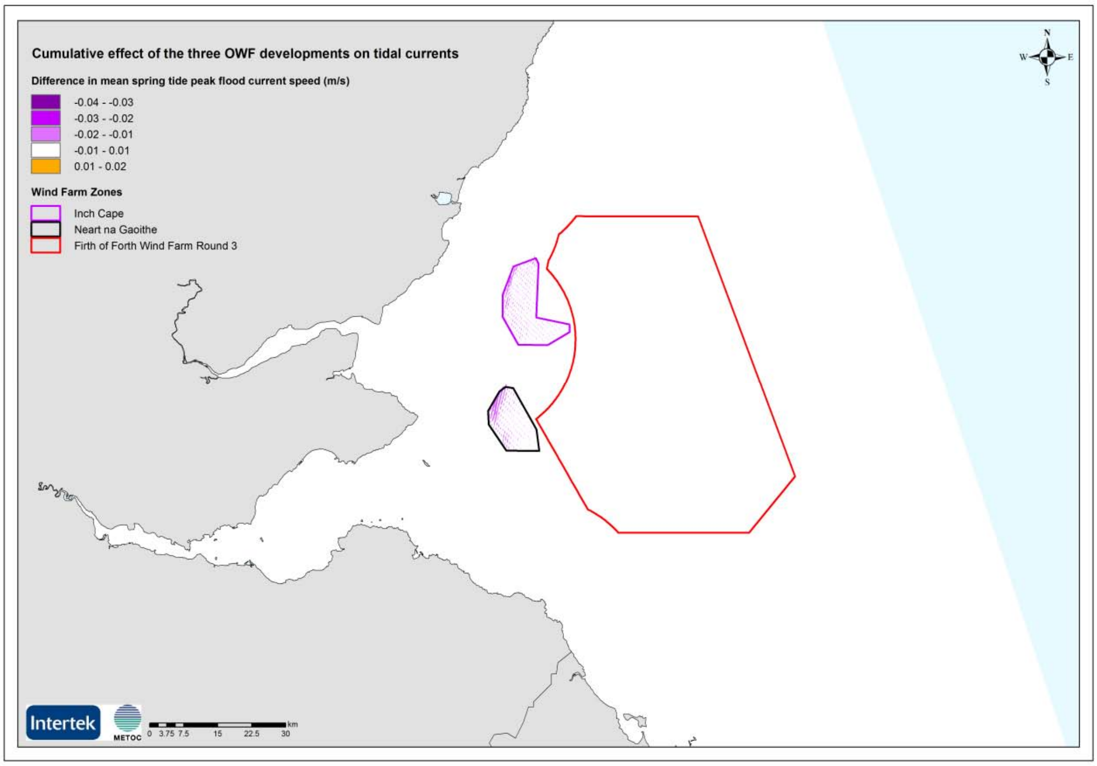


Figure H-122b: Cumulative difference to mean spring tide peak flood current speed (m/s) – zoom

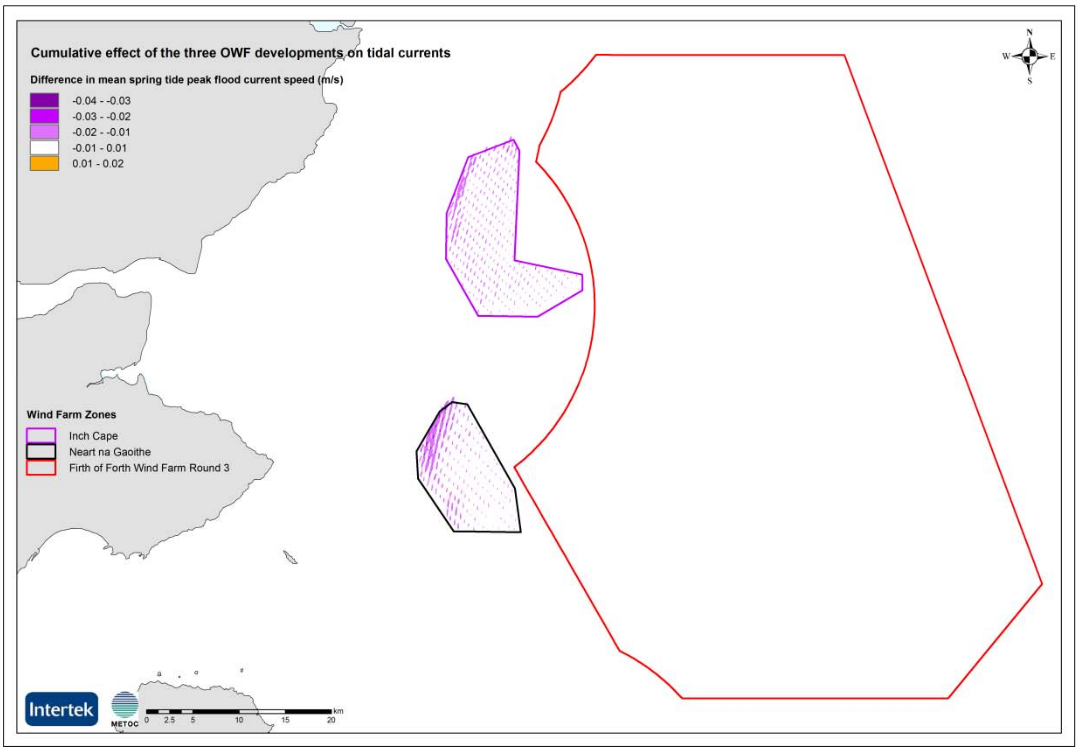


Figure H-123: Cumulative difference to mean spring tide peak ebb current speed (m/s)

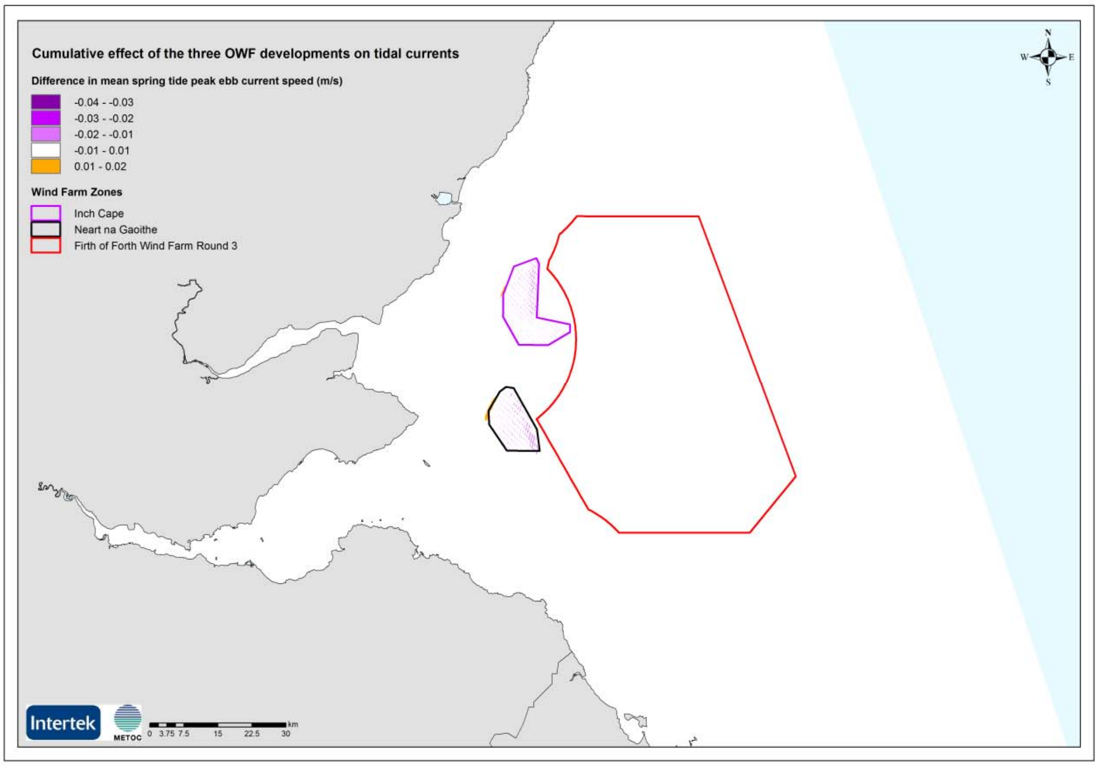


Figure H-123b: Cumulative difference to mean spring tide peak ebb current speed (m/s) – zoom

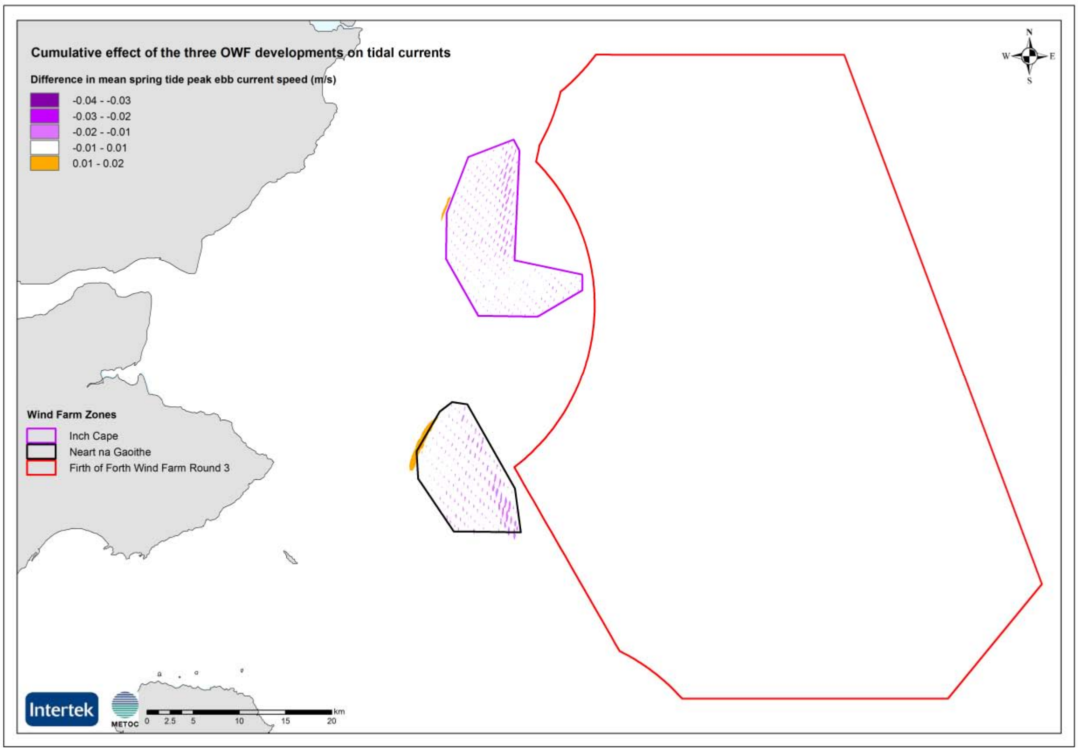


Figure H-124: Cumulative difference to mean neap tide peak flood current speed (m/s)

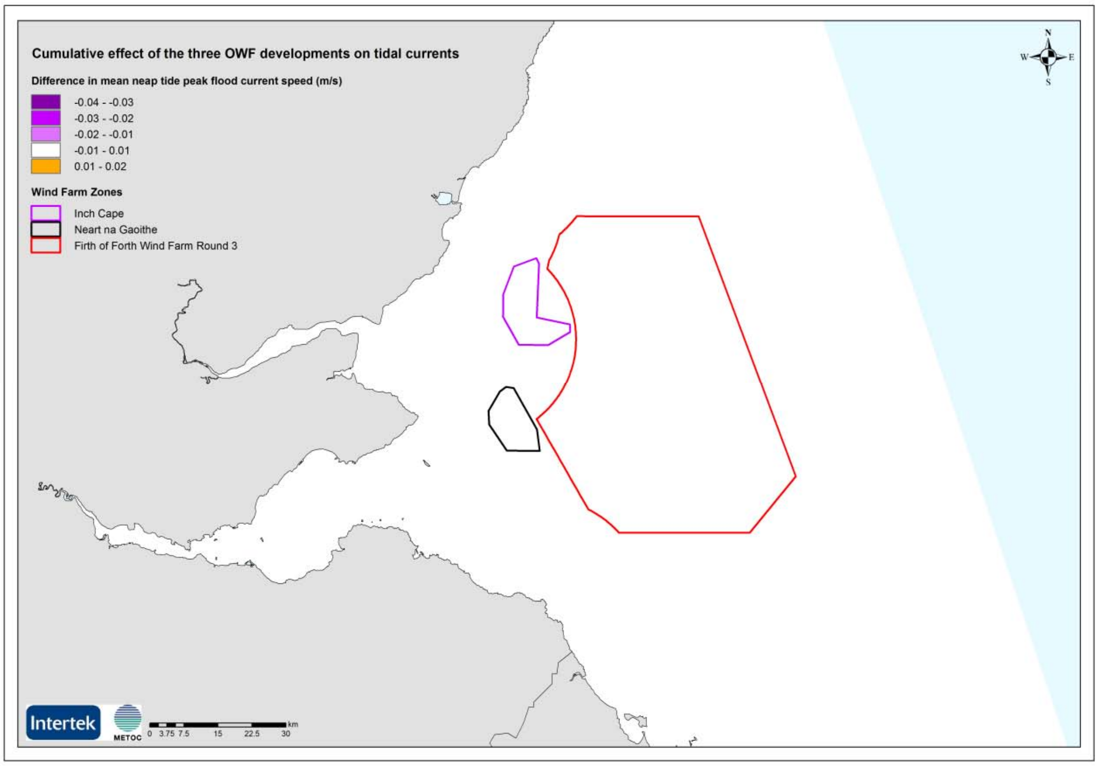


Figure H-124b: Cumulative difference to mean neap tide peak flood current speed (m/s) – zoom

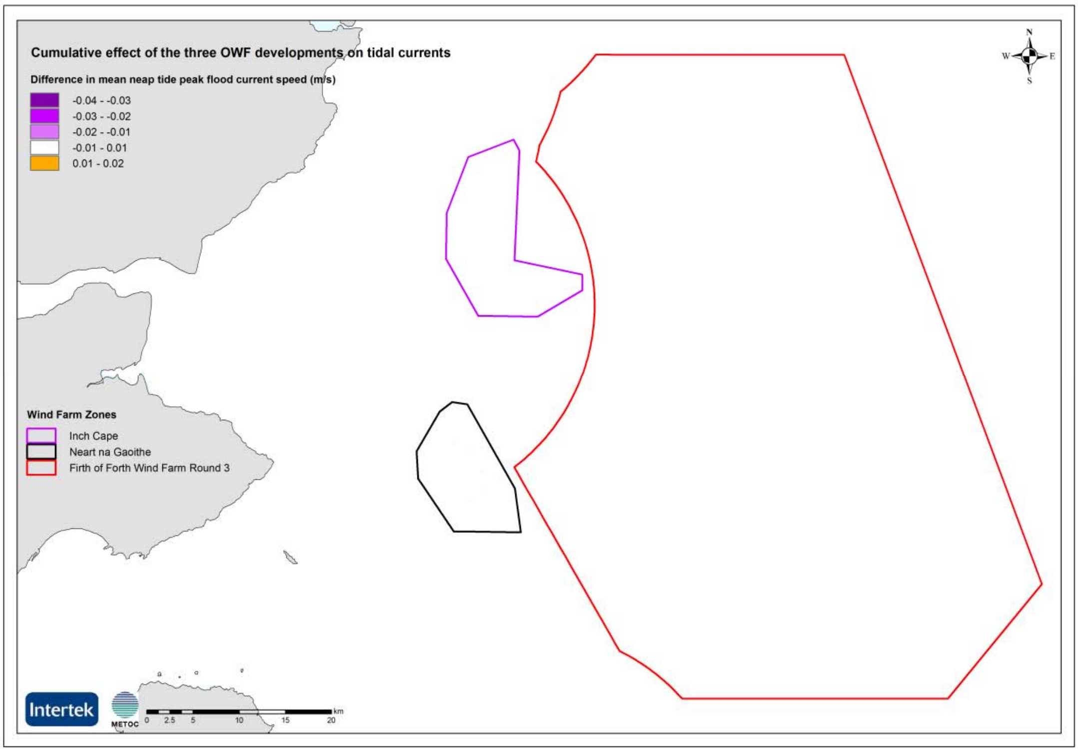


Figure H-125: Cumulative difference to mean neap tide peak ebb current speed (m/s)

