Environmental Recources Management

Humber Gateway Offsore Wind Farm: Coastal Processes Baseline Assessment

Date:	**February 2008**
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Environmental Resources Management

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Summary

A comprehensive coastal process investigation has been completed for Humber Gateway Offshore Wind Farm. Hydrodynamic (tidal) wave, sedimentological and morphological regimes have been investigated, using information from a variety of sources. It is shown that the tidal regime is the dominant process with regard to sediment mobility across the wind farm site, with the waves becoming more dominant in the shallower waters. Of note is that the sea bed sediment is generally coarse and as such there is a limited potential for mobility under tides. The most extreme waves originate from the 330°N to 030°N directions, with the typical significant wave height being in the range 0.25m to 0.50m in the wind farm site. Sea bed conditions across the area proposed for development appear to be relatively stable, with only isolated morphodynamic features present. To the south of the development site, New Sand Hole and Silver Pit are noteworthy bathymetric features, providing a natural boundary between the Humber Gateway and those proposed for development to the south, also within the Greater Wash SEA. Sediment transport is typically in a southerly direction, with littoral transport along the adjacent coastline providing a pathway for material reaching the Humber Estuary, the Lincolnshire shore and The Wash.

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Abbreviations

ABPmer	ABP Marine Environmental Research Ltd
ABS	Acoustic Back Scatter
AWAC	Acoustic Wave and Current Meter
BAP	Biodiversity Action Plan
BGS	British Geological Survey
BMAPA	British Marine Aggregate Producers Association
BODC	British Oceanographic Data Centre
CD	Chart Datum
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
Defra	Department for Environment, Food and Rural Affairs
Dft	Department for transport
DHI	Danish Hydraulic Institute
D_{50}	mean grain size
EA	Environment Agency
EIA	Environmental Impact Assessment
ERM	Environmental Resources Management Ltd
ICES	Institute of Coastal and Estuarine Studies
HGOWF	Humber Gateway Offshore Wind Farm
HW	High Water
LAT	Lowest Astronomical Tide
LOIS	Land-Ocean Interaction Study
LW	Low Water
NERC	National Environmental Research Council
OBS	Optical Back Scatter
ODN	Ordnance Datum Newyln
OWF	Offshore Wind Farm
pRamsar	potential Ramsar
pSAC	possible Special Area of Conservation
PSA	Particle Size Analysis
pSPA	potential Special Protection Area
SEA	Strategic Environmental Assessment

SMP	Shoreline Management Plan
SPA	Special Protection Area
SSC	Suspended Sediment Concentrations
SSSI	Sites of Special Scientific Interest
UK	United Kingdom
UKHO	UK Hydrographic Office

Humber Gateway Offshore Wind Farm: Coastal Processes Baseline Assessment

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1. Introduction

ABP Marine Environmental Research Ltd (ABPmer) has been commissioned by E.ON, through Environmental Resources Management Ltd (ERM), to undertake a coastal process study for the proposed Humber Gateway Offshore Wind Farm (HGOWF). The proposed development site is within the Greater Wash area, established from the Strategic Environmental Assessment (SEA) for Round 2 offshore wind farms (BMT Cordah, 2003). More specifically, the site is located approximately 8km outside the approaches to the Humber Estuary, with the southern boundary running parallel to a natural sea bed depression (glacial valley) referred to as New Sand Hole.

The proposed wind farm will occupy around 35km^2 of relatively uniform sea bed. E.ON is seeking permissions for the installation of between 42 and 83 turbines, with a maximum installed capacity of 300MW.

This report provides a description of the baseline coastal process conditions and a detailed technical assessment of the potential significant impacts of the proposed development. An assessment is also made of the potential in-combination and cumulative impacts of the proposed development.

2. Study Requirements

2.1 Regulatory Issues

The coastal process investigation has been developed in accordance to current guidance and best practise: Defra, CEFAS and Dft (2004), OfDPM (2001) and Defra (2005). Furthermore, the detailed specification and required scope of investigations have been developed through discussions with CEFAS. Studies have considered the following phases of development:

- Baseline (pre-construction);
- Construction;
- Post-construction; and
- Post-decommissioning.

Each phase has also been considered over two spatial scales:

- Far-field. Defined as the coastal area surrounding the development site over which remote effects may occur. The far-field includes the coastal area surrounding the OWF site over which remote effects may occur. The boundaries to this area can be summarised as:

- Northern coastal boundary: Offshore parallel to Flamborough Head;
- Western inshore boundary: Flamborough Head to Donna Nook. Note that this includes the outer section of the Humber Estuary;
- Southern coastal boundary: Offshore parallel to Donna Nook; and
- Eastern offshore boundary: Silver Pit.

▪ Near field. Defined as the footprint of the entire development that resides in the marine environment, including the turbine support structures, foundations and cable route.

The baseline, or pre-construction, conditions include a description of the existing coastal process regimes prior to any works on the wind farm site, including a consideration of natural changes (i.e. sea level rise) which may result over the wind farm's operating period (notionally 40 years) to provide context for comparing natural changes against any introduced by the development.

2.2 Stakeholder Issues

The impact assessment has identified and responded to those stakeholder issues relevant to coastal processes, which have been raised as a result of the consultation of the Environmental Impact Assessment (EIA) Scoping Report (Emu Ltd, 2004). These issues are in addition to those generic issues listed in Section 2.1. In total, eight organisations responded to the consultation exercise with concerns relevant to coastal process issues. These concerns are summarised in Table 1.

The issues raised can be grouped into the following:

▪ The likelihood that littoral drift will be affected such that coastal archaeological features will be exposed;
▪ Changes to shoreline processes which may impact Spurn Head and other coastal conservation sites;
▪ Turbidity changes during both construction and operation;
▪ Seabed scour, with the potential to expose paleo features and displace benthic features; and
▪ Scour during construction and installation, with the potential to effect sea bed habitats.

2.3 Assessment of Significance

Coastal process investigations have been undertaken for the far-field and near-field scales, with interpretation offered in terms of the following:

- Baseline Assessment:
  - Coastal processes which maintain the existing system, explanations for past changes and the sensitivity of the system to changes in these processes;
  - Relative importance of high-energy, low-frequency (episodic) events versus low-energy, high-frequency events;
  - Coastal processes controlling morphological change;
  - Identification of sediment sources, pathways and sinks; and
  - Identification of the geological, geophysical and geotechnical sediment properties and the depth of any sediment strata within the wind farm site.

- Impact Assessment. This stage of the coastal process study is reported in ABPmer (2007b):
  - Scour around the turbine structures and consideration of scour protection;
  - Stability of buried cables under the influence of coastal processes;
  - Scour around any cabling overlying the sediment surface;
  - Effect on the spatial distribution of wave patterns, tidal flows and sedimentation (all near-field) and wave direction and energy (far-field);
  - Non-linear interaction of waves and currents and the extent of sea bed sediment mobilisation;
  - Sediment mobility and the natural variability of sediment depth across the near-field and the effect on turbine foundations and cable burial depth;
  - Effect of cable laying on local levels of suspended sediment;
  - Assessment of the scales and magnitudes of processes controlling sediment transport rates and pathways; and
  - Assessment of climate change impact on the coastal process regime.

Table 2 provides an overview of the assessment of significance for each specific issue. This assessment matrix allows potential issues that are clearly insignificant to be determined. If an issue is shown to be significant, this has been assessed further based on the magnitude of the anticipated change (relative to baseline values), the location of the change (i.e. proximity to key features or interests), the measurability of the change, and expert-led judgement.

Table 1. Consultee responses of relevance to coastal process issues

Coastal Process Issue	Body										
	ERM	Wessex Archaeology	Humber Archaeology Partnership	ABP Humber Estuary Services	Countryside Agency	English Heritage	Fisherman	Environment Agency	North Lincolnshire Council	RMC	Statoil ASA, Langeled Project
Hydrodynamic (waves)				Directions, speeds and surges		Tidal ellipses					
Hydrodynamic (tides)				Pilotage routes							
Bathymetry						Scour	Suspension and deposition; plumes			Suspended Sediment Concentration	
Sediment regime	Spurn Head			Spurn Head	Spurn Head						
Morphology			All other resources					Other OWF and offshore developments	Shoreline defences		Statoil Pipelines
In-combination/ cumulative effects	Benthic receptors, Sabelleria	Archaeology, wrecks and paleo-features	Coastal erosion rates		Erosion and deposition				Saltmarsh loss; geomorphology of intertidal mudflats		
Coastal				Scour							
Foundations			All proposed routes					Exposure by erosion			
Cables								All coastal processes			
General											

Table 2. Criteria for the initial assessment of 'insignificance' applied to various potential coastal process changes

Near/Far Field	Regime	Issue	Specific Question to be Addressed	Criteria for 'Insignificance'
Far	Tidal	Changes to flows	Direction/magnitude	No anticipated large scale alteration to tidal flow speeds and/or direction on a regional scale. Assessment to take into account the magnitude of baseline flows and the magnitude of the change with respect to these baseline flows.
			Tidal residuals	No anticipated changes to the direction and magnitude of residuals, relative to the baseline, that represent a switch in tidal dominance (i.e. flood to ebb or visa versa) or alterations to gross residual circulations around banks, sufficient to affect bank maintaining processes.
	Wave	Changes to wave climate	Alteration to regime wave climate characteristics	No anticipated changes to the regional wave climate that would be expected to impinge upon other sea bed uses/features or along adjacent coastline.
	Sediment	Increase in Suspended Sediment From Foundation spill	Creation of Plume	No anticipated increases in background suspended sediment levels with a duration and extent considered to impact upon sea bed/coastal interests.
			Fate of Sediment	No anticipated deposition of sediment on the sea bed arising from foundation spill impacting upon sea bed features/users, for example smothering of benthos, reduction in navigable depths.
	Sediment	Increase in Suspended Sediment	Impacts from cable laying (Sediment Disturbance)	No anticipated increases in background suspended sediment levels arising along the cable route due to the cable burial process with a duration and extent considered to impact upon other adjacent sea bed/coastal interests.
	Sediment	Changes existing transport pathways	Changes to bed load pathways	No anticipated alteration to a known bed load transport pathway that is likely to impinge on features supplied by the pathway. The direction and magnitude of the pathway to be considered where possible along with the sensitivity of the environment.
			Changes to suspended sediment pathways	No anticipated alteration to a known suspended load transport pathway that is likely to impinge on downdrift features or features affected by any newly created pathway. The direction and magnitude of the pathway to be considered where possible along with the sensitivity of the environment.
	Sediment	Changes to coastal sediment transport	Alteration to existing transport along the Holderness and North Lincolnshire coasts	No anticipated alteration of longshore or cross-shore coastal sediment transport along adjacent stretches of coast likely to have a detrimental effect on the form and function of coastal and associated features. The direction and magnitude of the pathway to be considered where possible along with the sensitivity of the environment.
	Sediment	Scour	Creation of Plume	No anticipated increases in background suspended sediment levels with a duration and extent considered to impact upon sea bed/coastal interests.
			Fate of scour material	No anticipated deposition of sediment on the sea bed arising from scour around foundations impacting upon sea bed features/users, for example smothering of benthos, reduction in navigable depths.
	Sediment	Humber Gateway/Ag. Dredging interaction	Interaction of sediment plumes	Assessment of the potential for the interaction of any sediment plume arising from the two activities. Considered insignificant if no anticipated interaction that leads to a greater effect than would be reasonably expected from the two individual activities not acting 'in combination'.
Near	Tidal	Changes to flows	Bifurcation (splitting into two parts) of flows around structures	Structures in the marine environment will inevitably lead to flow bifurcation. However, these changes would be expected to be localised and should be confined to within the wind farm site and a narrow strip outside of the site boundaries. To consider the significance in more detail requires placing the changes to flows into the context of their implications for sediment transport. Therefore, changes to near field flows are considered insignificant if they do not lead to scour effects that are considered significant (see 'Scour around Structures' section below).
	Wave	Changes to wave heights	Changes to wave transmission	As above, structures in the marine environment will inevitably lead to a change in wave transmission past the structure. However, these changes to waves would be expected to be localised. Therefore, if the changes to wave transmission do not translate to a significant change to the regional wave climate, then these changes are considered insignificant (See: far field changes to wave climate, above).
	Sediment	Scour around structures	Creation of scour holes	The turbine structures will also inevitably lead to a degree of scour (in the absence of scour protection). However, provided the scour holes created by each individual structure do not interact with adjacent scour holes then this can be considered to be insignificant, in the context of physical processes and the physical environment.

3. Study Area

3.1 Overview

HGOWF is located approximately 8km offshore from the Yorkshire Coast, near the Humber Estuary in the Greater Wash SEA, as shown in Figure 1. The 35km² of sea bed proposed for the development is in relatively shallow water (approximately 15m Chart Datum (CD)) where the sea bed is generally flat and stable. Depths are given below Lowest Astronomical Tide (LAT), which in this region is approximately 3.9m below Ordnance Datum Newlyn (ODN).

Details pertaining to the bathymetric and morphodynamic features within the far- and near-field area are given in Section 5.3.

3.2 Other Sea Users

The range of other sea bed users present within the far-field region of the study area are detailed in the following text.

3.2.1 Aggregate Dredging

There are currently eleven licensed and two proposed dredging areas situated off the Holderness coast, three of which are located close to the site (Figure 2). Brief site details are shown in Table 3.

Table 3. Licensed dredging areas in the vicinity of proposed development site

Company	Site	Distance from HGOWF (km)
British Dredging Ltd	102	0.0
	105	5.5
	107	43.5
Hanson Aggregates Marine Ltd	106A	19.2
	106B	27.3
	106C	30.0
	408	87.5
Cemex (proposed sites)	448	0.0
	449	4.0
Westminster Gravels Ltd	440	40.6
	441/1	50.5
	441/2	53.0
United Marine Dredging Ltd	197	20.0

The main possible in-combination effect between an OWF and dredging activity would be the potential for overlapping plumes of sediment (e.g. combination of plumes arising due to OWF construction impacts and aggregate dredging overspill). In terms of the present study, it is therefore apparent that in-combination effects should be considered between a wind farm and an aggregate extraction site where the potential for *significant* overlap exists between sites in the transport of suspended sediment plumes, based on pathways defined by ellipses representing one tidal excursion.

The area available to be dredged (the active area) is normally the area covered by the licence, however it can be reduced through zoning; this is imposed either through licensing regulations or through voluntary measures by the dredging company to reduce the extent and environmental impact of their activities. Since 1999, The Crown Estate and BMAPA have, produced annual reports showing the area of seabed licensed, the 'active' area (the area available to be dredged) and the locations actually dredged. Information from the reports relating to the Humber seabed region is summarised in Table 4.

Table 4. Humber region dredging statistics

Report		Area (km²)			Total Extraction (million tonnes)
No	Date	Licensed	Active	Actually Dredged	
1	1999	468.5	-	51.3	-
2	2000	478.4	-	57.5	2.84
3	2001	478.4	-	33.11	3.81
4	2002	518.30	334.95	27.61	-
5	2003	483.68	386.82	30.40	3.11
6	2004	483.68	266.12	24.5	3.23
7	2005	483.68	146.70	31.2	4.58

(Source: The Crown Estate/BMAPA, The Area Involved Reports)

As Table 4 shows, the area dredged is relatively small when compared to the active and licensed dredging areas. This information has been taken into consideration when assessing the need for in-combination studies.

Aggregate site 102 and Cemex's proposed sites 448 and 449 are located closest to the OWF development site. Aggregate site 102 adjoins the OWF to the east and the proposed Cemex sites (448 and 449) to the south of the OWF and 102. Within site 102 the southern half is dredged more intensively elsewhere, as denoted by the blue cross-hatching in Figure 2.

British Dredging Ltd is part of the same group as Cemex. Cemex has expressed concerns about the HGOWF having the potential to disrupt existing and proposed extraction, dredger manoeuvring, dredger transit routes, navigation and communication systems.

3.2.2 Disposal Sites

There are three licensed disposal sites within the far-field; (1) HU100 at Spurn Head, which overlaps dredge site 105; (2) HU110 at Humber 1; and (3) HU111 at Bull Sand Fort. Spurn Head is by far the largest of the three sites. Importantly, there are no spoil disposal sites directly within HGOWF (Figure 1).

3.2.3 Sub-Sea Cables and Pipelines

Of those listed in Table 5, the first crosses the northern section of the HGOWF site around which a 250m no-build zone exists. This pipeline is maintained by Brit Oil.

Table 5. Details of the offshore sub-sea cables and pipelines for consideration

From - To	Length (km)	Diameter (mm)	Material Conveyed	Operator	Year Commissioned
Amethyst - Easington	48	762	Natural Gas	Britoil	1990
West Sole - Easington	67.6	406.4	Natural Gas	British Petroleum	1967
West Sole - Easington	70	610	Natural Gas	British Petroleum	1982
Rough - Easington	29.6	406.4	Natural Gas	British Gas	1975
Rough - Easington	29.9	914.0	Natural Gas	British Gas	1984

(Source: DTI Brown Book, 2001)

3.2.4 Offshore Wind Farms

The location of other offshore wind farms within the far-field area are shown in Figure 1.

3.2.4.1 Round 1 offshore wind farms

The allocation of sites from Round 1 provided for three offshore wind farm in the Greater Wash SEA region; Lynn, Inner Dowsing and Cromer all located south of HGOWF. These sites are considered too remote from HGOWF to be relevant to any cumulative impact issue.

3.2.4.2 Round 2 offshore wind farms

Seven sites have been allocated within Round 2, as listed in Table 6. It is only the Westermost Rough site that requires consideration in this coastal process study. This proposed development site is located some 8km offshore from the Yorkshire coastline, as illustrated in Figure 1. The predicted tidal ellipses between this and the HGOWF sites are considered by CEFAS to be sufficiently large enough to transport sediment between them, as shown in Figure 3. More importantly, both sites lie on a major sediment transport pathway and thus these two offshore wind farm sites should have a cumulative impact assessment in terms of coastal processes.

Table 6. Round 2 offshore wind farms in the Greater Wash SEA region

Company	Project Name	Total MW Awarded
Centrica	Docking Shoal	500
Centrica	Race Bank	500
Ecoventures	Sheringham	315
Npower renewables	Triton Knoll	1,200
Offshore Wind Power	Lincs	250
Warwick Energy	Dudgeon East	300
DONG Energy	Westermost Rough	240

3.3 Cumulative Impacts

Concern has arisen regarding the cumulative, and in-combination, effects of the Round 2 developments as a consequence of (i) a general increase in the footprint; and (ii) clustering of activities within a strategic area. Discussions with regulators, i.e. CEFAS and Defra, has led to the following recommendations:

- Other users must include other wind farm developments. This is to be done sequentially in time i.e. consideration must be made of those that are likely to already be developed;
- All developments, both known, under consideration and in existence must be considered; and
- All developments within one tidal excursion must be considered. (Tidal excursions with respect to The Wash are shown in Figure 3).

These considerations have been acknowledged in a report produced for The Wash developers, (Posford Haskoning, 2004), entitled 'Greater Wash Round 2 Offshore Wind Farms: Cumulative Effects'', which stated that:

> *"in the context of offshore wind farms, cumulative effects might occur as a result of the development of an offshore wind farm at a single site, from multiple sites in close proximity, or in combination with effects from other human activities, such as aggregate extraction, marine disposal, dredging operations, pipeline construction, natural processes and also other users of the sea".*

Agreement with the stakeholders was reached such that the HGOWF need not consider any sea bed users to the south of Silver Pit (the location of which is shown in Figure 1). This is because this feature, in addition to New Sand Hole, act as a major process divide, thereby reducing the cumulative effects of offshore wind farms to the south of the HGOWF site. Further constraints on the other sea-bed users for consideration are in relation to tidal excursions; Figure 3.

The relevant users which need consideration for HGOWF are presented in Table 7 and Figure 4, based on consideration of likely transport pathways between sites.

Table 7. Sea bed users for consideration of cumulative and in-combination effects

Aggregate Site	Sub-Sea Cables and Pipelines	Port Development	Dredging (Capital and Maintenance)	Offshore Wind Farms
102	Amethyst to Easington	n/a	n/a	Westermost Rough (Round 2)
448	West Sole to Easington			
449	Ravenspurn to Easington			
	Rough to Easington			
	Langeled			

4. Phases of Development

There are four main phases of development that require consideration in the coastal process assessment. As stated in Section 2.1, these are:

- Baseline (including the pre-construction);
- Construction phase;
- Post-construction; and
- Post-decommissioning.

Details pertaining to these developmental stages, as provided in the Humber Gateway Environmental Statement Project Description are given in the following sections. It is expected, due to the risk of unfavourable weather conditions, any offshore works to the wind farm development will be restricted between 1 April and 31 September. It should also be noted that further restrictions may also apply due to ecological and environmental reasons.

4.1 Pre-Construction

The pre-construction phase considers the coastal processes prior to any wind farm works. The investigation of this phase is relevant as it provides a condition to which the coastal processes during all other phases can be compared. It should be noted that any changes to the coastal processes within the lifetime of the array due to natural variability (i.e. storm events) and changes (i.e. sea level rise) will also be compared to this phase.

Pre-construction conditions are detailed in Section 5.

4.2 Construction

It is anticipated that, based on the installation of 80 turbines, the construction phase will take two years to complete with all foundations installed in the first year, and turbines and cables in the second. The indicative construction programme, as provided in the Humber Gateway Environmental Statement Project Description, is given in the table below.

Table 8. Proposed construction programme for Option 1 (300MW)

Task Name	2011				2012			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
Foundations								
Export Cables								
Array Cables								
Turbines								
Commissioning								

(Source: Humber Gateway Environmental Statement Project Description)

4.2.1 Hydrodynamic and Wave Regimes

Impacts upon the hydrodynamic regime, as a consequence of the construction phase, are typically only likely to be associated with the presence of engineering equipment, for example jack-up barges, placed temporarily on site to install, for example, the turbine structures. As such equipment is only likely to be positioned at one site at a time for a relatively short duration (of the order of days), the consequential effects upon the hydrodynamic regime is deemed to be small in magnitude and localised over both temporal and spatial scales.

In addition, health and safety regulations are such that it is likely that operations will only be undertaken during conditions of relatively small waves.

4.2.2 Sedimentological Regime

It is during the construction phase that the greatest impact upon suspended sediment concentrations and consequential sediment deposition is anticipated. However, this impact is only expected to occur over the short-term (order of days) during the period of construction. The effects could be as a consequence of the:

- Release of material during the installation of the structures; and /or
- Release of material during the cable laying process.

To further investigate the potential impacts due to these activities, a plume dispersion model has been used. This model is able to simulate the spatial and temporal distribution of suspended substances discharged into coastal areas or open seas, using the flow conditions provided by the hydrodynamic model.

4.3 Operation

It is intended to extend the existing site lease that E.ON hold to 40 years. Further, the lifetime of the turbines is expected to be 25 years.

4.3.1 Hydrodynamic Regime

It is the effects during the operational phase that have the potential to be both larger in magnitude and may exist over the extent of the array over the near- and far-fields. In addition, the effects could last over greater temporal scales. Potential changes may occur to the water levels, current speeds and directions. Impacts during this phase have been investigated further with numerical modelling techniques, as shown in Section 5.2.2.1.

4.3.2 Wave Regime

It is the effects during the operational phase of the development upon that are likely to have greater effects upon the wave regime, both in the near- and far-fields. The parameters of the wave climate that may undergo change are the wave heights, periods and directions. The potential effects during this phase have been assessed using parametric and numerical modelling techniques, as detailed in Section 5.

4.3.3 Sedimentological Regime

Effects upon the sediment regime during the operational phase of the modelling may occur through:

- The alteration of suspended and/or bed load sediment transport pathways within the regional and/or local domains;
- As scour around the turbine foundations and/or the cables, with the potential for material to be transported away from the development location; and
- Changes to the littoral drift processes on the coastline.

The potential effects during this phase have been assessed using parametric and numerical modelling techniques, as detailed in Section 5.

4.4 Decommissioning

It is anticipated that, based on the installation of 80 turbines, this phase will last six years, of which the ‘physical’ decommissioning programme will take one year.

In the instance of monopile and tripod foundations, it is anticipated that the structure will be cut such that any pile that remains in the sea bed are unlikely to be uncovered. For the gravity base and suction caisson foundations, it is expected that the entire foundation will be removed from the sea bed.

4.4.1 Hydrodynamic and Wave Regimes

It is assumed that the decommissioning phase will involve the removal and/or burial of any structures related to the wind farm development. Therefore, impacts upon the hydrodynamic and wave regimes as a consequence of this phase will be comparable to those identified for the construction phase, and thus no significant post-decommissioning impacts are anticipated.

4.4.2 Sedimentological Regime

The effects upon the sedimentological regime during the decommissioning phase are anticipated to be comparable to those of the commissioning phase.

5. Pre-Construction Assessment

5.1 Introduction

The pre-construction and baseline has been established using the best available resources to date. This includes literature and reports (both academic and commercial), surveys (undertaken both outside and within the wind farm EIA process) and numerical modelling.

5.2 Data and Information Sources

The study has successfully collated and utilised a number of important data sets and reports to: (i) develop a comprehensive understanding of the study area; (ii) form the basis of model configuration and calibration; and (iii) assist in gaining a conceptual understanding of coastal process linkages.

Information from the following principal surveys has been used in the project, the details of which can be found in the coastal process scoping study ABPmer (2005).

5.2.1 Surveys

5.2.1.1 Metocean surveys

A hydrodynamic deployment was undertaken between the 26 March 2004 and 16 November 2004. A Nortek AWAC Buoy was deployed at a location central to the proposed OWF site, as illustrated in Figure 6, where the depth is, approximately, 11m (CD). It should be noted, that due to the uniformity of the proposed site, and the absence of any major sand bodies, the data collected at this location are expected to be representative to the whole site.