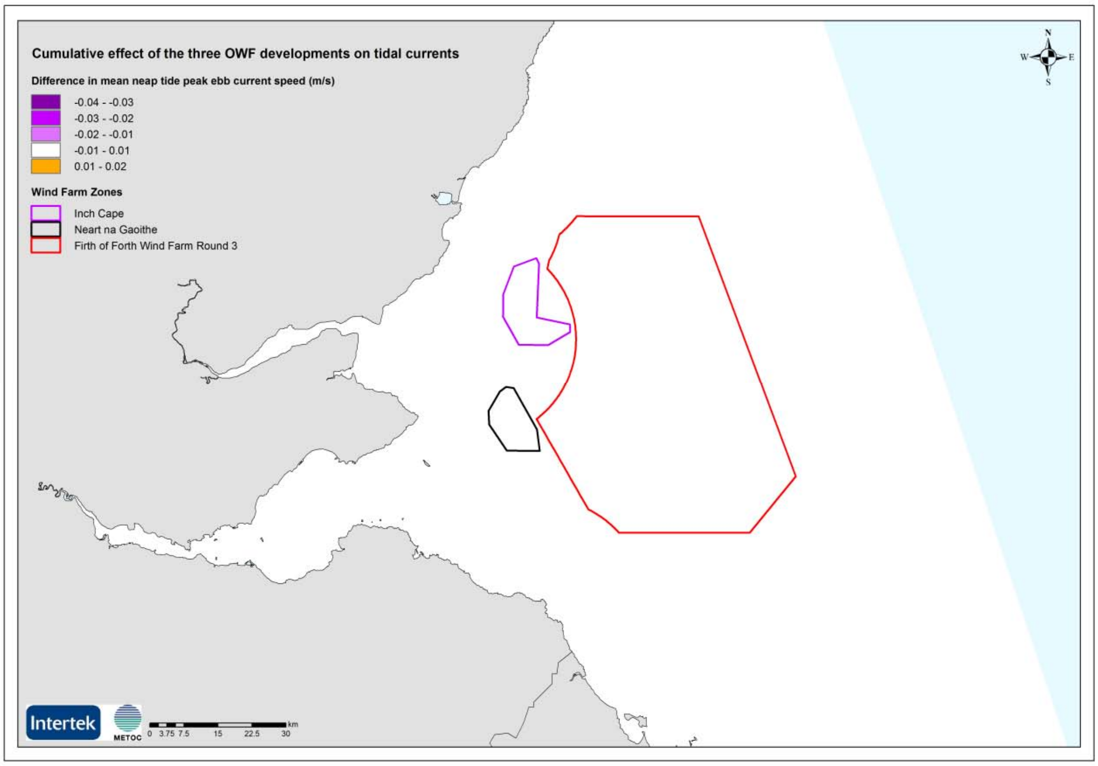


Figure H-125b: Cumulative difference to mean neap tide peak ebb current speed (m/s) – zoom

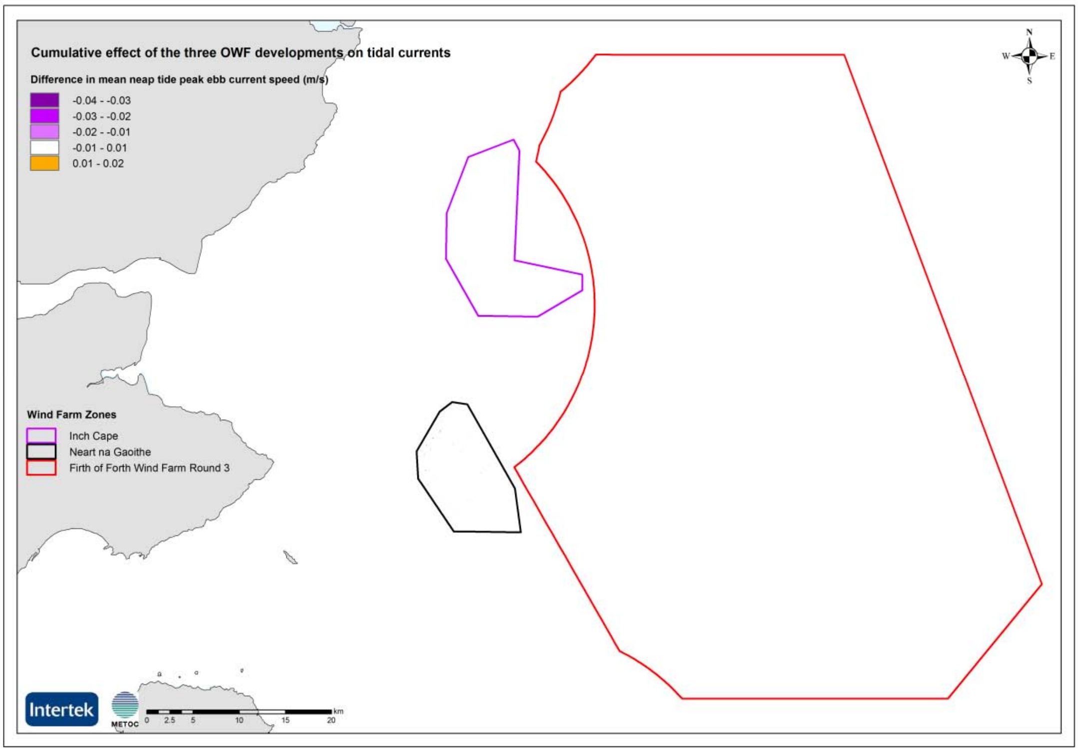


Figure H-126: Cumulative difference to 50-percentile current speed (m/s)

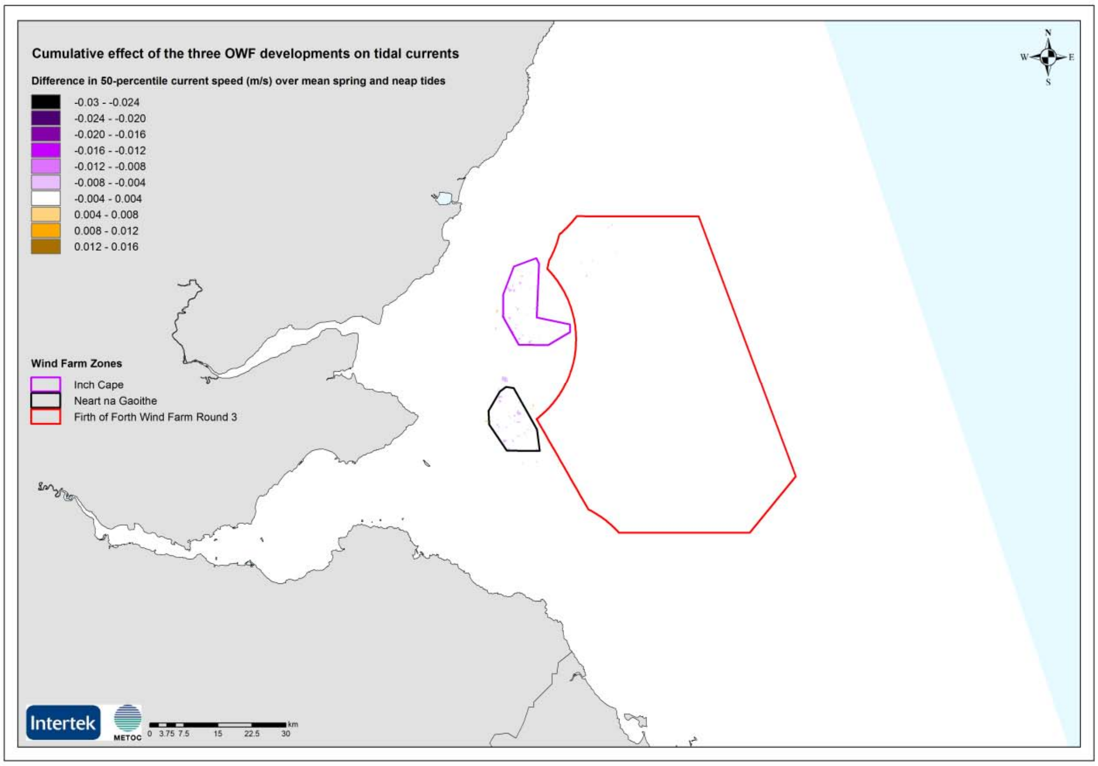


Figure H-126b: Cumulative difference to 50-percentile current speed (m/s) – zoom

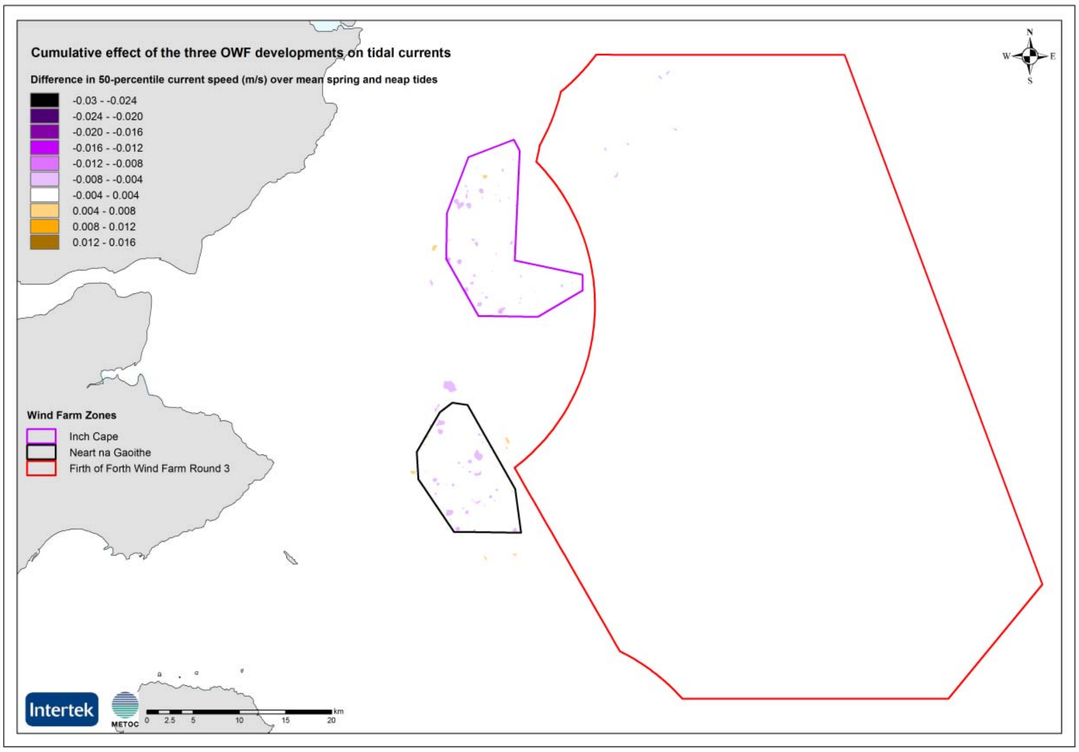


Figure H-127: Cumulative difference to 90-percentile current speed (m/s)

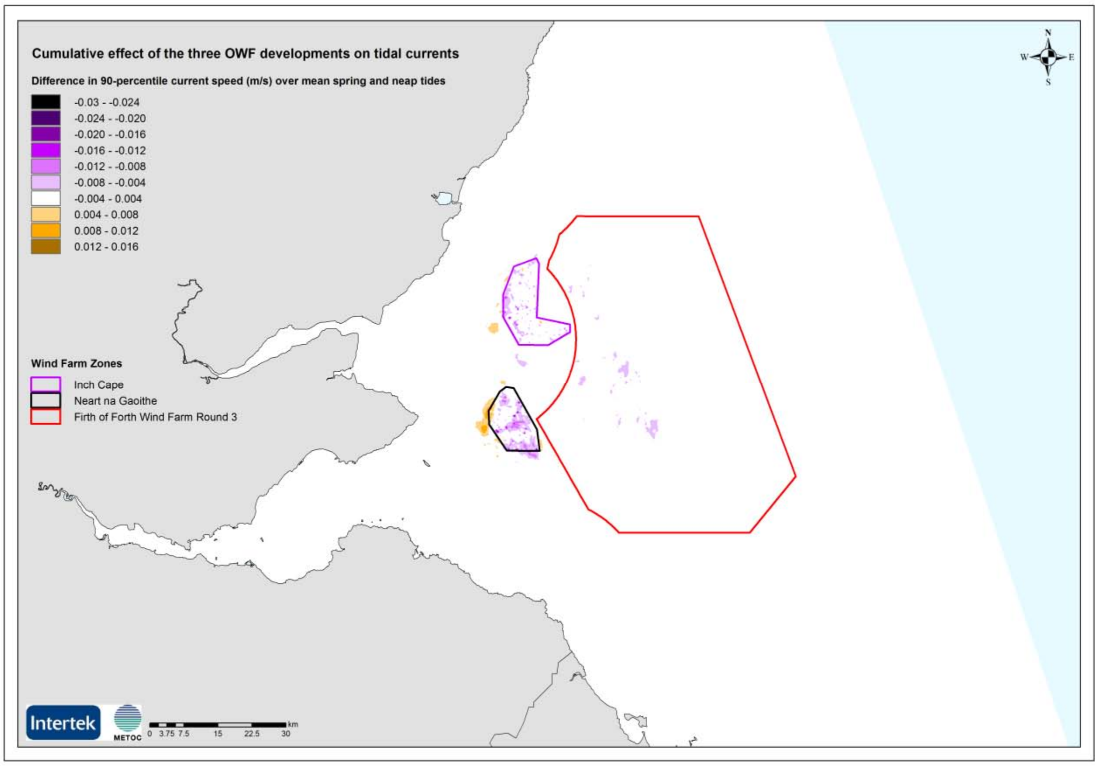


Figure H-127b: Cumulative difference to 90-percentile current speed (m/s) – zoom

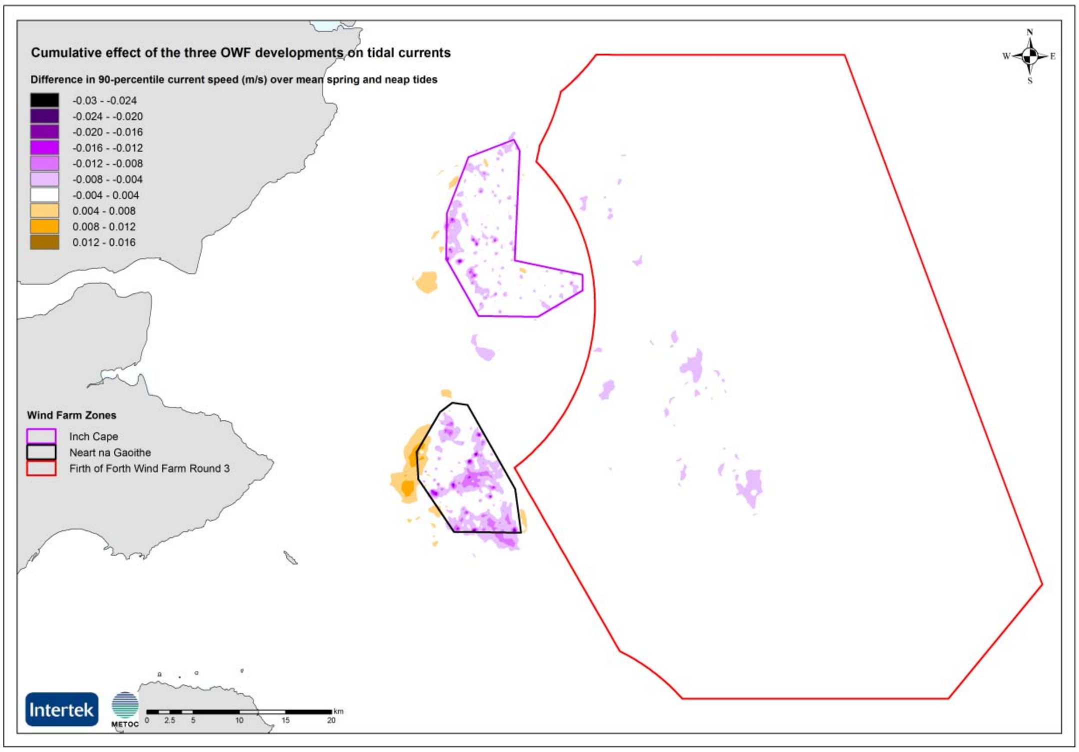


Figure H-128: Cumulative difference to 95-percentile current speed (m/s)

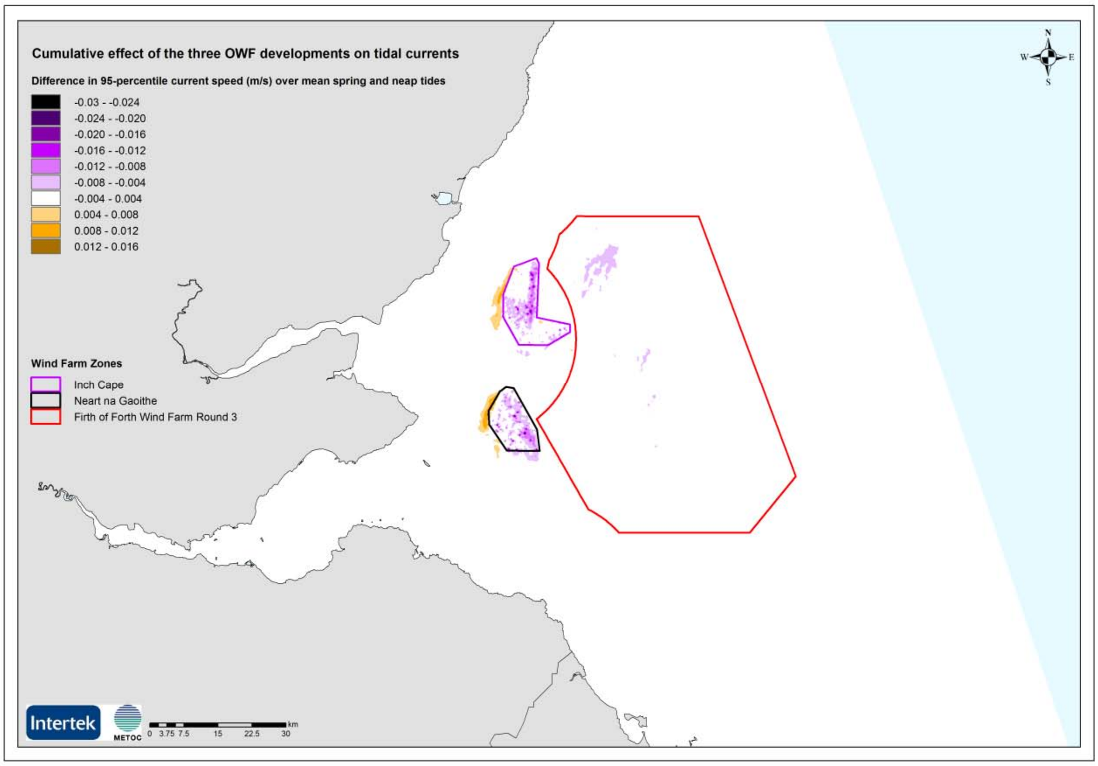


Figure H-128b: Cumulative difference to 95-percentile current speed (m/s) – zoom

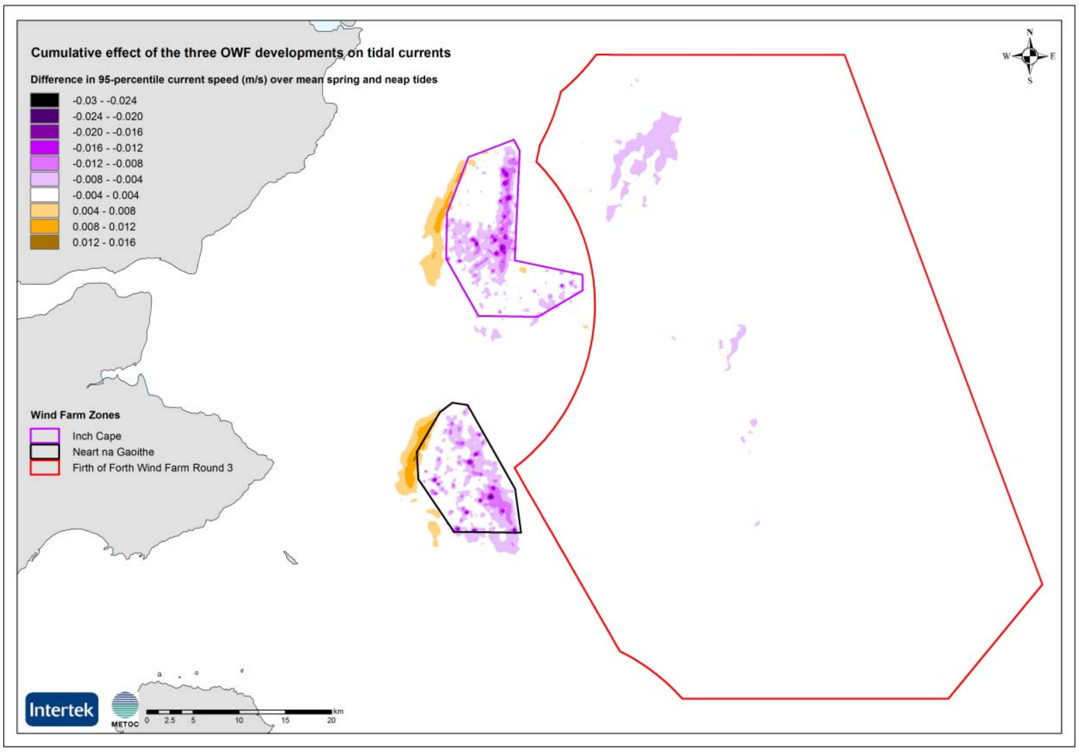


Figure H-129: Cumulative difference to 99-percentile current speed (m/s)

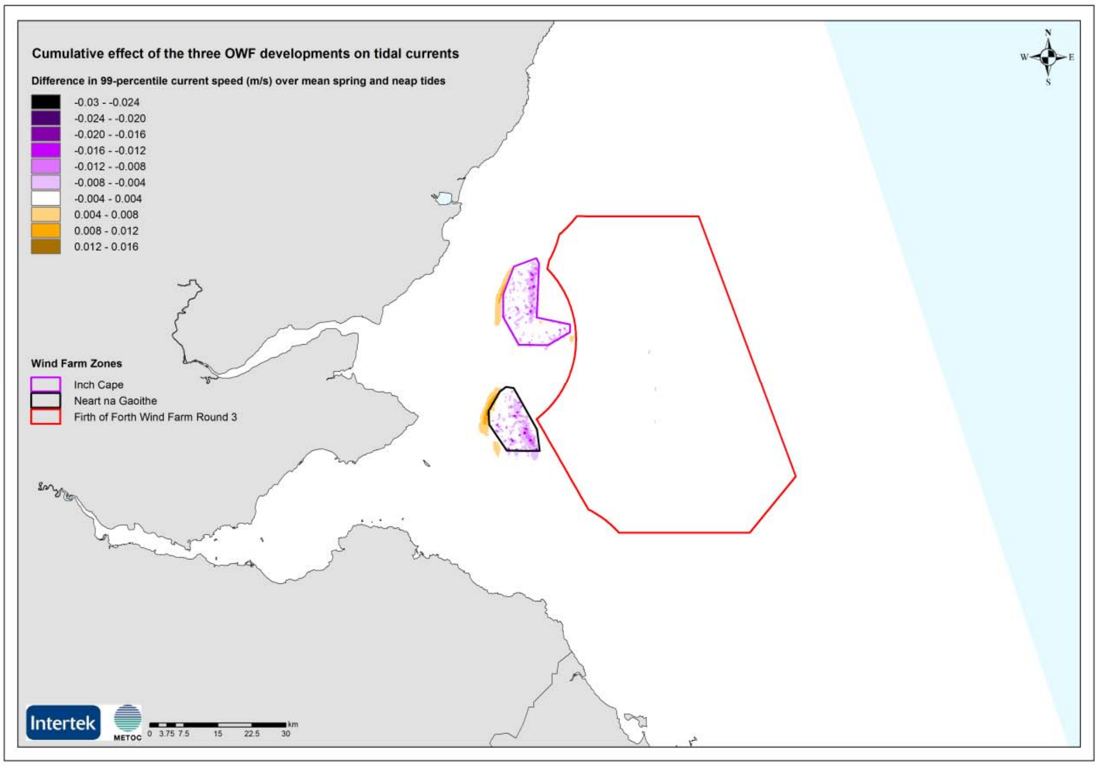
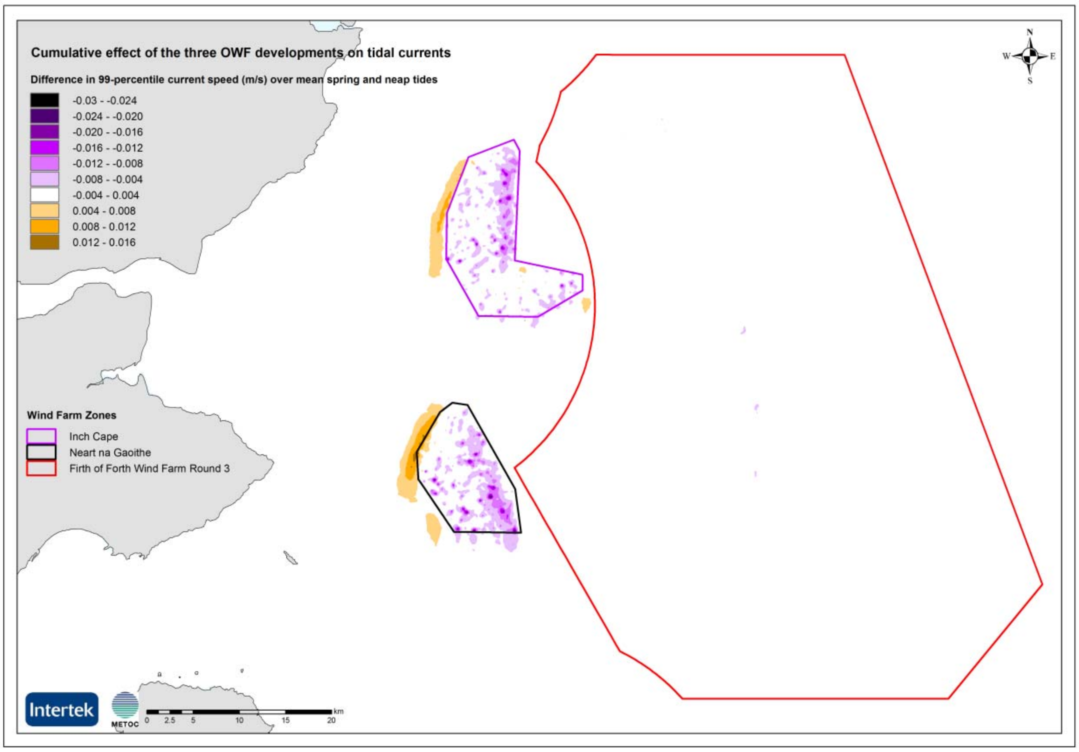


Figure H-129b: Cumulative difference to 99-percentile current speed (m/s) – zoom



H.2.2 CUMULATIVE CHANGES TO THE WAVE CLIMATE – REGIONAL AREA (FAR-FIELD)

Figure H-130: Cumulative difference to 50-percentile significant wave height (m)

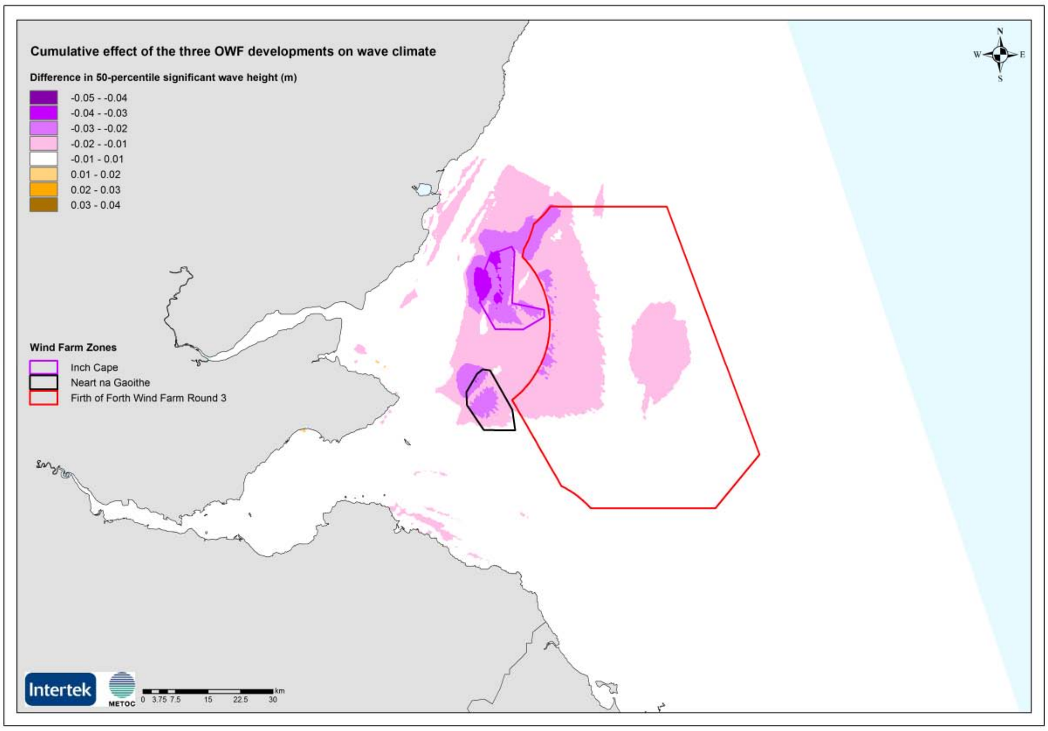


Figure H-130b: Cumulative difference to 50-percentile significant wave height (m) – zoom

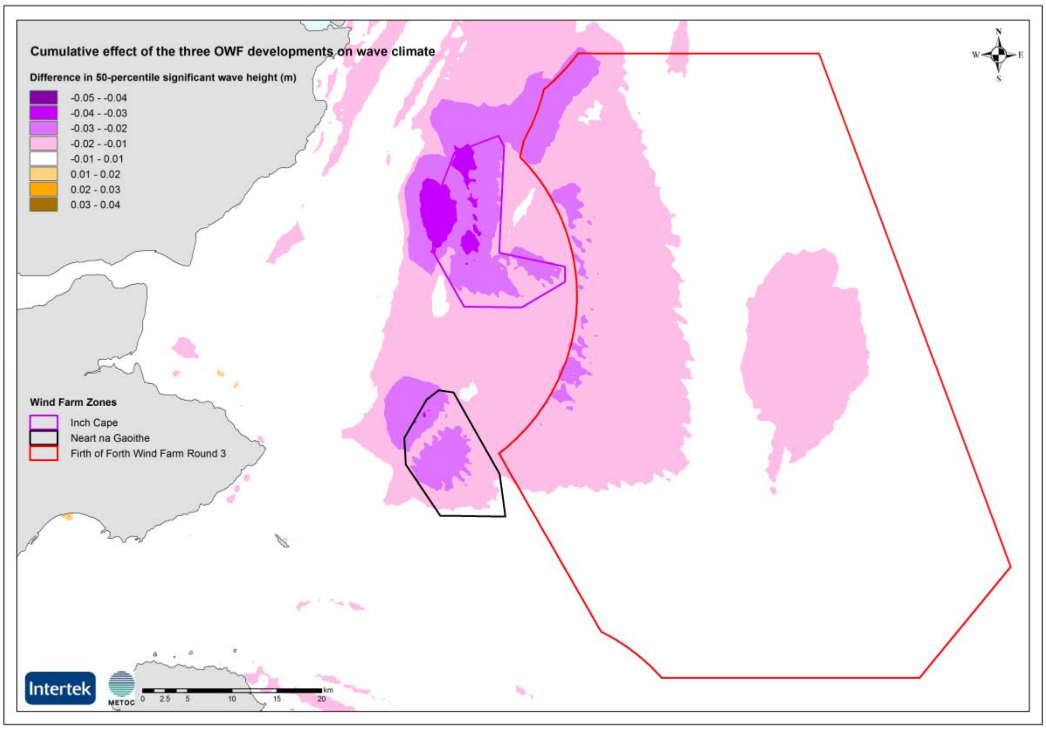


Figure H-131: Cumulative difference to 90-percentile significant wave height (m)

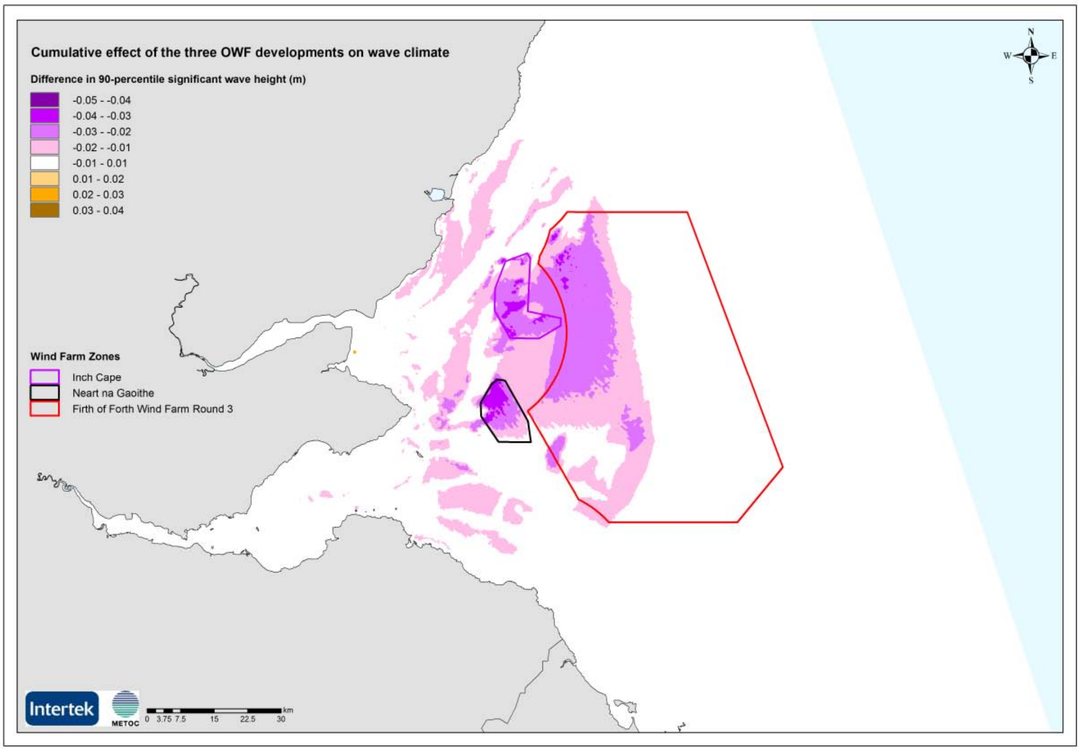


Figure H-131b: Cumulative difference to 90-percentile significant wave height (m) – zoom