In general, the survey shows that the:

- Dominant wave direction is from the north north-east (42% occurrence);
- Largest waves originate from the north north-east;
- Most common wave period is in the range 5 to 6s (19% occurrence);
- Most common wave height is in the range 0.25 to 0.5m (25% occurrence);
- Largest waves are in the class 3.50 to 3.75m, and are generally associated with the mean wave period in the range 6 to 7s;
- Tidal range is, for neap and spring tides, of the order of 2m and 7m, respectively;
- Maximum tidal currents are of the order of 1.5m/s. It should be noted that this recording coincides with a storm event; and
- Ambient suspended sediments are generally a function of occasional fluxes across the site derived from an alternative source.

5.2.1.2 GeoPhysical surveys

A geophysical survey was undertaken between the 27 September and 26 November 2004 by Titan Environmental Surveys, designed to provide detailed information on the bathymetry, sea bed morphology, sea bed sediments, obstructions and shallow geology within the proposed OWF site and along the cable route. Full details of the survey can be found in Titan Environmental Surveys Ltd (2004).

In general, the survey shows that:

- Bathymetry ranges from 16m to 21m (ODN) within the site;
- There is little topographic variation;
- Bedforms (sand waves; sand ribbons) are localised within the site. Close to the shore, low gravel ridges are present;
- Mobile sediment layer is limited; and
- The geological sequence is dominated by Bolders Bank Formation.

5.2.1.3 Benthic surveys

Detailed surveys were undertaken by Institute of Coastal and Estuarine Studies (ICES) during December 2004. Within the survey, 55 grab samples were collected, of which 21 were directly within the site, the location of which are shown in Figure 6. Particle Size Analysis (PSA) was undertaken by ABPmer using the grab sample data provided by ICES, for full details the reader is referred to ABPmer (2005).

In general, the survey shows that:

- General sediment type across the site is classified as sandy gravel, with occasional gravels and occasional muddy sandy gravels; and
- At sites with descriptions of muddy sandy gravel, the mud content is generally very low and is always less that 5.6%.

An additional survey was undertaken in 2007 to determine the sedimentary characteristics of some 'spiky features' identified from the geophysical survey along the export cable routes. PSA work was undertaken and is reported in Ambios Environmental Consultants Ltd (2007). In summary, the survey indicated that these features are composed of gravels and sands.

5.2.2 Data Acquisition

Additional information has also been obtained from other sources to complement that obtained from the metocean, geophysical and benthic surveys previously described. The additional data acquisition has included:

- East Riding Council. Datasets obtained include cliff erosion rates along the Holderness coast and beach profile data between Mappleton and Spurn Head. This data has been used to setup and calibrate the littoral drift model and provide a baseline which to compare the effects of the wind farm against;

- SeaZone charted vector and hydrospatial bathymetric data. This data has been used to inform the far-field model domain and provide basemapping;

- WaveNet Data. On behalf of Defra, CEFAS operates 'WaveNet', a strategic wave monitoring network for England and Wales that provides a single source of real time wave data from a network of wave buoys located offshore from areas at risk from flooding. One of the buoys is located 50km to the east of the HGOWF site at 53°31.74'N and 001°3.21'E in approximately 22m CD of water. Data were obtained from this buoy for the period October 2003 to November 2004;

- ABP Wave Buoy. A sea-bed mounted wave recorder is located, approximately, 14km from the HGOWF in the entrance to the Humber Estuary. However, it should be noted that this recorder provides intermittent data records;

- TotalTide tidal level data. The TotalTide numerical modelling package has been used to synthetically generate astronomical tidal level data and current speed so that measured data from the metocean surveys can be compared against the model data for an assessment of consistency;

- British Geological Survey (BGS) surface sediment information has been used to provide a more regional indication of the sea bed material. It also provides confidence in the grab samples provided by the benthic survey;

- Met Office data. Wind and wave timeseries from the European Wave Model provides details on the offshore wave climate. Timeseries data has been provided between 1997 and 2006 at a point located at 54.0N 0.34 E, and extremes calculated for directions 330º, 0º and 30º, for return periods of 10:1, 1:1, 1:10 and 1:50;

- CEFAS current meter data from the iSEA website has been used to help calibrate current speeds within the hydrodynamic model; and

- In addition, current meter data from the British Oceanographic Data Centre (BODC) at alternate sites to the CEFAS data, has been used for the same purpose.

Further to the additional data sets acquired for use in this study, a number of reports have also been used which hold direct relevance to this project. These include, but are not limited to:

- Ground conditions at Humber Gateway Wind Farm, D'Olier 2006a;
- Humber Gateway Wind Farm, The projected cable route 'spiky features', D'Olier, 2006b;
- Offshore Humber - Sites A, B, E. Geological Desk Study, D'Olier, 2003;
- Land Ocean Interaction Study (LOIS) reports;
- Humber Gateway Environmental Statement Project Description; and
- Rochdale Envelope, ERM 2007.

5.2.2.1 Numerical modelling

Numerical models have been developed to provide a baseline assessment of coastal processes within the study area (as previously defined in Section 3). These will also be used to assess the effects of the potential development phases (construction; operational; decommissioning; Section 4) upon the existing coastal processes. This has been performed over the far- and near-field scales allowing different effects to be determined

The Danish Hydraulics Institute (DHI) suite of numerical models (MIKE21 and MIKE FM) have been used within this study. The selection of modules used is defined within the matrix below, which identifies the module used to simulate each regime.

Table 9. Matrix of numerical model modules

Process/Module	Mike FM HD	Mike FM SW	LITDRIFT	Mike 21 PA	Mike 21 ST
Hydrodynamics	•				
Waves		•			
Sediment Transport					•
Sediment Plumes				•	
Littoral Drift			•		

Technical details of these models, in addition to the proving techniques, are provided in ABPmer, 2007a. The procedure for model proving is based on the need to demonstrate that each of the models are 'fit-for-purpose' for the range of scenario tests required. For example, in the context of hydrodynamics, this has required calibration and validation of the models over the full range of tides - from neaps to springs - and comparing predicted values to equivalent measured data (i.e. water levels and current speeds and directions).

5.3 Sea Bed And Coastal Features

5.3.1 Bathymetry

The bathymetry of the proposed site is shown in Figure 7. Individual soundings across the site show that the depth typically varies between 16 and 21m (ODN). The shallowest part of the site is at the south-eastern corner where a small area of ground is shown to be 13.2m (ODN) whilst the greatest depths (23.0m ODN) are found in the north-eastern corner.

Sea bed slopes are gentle, as observed through the collection of the cable route bathymetry. It is shown (Titan Environmental Surveys Ltd, 2004) that along the route, the sea bed gradients are typically less than 1º. As would be expected these increase in the nearshore, as a consequence of nearing the shoreline. Gradient increases are observed 1.25km and 0km from the shore for the northern and southern routes, respectively. A maximum slope of 80º and 70º are observed for these routes, respectively.

5.3.1.1 Inner Silver Pit and New Sand Hole

Two bathymetric depressions are present to the south west of the HGOWF site, Inner Silver Pit and New Sand Hole (Figure 1). The characteristics of these features are given in Table 10.

Table 10. Characteristics of Inner Silver Pit and New Sand Hole

Feature	Location	Length (km)	Width (km)	Depth (m)
Inner Silver Pit	130km east of the Yorkshire coast. Extends into axis of The Wash as the Lune Deep	55	2 - 5	< 70m
New Sand Hole (2)	15km east of the Spurn Head peninsula	10	1.5	< 45m below mean sea level (MSL)

(Source: (2) Balson, 1997 in LOIS)

These palaeovalleys are incised into deposits of the last glacial episode and have been studied extensively in the National Environmental Research Council's (NERC) Land-Ocean Interaction Study (LOIS) providing detailed bathymetry (Balson, 1997 in Proctor *et al*., 2001).

Across Inner Silver Pit, a path for fine sediment is established but does not significantly modify the sediment dynamics of the pit (Proctor *et al*., 2001). The Outer Silver Pit is partially infilled with muddy deposits and may be a further sink for mud.

5.3.2 Coastal Features

There are a number of notable features. These are discussed in more detail here.

5.3.2.1 Holderness coast

As previously stated, the Holderness coast stretches for over 50km from Flamborough Head in the north to Spurn Head at the mouth of the Humber Estuary in the south. Most of this length of coastline consists of cliffs up to 38m high of glacigenic sediments. The cliffs are undefended for most of their length and are subject to severe erosion and rapid recession with long-term recession rates typically 1 to 3 m per annum (Land Ocean Interaction Study, 2000). However, some regions of the coast may experience erosion rates of up to 20m per annum (cf. IECS, 2007). Further, the nearshore sea bed also experiences erosion of the order of 2m per annum (IECS, 2007). Analysis of a monitoring programme along part of the Holderness coast suggest that the erosive behaviour follows a cyclic pattern of 3 to 5 years, within which the erosion rates respond to the prevailing weather conditions, for example in response to storm events (IECS, 2007). It is expected that the erosion rate will increase with rising sea levels. Conclusions are made that the area of the Holderness coast intended for the OWF cable landfall may undergo an erosion rate of between 95 and 200m over the next 40 years (IECS, 2007).

The rapid recession to the beaches and the nearshore coastal waters is a result of wave and tidal forces. The waves tend to undercut the cliffs, making them prone to failure and both waves and tides typically transport the material away from the source. Waves predominate from the north-east (for approximately 25% of the time). The dominant longshore transport direction along the coast is to the south (Balson *et al*. 1997).

The sediment supply to the North Sea is dominated by the inputs from the east coast of England, most notably from the Holderness coastline. The large-scale long-term transport path for this material has been known for many years to follow the anti-clockwise meteorologically driven flow in the southern North Sea, (Proctor *et al*., 2001). Further details of this sediment transport system are provided in Section 5.3.

A significant coastal feature is the large-scale (5.5 km long) sandy peninsula of Spurn Head. The present location of Spurn Head is the latest in a series of spits which have extended from the north across the Humber Estuary entrance. Through time, this feature has grown longer, been breached and subsequently re-formed further west (HR Wallingford *et al*., 2002). It is suggested that it is only due to anthropogenic intervention that the present spit has remained in its location for such a long period of time. Debate exists concerning whether or not Spurn Head is an example of a spit (cf. IECS, 1994) for, according to the prevailing hydrodynamic processes:

- The tidal range of the Humber Estuary is too large for the development of a spit (6m, compared to the 2 to 4m range present at all other spits around the UK); and
- The tidal currents are too fast to allow for the deposition of sandy material.

It has been hypothesised that Spurn Head originates from the accretion of sub-tidal sand banks on top of a gravel ridge, possibly of glacial origin. Gravelly sands are located to the north of The Binks and sands to the south, whilst within the Humber, mud and muddy gravelly sediment predominate.

5.3.2.2 Lincolnshire coast

The Lincolnshire coast stretches from Donna Nook at the mouth of the Humber Estuary southwards to The Wash. Historical evidence has shown that Donna Nook acts as a sediment sink for the finer grained sediments eroded from the Holderness Cliffs. This is supported by numerical modelling (HR Wallingford *et al*., 2002) which has shown that the convergence of tidal currents has resulted in sediment deposition such that the lower foreshore has undergone substantial accretion. The coastline to the south of Donna Nook is exposed to increased wave action such that the silts and muds are typically transported offshore and the sands to the south. It has been estimated that 0.045M tonnes per annum of fine sediments are transported from the Lincolnshire coast to the North Sea (ABP, 1996). This feature is designated as a Lincolnshire Wildlife Trust Nature Reserve, home to many breeding birds and one of the UK's largest breeding grey seal colonies.

Further south, the Mablethorpe to Skegness coastline has undergone erosion, partly attributed to foreshore reduction. A large portion of this shoreline has coastal defences installed, and has also undergone the largest beach recharge in the UK (HR Wallingford *et al*., 2002). In contrast, to the south of Skegness and in the approaches to The Wash a sediment sink is present such that spit features, sand banks and sand dunes are present at Gibraltar Point.

Sediment transport has been shown through field and numerical modelling studies to be in a southwardly direction along this coastline, with the effects of waves becoming more dominant towards the south and principally active on extreme storm surge events (HR Wallingford *et al*., 2002).

5.3.2.3 Estuaries; Humber Estuary

The Humber Estuary is characterised as a Type 4a single spit enclosed estuary (Defra, 2002). It is a tidally-dominated estuary, although there are significant freshwater inputs (Townend and Whitehead, 2003). The tidal asymmetry is ebb dominant and the cross sectional area ratio suggests that the estuary is sediment dominated (Defra, 2002). Sediment eroded from the Holderness coastline enters the estuary and it is suggested (Defra, 2002) that the estuary could be a strong sink for sediment, both coarse and fine. However, other reports suggest that the Humber is a mature sink with little capacity for further deposition (HR Wallingford *et al*., 2002). The Humber has a high suspended sediment concentration which is transported beyond the mouth on the ebb tide. Further details regarding suspended sediment transport is provided in Section 5.5.

At the estuary mouth is 'The Binks', a sand bank feature composed of gravelly sands which upon which high sand waves exist. Parts of this feature dry at Low Water (LW). Sand flats and linear banks are a common feature within the mouth, and intertidal mud flats exist both at the mouth and at the estuary head (Defra, 2002).

5.3.3 Contemporary Morphology

The recent bathymetric survey (Titan Environmental Surveys Ltd, 2004) shows that within the proposed development site, there is a topographic rise running from the southern central part of the survey along a south south-western to north north-eastern axis. On the eastern flank of this feature exist several ridges, of a maximum height of 3m, orientated west south-west to east north-east. To the west of this feature exists several gravel ridges, of a maximum height of 3.5m, orientated north-west to south-east. This latter feature is shown in Figure 8. It is suggested that these ridge features consist of englacial debris carried to the sea bed by faulting along inclined shear planes during the periods of glacial depositional activity (D'Olier, 2003). The presence of the coarser material has rendered the features resilient to erosion.

Sand waves with heights exceeding 5m are present in the south of the development site, and are illustrated in Figure 9. The orientation of these bed forms indicate a north-south sediment transport direction. These features suggest that the surface sediment has a mobile nature. Sand ribbons and patches have also been observed across the proposed HGOWF site. Indeed, D'Olier (2003) reported that localised, thin and ephemeral sand ribbons and sand patches were located on the sea bed. These features transverse from north to south, although this direction may be reversed at certain tidal states and strong wind-wave events, thus supporting the southerly/south-easterly sediment transport direction.

The geophysical survey (Titan Environmental Surveys Ltd, 2004) shows that, with the exception of the area to the south of the OWF which is covered by sand waves, there is little mobile sediment on the sea bed. Instead, there is a veneer of sediment which is typically composed of sandy gravel and gravely sand with pebbles, cobbles and small boulders. The depth of this veneer is typically a few decimetres to centimetres. In addition, boulders and areas of boulder clay exposure are also present within the site. It has been suggested (D'Olier, 2003) that there are unlikely to be scour effects within the development site due to limited availability of the mobile sediment and the dominance of the exposed Bolders Bank Formation, which is formed of stiff to very stiff clays (see Section 5.1.3).

Side scan sonar data recorded along both cable routes indicate that, with the exception of the shoreline, a veneer of sandy gravel and gravely sand is present over a layer of boulder clay. It is suggested that the veneer is derived from the boulder clay. Along the shoreline, beach sands are present. Morphological features in the form of vertical ridges, or 'Spiky Ridges' were observed along both routes. It has been shown (D'Olier, 2006b; Ambios Environmental Consultants Ltd, 2007) that these features:

- Resemble megaripples;
- Are composed of gravels and sands;
- Have gradients of between 35º and 40º; and
- May either migrate in a southwardly direction, or be induced by local (i) a sea bed feature; or (ii) wave/tidal effects.

5.3.4 Records of Geological Change

The contemporary morphology, as described above, is determined by the sequence of events that have occurred and shaped the continental shelf since the end of the last glaciation, approximately 10,000 years ago. These events have involved a series of post-glacial rises and falls in sea level, which have moved sediments around and formed various morphological features.

Over the past 4,000 years, the predominant process has undoubtedly been one of transgression (landward movement of the land-sea interface in response to sea level rise), with only minor regressions (seaward movements) or stand-stills. Over more recent historic time (i.e. the last few centuries) it is the contemporary processes, sediment characteristics and anthropogenic intervention that have controlled the location and pace of change.

In general, the site can be considered to be dominated by the Bolders Bank formation overlying Chalk bedrock (D'Olier, 2003; Titan Environmental Surveys Ltd, 2004). The geological sequence underlying the area is made up of the successions listed in Table 11.

Table 11. Geological sequence of the HGOWF

Age	Formation	Thickness (m)
Late Pleistocene	Botney Cut	< 8
	Bolders Bank	< 25
Upper Cretaceous	Chalk	-

(Details are taken from: D'Olier, 2003; and Titan Environmental Surveys Ltd, 2004)

Further details on the different formations are provided below:

- Botney Cut Formation:
  - Offshore equivalent to Dimlington Silts;
  - Typically fill the hollows/channels of the Bolders Bank;
  - Beds of very soft to soft clays, silts and fine sands often interspersed with sand and gravel layers;

- Bolders Bank Formation:
  - Offshore equivalent to Basement Till;
  - A chaotic, poorly bedded seismic character;
  - Will contain, approximately, 10% of cobbles and boulders;
  - Consists of calcareous, gravelly sandy clay with chalk erratics; and
  - Coarser elements found on sea bed as lag deposits, typically less than 0.5m thick;

- Chalk:
  - No sea bed exposure;
  - Buried by up to 25m of overlying sequence;
  - Channels often identified within the layer;
  - Erosion of this layer may have lead to the identified sink hole features; and
  - Weathering and subsequent erosion of the layer may be responsible for the thickening of the upper layers to the south of the site (where the thickness may be between 15 and 18m).

5.4 Exposure Conditions

It is the combination of the tidal and wave regimes that form the hydrodynamic regime, and provide forcings and controls upon the sedimentological regime (sediment transport; morphological features). These can also be known as the exposure conditions, and are discussed, with relevance to the HGOWF site, in the following sections.

5.4.1 Tides

5.4.1.1 Introduction

The tidal regime can be defined here as the behaviour of bulk water movements driven by the action of tides and non-tidal influences, such as river flows and meteorological conditions (e.g. winds, atmospheric pressure and storm events). The baseline hydrodynamic regime has been characterised in terms of: (i) water elevations (due to tidal patterns, non-tidal influences and sea level rise); and (ii) currents (due to both tidal and non-tidal influences).

The baseline is defined not only by the present coastal process characteristics, but also by any natural changes in key processes or morphological features that might be anticipated over the operation life of the scheme (i.e. nominally 50 years). This definition provides the appropriate context for comparing scheme-related changes against the natural variability within the coastal system.

The pattern of tidal elevations within the North Sea and along the Holderness Coast result from the gravitational forces of the moon and sun acting on the Atlantic Ocean. The resulting oscillations propagate across the shelf edge, entering the North Sea both across the northern boundary and through the English Channel. Semi-diurnal tides (two per day) predominate at the latitudes concerned and are further amplified in the North Sea by a degree of resonance with the configuration of the coasts and depth of the sea bed (Vincent and Le Provost, 1988).

In addition to the tide's predominantly oscillatory nature, this cyclonic propagation of tidal energy from the ocean also forces a net residual circulation in the same direction. Although much smaller (typically 1 to 3 cm/s compared with the oscillatory tidal currents which typically exceed 1m/s), the resulting net currents are persistent and account for approximately 50% of the water transport in the western North Sea, (OSPAR Commission, 2000).

The Co-tidal Chart (5098) for the British Isles indicates that a tidal amphidrome (a nodal position with zero tidal influence) governs the tidal conditions in the Southern

North Sea, with the tidal wave rotating anticlockwise, indicating the flood tide sweeps down the coast from north to south. The tidal range increases with distance from the amphidrome leading to a range of approximately 5.5m along the Holderness coast, and increasing into the Humber Estuary.

5.4.1.2 Astronomical tidal levels

The gravitation pull of the moon and, to a lesser extent, the sun combine with the centripetal force of the earth to influence the movement of oceanic water and create tides. These ocean scale water movements are defined as massive 'waves' that peak and trough to create high and low water levels. The frequency of these successive high and low tides is described as the tidal period, whereas the difference in water level between high and low tides is defined as the tidal range.

Table 12 presents astronomical tidal characteristics from the Admiralty Tide Tables for Spurn Head, being the nearest standard port to the development site at a distance of, approximately, 10.5km.

Table 12. Summary tidal data for Spurn Head (m above CD)

Tidal Data			Spurn Head 53°35'N, 0°07'E
Tidal Level	Highest Astronomical Tide	HAT	7.7m
	Mean High Water Springs	MHWS	6.9m
	Mean High Water Neaps	MHWN	5.5m
	Mean Sea Level	MSL	4.07m
	Mean Low Water Neaps	MLWN	2.7m
	Mean Low Water Springs	MLWS	1.2m
	Lowest Astronomical Tide	LAT	0.2m
Tidal Range	Extreme Difference	7.5m	
	Spring Range	(MHWS - MLWS)	5.7m
	Neap Range	(MHWN - MLWN)	2.8m
NB. Predicted heights are in metres above Chart Datum (3.9m above ODN)			

The relevance of varying tidal elevations in time is that 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) the outer Humber Estuary is higher during springs than neaps. This feature of the tidal regime is important in influencing rates of sediment transport.

Water level information was recorded within the proposed HGOWF site, using the Nortek AWAC (see Section 3), as illustrated in Figure 10 for the period 25 October to 14 November 2004. This chart illustrates water levels at the site including (raw) and excluding (processed) surge effects. From this it can be observed that the tidal range is, for neap and spring tides, of the order of 2m and 7m, respectively.

Of note, is the extended water levels on the 13 November 2004 which relates to a storm event, as discussed further in Section 5.4.3. This event has been shown to represent a 1:1 year event.

It should be noted that the data collected at the Nortek AWAC has been used within the numerical modelling work to ensure the correct replication of the hydrodynamic regime within the proposed development site. However, the measured data will inherently include the effects of such processes as surges, which are not replicated in the numerical model.

5.4.1.3 Currents

Water flows within the North Sea vary temporally as a function of the tide and tidal range, and spatially as they interact with various morphodynamic features. In addition, non-tidal effects may alter tidal currents, for example effects from river discharge, wind or lateral density currents. The main axis for tidal flows is to the north during the ebb phase (Figure 11a) and to the south during the flood phase (Figure 11b). Generally, the significance of such non-tidal effects is more likely to be evident during periods of neap tides when the tidal signal is at its weakest.

Current speeds within the proposed development site have been recorded using the Nortek AWAC instrument. Figure 12 shows a timeseries of current speeds at this location, with the corresponding water levels. Current speeds are typically low, with the average speed being of the order of 0.55m/s. Maximum and minimum speeds recorded were 1.27m/s and 0.07m/s, respectively.

5.4.1.4 Non-tidal influences

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. Atmospheric pressure variations can also depress or raise the water surface to generate positive or negative surges, respectively.

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 North Sea is particularly susceptible to storm surges and there is a long history of such events, with recorded evidence ranging back to at least the 13th Century (van Malde, 1997). Flather and Williams (2000) defined a 1 in 50 year return period storm surge has having a height of 1.93m in the North Sea. The most intense surge of recent history took place between 31 January and 2 February 1953 and resulted in the loss of almost 2,000 lives, mainly in the Netherlands. This surge elevated water levels up to 3m above the astronomical tidal level and was caused by an externally-generated surge event propagating through the North Sea and becoming enhanced by an internally-generated surge caused by intense wind speeds.

The currents induced by surges play an important role in the sediment regime. Positive surges have obvious consequences for flooding but also can have a profound effect on wave orbital currents and sediment transport in the nearshore zone. The Southern North Sea Sediment Transport Study (HR Wallingford *et al*., 2002) did not present any evidence of this directly for the North Sea, but made recommendations for further research into this topic.

The Environment Agency (EA) previously commissioned ABPmer to produce the Humber Tidal Database (ABP R&C, 1999) which includes an estimate of the marginal extremes in water levels for closest site at Easington (approximately 8km east of the HGOWF site). These estimates are shown in Table 13.

Table 13. Extreme water levels for Easington

Return Period (years)	Extreme Water Level (m ODN)
1	3.88
2	3.97
5	4.09
10	4.21
20	4.31
50	4.44
NB. ODN is 3.9m (above CD)	

(Taken from: ABP R&C, 1999)

Hydrodynamic conditions used within the engineering feasibility study (SLP, 2006) indicate that the 50 year maximum return period water level is 7.3 m LAT (Lowest Astronomical Tide), where LAT is approximately equal to CD.

5.4.1.5 Climate change

Over relatively short time periods (e.g. months) the tidal signal can be regarded as varying relative to a stationary level referred to as mean sea level (MSL). However, over longer time periods (e.g. several years) MSL varies in response to both long period tidal trends (e.g. 18.6 year lunar nodal cycle) and sea level rise over geological timescales. Hence, a baseline definition is non-stationary in situations when MSL varies.

Past and anticipated future changes in relative sea level in the study area will be the result of the interaction between a number of mechanisms, as follows:

- Eustatic changes: these changes in absolute water elevation tend to be relatively uniform geographically and are caused, for example, by glacio-eustacy (ice melt) or thermal expansion (changes in water volume due to warming); and

- Local changes: these are due to changes (both positive and negative) in the elevation of the land surface. Such changes are likely to be the result of isostatic adjustments (changes in land elevations due to the redistribution of weight on the land surface e.g. due to glacier ice).

The relative rate of sea level rise will therefore be made up of a component of both eustatic changes in sea level and local changes due to isostatic land movements. The recommended value for flood and coastal defence planning for the study area is 4mm/year to 2025 and then 8.5mm/year from 2025 to 2055 (Defra, 2006). This assumes a vertical land movement of -0.8mm/year.