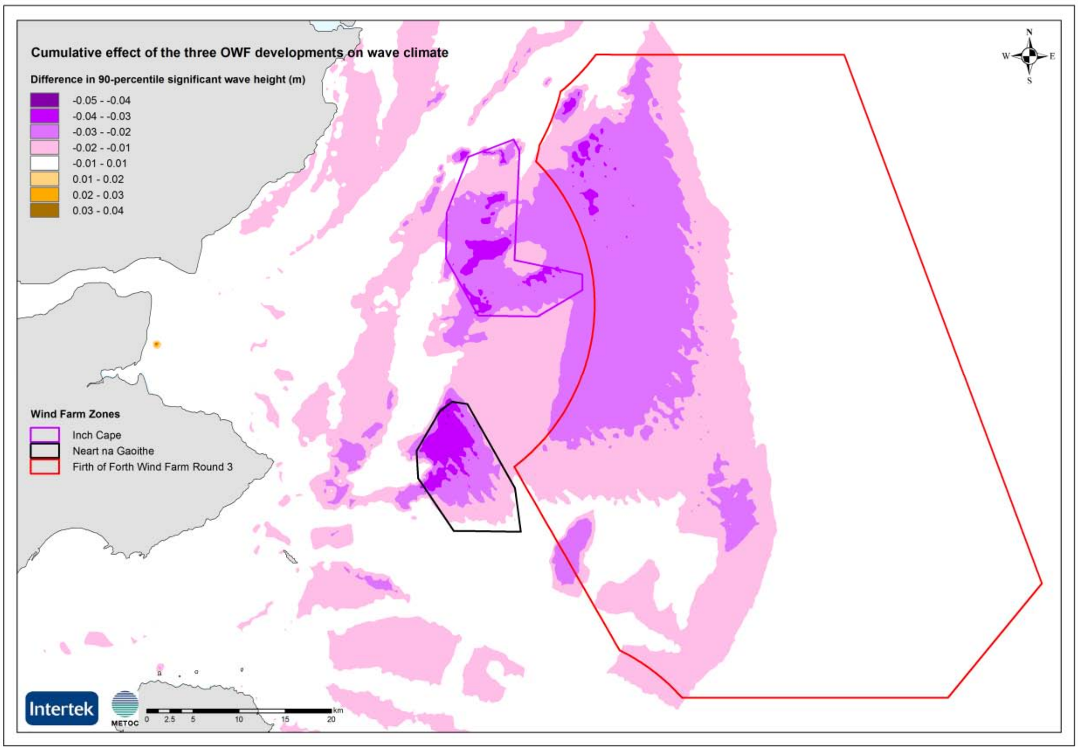


Figure H-132: Cumulative difference to 95-percentile significant wave height (m)

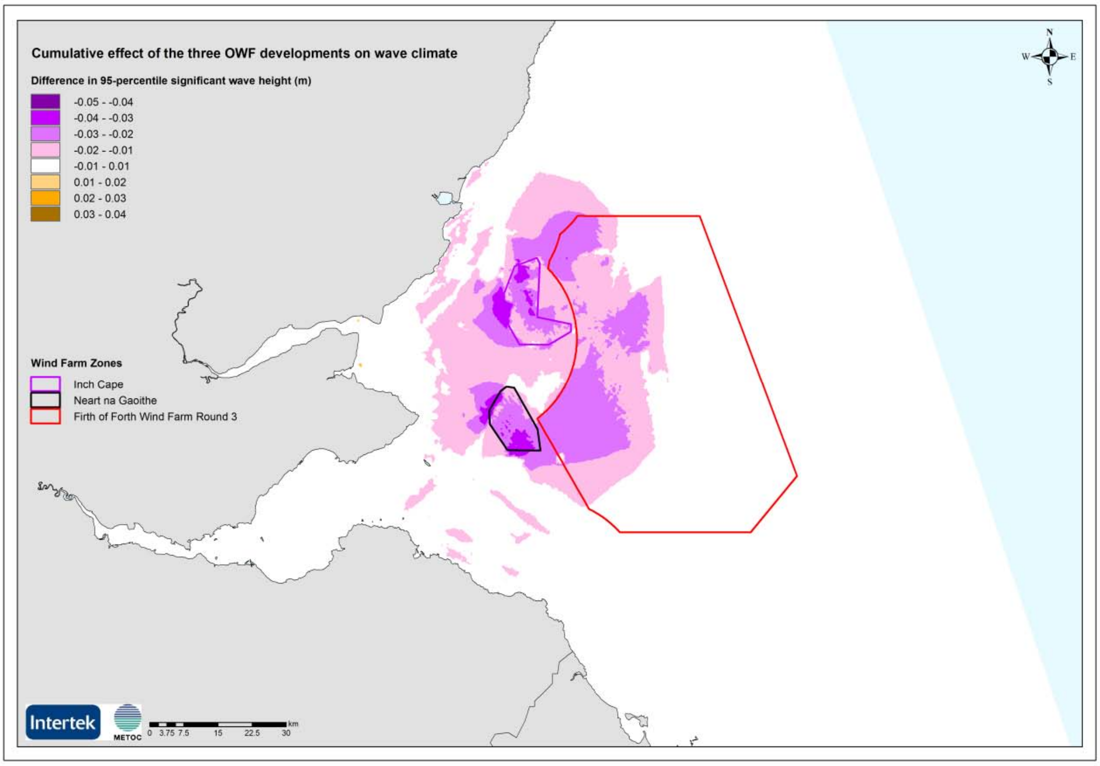


Figure H-132b: Cumulative difference to 95-percentile significant wave height (m) – zoom

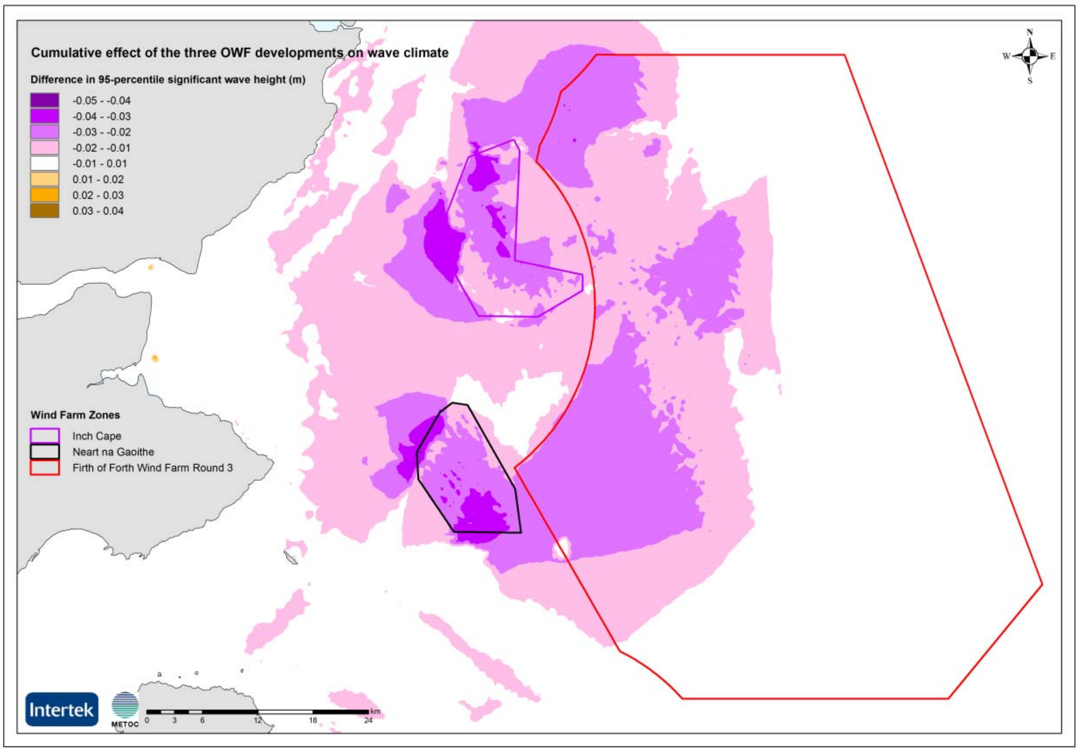


Figure H-133: Cumulative difference to 99-percentile significant wave height (m)

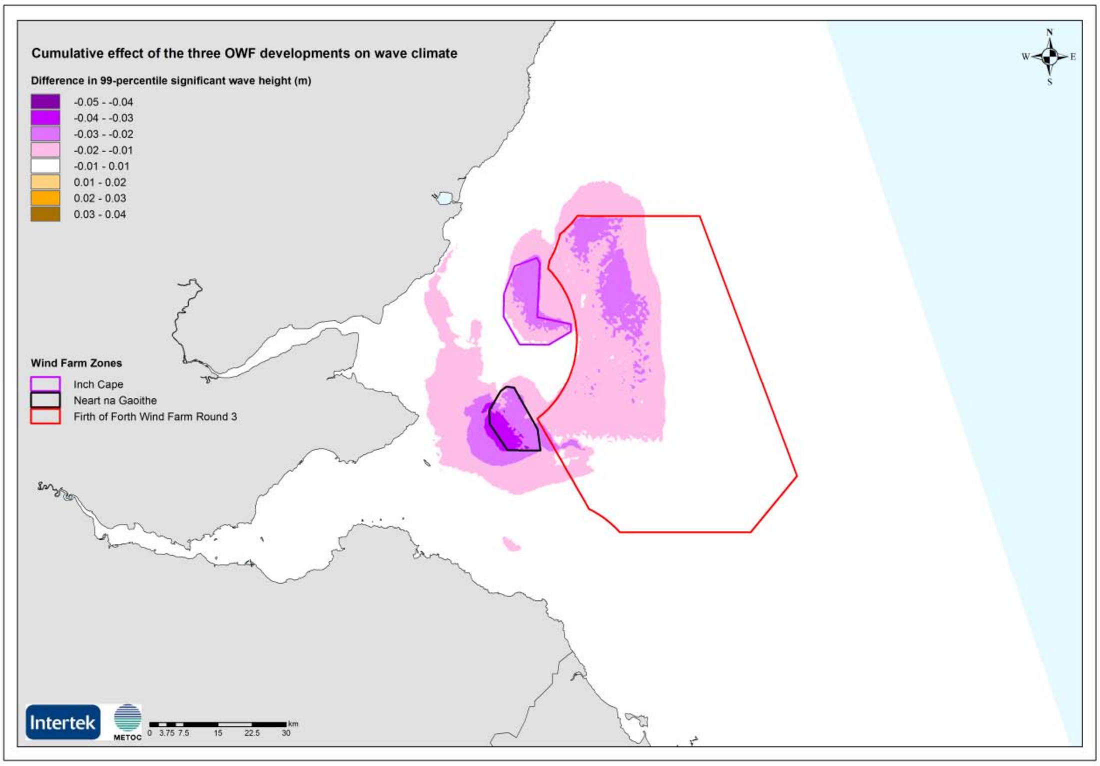
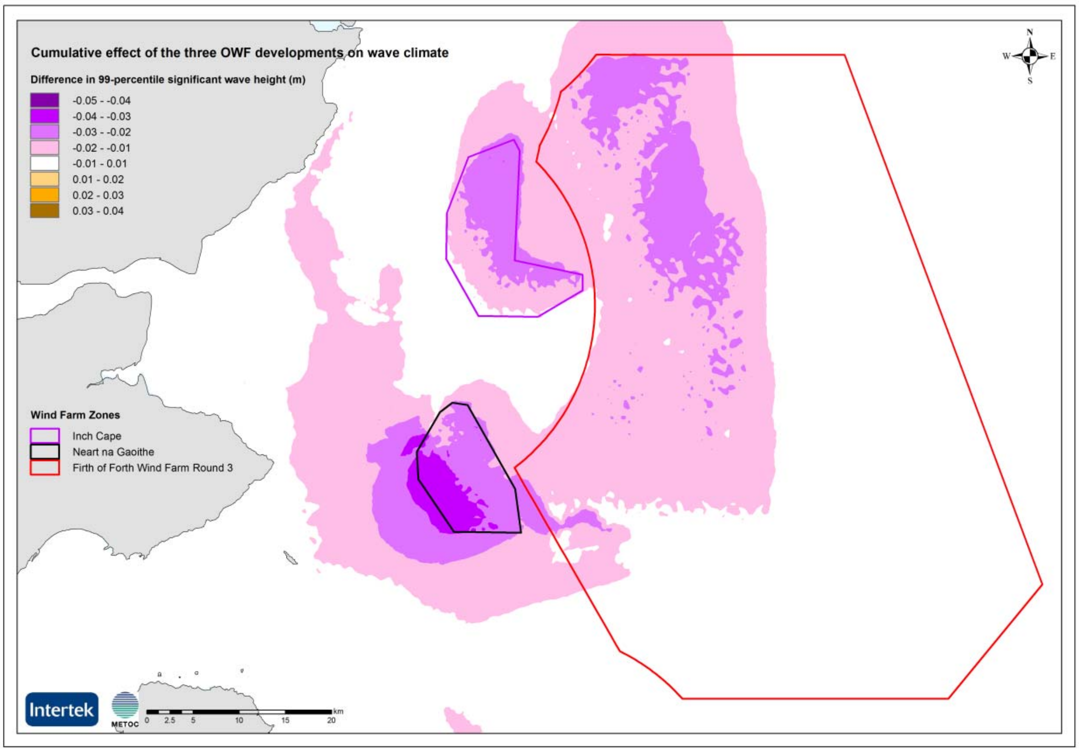


Figure H-133b: Cumulative difference to 99-percentile significant wave height (m) – zoom



H.2.3 CUMULATIVE CHANGES TO THE SEDIMENT REGIME – REGIONAL AREA (FAR-FIELD)

Figure H-134: Cumulative difference to exceedance of critical shear stress – based on combined (currents plus waves) maximum bed shear stress

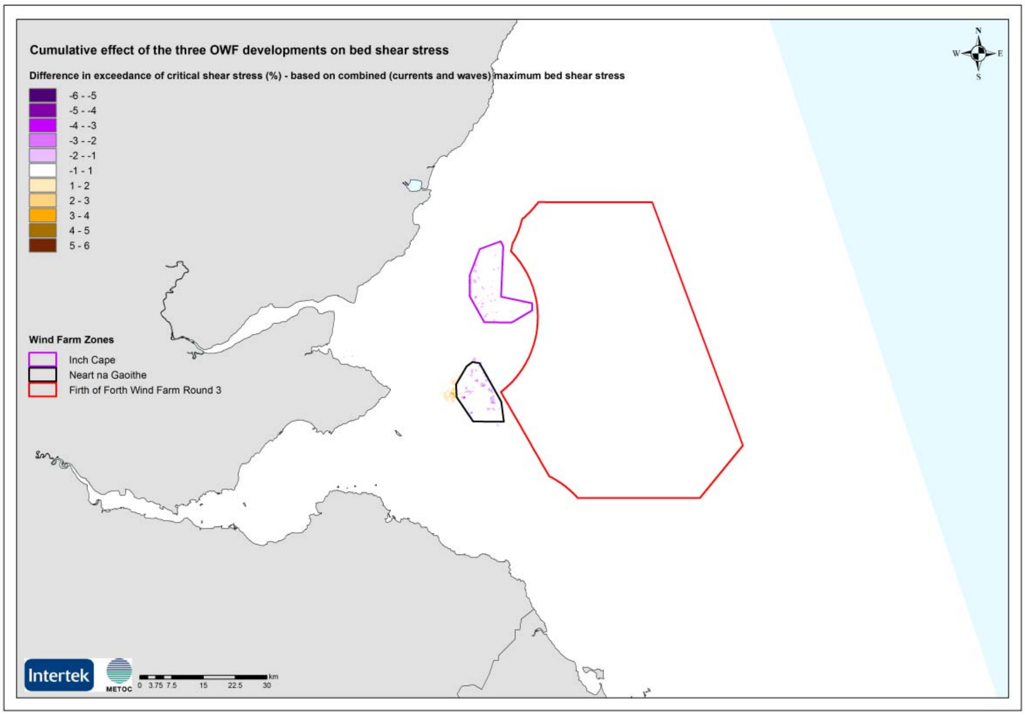


Figure H-134b: Cumulative difference to exceedance of critical shear stress – based on combined (currents plus waves) maximum bed shear stress – zoom