5.4.2 Freshwater Flow

The Humber is the largest estuary in the UK and drains 24,240km², one fifth of the land area of England. The primary contributors of freshwater input into the Humber Estuary are the Rivers Trent, Aire, Ouse, Derwent and Wharfe tributaries. The gauging stations along these tributaries where river flow data is recorded are located upstream of tidal influences.

The National River Flow Archive has published archived data between 1973 and 2003. Monthly flow data for five tributaries within the Humber catchment for 2004 were made available. From the tributaries listed in Table 14, the Trent has the largest catchment area (7486 km²) and mean daily flow (84.98 m³/s). In 2004, the mean daily flow increased marginally to 85.32 m³/s, an increase of 0.4% from the long-term average (1958 to 2003). This trend is not continued through all of the rivers listed in Table 14; mean daily flow values for 2004 show slight increases and decreases from the long-term average dataset. Overall, it is suggested that 2004 flows were not atypical.

Table 14. River flow data within the Humber Estuary catchment area

River	Catchment Area (km ²)	Long-term Average (1958-2003)			2004
		Mean Daily Flow (m³/s)	95% Exceedance (m³/s)	10% Exceedance (m³/s)	Mean Daily Flow (m³/s)
Ouse at Skelton	3315.0	50.01	7.434	125.0	52.15
Derwent at Buttercrambe	1586.0	16.76	4.096	34.17	21.48
Aire at Beal Weir	1932.1	35.56	8.264	78.62	31.68
Wharfe at Flint Mill Weir	758.9	17.22	2.406	40.89	17.21
Trent at Colwick	7486.0	84.98	27.33	175.3	85.32

5.4.3 Waves

The wave regime is defined here as the combination of swell waves moving into, and propagating through, the study area (having been generated remotely from the area) and more locally-generated wind-waves. The wind farm site is open to offshore waves that are generated within the northern North Sea. The wave regime has been characterised in terms of: (i) offshore waves; and (ii) within-site and nearshore waves. The available wave data has been previously analysed in ABPmer (2005), therefore it is the resulting trends and patterns in this regime that are presented in the following text. For the ease of the reader, selected information from ABPmer (2005) are presented in Appendix A.

5.4.3.1 Offshore waves

Wave roses derived from the Dowsing WaveNet buoy demonstrates that the majority of waves are from the north-north-west direction (Figure 13). Analysis of the wave data for this period (Table A1; Appendix A) leads to the following observations:

- The primary direction for waves are events from north-north-west (between 330 and 360ºN) over 25% of all records; and
- Largest wave heights (class 5.75 to 6.00m) occur from the north-north-easterly sector (between 000 and 030ºN).

In addition to summaries of wave height against direction, the information has also been considered in the form of significant wave height against peak wave period. Figure 14 presents a wave scatter diagram and includes an estimate of the limiting wave steepness (ratio of wave height to wave length). This parameter helps the interpretation of how waves are shoaling as they move from deeper water into shallow water. The following observations (Table A2; Appendix A) are also made:

- Most frequent wave period is in the range 5 to 6 seconds, accounting for more than 19% of all records;
- Most common wave height is in the range 0.75 to 1.00m, accounting for over 15% of all records; and
- Largest waves are in the class 4.50 to 4.75m and are generally associated with the longer wave periods in the range 10 to 12 seconds.

A comparative analysis has been undertaken using the Met Office information. The wave roses demonstrates that the majority of waves are from the north-east direction (Figure 15; Table A3, Appendix A):

- The primary direction for waves are events from north-north-easterly (between 000 and 030ºN) over 33% of all records; and

- Largest wave heights (class 5.50 to 6.00m) occur from the north-north-easterly sector (between 000 and 030ºN).

Analysis of significant wave height against peak wave period (Table A4; Appendix A) shows that:

- Most frequent wave period is in the range 4 to 5 seconds, accounting for more than 39% of all records;
- Most common wave height is in the range 0. 5 to 1.00m, accounting for over 33% of all records; and
- Largest waves are in the class 5.50 to 6.0m and are generally associated with the longer wave periods in the range 8 to 9 seconds.

The wave data provided from the Met Office was used to derive different extreme wave characteristics, as given in Table 15. These values were ultimately used as input conditions for the numerical modelling. The wave conditions experienced over the far-field, as illustrated using numerical modelling output, are shown in Figure 16 for the greatest wave conditions (the 1 in 50 year return period from the north).

Table 15. Extreme wave characteristics for different return periods

Return Period (Years)	330 degrees N		000 degrees N		030 degrees N	
	Wave Height (m)	Period (s)	Wave Height (m)	Period (s)	Wave Height (m)	Period (s)
0.1 (10:1)	2.3	5.97	3.3	6.85	2.2	5.70
1 (1:1)	3.7	7.39	4.8	8.27	3.6	7.06
10 (1:10)	4.7	8.35	6.0	9.10	4.9	8.00
50 (1:50)	5.3	9.15	6.9	9.75	5.7	8.90

5.4.3.2 Wave climate at the development site

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

- Shoaling and refraction (due to both 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.

The wave data collected at the Nortek AWAC site covers the period from the 26 March 2004 to 16 November 2004 and is presented as a wave rose in Figure 17. The wave roses show a dominant wave direction from the north-north-east. From a consideration of wave height versus direction, (Table A5; Appendix A) for a period exclusive of winter, it is evident that the prevailing directions for waves are the following:

- From north-north-east (between 000 and 030ºN) over 42% of all records; and
- From north-east (between 030 and 060ºN) and east-north-east (between 060º and 090ºN) over 10% of all records.

Largest wave heights (class 3.75 to 4.00m) occur from the north-north-easterly sector (between 000 and 030ºN) with a frequency of occurrence of 0.04% and from the east-north-easterly sector (between 060º and 090º N) with a frequency of occurrence of 0.02%, during the survey period.

In addition to summaries of wave height against direction, the information has also been considered in the form of significant wave height against peak wave period. Figure 18 presents a wave scatter diagram and includes an estimate of the limiting wave steepness (ratio of wave height to wave length). This parameter helps the interpretation of how waves are shoaling as they move from deeper water into shallow water. An analysis of wave height against period (Table A6, Appendix A) show:

- Most common (frequent) wave period is in the range 5 to 6s, accounting for more than 19% of all records;
- Most common wave height is in the range 0.25 to 0.5m, accounting for over 25% of all records; and
- Largest waves are in the class 3.50 to 3.75m and are generally associated with the mean wave period in the range 6 to 7s.

Some caution should be expressed when considering the above results since the short-term deployment may not necessarily be representative of longer-term conditions. With awareness of this, analysis of the longer-term offshore wave record from WaveNet has been compared with the Nortek data collected within the development site. The data sets overlap sufficiently to enable a direct comparison to be made between the data sets. Figure 19 illustrates a comparison in recorded wave heights, periods and directions between the two wave climate records. Over the presented data period there is a very high level of similarity between the two data sets and across the three parameters indicating a common behaviour in the wave regime from offshore to nearshore. Slight differences are observed in magnitudes of wave heights and wave directions, which are considered to be a function of wave shoaling and refraction from deeper water into shallower water. The variation in monthly mean wave height determined from all available Dowsing and Nortek AWAC records is scheduled in Table 16.

Table 16. Variation in monthly mean wave height at Dowsing and Nortek AWAC

Month	Year	Dowsing Nov-03 to Nov-04		Nortek AWAC March to Nov-04	
		Mean Wave Height (m)	Maximum Wave Height (m)	Mean Wave Height (m)	Maximum Wave Height (m)
November	2003	1.08	3.04	No Data	
December	2003	1.68	5.82		
January	2004	1.62	4.39		
February	2004	1.81	5.62		
March	2004	1.17	3.53	0.64	1.70
April	2004	1.16	2.93	0.90	3.56
May	2004	0.83	2.51	0.79	2.06
June	2004	0.91	3.04	0.77	1.86
July	2004	0.80	3.40	0.74	3.80
August	2004	0.98	3.04	0.83	2.01
September	2004	1.39	3.80	1.07	3.14
October	2004	1.46	3.16	1.24	2.87
November	2004	1.53	4.24	1.23	3.79

It is noted that the data recorded from the Nortek AWAC device typically appear to be below the average monthly values for the equivalent Dowsing Buoy months. As expected, both datasets show seasonal variations, with summer demonstrating a slight decrease in the mean and maximum wave height, followed by an increase towards winter (i.e. September onwards).

By considering the entire wave record presently available from Dowsing (October 2003 to December 2004), it is possible to rank the data by wave height and determine a probability of exceedance. Table 17 summarises wave height values to percentage frequency exceedances.

Table 17. Wave exceedance at Dowsing (October 2003 to November 2004) and Nortek AWAC (March to November 2004)

Exceedance (%)	Dowsing Wave Height (m)	Exceedance (%)	Nortek AWAC Wave Height (m)
0.01	5.82	0.02	3.80
0.05	5.25	0.05	3.77
0.1	5.06	0.1	3.56
0.5	4.24	0.5	2.95
1	3.80	1.0	2.61
5	2.71	5	1.83
10	2.32	10	1.57
50	1.21	50	0.85

During the survey period (March to November 2004), the maximum wave height at Dowsing was 4.24m, recorded on the 12 and 13 November 2004, which represents

0.5% exceedance of all wave data presently available from Dowsing. The equivalent wave height at HGOWF was recorded as 3.77m.

5.4.4 Sediment Transport

5.4.4.1 Introduction

The contemporary sediment regime is comprised of:

- Sea bed surface sediments (bed load);
- Sediments suspended in the water column; and
- Sources and sinks of material.

The behaviour of these sediment populations is dependant upon their respective response to the hydrodynamic forcing conditions (waves; currents). Over the longer term, the sediment behaviour will determine the morphological development of the area.

Sediment mobilisation occurs when the hydrodynamic conditions exert a shear stress that exceeds a threshold relevant to the specific material type. When the shear stresses then fall below this threshold, the sediment will fall out of suspension to be deposited. It is the finer sized materials that are typically suspended at the lower shear stresses, remaining in the water column over longer periods of time. It is more likely that the coarser materials are transported as bed load. The forcing mechanisms responsible for sediment mobilisation and transport will show variation over spatial and temporal scales.

The consideration of the baseline sediment regime is an important aspect of the impact assessment of the proposed development on the physical environment. To describe the sediment regime and so evaluate any potential changes to the regime due to the scheme, the following issues have been considered:

- The sea bed sediment composition and distribution across both the proposed development site and the far-field study area;
- Sediment transport pathways in the vicinity of the proposed site in the form of a conceptual understanding of the sediment regime; and
- The key process controls on sediment mobility and thresholds of sediment motion.

Available data sets have been assessed to understand the local sediment regime, including:

- Southern North Sea Sediment Transport Study (HR Wallingford *et al*., 2002);
- BGS Sea Bed Sediments Map, (BGS, 1990);
- BGS short cores and vibrocore grab samples;

- D'Olier - Sea bed geology and grab samples;
- UKHO Historic Charts;
- Environment Agency (EA) coastal surveys;
- Titan geophysical survey (2004)- preliminary sea bed features; and
- Humber Estuaries Coastal Authorities Group, Shoreline Management Plan (SMP).

5.4.4.2 Sea bed composition and distribution

The BGS regional sediment coverage map with respect to the location for HGOWF is shown in Figure 20. The area is characterised by sands on the banks and sandy gravels over the general extent of the site. Patches of gravel, cobbles and pebbles are inter-dispersed along the south-eastern fringe of the site. It is noted that a major data gap in this dataset exists in the shallow coastal fringe inshore of the development site, with the exception of the export cable landfall area.

Previous investigations by D'Olier (2003) reveal that the majority of the site is not covered by any extensive areas of mobile sand, hence bedrock is usually found at the sea bed. The bedrock is comprised of occasional patches of Botney cut formation over Boulders bank formation over chalk. Overlying the bedrock are relatively thin deposits of gravel (5mm) and boulders (>256mm). The larger cobles and boulders are seldom moved. Only in the immediate coastal strip is there appreciable sand transport which takes place down the coast and in the nearly sub-littoral zone. Much of the finer grades of sediments pass on south towards the Humber Estuary, the Lincolnshire Coast and the Wash.

5.4.4.3 Conceptual understanding of the sediment regime

The sediment transport regime can be divided into two main parts, that which is:

- Mobilised as bed load; and
- Transported within the water column as suspended load.

The Greater Wash SEA has been the subject of many studies investigating the sediment transport regime, including the Southern North Sea Sediment Transport Study, Phases I and II (ABPmer, 1996 and HR Wallingford *et al*., 2002) and 'Sand banks, sand transport and offshore wind farms' (Kenyon and Cooper, 2005). Key findings are reported in the following sections.

Bed Load

Sediment transport pathways as inferred using bedform indicators and numerical modelling from the Southern North Sea Sediment Transport Study (HR Wallingford *et al*., 2002) are shown in Figure 21. This figure shows that:

- In the nearshore zone, and up to 7km offshore, sediment transport is generally to the south;
- Sediment enters the Humber Estuary from the north;
- There is a zone of re-working and re-circulation in the mouth of the Humber;
- Further offshore, and through the proposed HGOWF site, the transport is to the south;
- To the west of Silver Pit transport is to the north;
- To the east of the 40m contour, transport is typically of a variable direction; and
- Storm surge induced transport is to the south, shoreward of the 40m contour.

HR Wallingford *et al*., (2002) suggest that the amount of material transported as bedload is small. Side scan sonar interpretation within this study suggests that sediment is transported across The Binks and towards the Humber Estuary as ribbons, streaks and rippled sand patches. Some of the sand which enters the estuary is deposited in the sand flat system.

Further to this figure, revised sand transport pathways within the Greater Wash SEA have been published based upon existing and new data, including that given in Figure 22. This is illustrated in Figure 23 and shows that:

- Sand is generally transported to the south;
- Sand enters the Humber Estuary along the shoreline and exits through the channel in the centre of the estuary mouth;
- A bedload parting zone exists which runs through the proposed HGOWF site; and
- To the east of the bedload parting zone, sand is transported in a northerly direction.

Suspended load

Finer material suspended from the erosion of the Holderness coastline is transported to the south towards the Humber Estuary. Here, muds are transported out of the Humber to form a plume which moves offshore to the south-east towards the southern North Sea. This plume can be observed from satellite images, as illustrated in Figure 24. The majority of the suspended load from this plume is deposited beyond UK Territorial Waters (Defra, 2002). Within the study area, muddy material is deposited within the Humber Estuary and within the Outer Silver Pit (Procter *et al*., 2001), where there is evidence of some re-working of the deposited sediment (Eisma and Irion, 1988).

Regional measurements have been made of suspended sediment concentrations (SSC) by CEFAS as part of the Southern North Sea Sediment Transport Study (HR Wallingford *et al*., 2002). These show, as illustrated in Figure 25 that the summer and winter SSC within the study area are in the range of 4 to 256mg/l and 8 to 128mg/l , respectively. Note that the lower values are typically located over the proposed development site, whilst the higher SSC's are for the nearshore zone. The value of 256mg/l relates to a very narrow band along the coastline north of Spurn Head.

Suspended sediment concentrations have also been measured as part of the HGOWF field campaign. It is shown that the SSC over the site is typically low and more likely to result from occasional fluxes across the site derived from an alternative source, e.g. Holderness Coast and/or Humber Estuary, rather than from a locally disturbed sea bed.

Concentrations determined from water samples taken at times of equipment servicing provide a range of suspended sediment values from 0.2mg/l to 20.8mg/l, and an average of 12.6mg/l. Optical Back Scatter (OBS) measurements have been considered, but data quality checks suggest the instrument was not functioning correctly.

Raw Acoustic Back Scatter (ABS) recordings indicate increased sound attenuation at the times of storm events, indicating the possibility of sediment mobility at these times. This correlation is shown in Figure 26. It should be noted that the ABS is more likely to resolve sand sized sediments in suspension than other grain sizes.

Shoreline transport

The recent Humber Estuary Coastal Authorities Group Shoreline Management Plan (SMP) (Posford Duvivier, 1998, Volume 1) indicates that there is an offshore and residual longshore movement of sediment south of Easington. Wave action moves sand in a net southerly direction, muds and clays in suspension move south and offshore and larger cobles remain and collect. At Spurn Head, sediments move offshore or continue on to the Humber Estuary and then to beaches southwards, (www.eastriding.gov.uk - coastal processes).

Regular monitoring of the East Riding coastline began in 1951 with the establishment of over one hundred cliff erosion monitoring posts. These posts are used to measure distances to the cliff edge on a regular basis, thus building up a record of recession. Over the years as this data set increases, annual variances that can give inaccurate short-term erosion rates are averaged and eventually converge towards a more reliable annual value. In making use of these erosion rates, it should be remembered that therefore future or short-term erosion losses might be quite different from these figures.

It is the hydrodynamic regime and available sediment that control the natural coastal erosion rate and without further interference this erosion would tend towards a constant average value for all locations. This steady state is however further controlled by natural and anthropogenic obstructions and changes in the coastline orientation. Prior to man's intervention, the shelter given by Flamborough Head reduced erosion in its lee to near zero, southwards erosion steadily increased reaching approximately 1.5m/yr at Hornsea and a maximum of about 1.8m/yr at Easington. However, this has been complicated by the construction of the numerous defended frontages, which in holding on to sand, tend to protect cliffs to the north creating the saw tooth pattern in erosion as shown in Figure 27. This figure illustrates that, onshore from the HGOWF site, between Easington and Spurn Point, average cliff erosion rates have varied between 0.86 and 4.15 m/yr between 1951 and March 2004. Further, from March to September 2004, the depth of actual cliff lost along the same stretch ranged between 0 and 1.2m. Further analysis of the cliff erosion rates (ICES, 2006) has been used to derive values for the present, predicted and worst case scenarios for the posts located within the landfall window for the preferred cable route to the north. This is shown in Table 18. The information presented has been further used to derive the existing and projected erosion rates for the entire length of cliff in the cable landfall, as illustrated in Figure 28. It can be seen that whilst the cliff line follows a similar pattern between 1997 and 2006, there is a considerable loss over the next 40 years. This pattern has been determined using two erosion rates calculated from the previous analysis; 2 and 5.6 m/yr.

An analysis of these posts (ICES, 2006) shows that the erosion of the Holderness coast follows a cyclic pattern of between 3 and 5 years. Further, the erosion rates may fluctuate on a yearly basis as a response to prevailing weather conditions.

Table 18. Present, predicted and worse case scenario erosion rates. Posts 108 to 110 relate specifically to the landfall window

Erosion Post	Present Rate of Erosion (m/year)	Predicted Loss Over Next 40 Years (m)	
		(1)	(2)
105 Corner of farm, Dimlington	1.07	42.8	224
106 Fence line off Old Dimlington Road, Easington	1.47	-	-
107 Opposite Gas Terminal, Easington	1.66	-	-
108 Fence line south of Gas Terminals, Easington	1.69	-	-
109 On north boundary of campsite, Easington	1.34	53.6	224
110 At toilet block off seaside Road, Easington	1.52	60.8	224
111 Pill box south of seaside Road, Easington	0.83	33.2	224
112 Opposite Easington Dunes SSSI	2.36	94.4	224
113 Opposite Easington Dunes SSSI	1.23	49.2	224

Note: (1) based on present rate.
(2) based on worse possible scenario
(-) no further erosion predicted as cliff line now defended

(Taken from: ICES, 2006)

The spacing between erosion posts will influence the validity of the resulting measurements. Spatial variations at scales of less than the distance between each post cannot be measured. Further, failures may be no more than 10-20m in width, thus that the variability in recession rates over short distances can remain undetected.

The potential longshore drift rate (that would occur if there was a sufficient supply of sand at all times and at all locations) is in the range, 200,000m^3/year and

350,000m³/year between Hornsea and Easington. The estimated drift rate into Spurn Point is around 125,000m³/year (Valentin, 1954 in HR Wallingford *et al*., 2002), which is less than the potential drift rate. It is likely that small variations in the local bathymetry north of Withernsea deflect some sediment offshore from the inter-tidal zone.

Sediment transport within the nearshore zone is controlled by the wave forcing. Fine sediment originating from the Holderness cliffs is typically suspended when the significant wave height is greater than 1m (Prandle *et al*., 2000). The southerly sediment transport along the shore is responsible for the progradation of the Wash, north Norfolk coast and siltation of the East Anglian estuaries (McCave, 1987). Sediment transport in the immediate vicinity of the Humber Estuary is also modified by the tidal flow, in and out of the estuary.

Process controls on sediment mobility

An assessment has been made of sediment mobility within the HGOWF development site by identifying the modal sizes of all available sediments, derived from grab sample data, and calculating the combined wave and tide bed shear stresses required to initiate transport (using standard methods described in Soulsby, 1997).

A summary of the each of the modal classes, their respective grain size, descriptions and critical shear stress values for transport is provided in Table 19. The frequency of occurrence of model size is also included.

Table 19. Summary of main sediment types within the wind farm site

Modal Size (micron)	Size Class	Bed Shear Stress (N/m²)	Number of Occurrences (in 21 samples(*))
750	Coarse sand	0.358	4
1200	Very coarse sand	0.595	15
2400	Granule gravel	1.505	11
4800	Pebble gravel	3.800	3
6000	Pebble gravel	5.744	1
9000	Pebble gravel	7.873	19
(*) Number of samples that all within the OWF site			

This table shows that the smallest model class is coarse sand (750 microns), which occurs at 19% of sample sites, with pebble gravel sediments (9000 microns) being most frequent, occurring at 90% of the sites.

A derived bed shear stress value has then been calculated, based on the direct measurement of local water depths, current speeds and wave conditions from the Nortek AWAC (see Section 3). A 16 day spring-neap time series for each of these parameters is provided in Figure 29, which illustrates the thresholds related to a key event. It can be observed that:

- Significant wave height data from Nortek AWAC and Chequer Shoal follow a similar trend. During Event 4 the significant wave height measured on site exceeds 3m, reaching a maximum of 3.79m on the 12 November 2004;
- Water elevations recorded at both Nortek AWAC and Spurn Point indicate a clear spring neap spring cycle, with Event 4 coinciding with a spring tide; and
- Currents also oscillate in line with the spring-neap-spring tidal cycle, indicating an increase in velocity during springs and a comparable decrease in velocity during the neap. During the 12 November 2004, the velocity appears to peak at 1.5m/s (above the normal spring trend), and is suggested to be enhanced by the storm event.

The derived bed shear stress parameter is presented alongside respective thresholds for transport of the ambient model sediment sizes. It can therefore be concluded that:

- Coarse sand (750 micron) is responsive on spring tides and only during peak flows on neap tides. The percentage of time these events occur is determined to around 50%;
- Larger granule sized gravel (2400 micron) appears to be limited to peak events on spring tides only. The percentage of time these events occur is determined to be around 13%; and
- The limit of sediment mobility appears to be close to sediments sized at around 4800 micron (equivalent to pebble gravel), with all larger sediments regarded as immobile.

The nature of transport for such large sediments is considered to be limited to bedload, as the fall velocity of this material will be very fast, limiting the time the sediment can be held in suspension. These interpretations are consistent with the site being regarded as a lag gravel deposit (BGS, 1990; D'Olier, 2003).

By calculating bed shear stress for the entire deployment period (26 March to 16 November, 2004) the frequency at which the threshold of each modal class is exceeded, under the influence of waves, currents and combined wave-currents can be analysed. An overview of each of these criteria is presented in Table 20 and Figure 30.

Table 20. Summary of bed shear stress exceedance

Modal Class	Currents Only (% Exceedance)	Waves and Currents (% Exceedance)
Medium sand	71	88
Coarse sand	62	78
Very coarse sand	48	62
Granule sand	14	20
Pebble gravel	No exceedance	No exceedance

The mean grain size (D_{50}) for sediments across the development site is equivalent to a pebble gravel. It is noted from Table 22 and Figure 30 that pebble gravel is not within the 'live bed' regime, in response to local wave and tidal conditions.

5.4.5 Shoreline Processes

The hinterland of this area of shoreline is primarily characterised by Centrica, BP Easington and Dimlington Gas Terminals which cover, approximately, 70 hectares. These sites comprise treatment and processing facilities supplying up to 25% of Britain's gas supply. Gas pipelines located under the foreshore are visible at Low Water. There is also a beach holiday and leisure park to the south of the proposed landfall. The remaining land in the vicinity to the landfall site is predominantly Grade 3 agricultural.

The glacial cliffs in this location are composed of glacial till underlain by chalk and are receding at an average rate of approximately 1.5m/yr. The foreshore comprises sand with some shingle overlaying the clay. There are also brackish lagoons located along this coastline. The designated sites which are located in proximity to the proposed landfall are (ICES, 2007):

- Several geological Sites of Special Scientific Interest (SSSI) along the Holderness coast;
- Easington Lagoons comprise a variety of coastal habitats including saltmarsh, shingle, sand dune and most importantly, saline lagoons and pools. These are designated as:
  - The Lagoons SSSI;
  - potential Special Protection Area (pSPA);
  - potential Ramsar (pRamsar) site;
  - possible Humber Estuary Special Area of Conservation (pSAC);
  - Biodiversity Action Plan (BAP); and

  - Spurn Heritage Coast management strategy plan. Spurn Head, a sand and shingle spit extends 5.5km, reaching across the mouth of the Humber Estuary;
- Dimlington SSSI (2.5km to the north of the landfall window); and
- Spurn Head and most of the intertidal mud flats of the Humber Estuary are included in the Humber Flats, Marshes and Coast SPA.

6. Summary of Baseline Understanding

6.1 Background

A baseline description of coastal processes is provided for the northern Greater Wash SEA area, paying particular attention to the proposed location of the Humber Gateway Offshore Wind Farm development. This has involved:

- Appreciation of guidelines for the development of offshore wind farms with respect to coastal process issues;
- Appreciation of particular concerns regarding coastal process issues raised by stakeholders;
- Collation and review of available data, including that obtained from literature reviews and collected during survey campaigns; and
- The development of a baseline understanding of the coastal system.