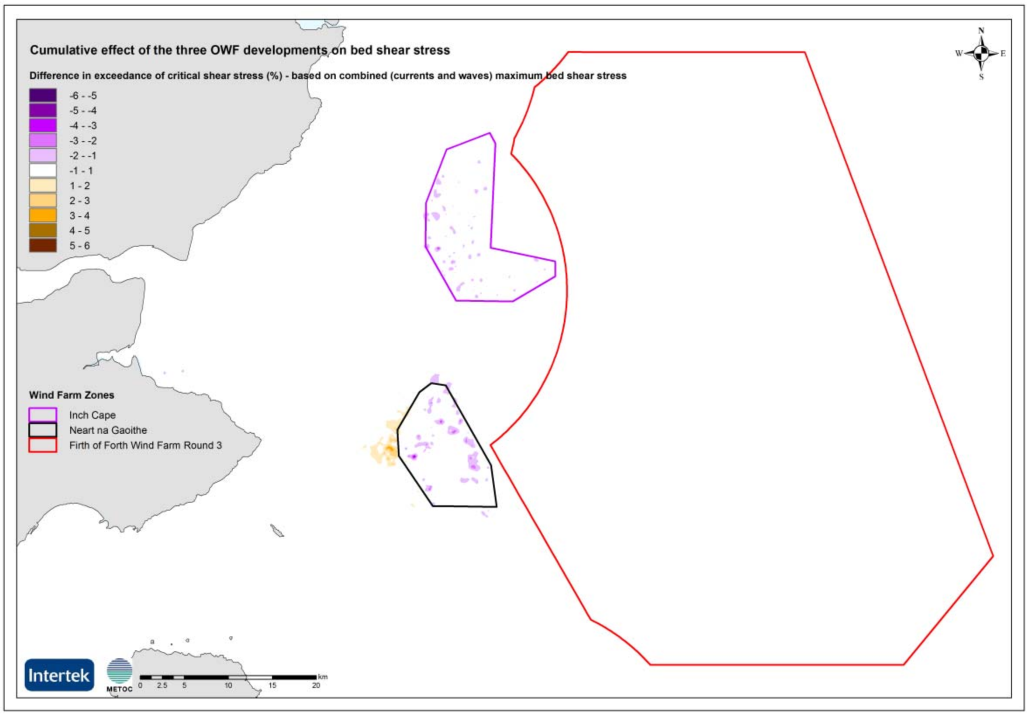


Figure H-135: Cumulative difference to exceedance of critical shear stress – based on combined (currents plus waves) mean bed shear stress

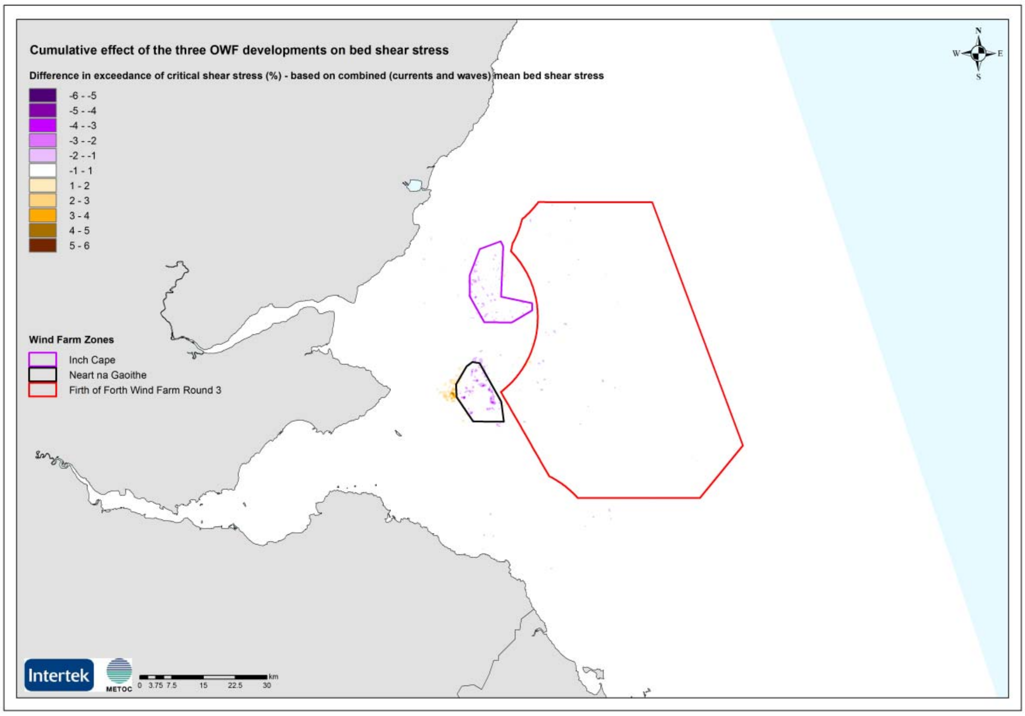


Figure H-135b: Cumulative difference to exceedance of critical shear stress – based on combined (currents plus waves) mean bed shear stress – zoom

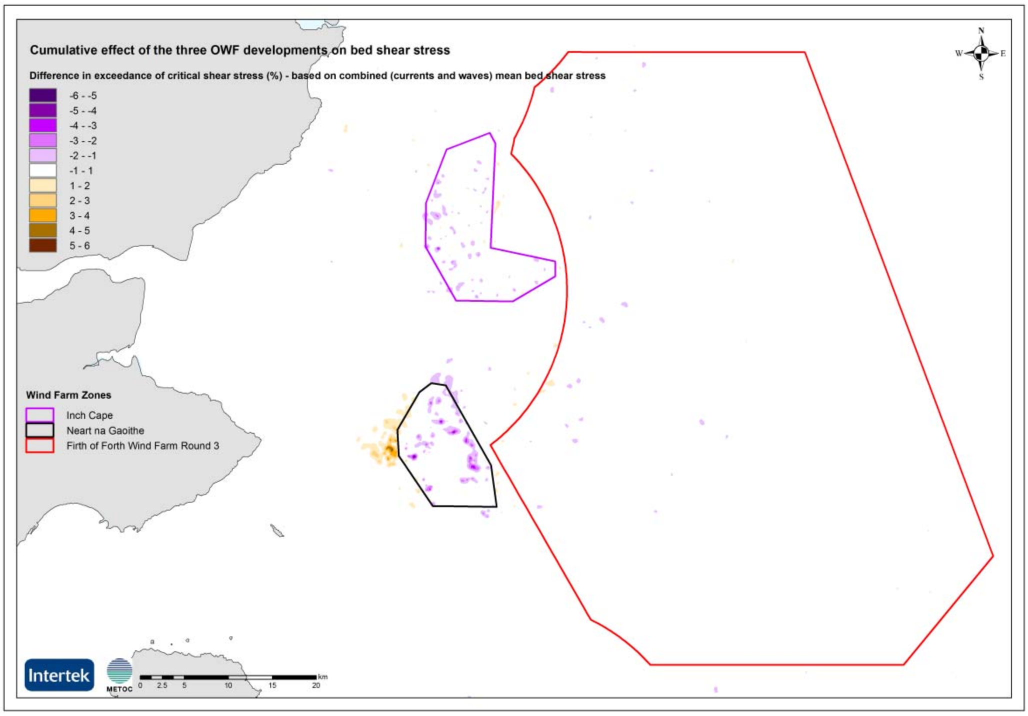


Figure H-136: Far-field suspended sediment transport pathway with no developments (baseline) – 7 days after release

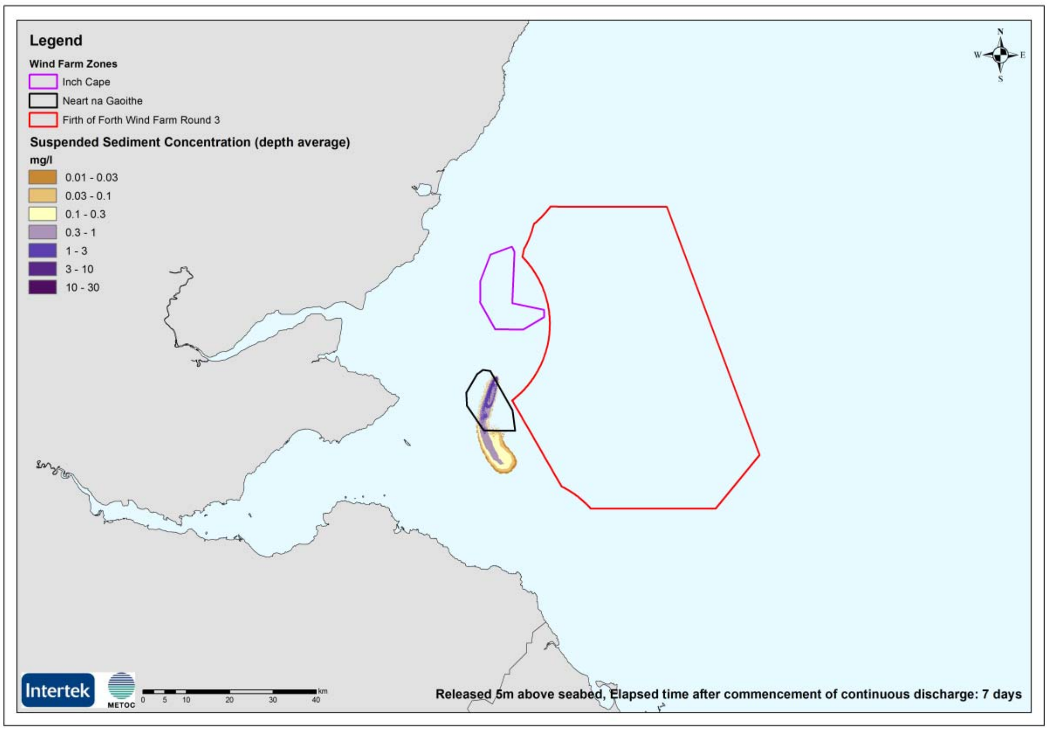


Figure H-137: Far-field suspended sediment transport pathway with three OWF developments in place – 7 days after release

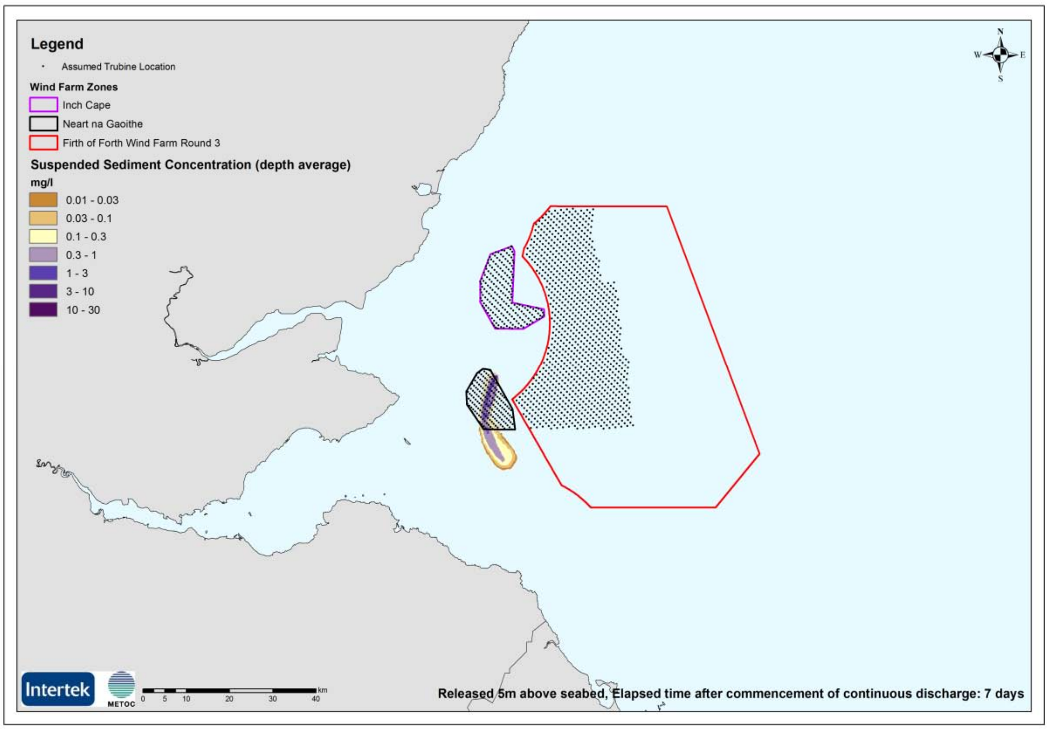


Figure H-138: Far-field suspended sediment transport pathway with no developments (baseline) –15 days after release

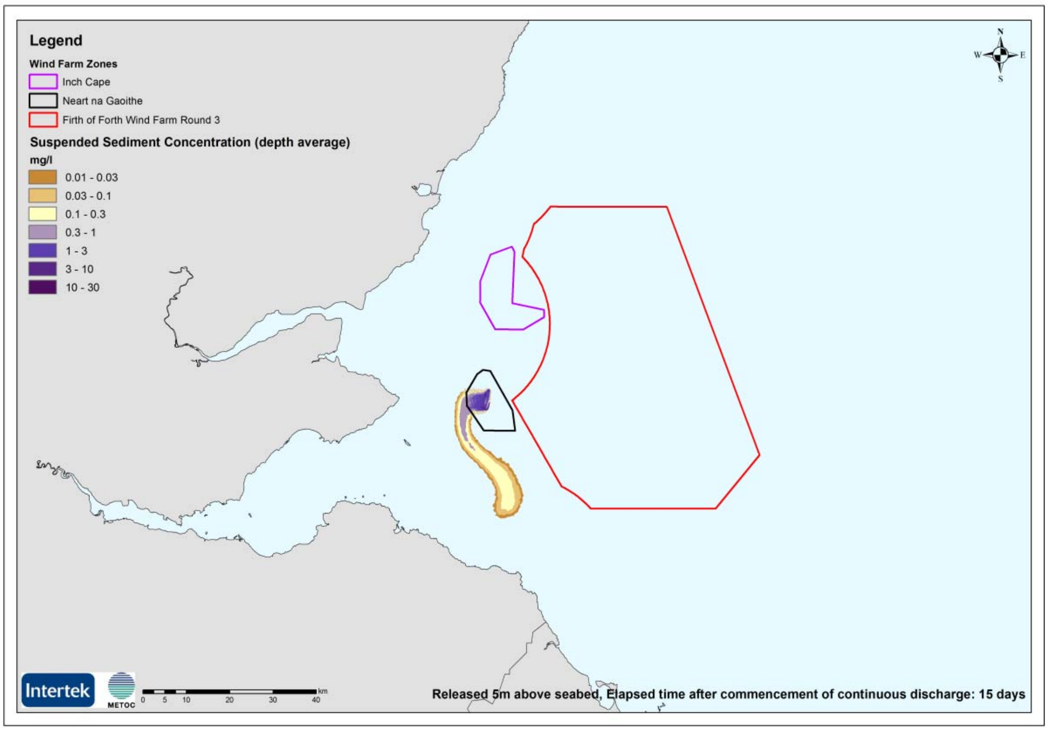
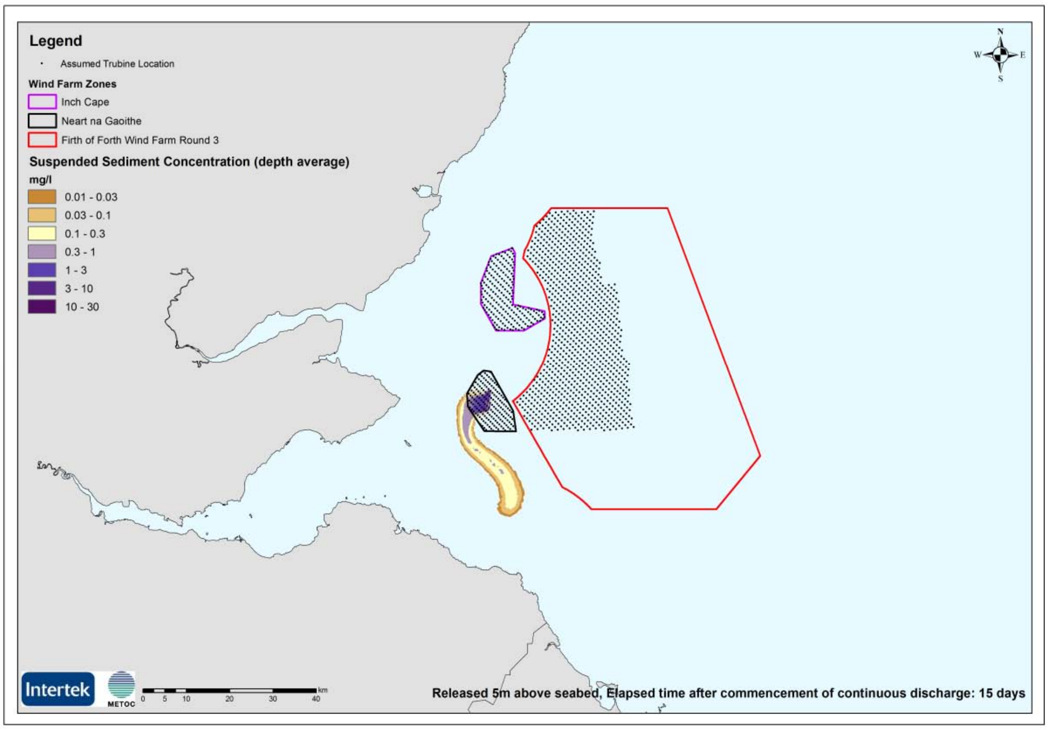