6.2 Regional Setting

The HGOWF is located, approximately, 8km offshore from the Yorkshire Coast near the Humber Estuary in the Greater Wash SEA. The 35km² of sea bed proposed for the development is in relatively shallow water (approximately 15m (CD)) where the sea bed is generally flat and stable.

6.3 Data Availability

Numerous survey campaigns have been undertaken as part of this project. Those with relevance to the coastal process investigation include:

- Geophysical surveys;
- Geotechnical surveys;
- Benthic surveys, of which grab sample collection was included; and
- Metocean surveys, collecting wave, tidal and suspended sediment information.

Additional data has also been brought into the project to offer additional value and enhance confidence in the study output. These have included purchases from the Met Office and freely-available data from the CEFAS WaveNet buoys.

6.4 Baseline Coastal Process Regime

The hydrodynamic regime has been considered in terms of both tidal characteristics (water levels and current flows) and wave conditions (wave heights, periods and directions). Information available from both the Metocean Survey and additional sources have been used to determine the regime.

The tidal range at the development site is 2m and 7m for neap and spring tides, respectively. The flood tide is in a southerly direction and the ebb flow towards the north. Current speeds are typically low, with the average speed being of the order of 0.55m/s. Maximum and minimum speeds recorded within the HGOWF site were 1.27m/s and 0.07m/s, respectively.

The waves within the development site are representative of those generated within the northern North Sea. The similarity between the waves at the development site and locations further offshore have been confirmed through comparison with CEFAS WaveNet and Met Office wave data. Maximum wave heights at the site are 3.75m, with mean heights being of the order of 0.25 to 0.5m. The most common wave period is in the range 5 to 6s. Prevailing directions are from the north-north-east.

The baseline sediment regime has been investigated by considering the distribution of sea bed sediments, developing a conceptual understanding of bed load and suspended load transport across the far-field area, and through assessment of the process controls on sediment mobility. This has identified that the predominant sediment type over the general extent of the development site is sandy gravels. Tides are predominately responsible for sediment transport in the offshore region, whilst waves predominate along the shoreline. It has been shown that the dominant direction of sediment direction is towards the south, with material entering the Humber.

6.5 Scheme Assessment

The understanding obtained whilst determining the baseline conditions will be used to assess the effects of the proposed wind farm on the hydrodynamic, sedimentological and morphological regimes both on regional and local scales. These effects will be considered over a range of temporal scales and will also be determined in the context of natural changes to these regimes.

A scale of significance will be applied to any changes predicted by the wind farm development, as categorised in Table 1 and will be combined with criteria described in ERM (2007).

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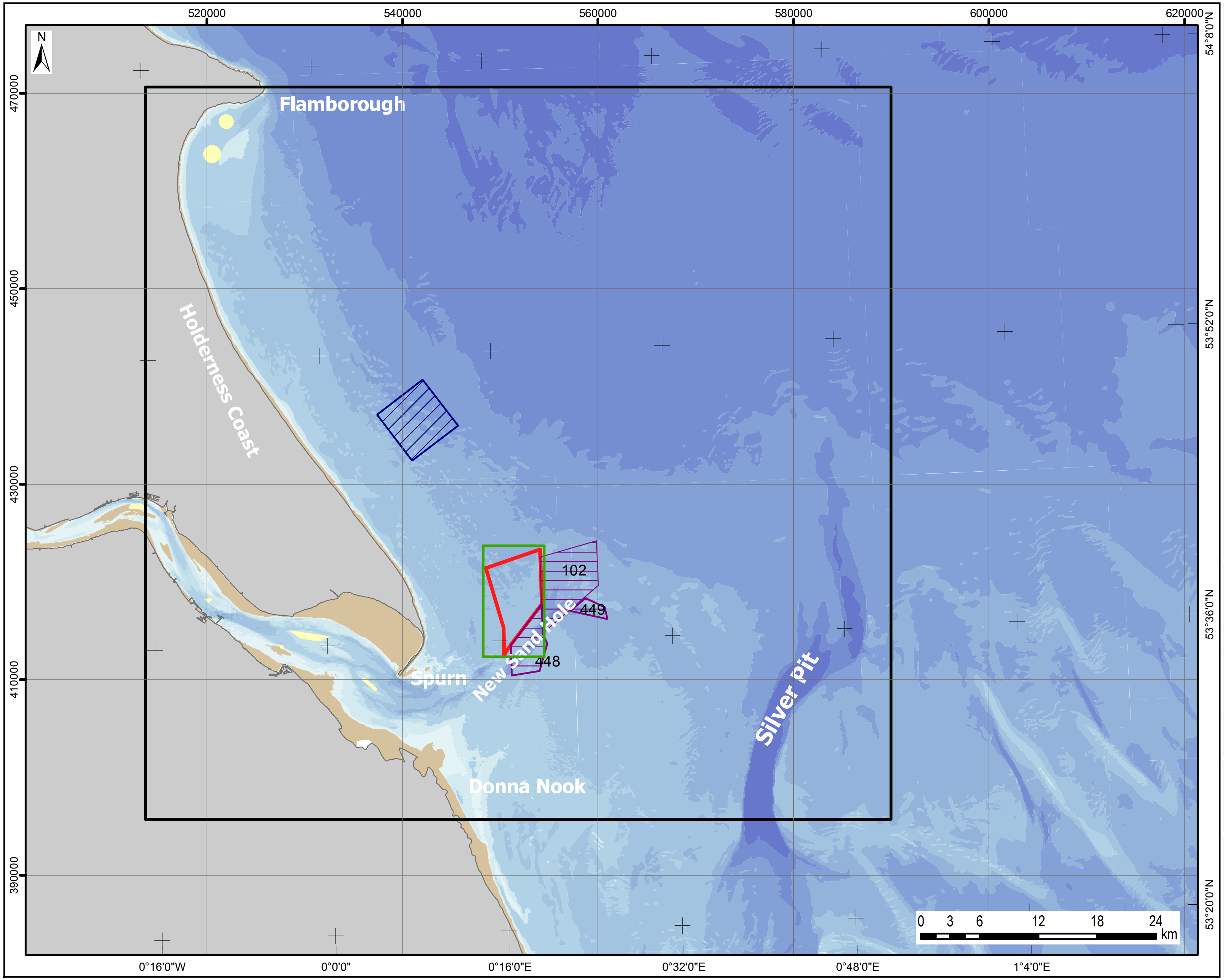
Figures



HGOWF Site
Far Field
Near Field
Round 2 Windfarms
Dredge Sites
Disposal Sites

Depth (m CD)

- <0
- 0 - 2
- 2 - 5
- 5 - 7
- 7 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- 30 - 50
- > 100

Date	By	Size	Version
Dec 2007	DP	A4	2
Projection		Scale	
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3682 - Figure1.mxd			
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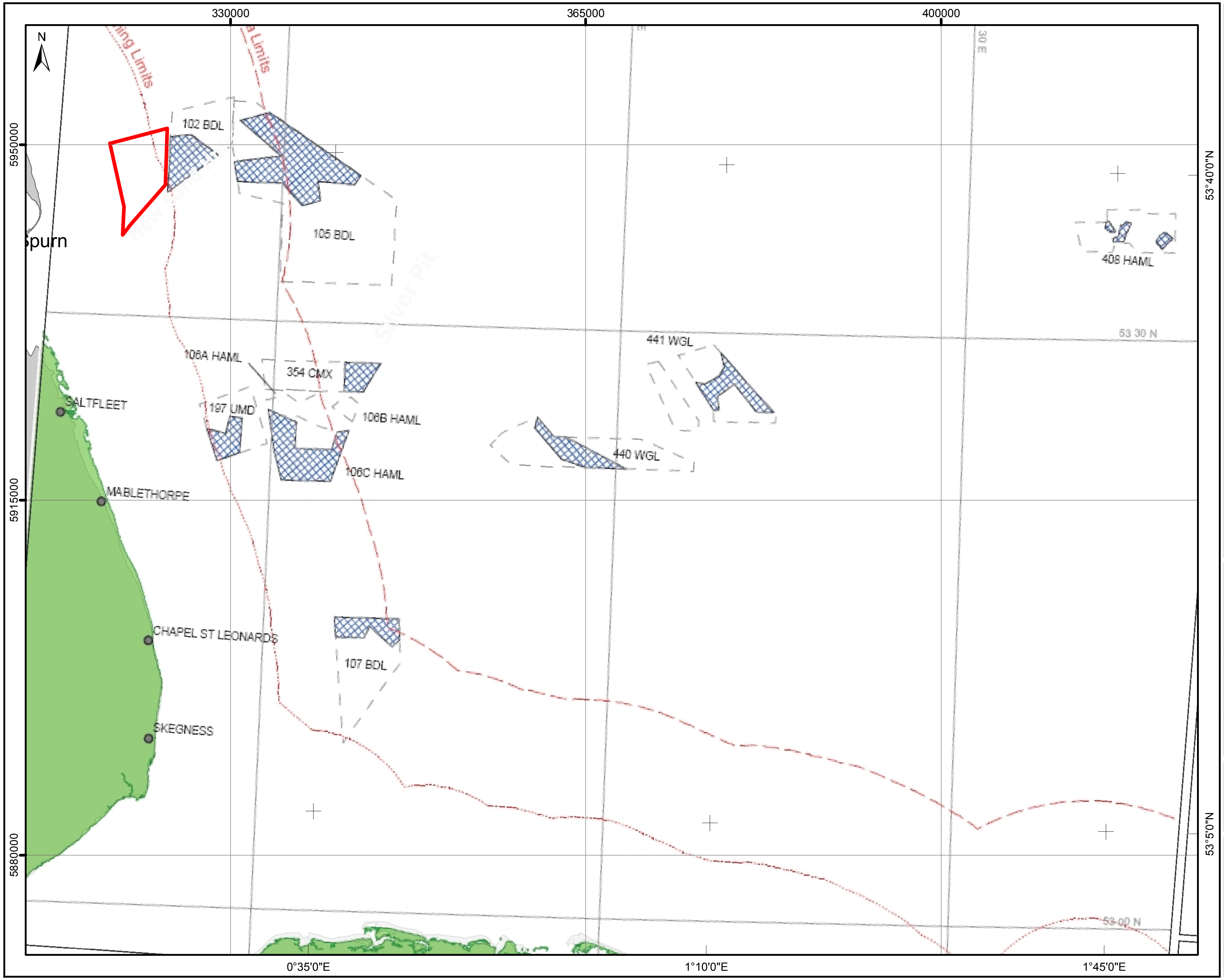
Location of relevant seabed users and bathymetric features

Figure 1



HOWF_site

LICENCE AREA

ACTIVE DREDGE AREA

INDICATIVE 6 MILE LIMIT

INDICATIVE 12 MILE LIMIT

The Active Dredge Area defines the area available to be dredged at any one time. While under normal circumstances this is defined by the limits of the licence, zoning schemes (introduced either as licence conditions or as voluntary initiatives by licensees) can significantly reduce this area. The limits of the Active Dredge Areas defined on this chart are monitored through the analysis of Electronic Monitoring System data.

Any changes to Active Dredge Areas presented on this chart after 31/01/2007 are the responsibility of individual licensees, as bound by specific licence conditions or agreed arrangements.

This map is produced from the OS Map with the permission of Ordnance Survey on behalf of HM Stationary Office.

SCALE : 1:500,000

NOTE: NOT TO BE USED FOR NAVIGATION

Taken from The Crown Estate

Date	By	Size	Version
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Projection		Scale	
OSGB 1936			
Reference			
3682 - Crown Estate.mxd			
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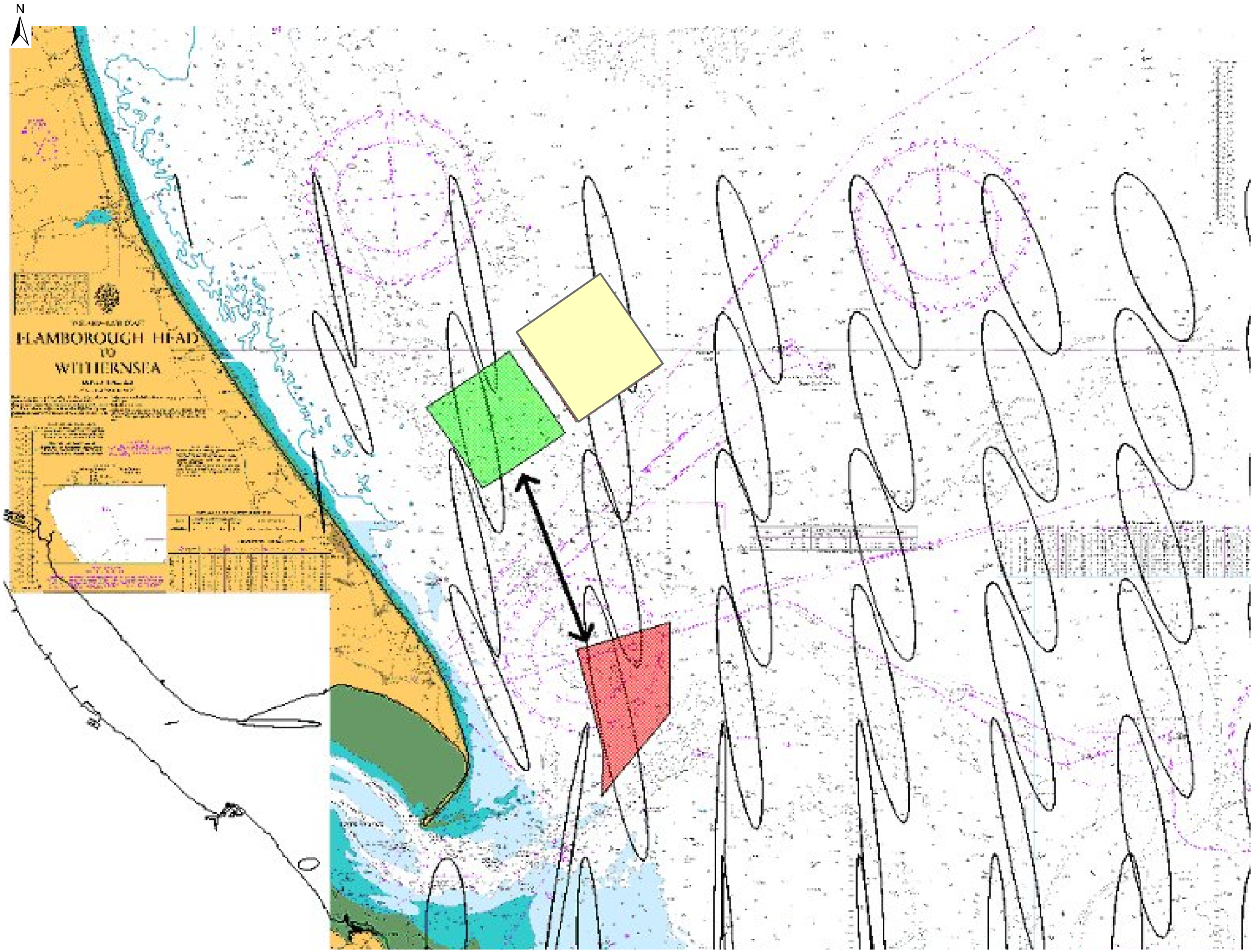
marine environmental research

Active Dredge Area Map For The Humber Region

Figure 2



Old Westermost Rough

New Westermost Rough

HGOWF

Date	By	Size	Version
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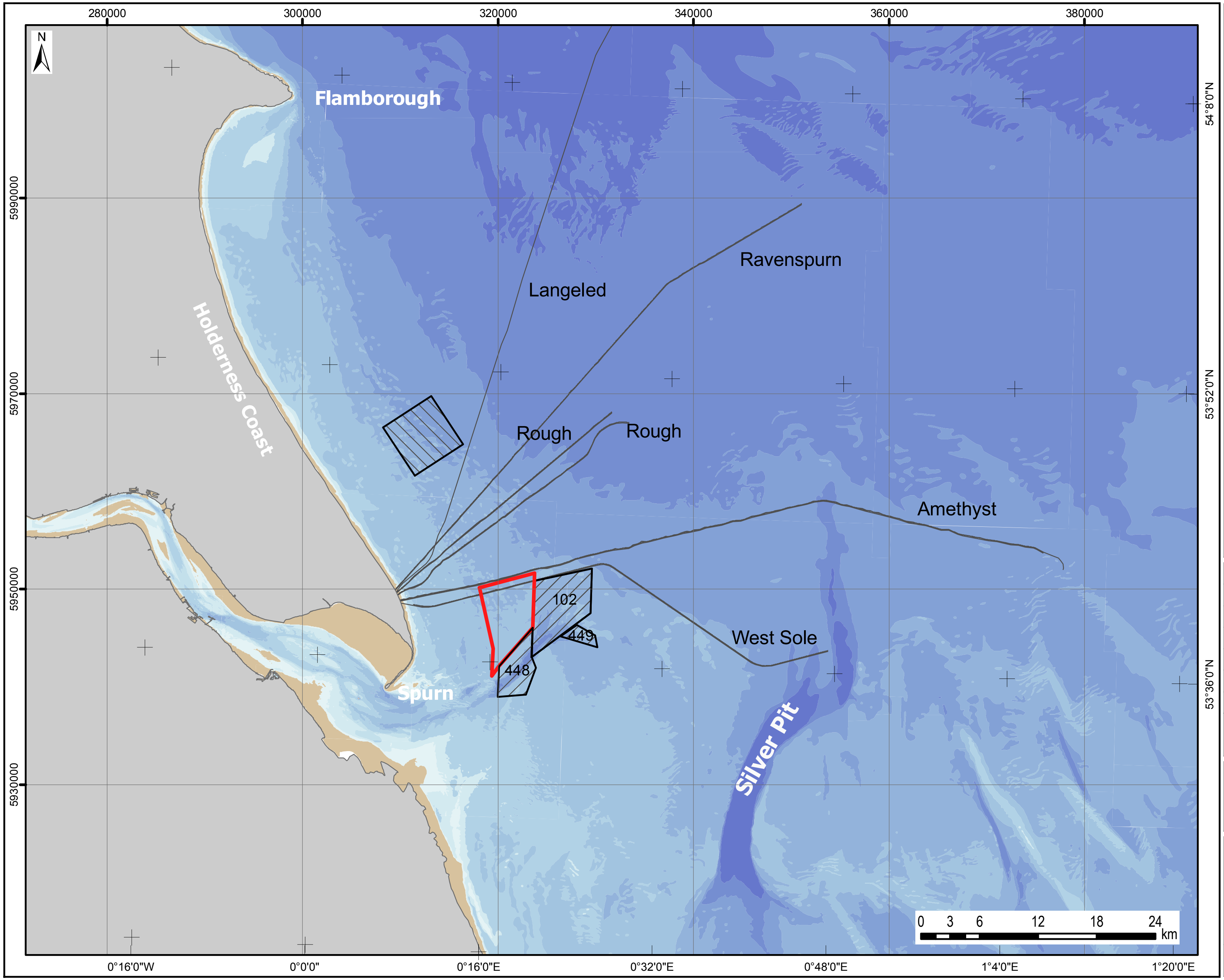
CEFAS Tidal Ellipses

Figure 3



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3682 - Fig4_Pipeline_cables.mxd			
Produced by ABPmer Ltd			

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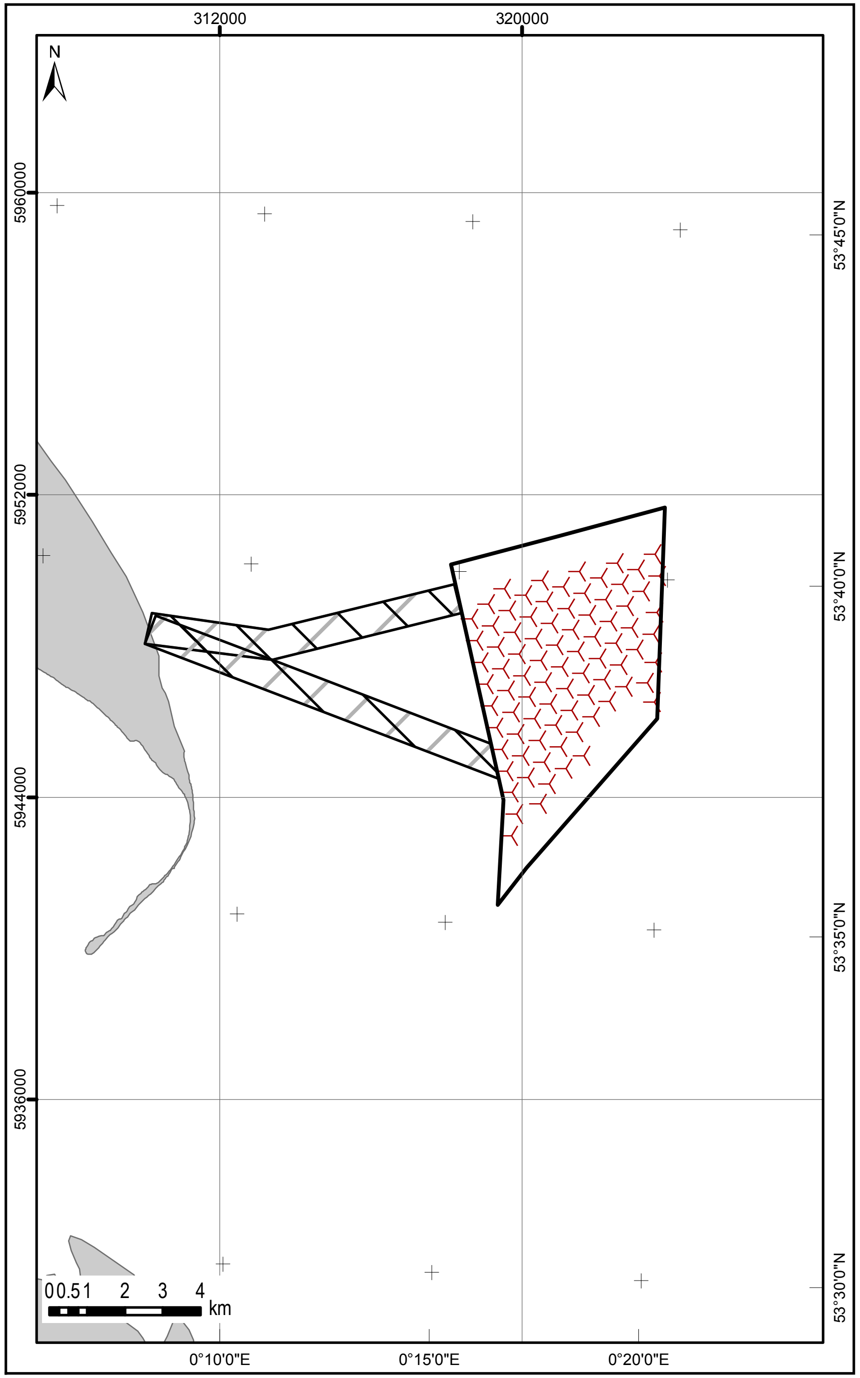
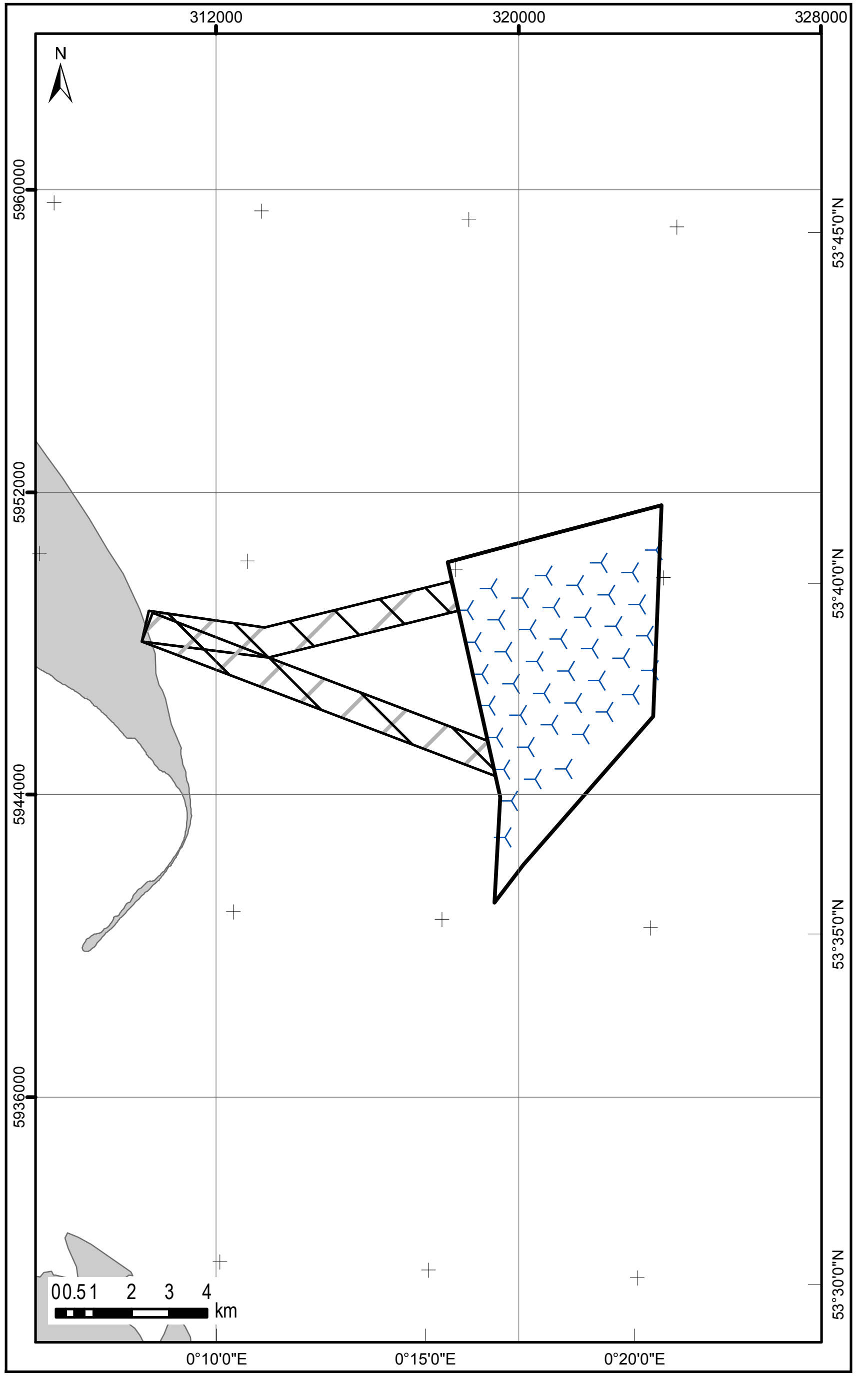
Other sea-bed users to be included in the assessment of cumulative and in-combination impacts