Figure H-139: Far-field suspended sediment transport pathway with three OWF developments in place – 15 days after release



H.3 Effects due to Potential Climate Change

H.3.1 Changes to the Hydrodynamic Regime – Regional Area (Far-Field)

Figure H-140: Difference due to potential climate change to mean spring tide high water level (m) – far-field

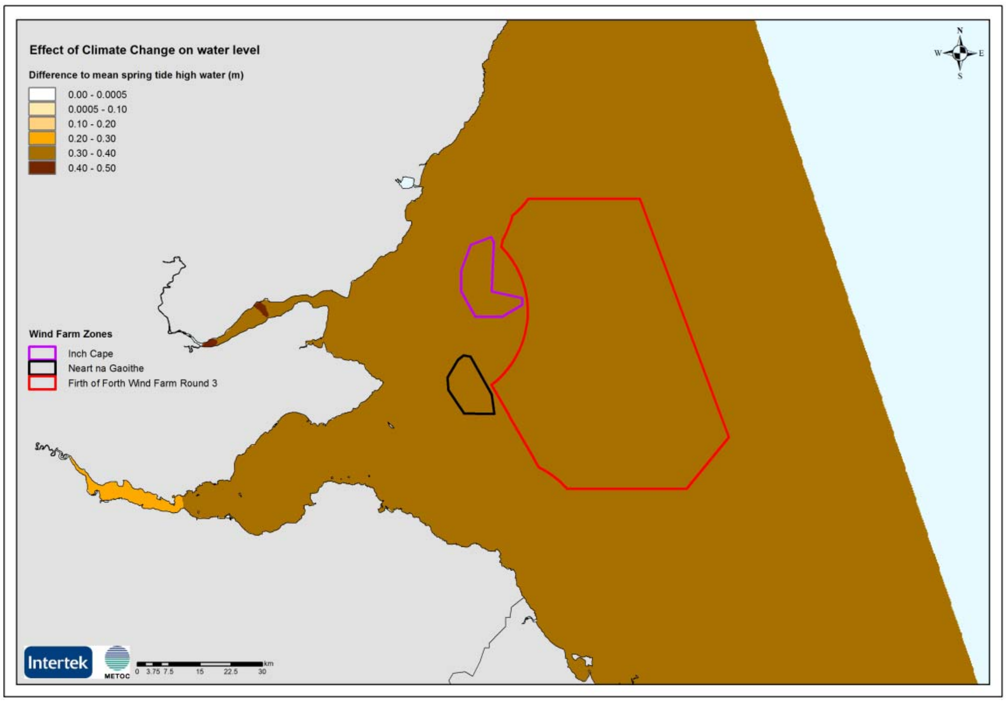


Figure H-141: Difference due to potential climate change to mean spring tide low water level (m) – far-field

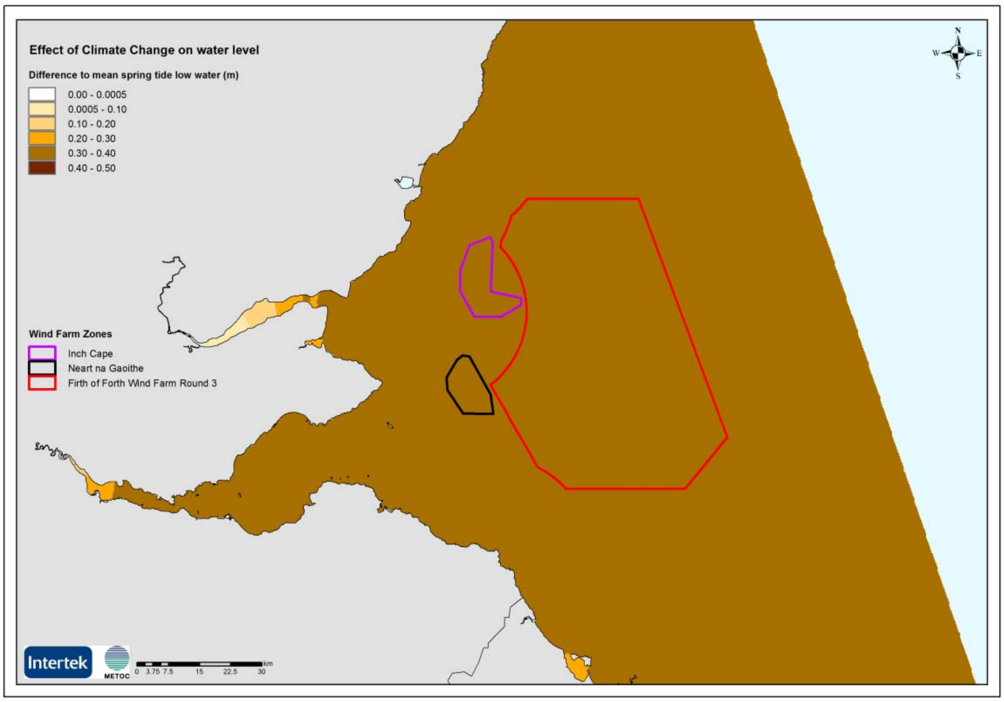


Figure H-142: Difference due to potential climate change to mean neap tide high water level (m) – far-field

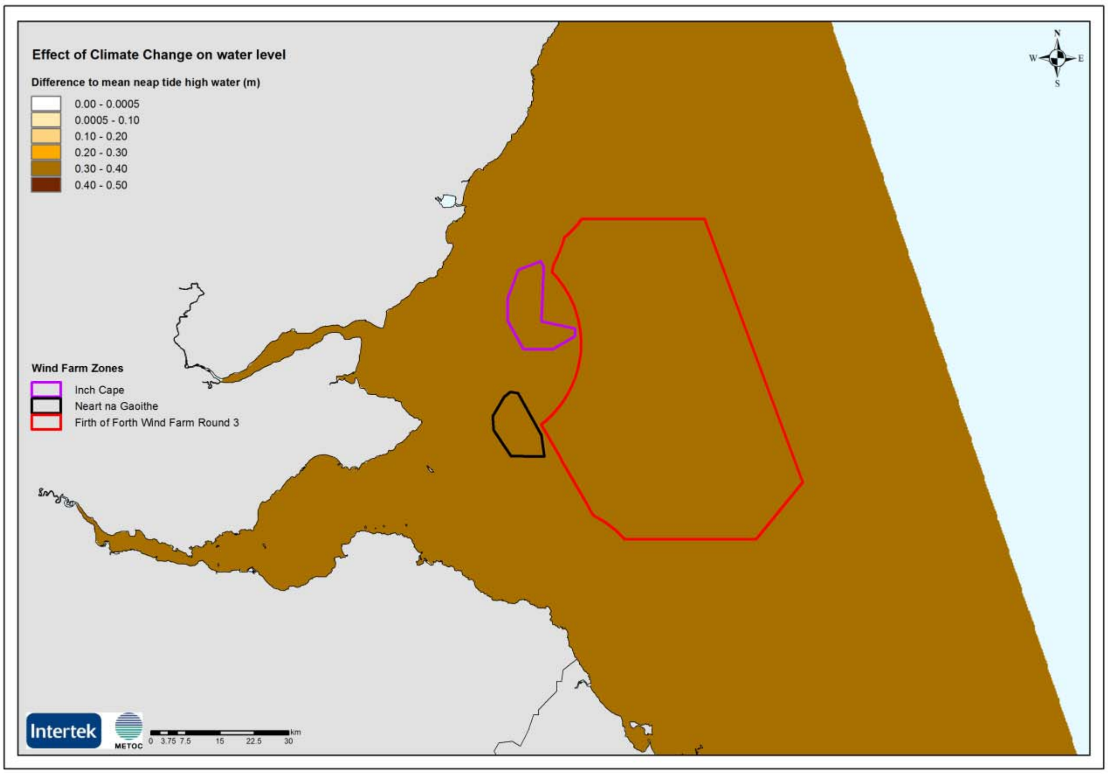


Figure H-143: Difference due to potential climate change to mean neap tide low water level (m) – far-field

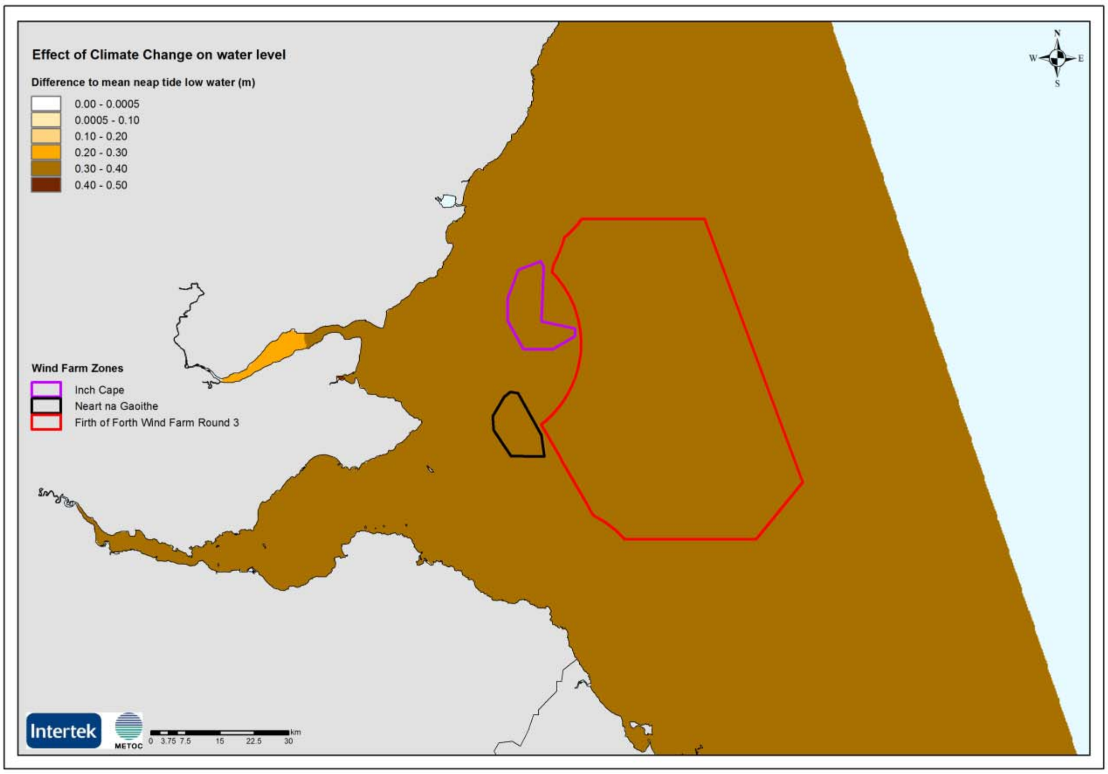


Figure H-144: Difference due to potential climate change to mean spring tide peak flood current speed (m/s) – far-field

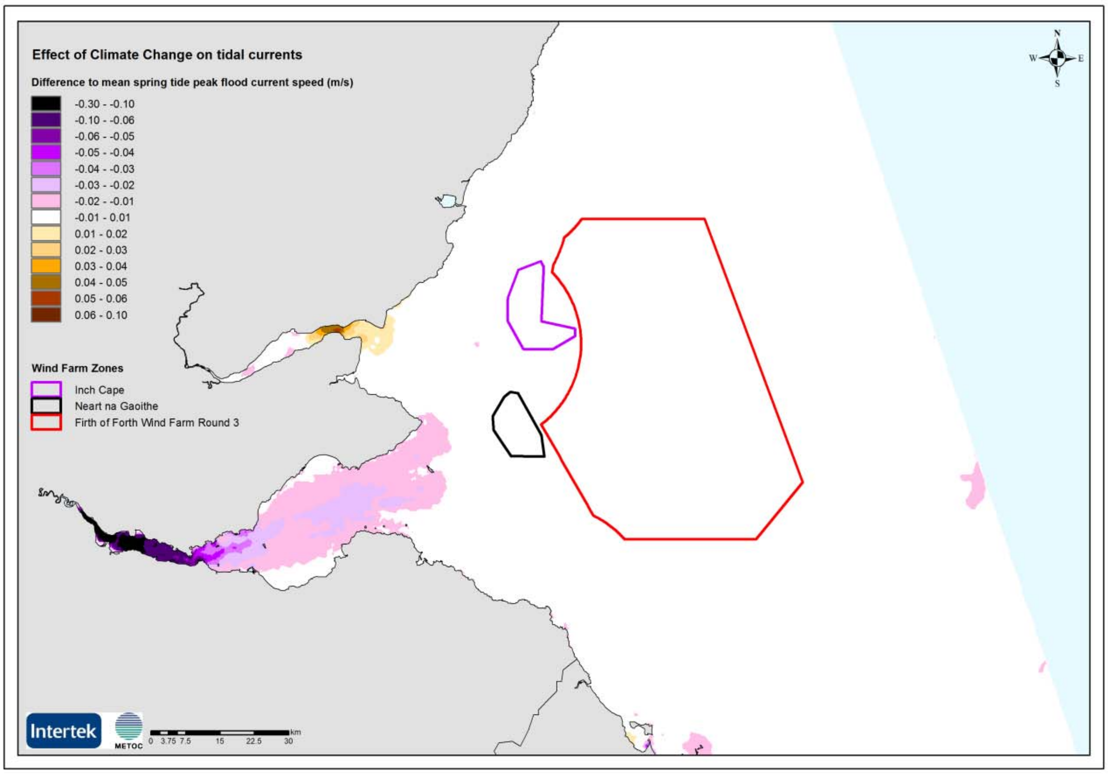


Figure H-145: Difference due to potential climate change to mean spring tide peak ebb current speed (m/s) – far-field

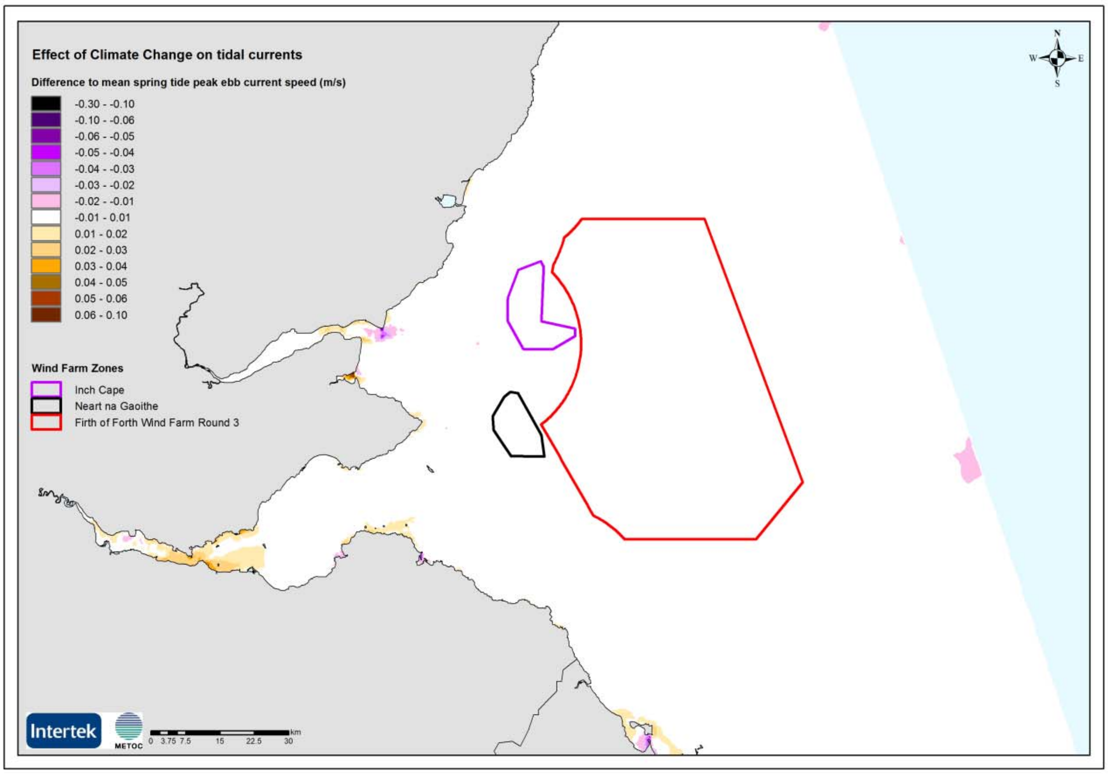


Figure H-146: Difference due to potential climate change to mean neap tide peak flood current speed (m/s) – far-field