Figure 4





HOWF Site
Cable Routes
Layout 2 - 20m GBS
Layout 5 - 40m GBS
Land

Date	By	Size	Version
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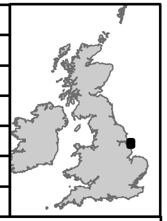

Data supplied by ERM

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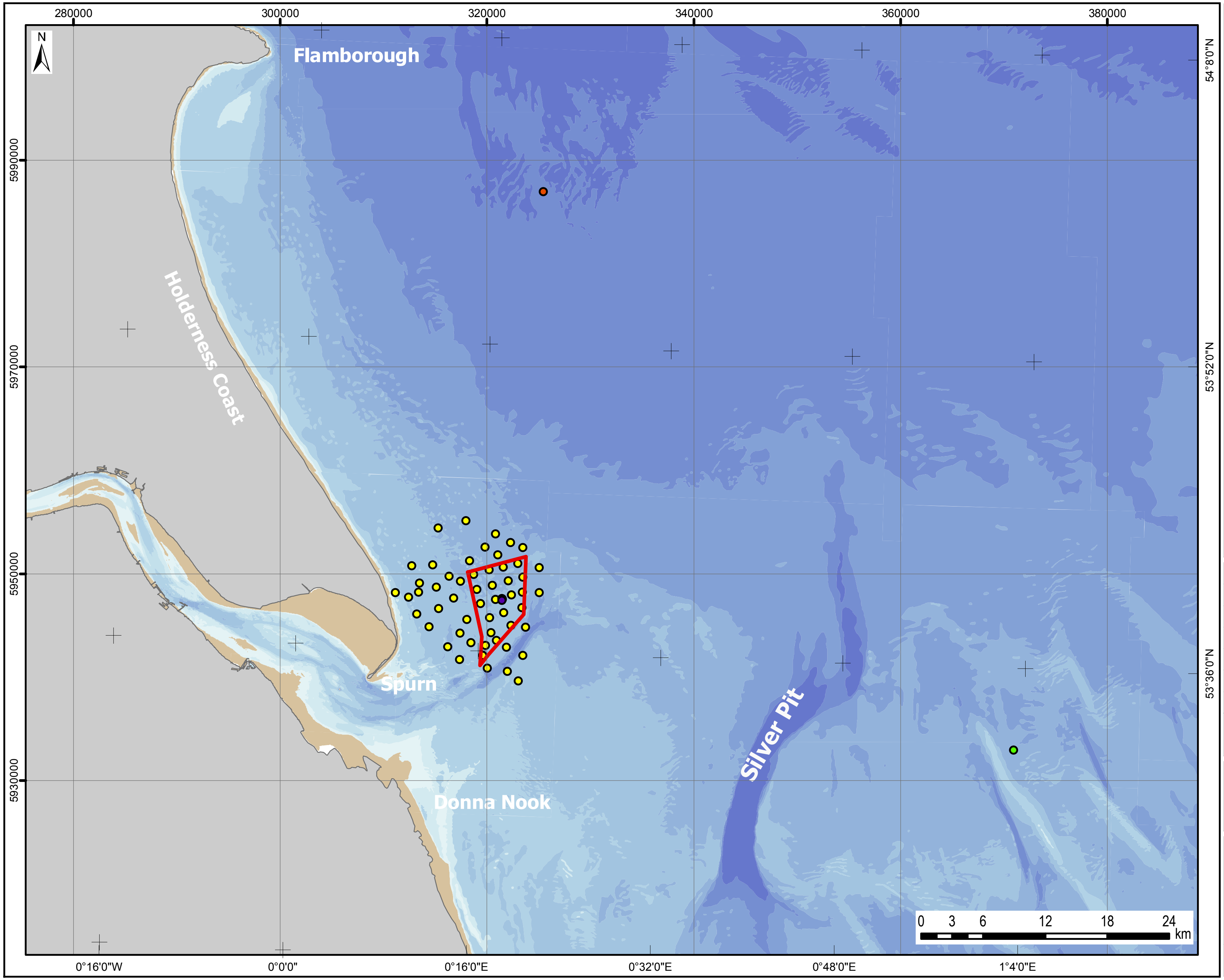
Humber Gateway Offshore Wind Farm Scheme Turbine Layouts

Figure 5



HGOWF Site
Nortek AWAC
Dowsing Wavenet Buoy
Met Office Bouy
PSA Grab Samples

Date	By	Size	Version
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Projection	Scale
WGS84 UTM31N	1:520,000

Reference
3682 - Figure6.mxd
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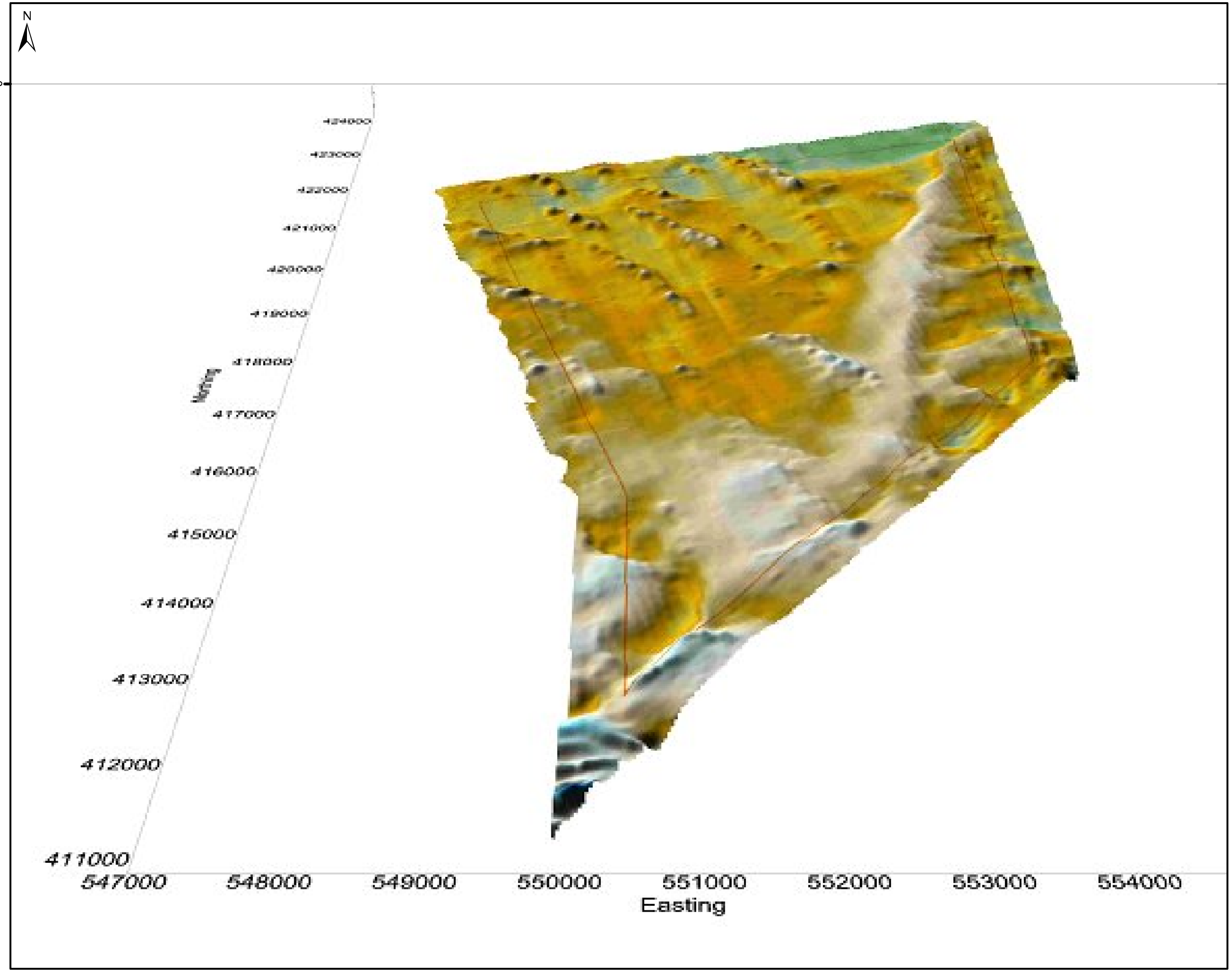
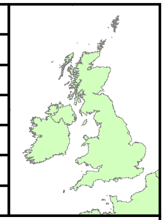
Location of Project Specific Surveys and Other Data Sources

Figure 6





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3682 - Figure1.mxd			
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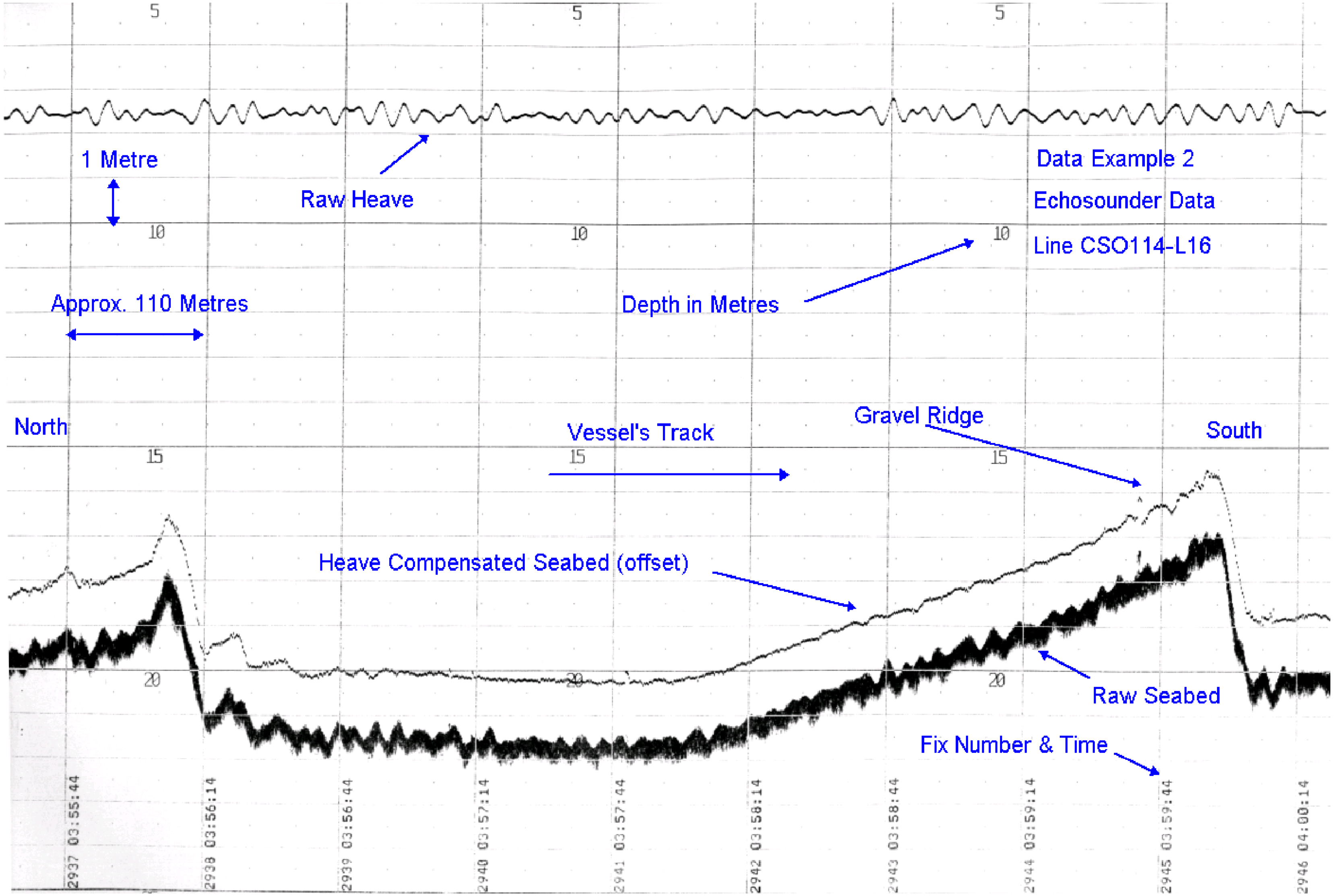
Detailed Bathymetry Within The Wind Farm Site (Source: Titan)

Figure 7



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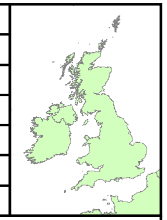

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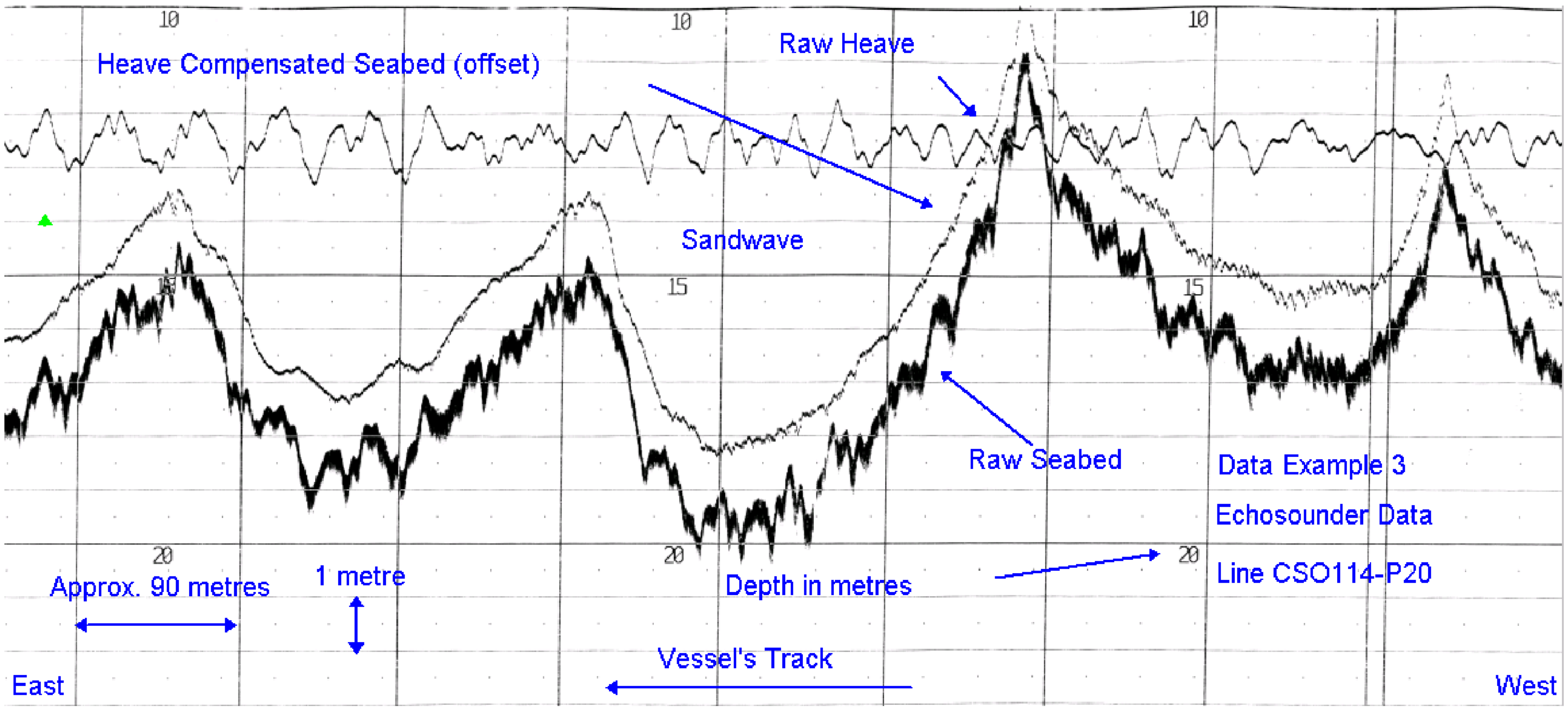
Gravel Ridges Observed Within The Bathymetric Survey (Source: Titan)

Figure 8



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3682 - Fig9_Sandwaves.mxd			
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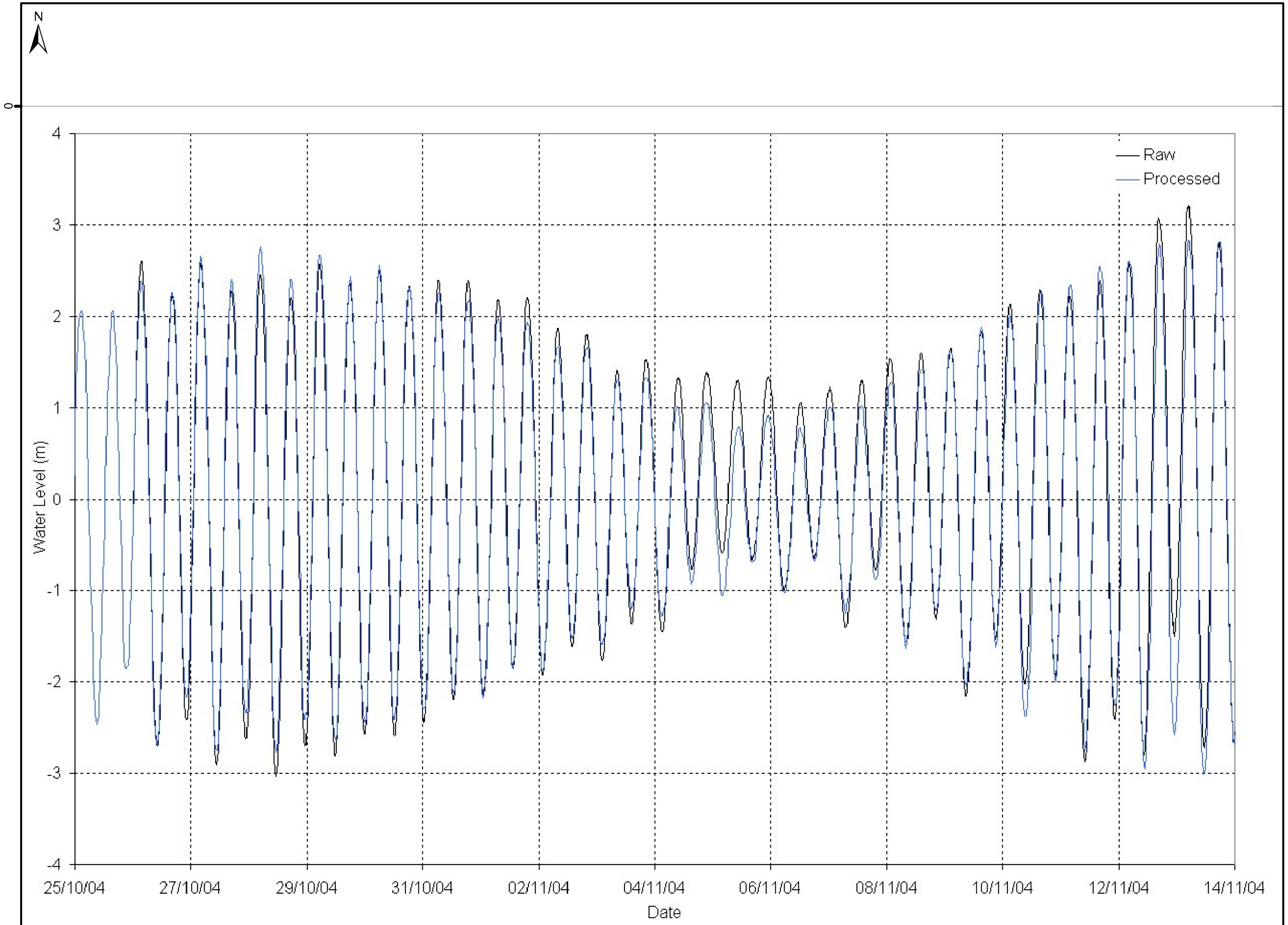
Sand Waves Observed within the Bathymetric Survey (Source: Titan)

Figure 9



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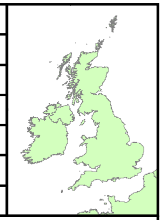

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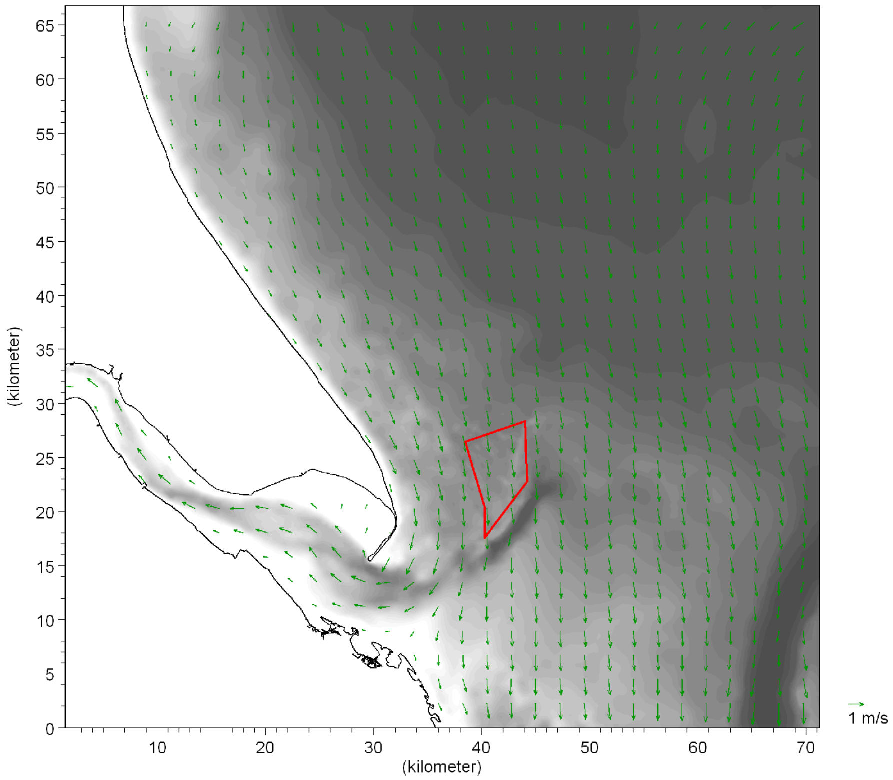
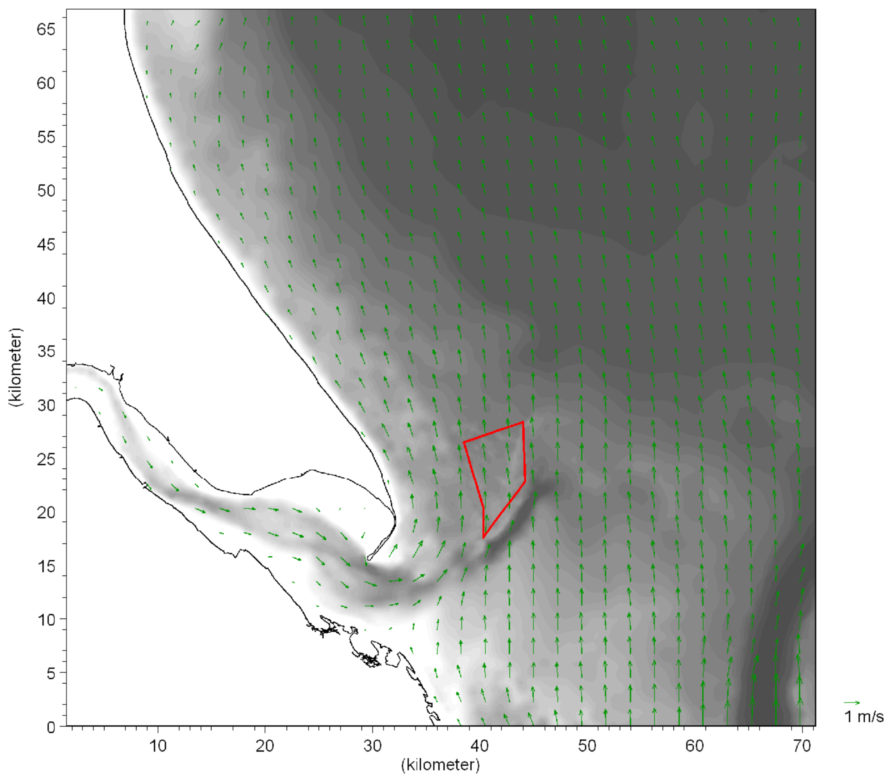
Water Levels At The AWAC Site