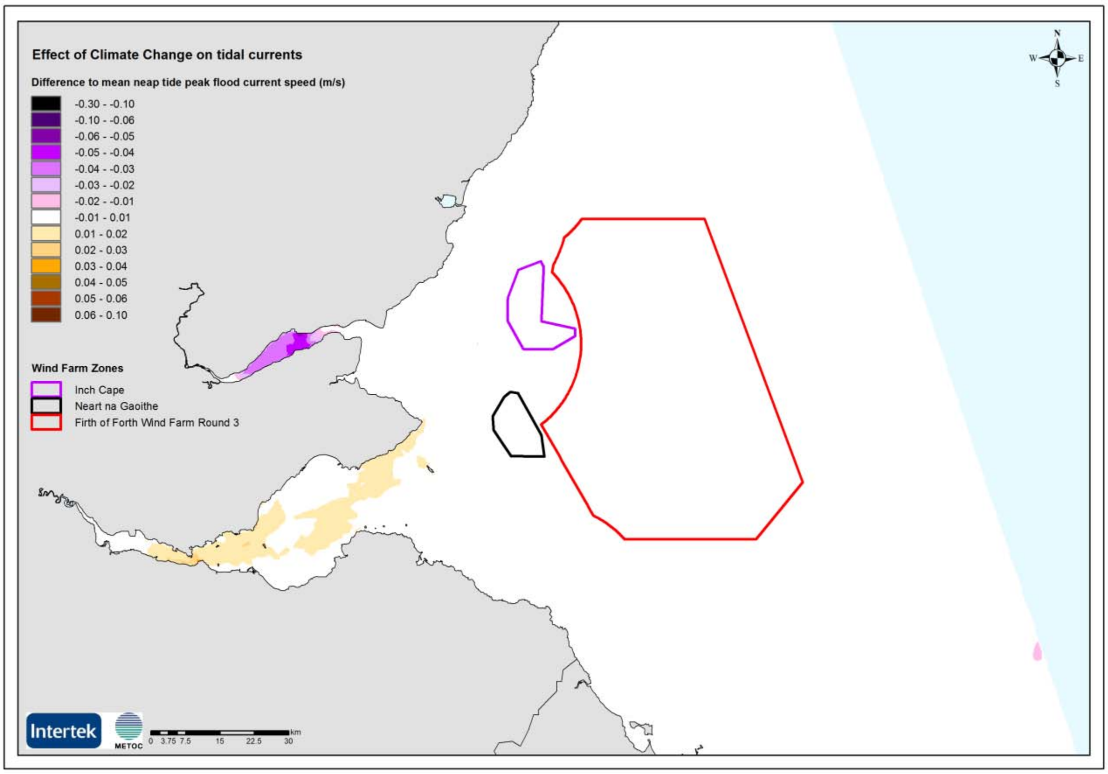


Figure H-147: Difference due to potential climate change to mean neap tide peak ebb current speed (m/s) – far-field

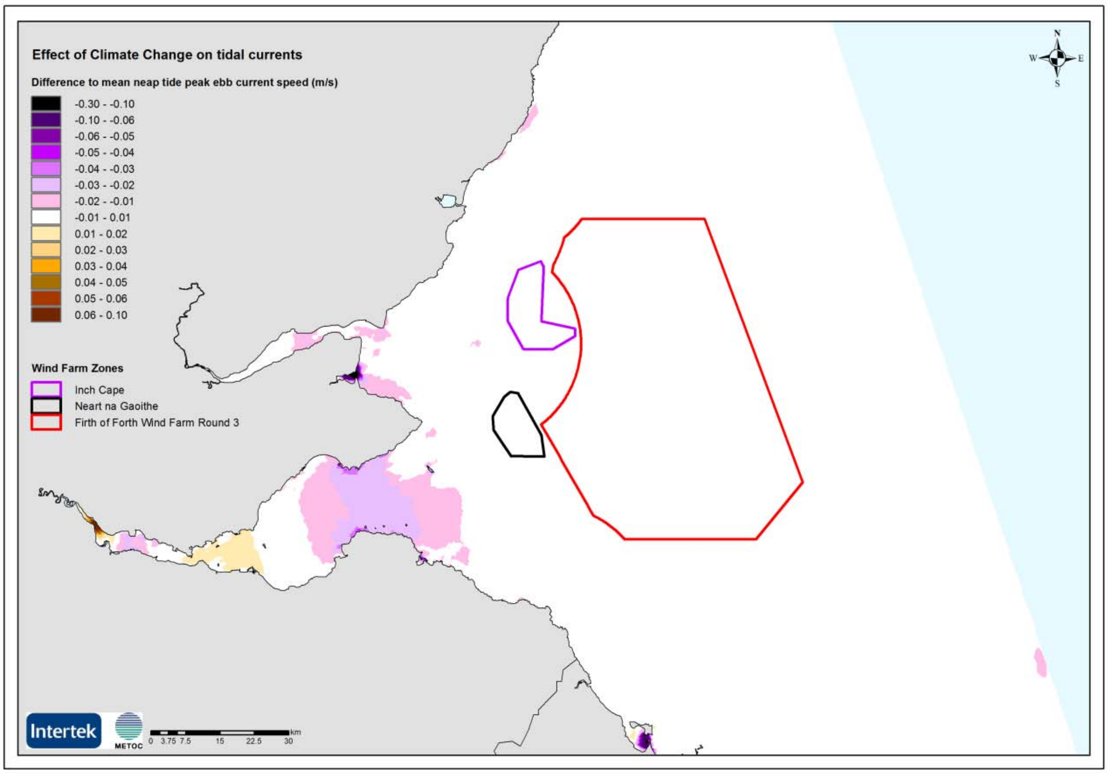


Figure H-148: Difference due to potential climate change to mean spring tide peak ebb current speed (m/s) – far-field

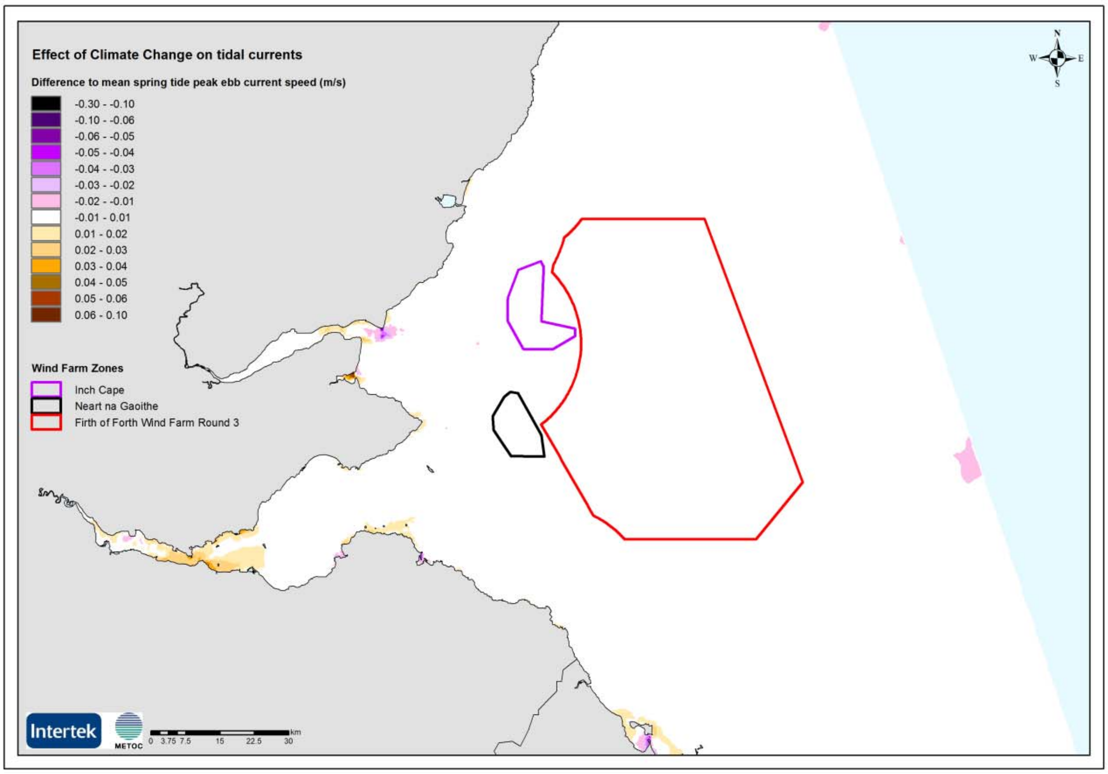


Figure H-149: Difference due to potential climate change to 50-percentile current speed (m/s) – far-field

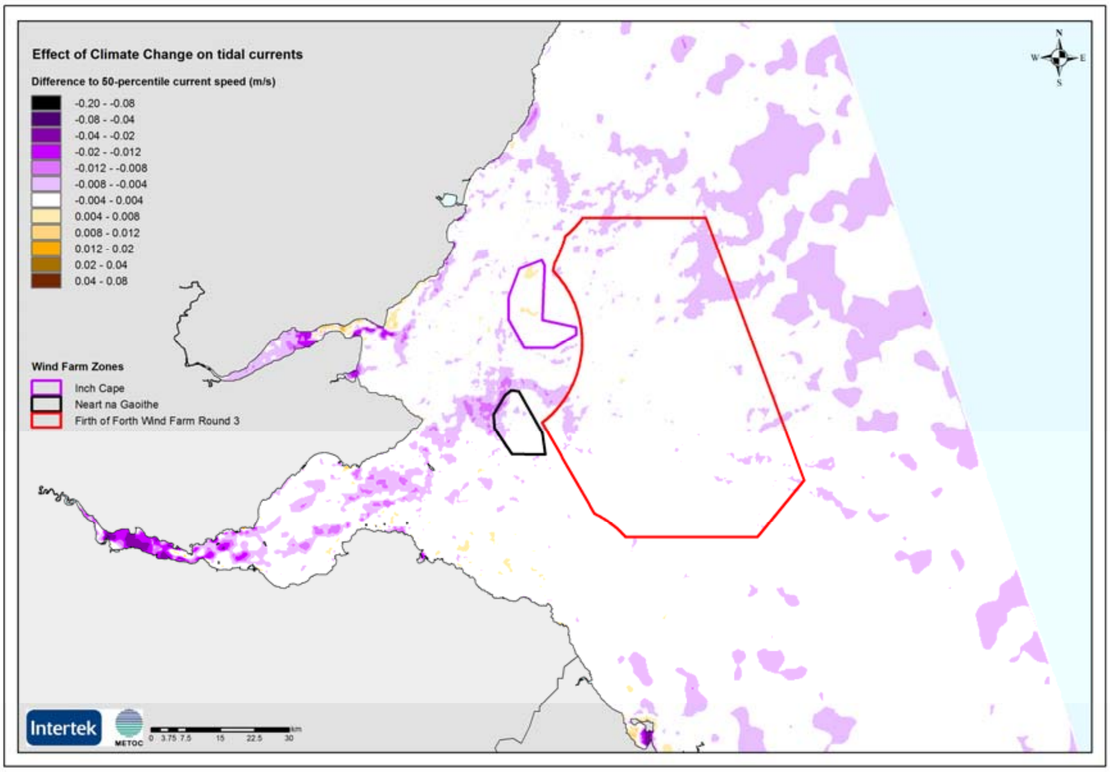


Figure H-150: Difference due to potential climate change to 90-percentile current speed (m/s) – far-field

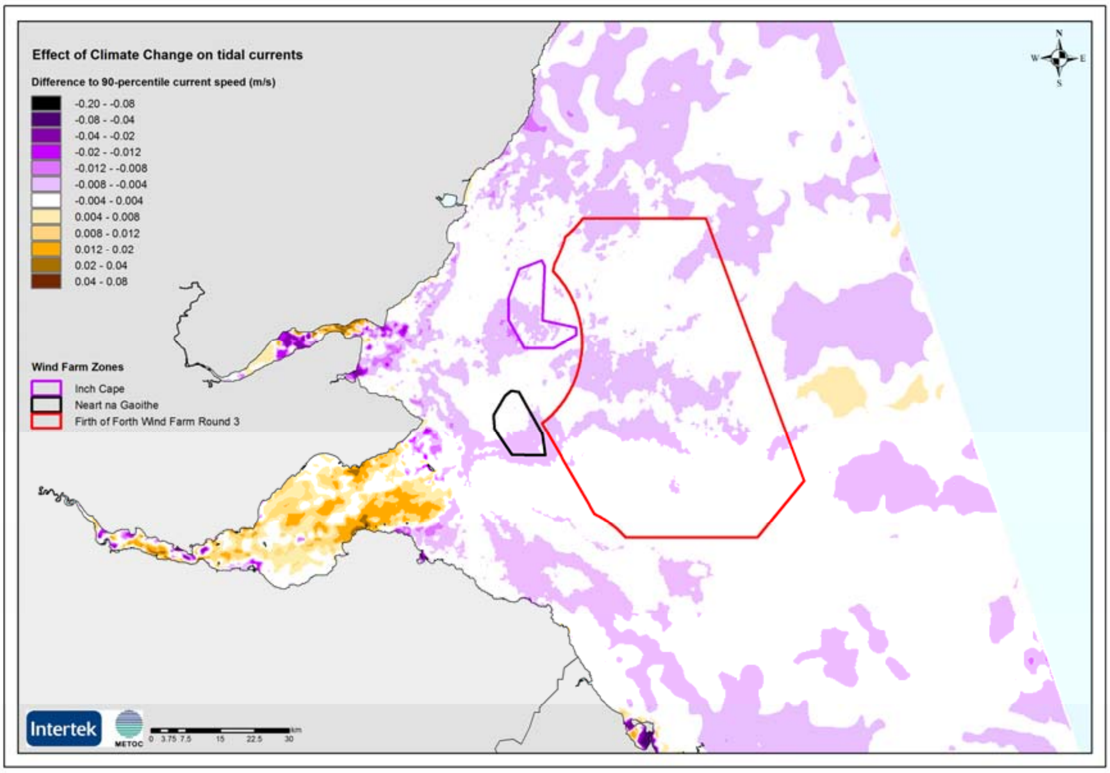


Figure H-151: Difference due to potential climate change to 95-percentile current speed (m/s) – far-field