Figure 10





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Reference			
3682 - Fig11 Direction.mxd			
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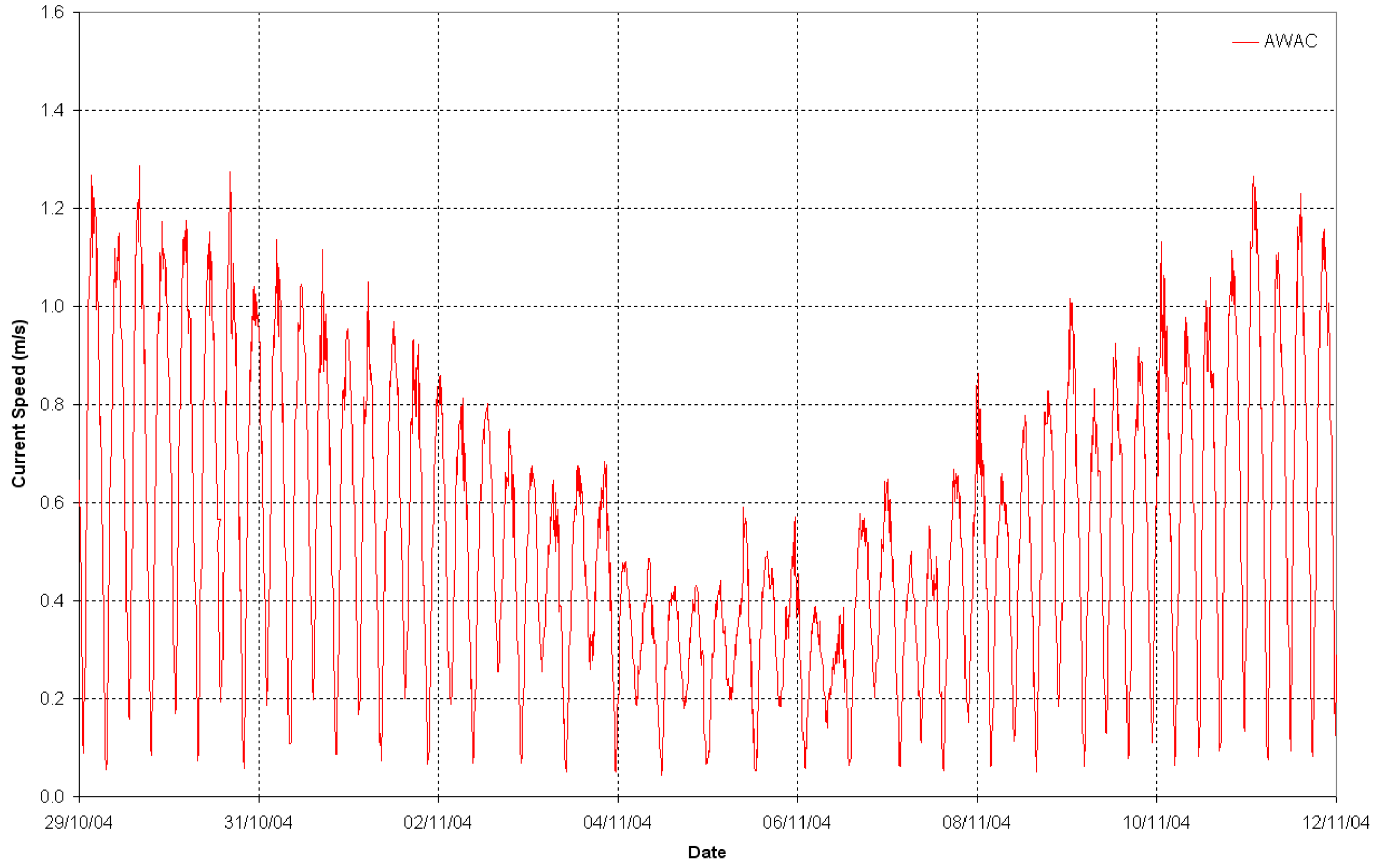
Current Direction Over Far-field Area for Spring Tide at (a) Peak Flood and (b) Peak Ebb

Figure 11



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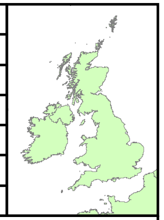

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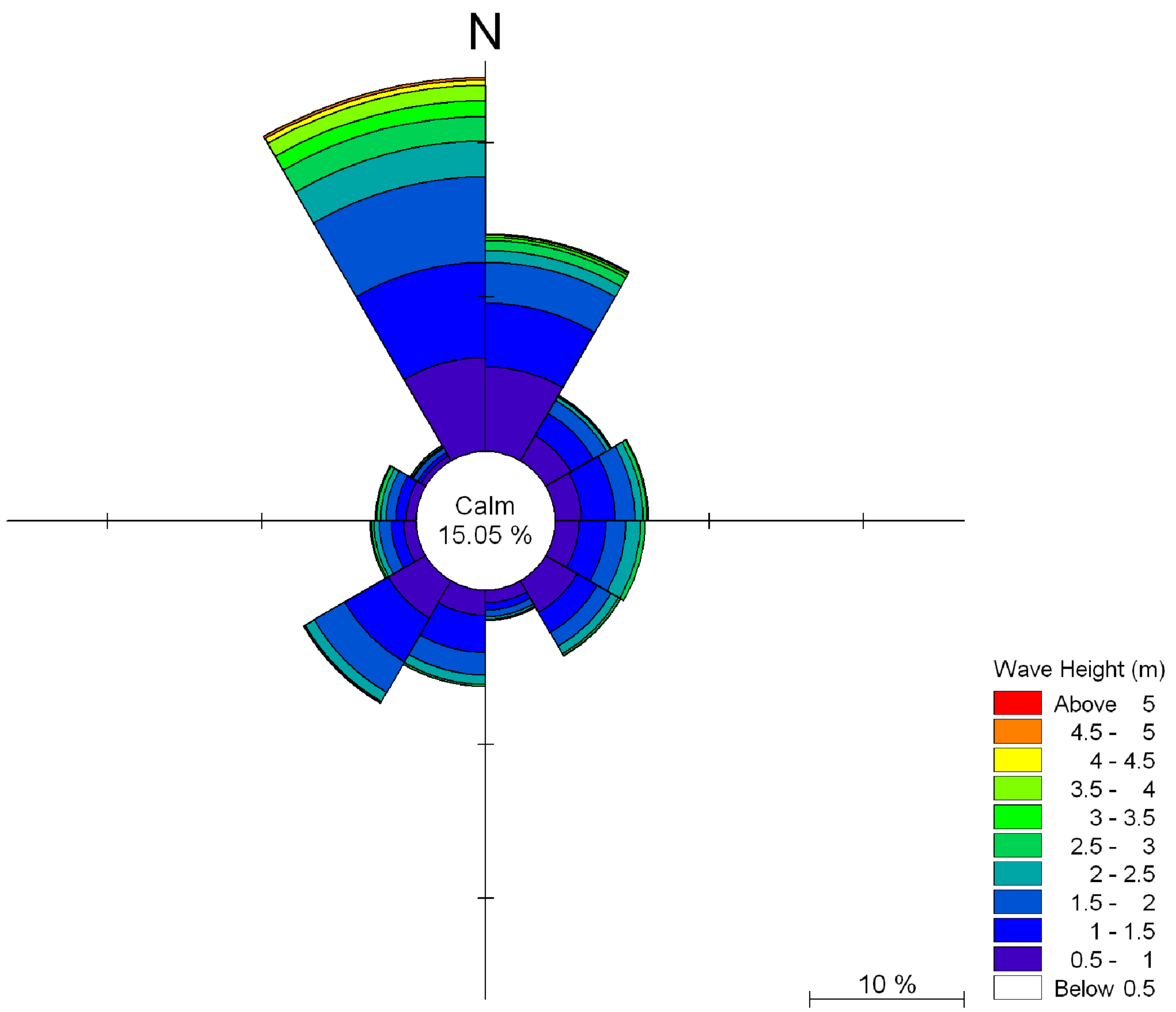
Current Speeds Recorded At The AWAC Site

Figure 12



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Reference			
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Produced by ABPmer Ltd			

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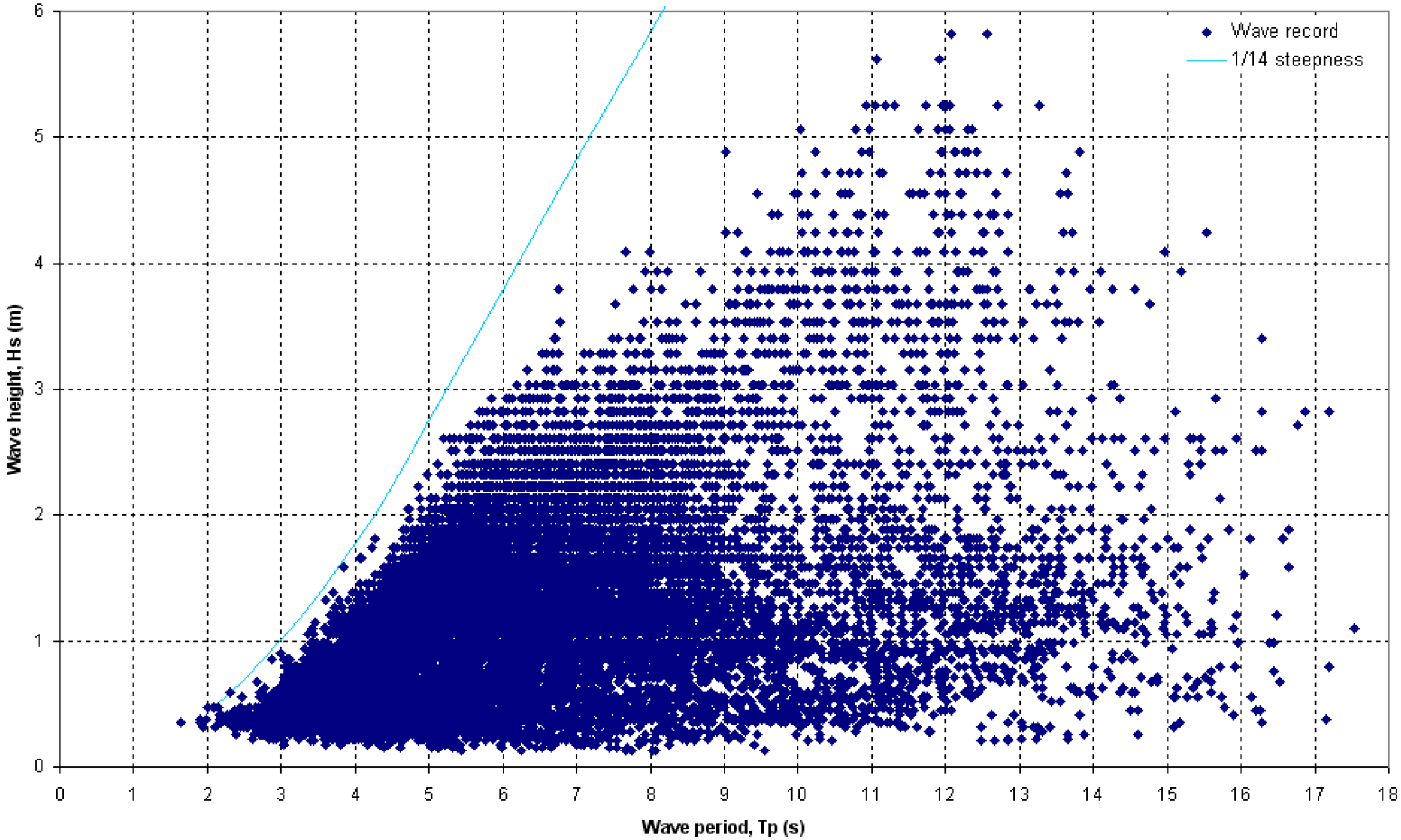
Wave Rose From Dowsing Wavenet

Figure 13



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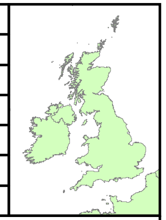

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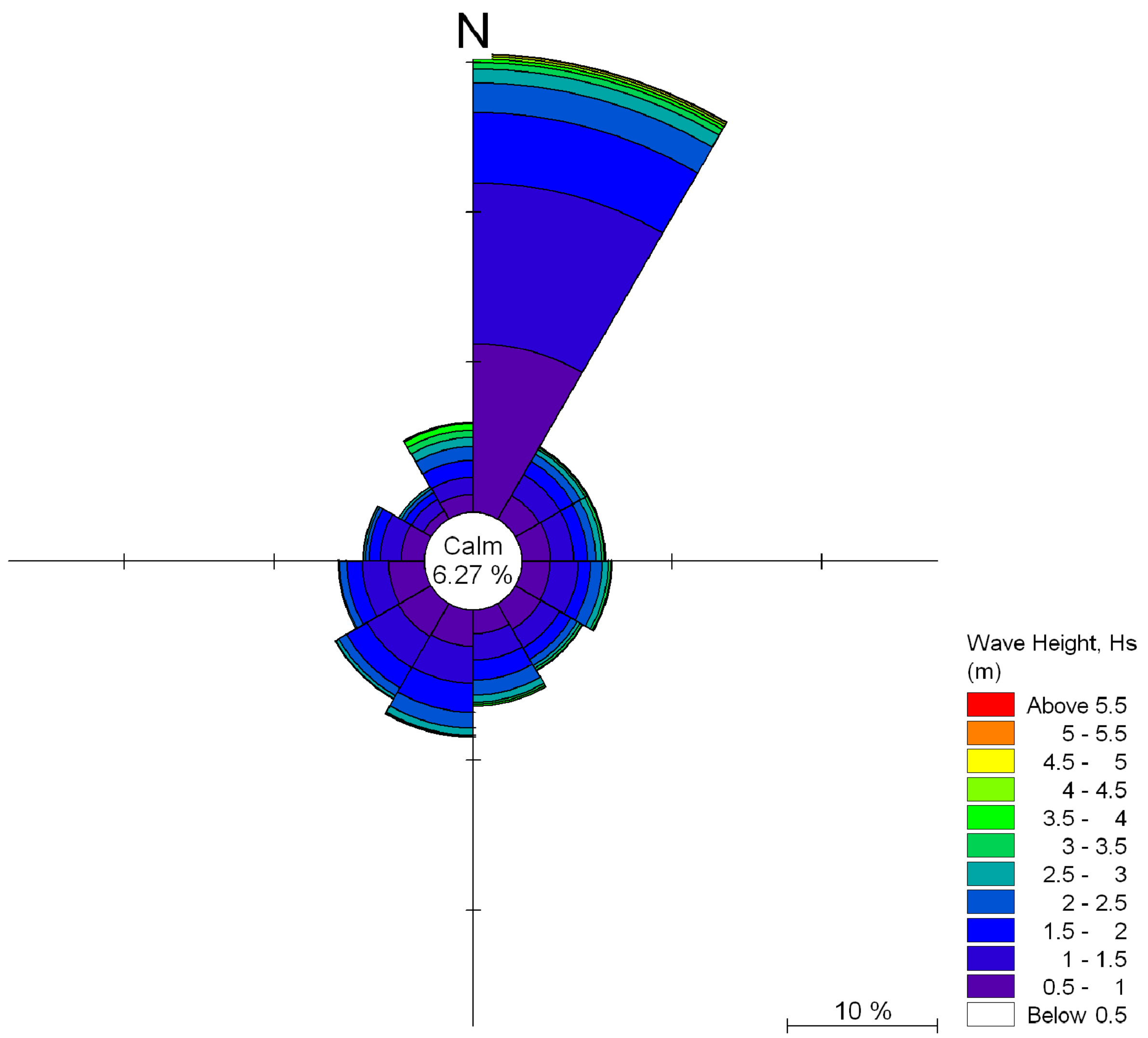
Wave Scatter Diagram
Dowsing Buoy
(Oct 2004 - Nov 2004)

Figure 14



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Produced by ABPmer Ltd			

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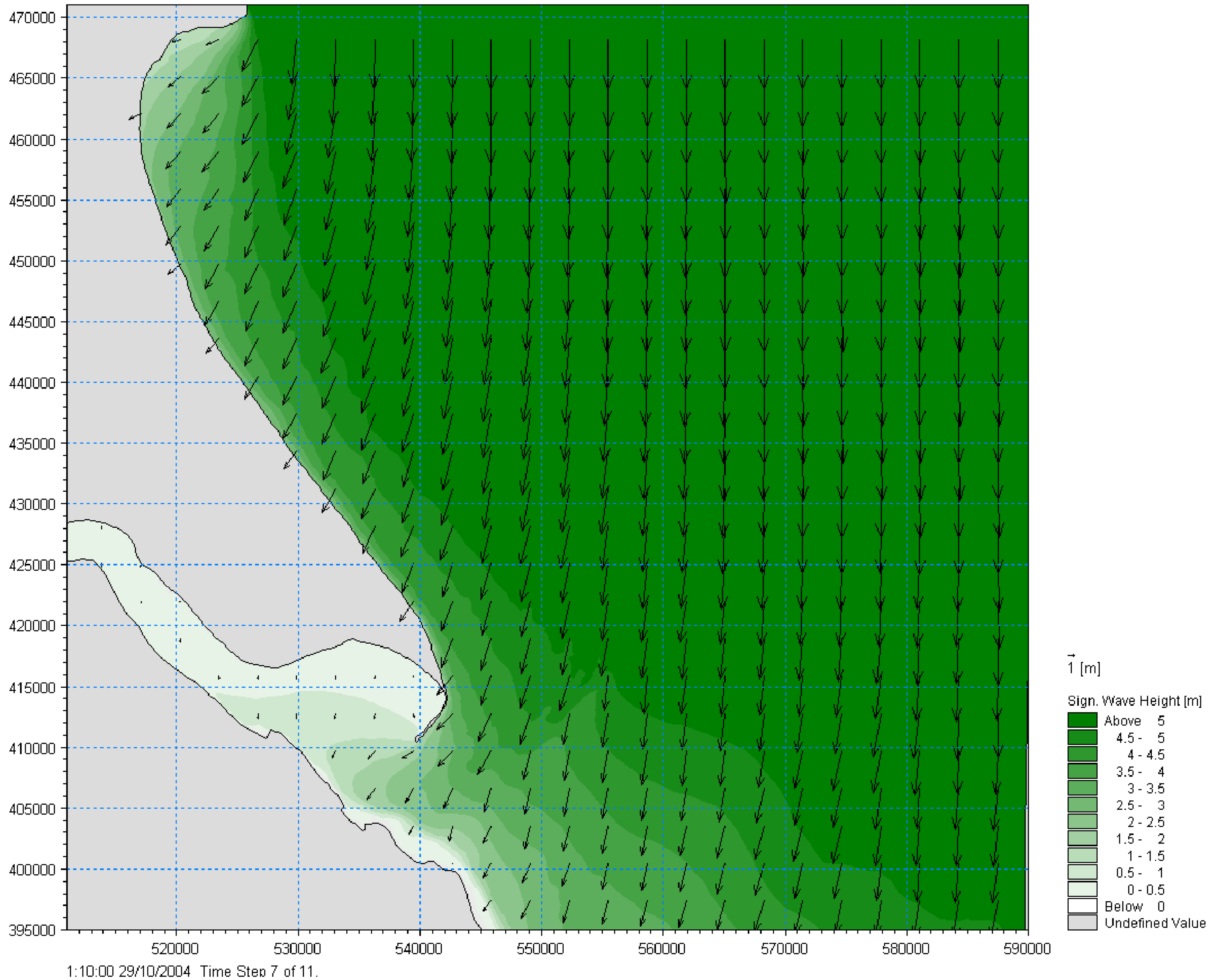
Wave Rose from Met Office Wave Data

Figure 15



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Produced by ABPmer Ltd			

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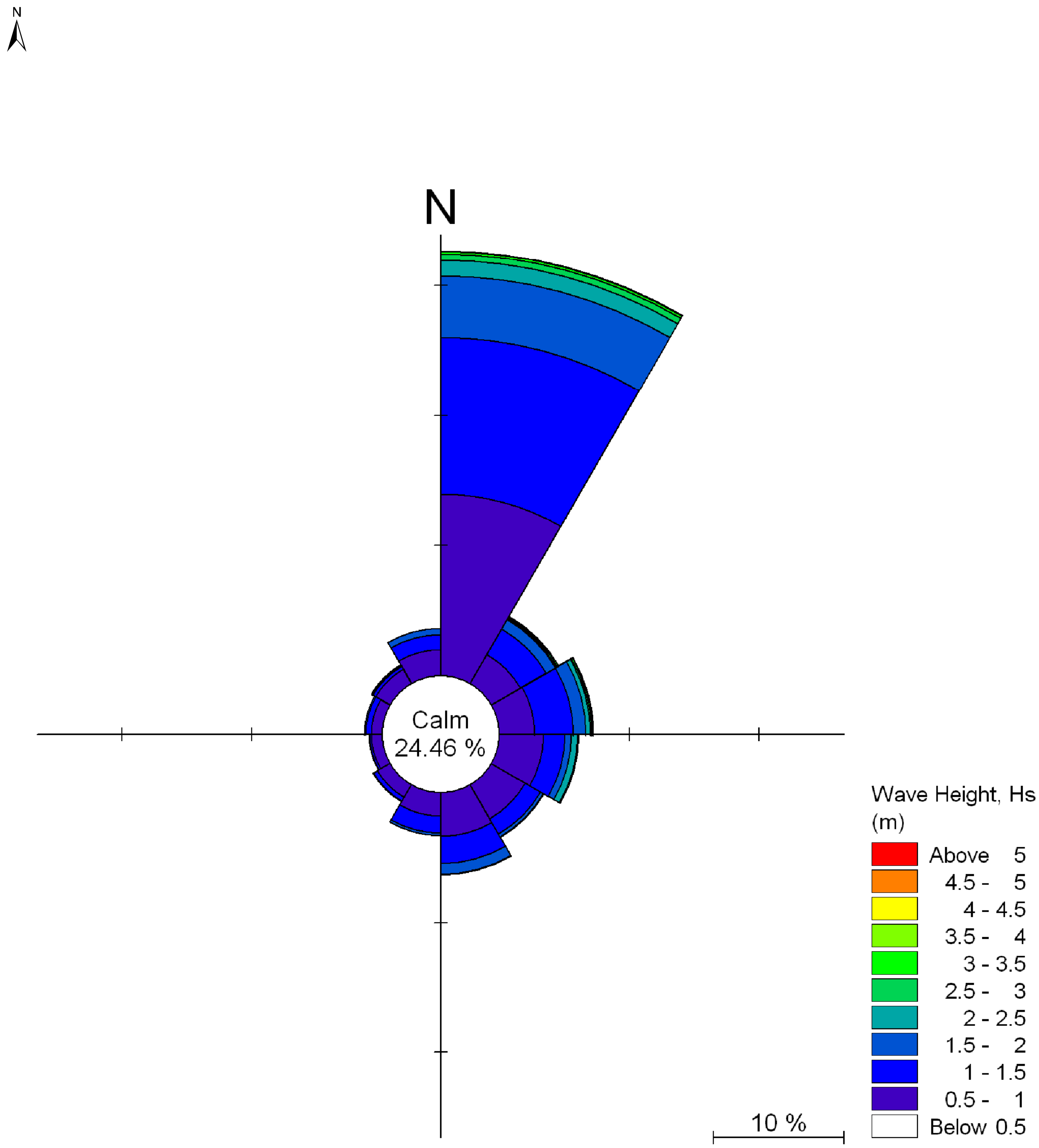
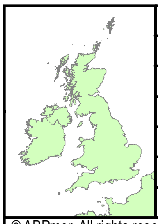
Baseline Conditions For The 1 in 50 Year Return Period from 000ºN

Figure 16





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Produced by ABPmer Ltd			

Taken from R1159b, figure 3

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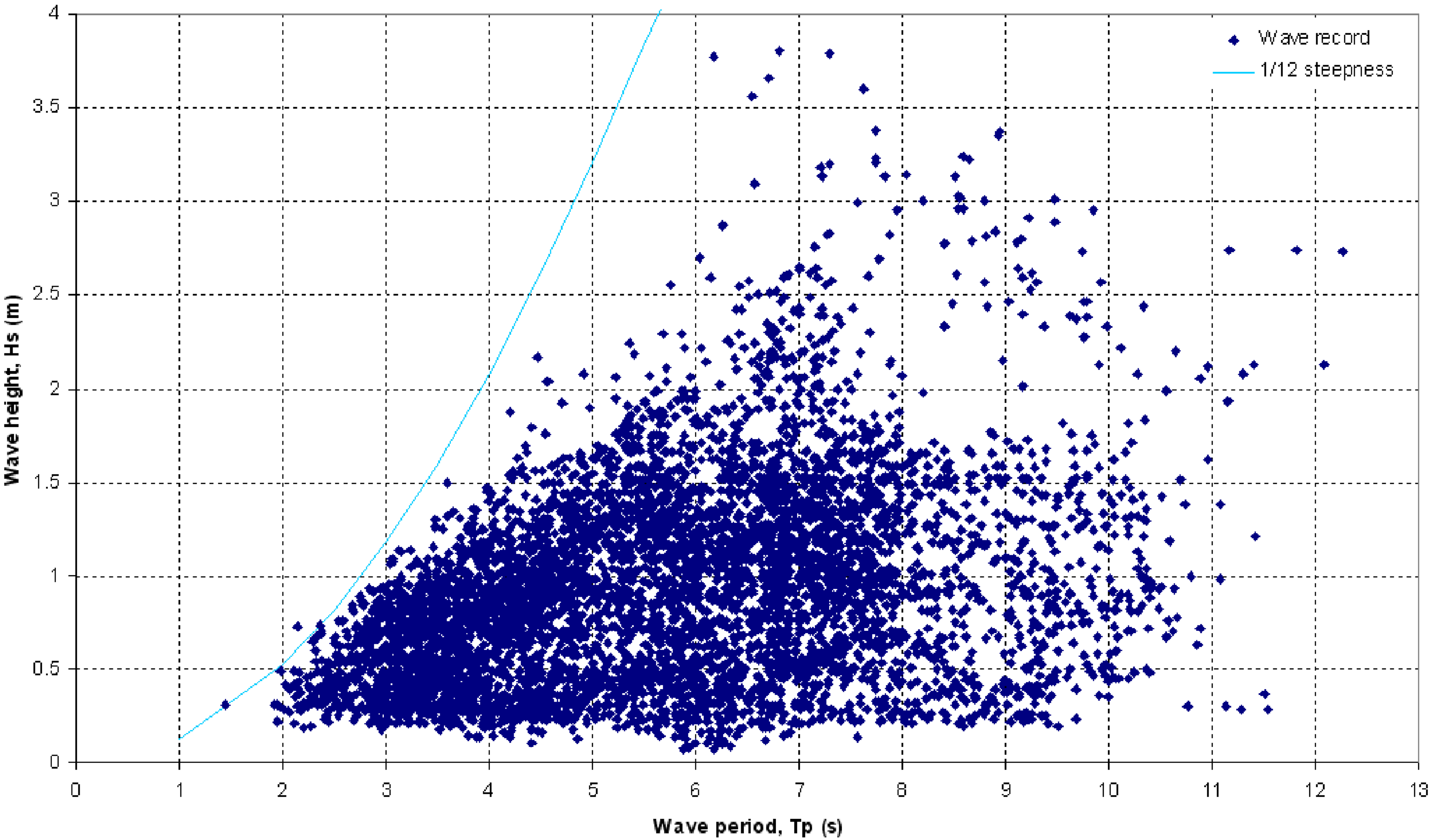
Wave Rose From Nortek AWAC

Figure 17



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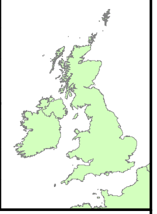

Reference

3682 - Nortek Wave Scatter.mxd

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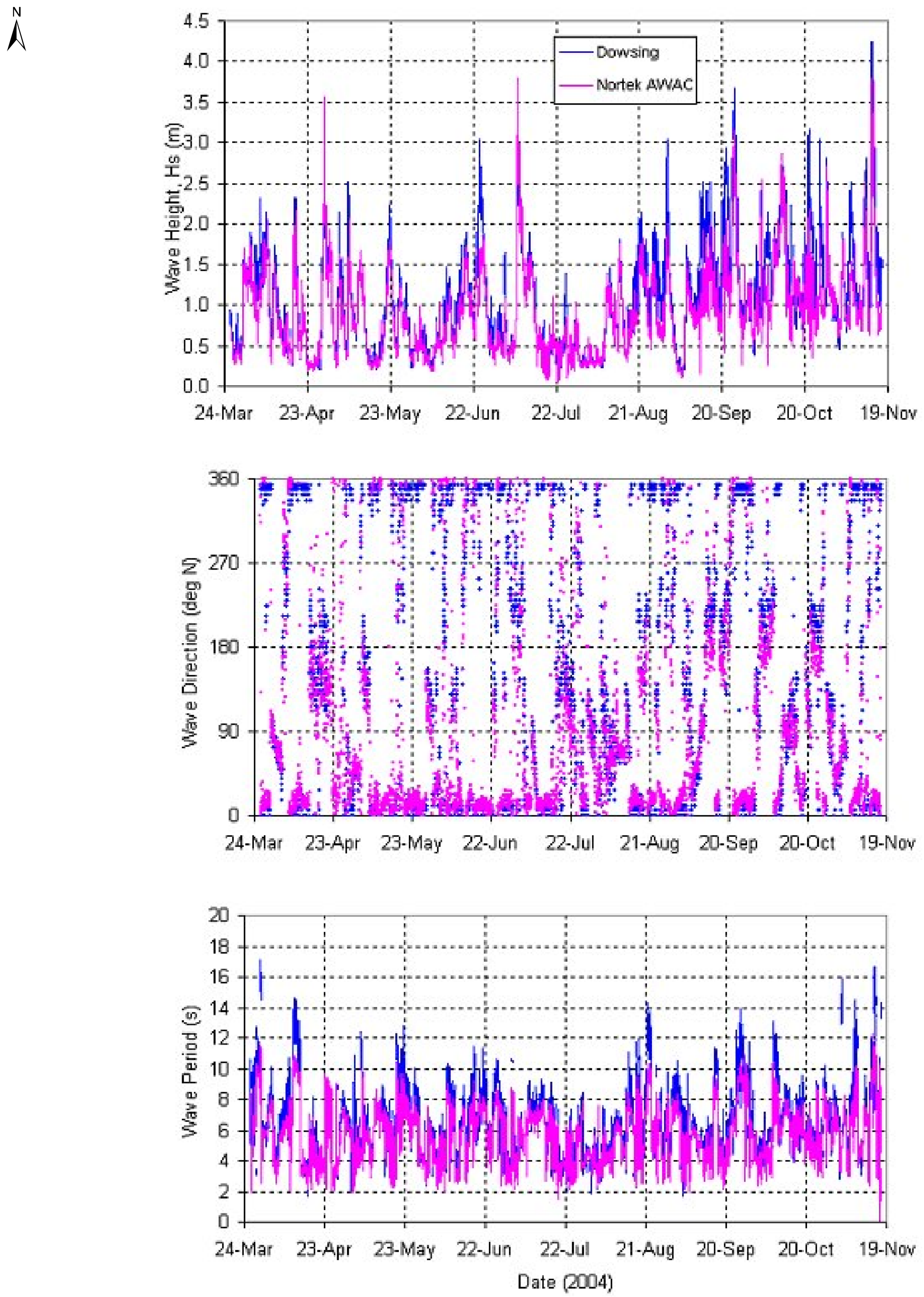
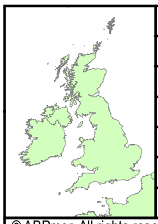
Nortek AWAC Wave Scatter Diagram (March - Nov 2004)

Figure 18





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Taken from R1159, figure 7

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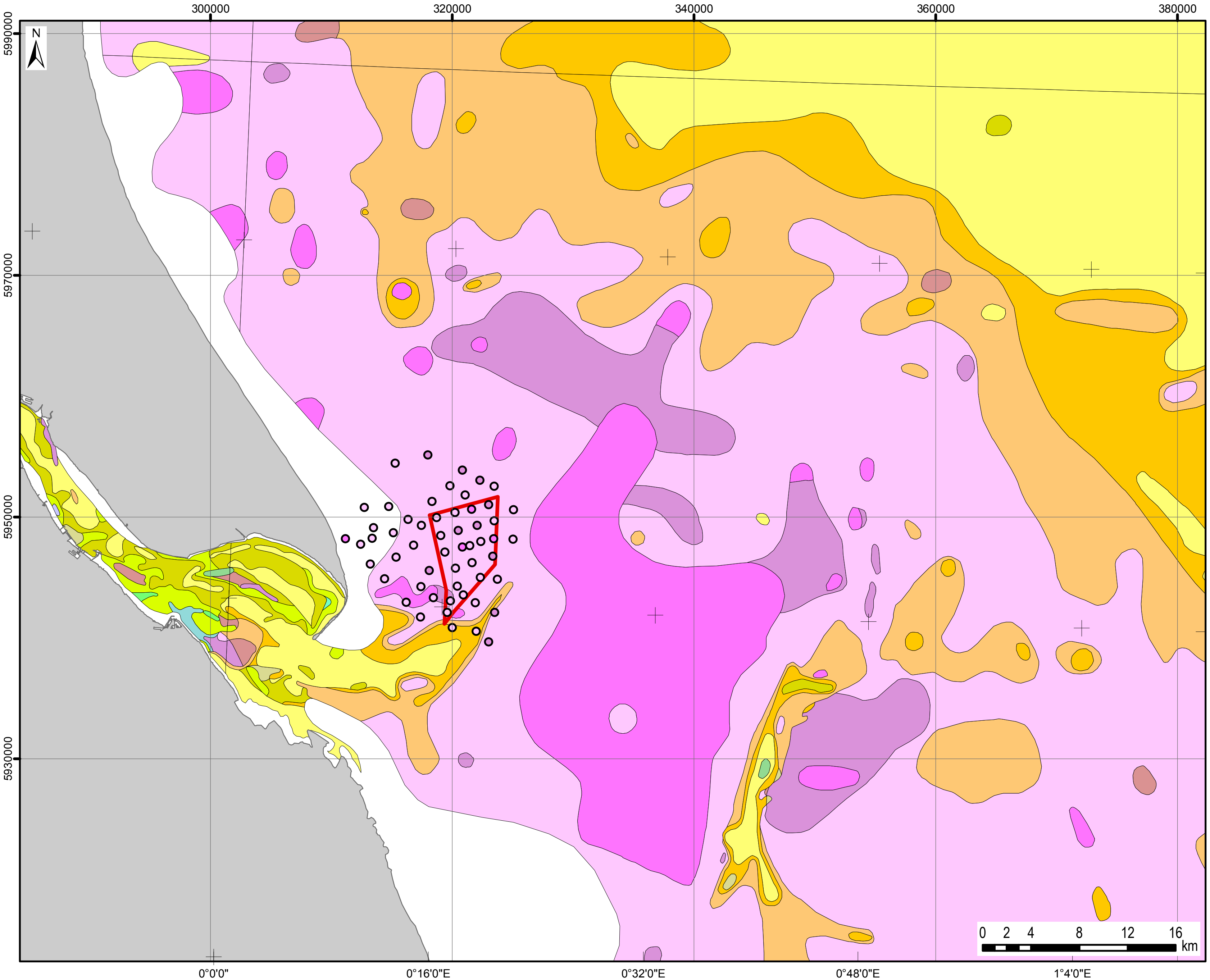
Comparison Of Metocean Data Between Nortek AWAC and Dowsing

Figure 19



HGOWF Site
Gravelly muddy sand
Gravel
Gravelly mud
Gravelly sand
Muddy gravel
Muddy sandy gravel
Mud
Muddy sand
Sandy gravel
Sandy mud
Slightly gravelly muddy sand
Slightly gravelly mud
Slightly gravelly sand
Slightly gravelly sandy mud
Sand
Rock

Date	By	Size	Version
May 2007	RJR	A4	1

Projection	Scale
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Reference
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Produced by ABPmer Ltd

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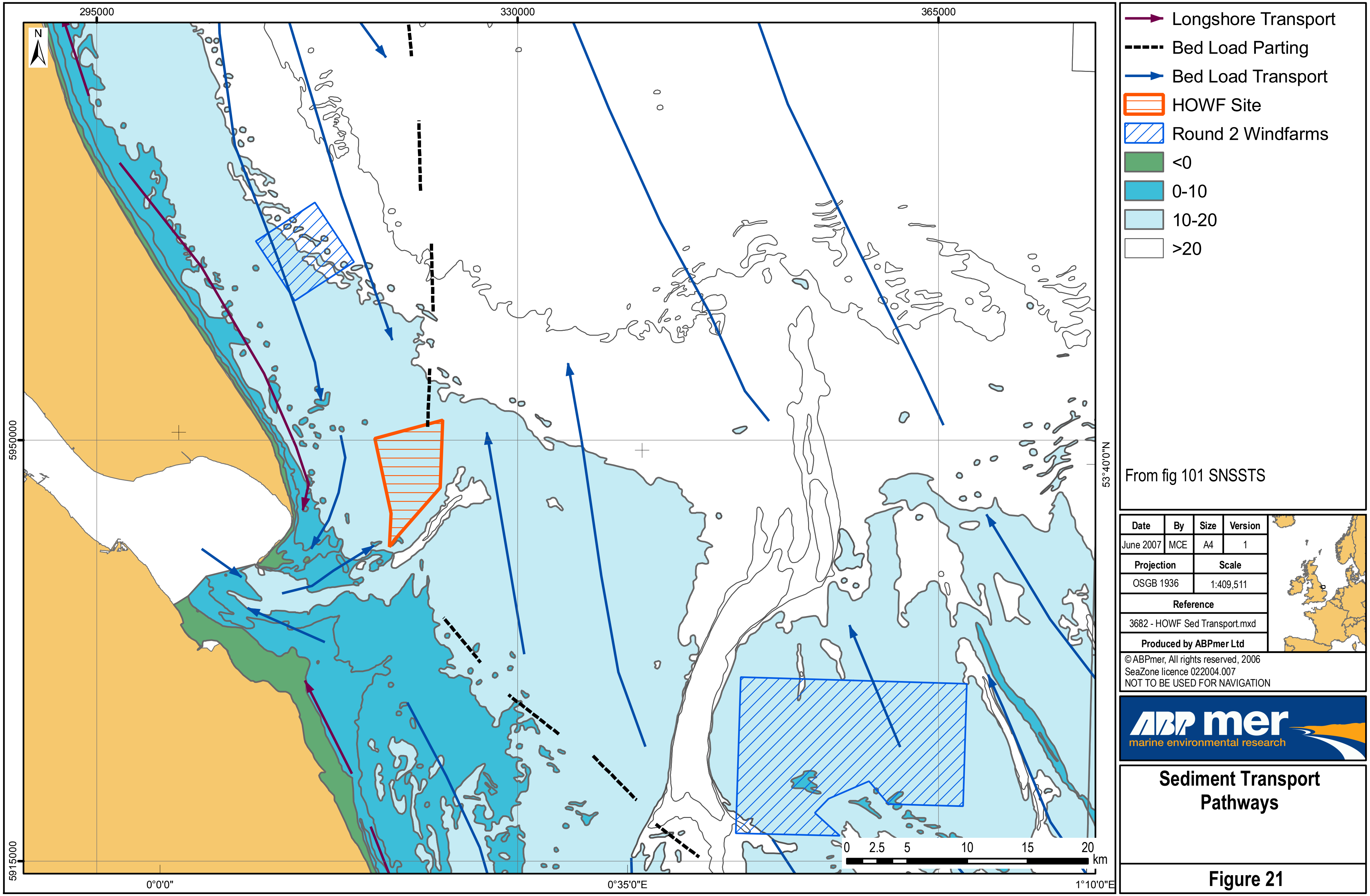
Bed Sediment Composition

Figure 20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365000
5950000
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0°35'0"E
1°10'0"E
53°40'0"N
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2.5
5
10
15
20
km
Longshore Transport
Bed Load Parting
Bed Load Transport
HOWF Site
Round 2 Windfarms
<0
0-10
10-20
>20
From fig 101 SNSSTS
Date
By
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Version
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Reference
3682 - HOWF Sed Transport.mxd
Produced by ABPmer Ltd
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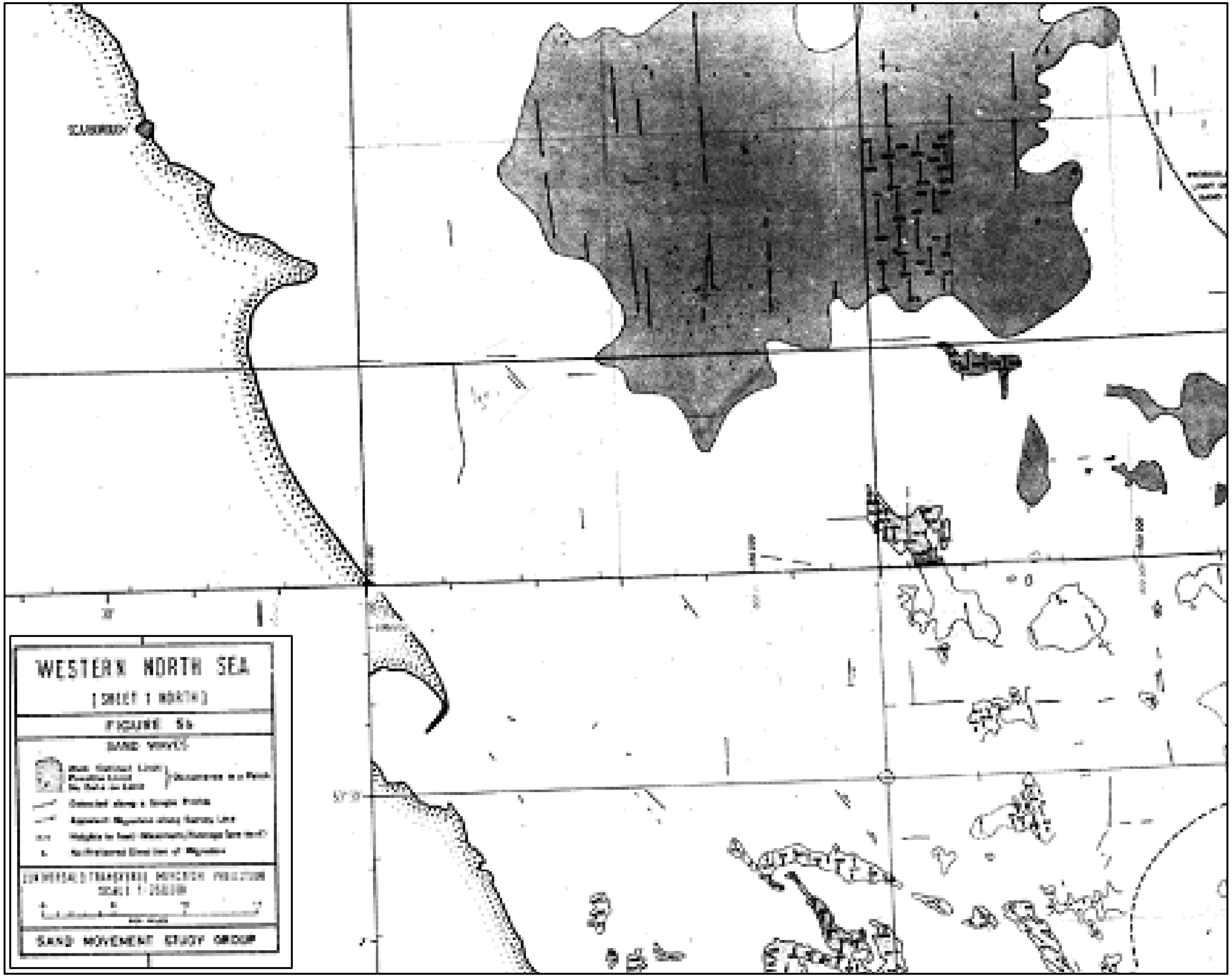
SeaZone licence 022004.007
NOT TO BE USED FOR NAVIGATION
ABP mer
marine environmental research
Sediment Transport Pathways
Figure 21



From an unpublished analysis
(Marine Geology Group, 105 Wormley)

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Reference
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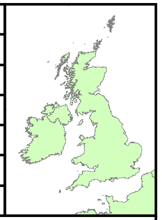

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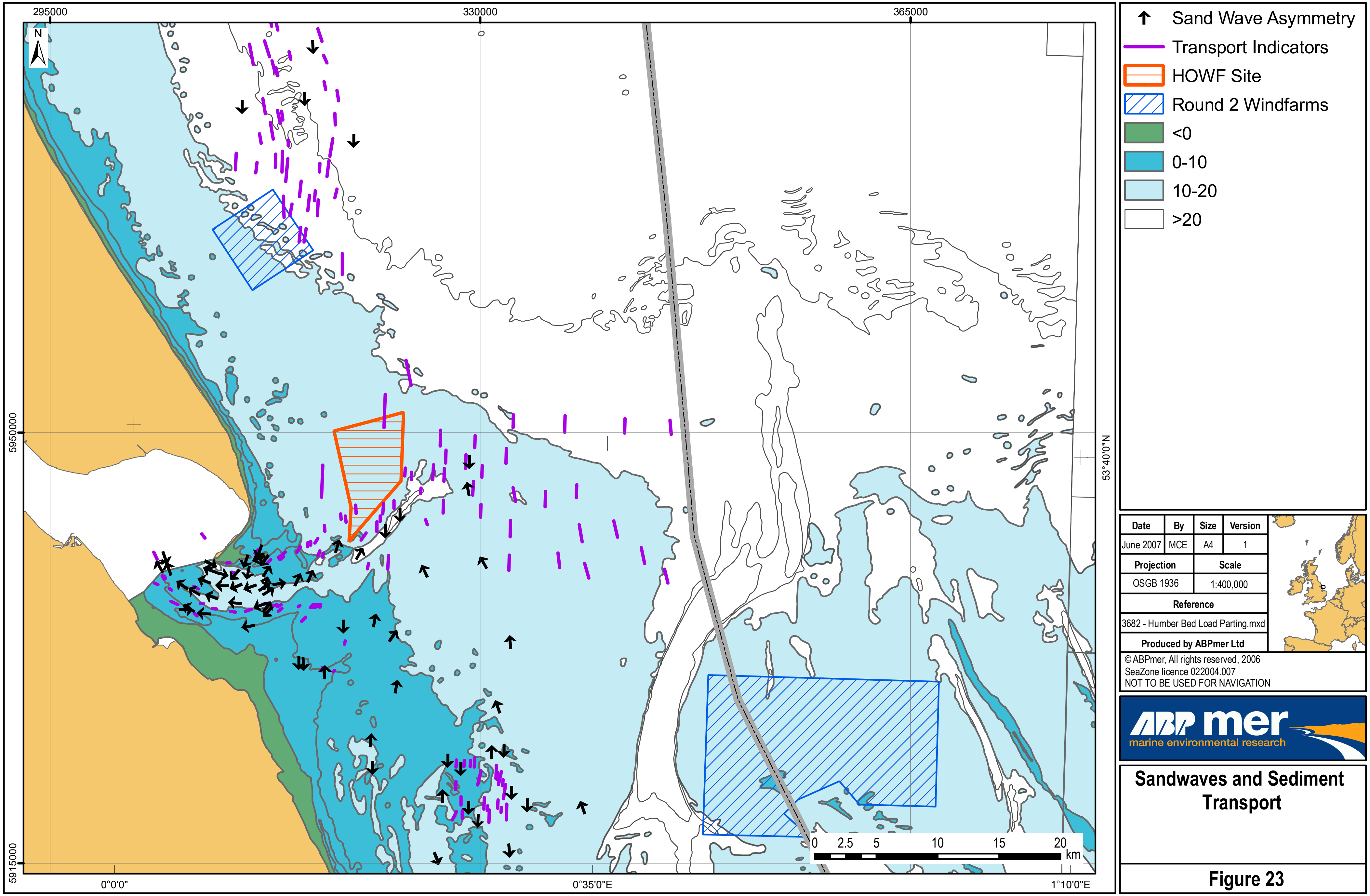
Distribution of large sandwaves in the Greater Wash area

Figure 22



Sandwaves and Sediment Transport

Figure 23

Date	By	Size	Version
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Produced by ABPmer Ltd			

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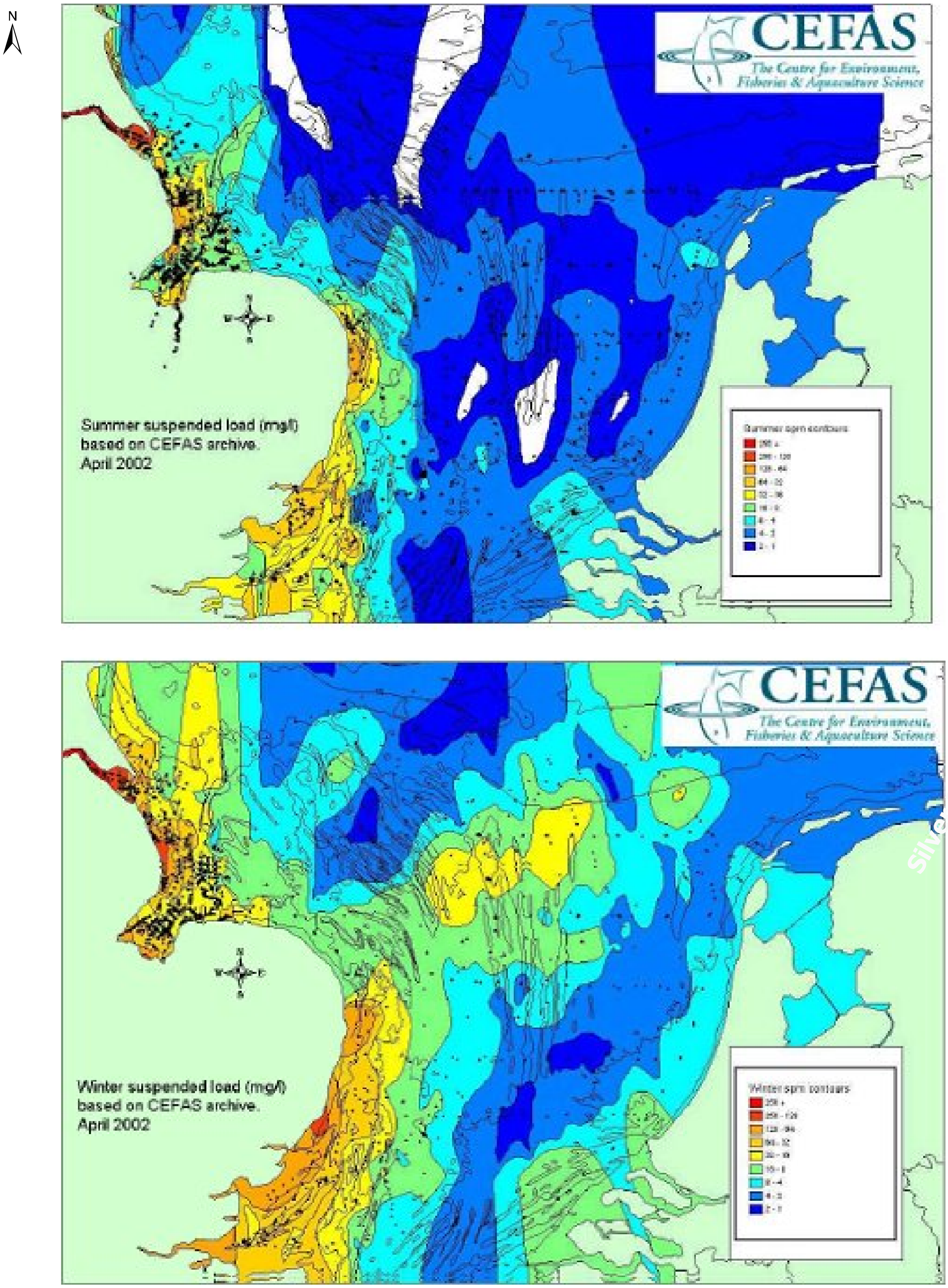
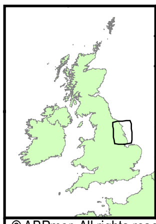
Landsat Image of suspended Sediment Plume