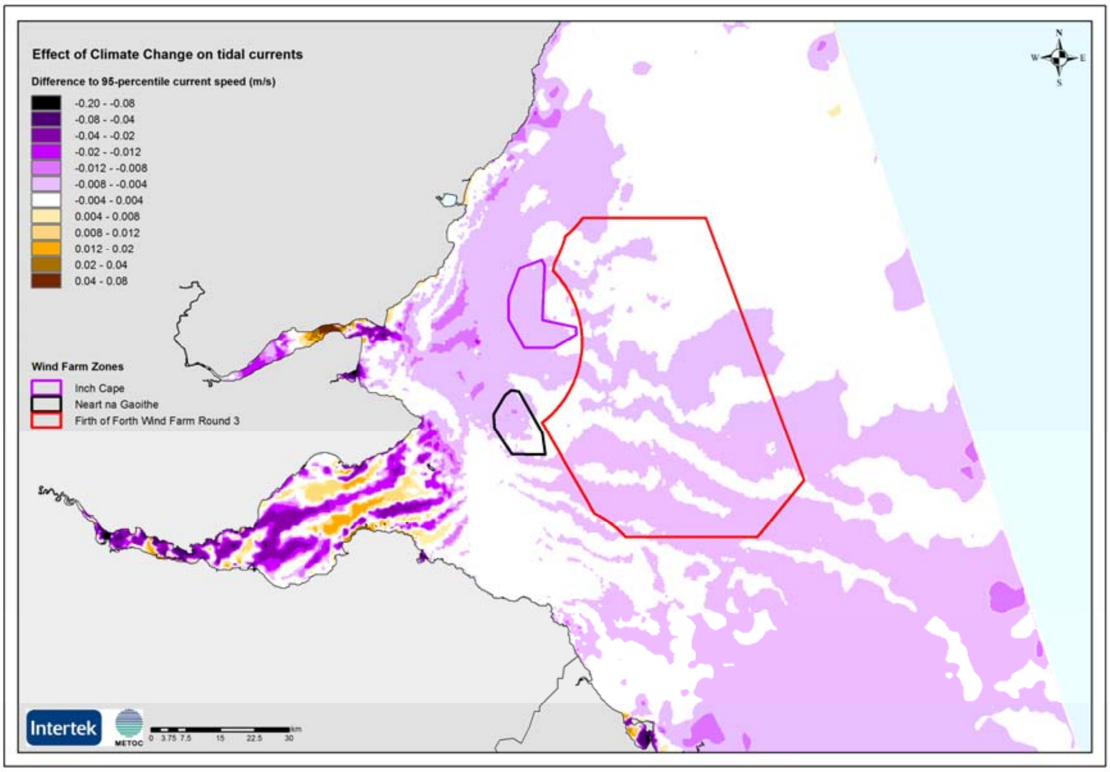
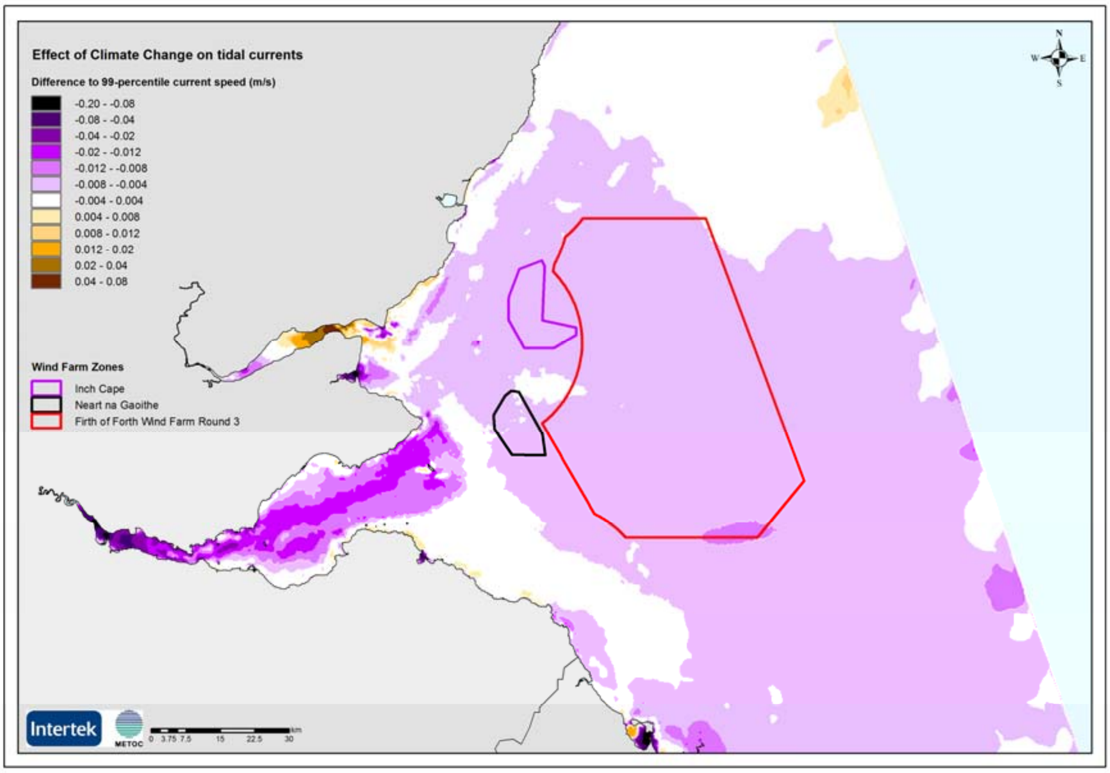


Figure H-152: Difference due to potential climate change to 99-percentile current speed (m/s) – far-field



H.3.2 CHANGES TO THE WAVE CLIMATE – REGIONAL AREA (FAR-FIELD)

Figure H-153: Difference due to potential climate change to 50-percentile significant wave height (m) – far-field

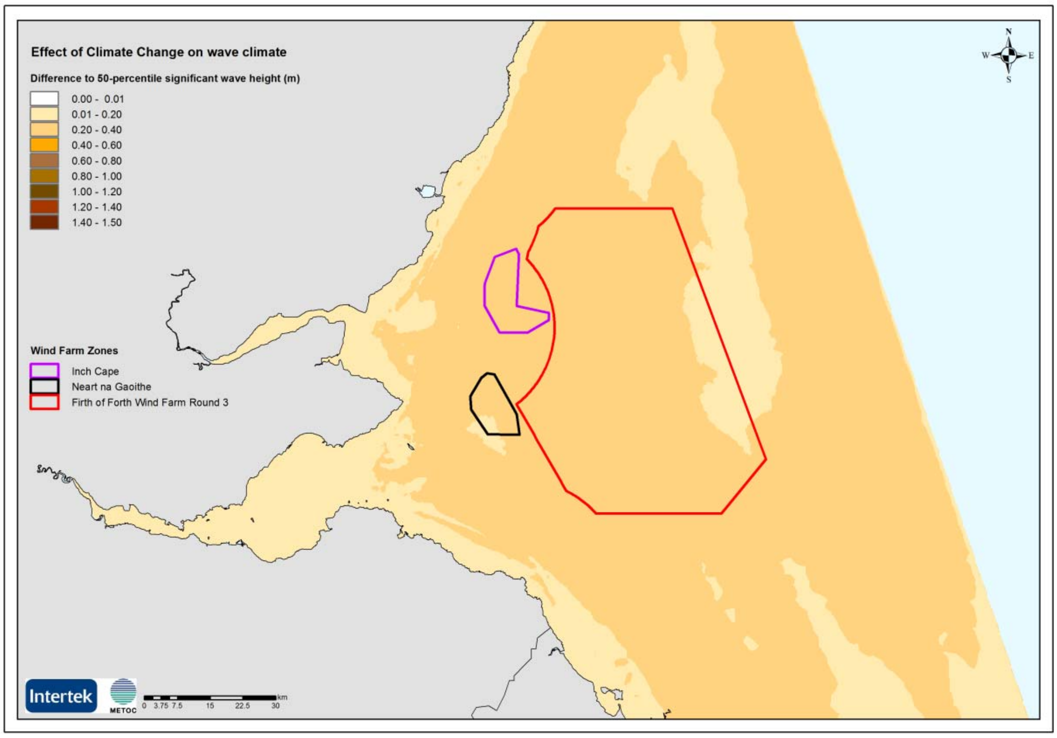


Figure H-154: Difference due to potential climate change to 90-percentile significant wave height (m) – far-field

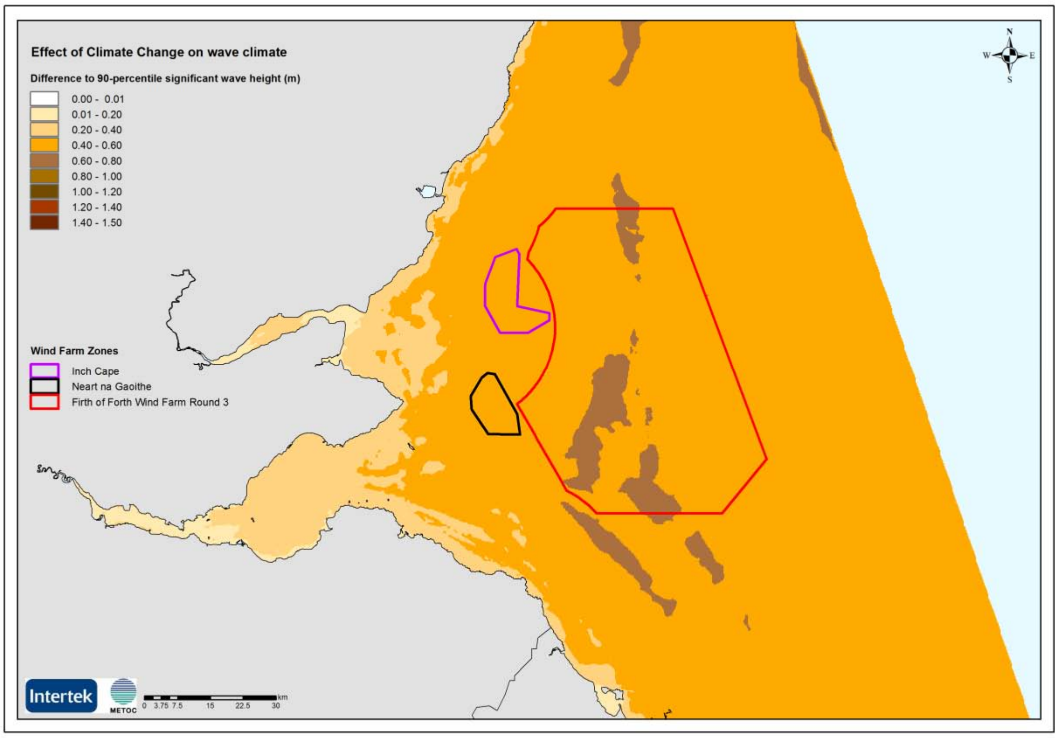


Figure H-155: Difference due to potential climate change to 95-percentile significant wave height (m) – far-field

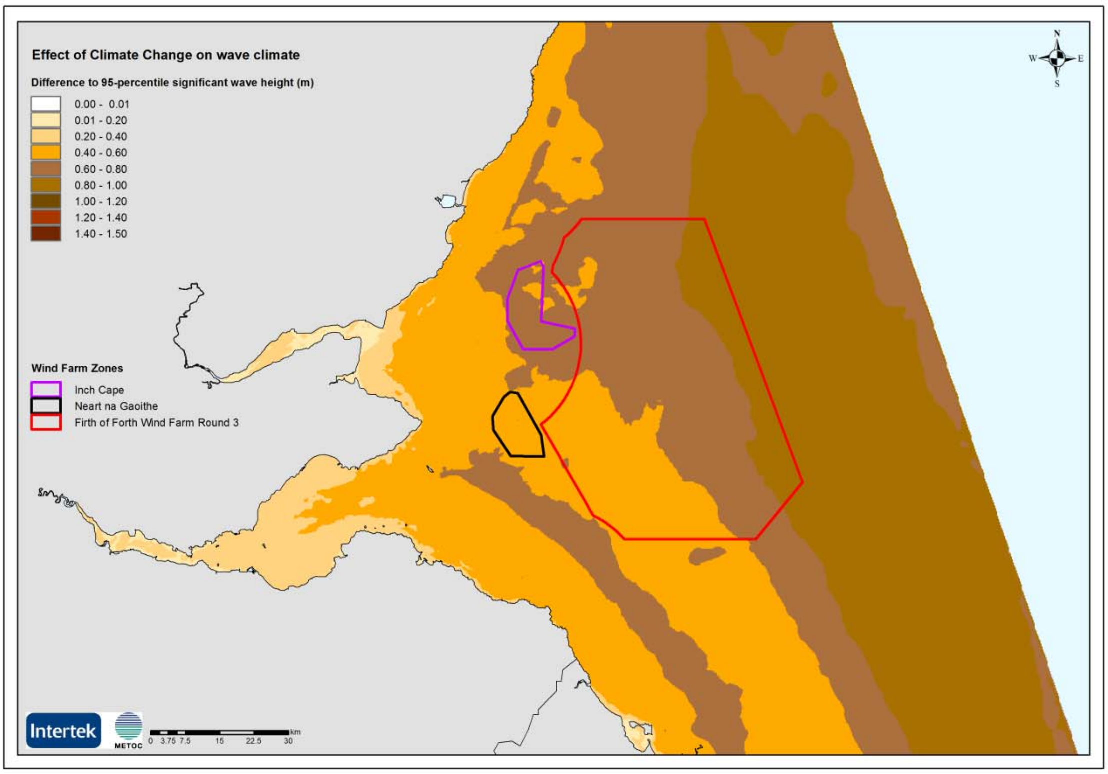
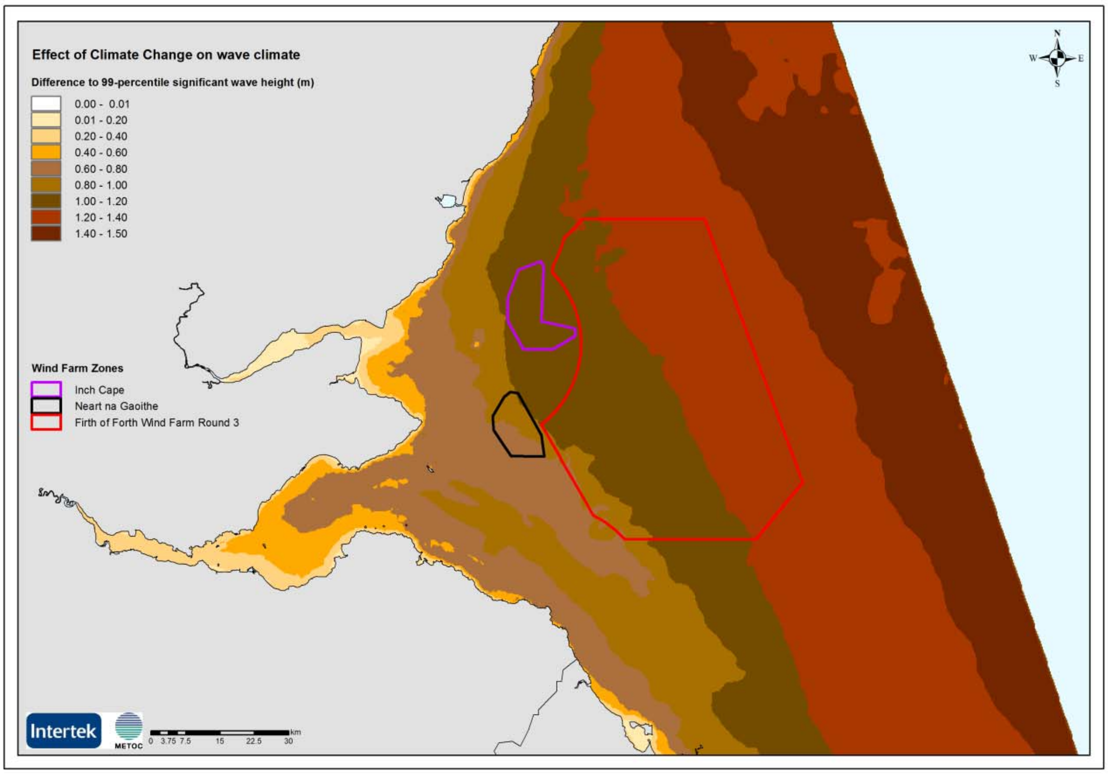


Figure H-156: Difference due to potential climate change to 99-percentile significant wave height (m) – far-field



H.3.3 CHANGES TO THE SEDIMENT REGIME – REGIONAL AREA (FAR-FIELD)

Figure H-157: Difference due to potential climate change of critical shear stress – based on combined (currents plus waves) maximum bed shear stress – far-field

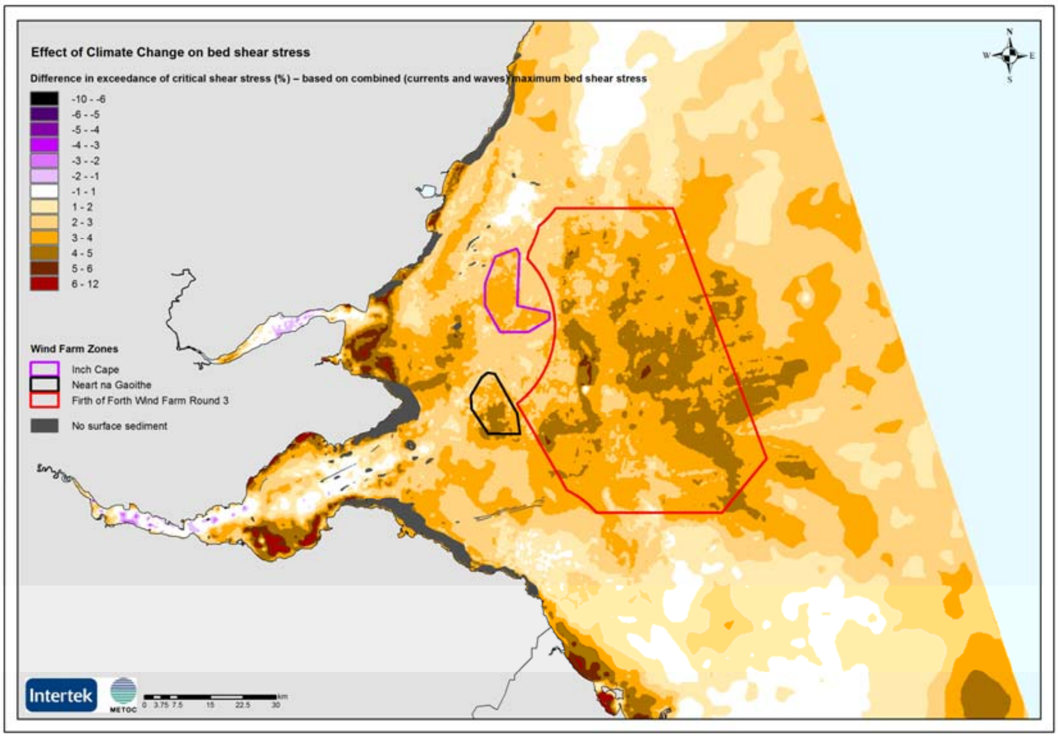


Figure H-158 Difference due to potential climate change of critical shear stress – based on combined (currents plus waves) mean bed shear stress – far-field