Figure 24





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Taken from SNSSTS, figs 29 & 30

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Suspended Sediment Concentrations

Figure 25

N

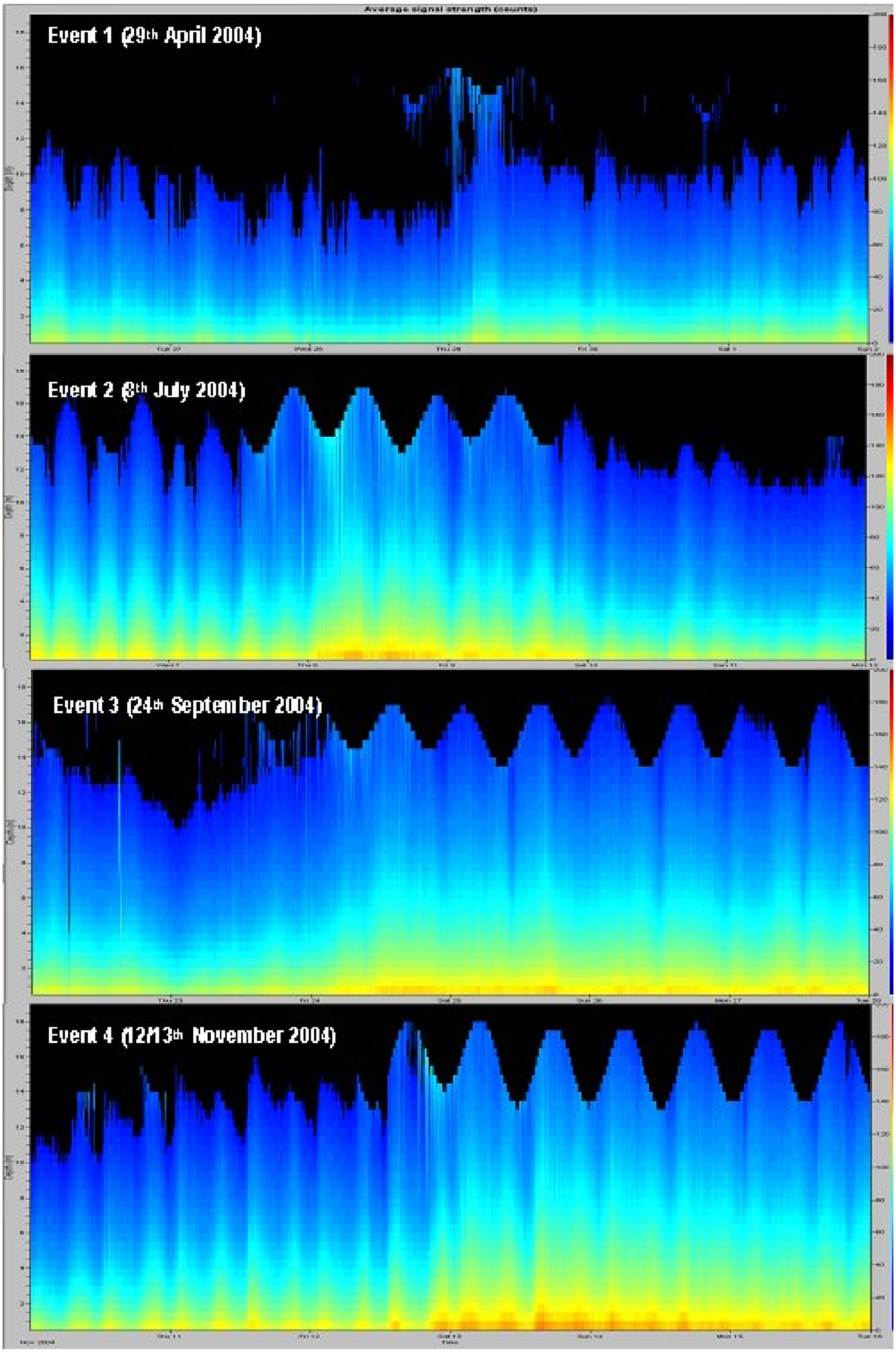

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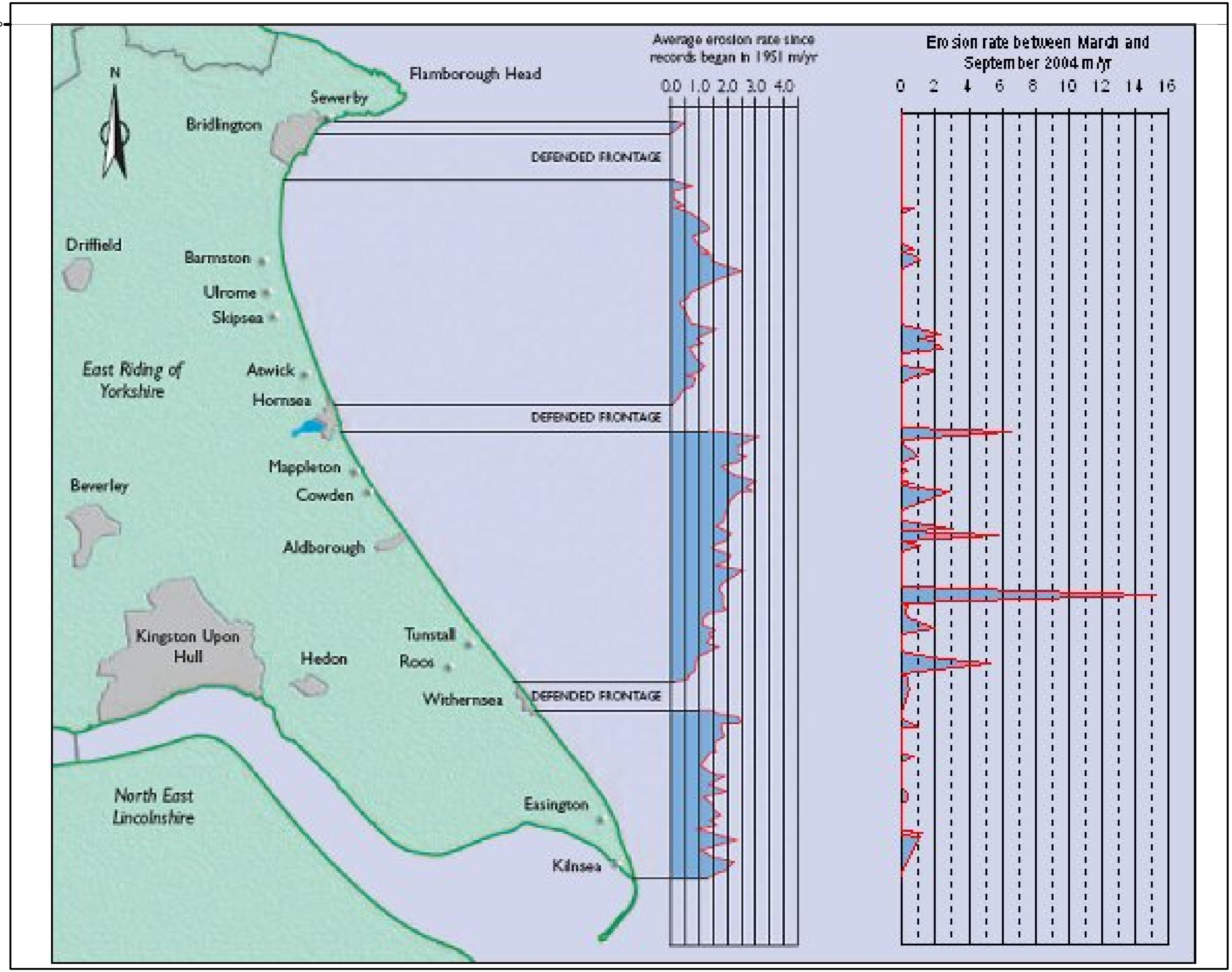
Fig 11 from R1159a

ABP mer marine environmental research

Acoustic Back Scatter at Nortek AWAC Site

Figure 26



From R1159b, figure 14

Date	By	Size	Version
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Produced by ABPmer Ltd			

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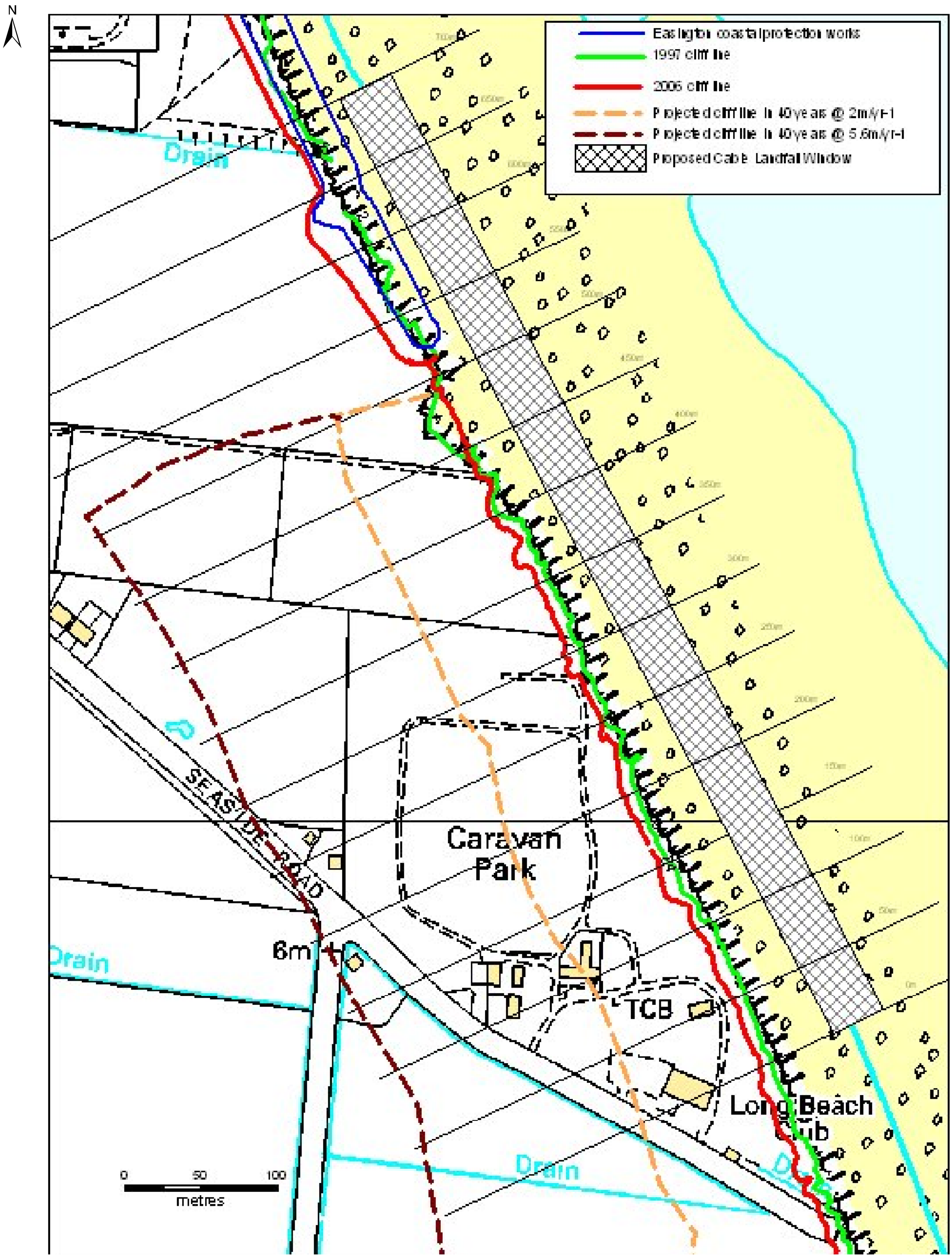
marine environmental research

Erosion At Monitoring Posts Along The Holderness Coastline

Figure 27



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Reference			
3682 - Cliff Erosion IECS.mxd			
Produced by ABPmer Ltd			

Taken from IECS Report, Fig 4

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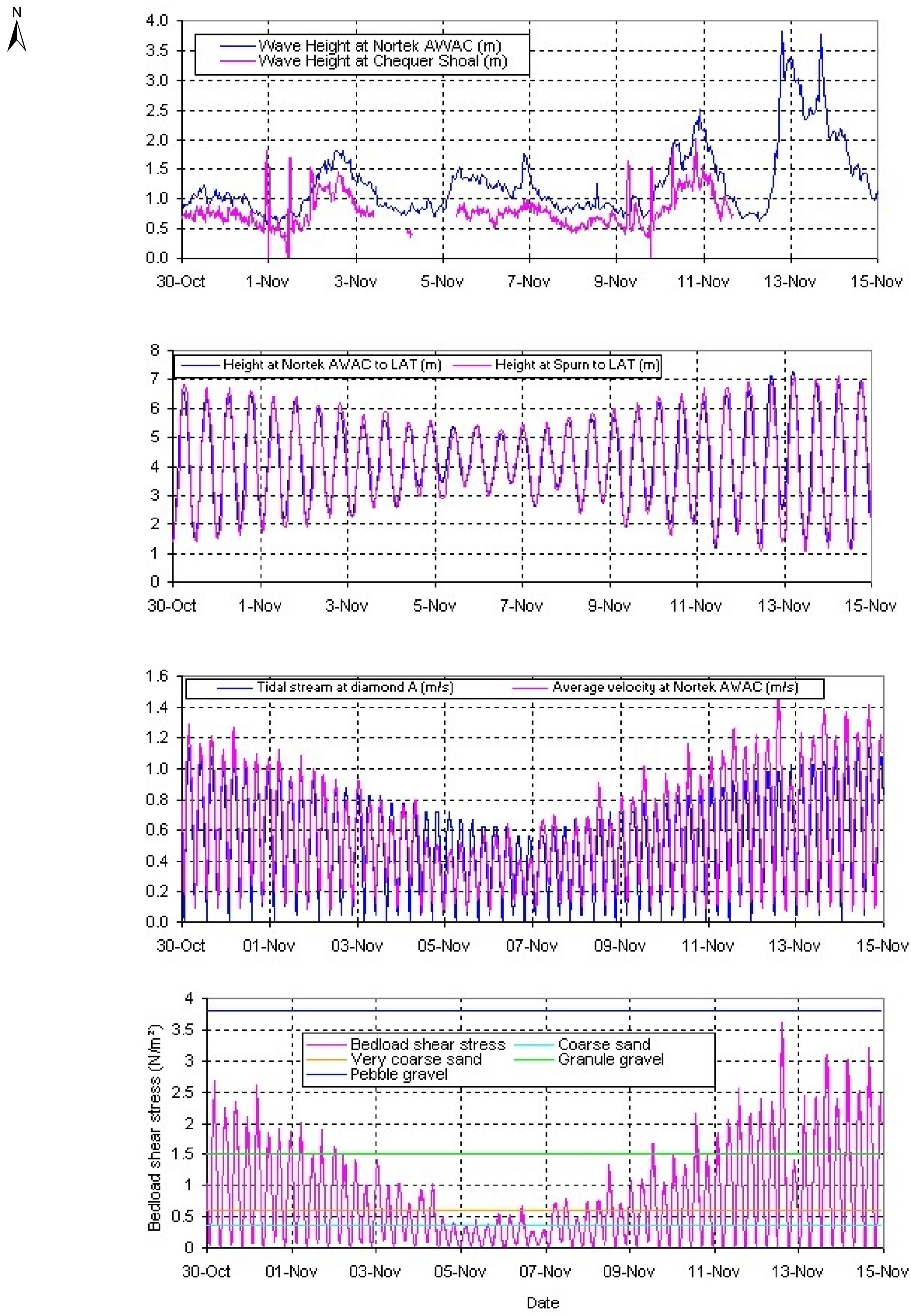
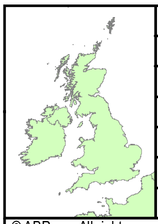
Cliff Erosion Along The Holderness Coastline

Figure 28





Date	By	Size	Version
June 2007	MCE	A4	1
Projection		Scale	
OSGB 1936			
Reference			
3682 - Bed Sheer Stress.mxd			
Produced by ABPmer Ltd			

Taken from R1159b, figure 9

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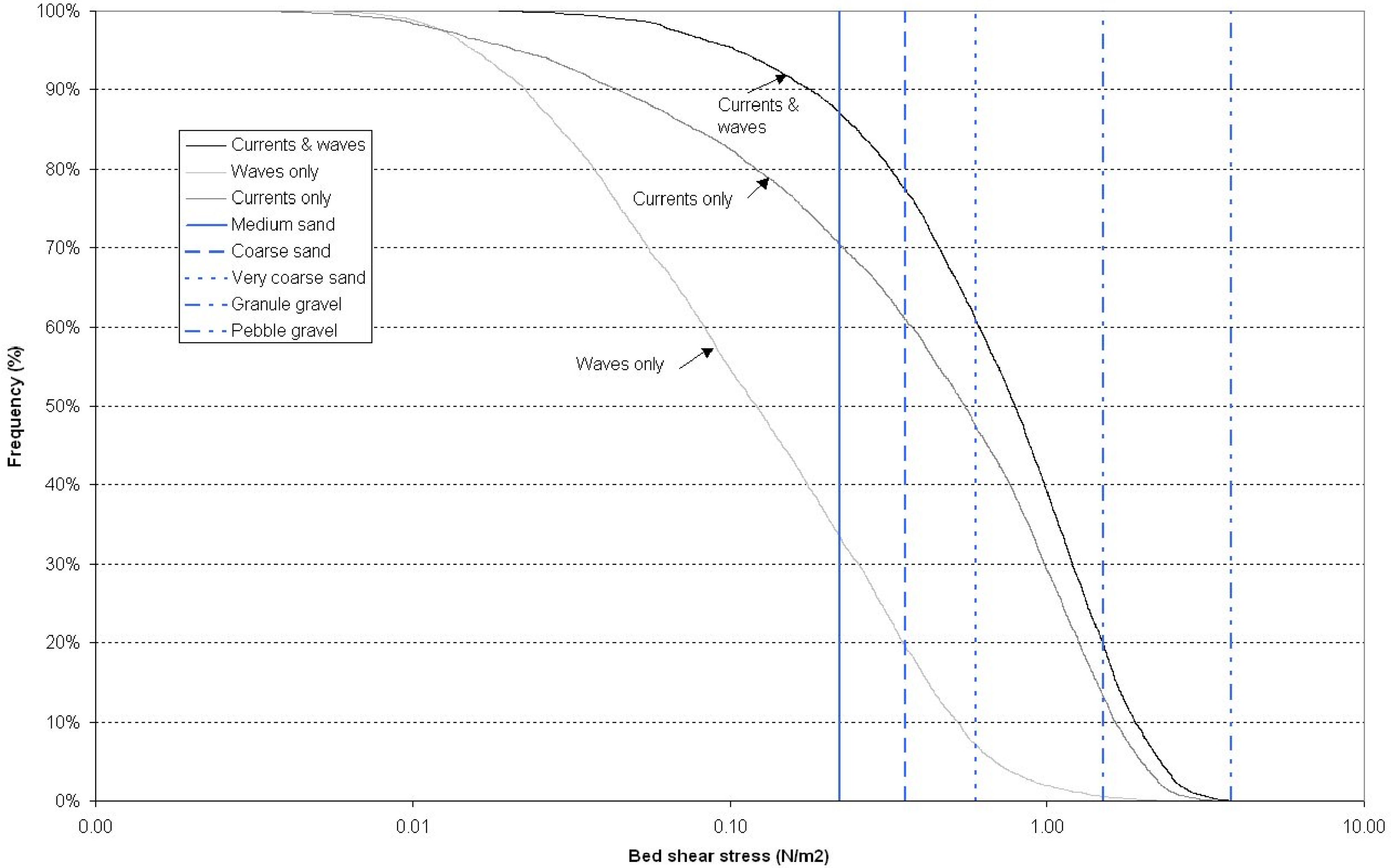
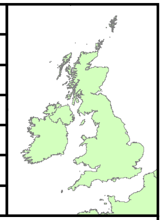
Bed Shear Stress at Nortek AWAC Site

Figure 29



Date	By	Size	Version
June 2007	MCE	A4	1
Projection		Scale	
OSGB 1936			
Reference			
3682 - Exceedance Curves.mxd			
Produced by ABPmer Ltd			



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Exceedance Curves

Figure 30

Appendix A

Wave Frequency Tables

Appendix A. Wave Frequency Tables

Table A1. Wave frequency table for Dowsing Buoy; wave height versus direction (October 2003 to November 2004)

Direction (ºN)	0 - 30	30 - 60	60 - 90	90 - 120	120 - 150	150 - 180	180 - 210	210 - 240	240 - 270	270 - 300	300 - 330	330 - 360
Wave Height (m)	Values are expressed in percentage units											
0.00 - 0.25	1.1	0.9	0.3	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.2	0.3
0.25 - 0.50	10.2	3.3	1.2	2.5	2.3	2.1	0.9	0.6	0.6	0.6	0.1	1.1
0.50 - 0.75	6.9	0.9	0.4	1.5	2.4	1.5	0.9	0.3	0.4	0.3	0.7	0.9
0.75 - 1.00	5.2	1.4	0.3	0.6	3.2	0.8	0.2	0.1	0.2	0.3	0.3	0.8
1.00 - 1.25	4.4	1.9	1.7	0.2	1.5	0.9	0.3	0.2	0.3	0.7	0.3	1.1
1.25 - 1.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.50 - 1.75	2.1	0.6	0.9	0.6	0.2	0.0	0.0	0.0	0.1	0.1	0.0	1.9
1.75 - 2.00	2.1	0.2	0.6	1.0	2.3	0.0	0.4	2.4	1.3	0.4	0.1	4.3
2.00 - 2.25	0.3	3.5	2.9	1.3	2.1	1.2	2.4	4.7	1.2	0.0	0.0	0.8
2.25 - 2.50	0.6	4.0	3.8	0.8	1.8	0.2	0.8	2.3	0.0	0.0	0.1	1.5
2.50 - 2.75	0.6	1.0	1.4	0.3	1.1	0.6	1.5	1.6	0.0	0.0	0.1	3.0
2.75 - 3.00	0.3	0.0	0.4	0.1	0.3	1.0	1.2	1.0	0.2	0.1	0.0	3.4
3.00 - 3.25	0.2		0.3	0.0	0.5	0.8	0.5	0.1	0.2	0.0	0.0	2.7
3.25 - 3.50	0.3		0.3		1.0	0.3	0.1	0.0	0.1	0.1	0.2	0.6
3.50 - 3.75	0.3		0.0		0.5	0.1	0.0		0.3	0.1	0.1	1.1
3.75 - 4.00	0.6				0.4	0.1			0.0	0.2	0.0	1.5
4.00 - 4.25	0.8				0.3	0.3			0.1	0.3	0.1	0.5
4.25 - 4.50	0.2				0.0	0.1			0.3	0.2	0.1	0.5
4.50 - 4.75	0.1					0.0			0.1	0.1	0.0	0.7
4.75 - 5.00	0.2								0.0	0.0		0.5
5.00 - 5.25	0.2											0.6
5.25 - 5.50	0.1											0.5
5.50 - 5.75	0.3											0.4
5.75 - 6.00	0.5											0.8
	NNE	NE	ENE	ESE	SE	SSE	SSW	SW	WSW	WNW	NW	NNW
Total %	10.1	9.3	10.6	4.3	10.4	4.7	6.8	11.9	3.8	1.5	0.7	25.9

Table A2. Wave frequency table for Dowsing; wave height verses period (Tpeak) (October 2003 to November 2004)

Wave Period (s)	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16	16 - 17	Total %	Exceedance %
Wave Height (m)	Values are expressed in percentage units																
4.75 - 5.00									0	0						0	0.0
4.50 - 4.75									0.1	0.1	0					0.2	0.2
4.25 - 4.50									0	0	0.1					0.1	0.3
4.00 - 4.25								0	0.1	0.1	0.1					0.3	0.6
3.75 - 4.00								0.1	0.1	0.1	0.1					0.4	1.0
3.50 - 3.75						0	0	0.2	0.1	0.1	0.1					0.5	1.5
3.25 - 3.50					0	0.1	0.1	0.1	0.1	0.1	0.1					0.6	2.1
3.00 - 3.25					0.1	0.2	0.2	0.2	0.1	0.1	0					0.9	3.0
2.75 - 3.00				0	0.2	0.3	0.2	0.1	0	0.1	0	0				0.9	3.9
2.50 - 2.75				0.2	0.6	0.8	0.5	0.2	0.1	0.1	0.1	0.1				2.7	6.6
2.25 - 2.50				0.4	0.7	0.7	0.4	0.1	0.1	0.1	0.1	0				2.6	9.2
2.00 - 2.25			0	1.3	1.6	1.2	0.6	0.2	0.2	0.2	0.1	0.1			0	5.5	14.7
1.75 - 2.00			0.2	2.6	1.8	1.2	0.6	0.2	0.2	0.2	0.1	0.1	0		0.1	7.3	22.0
1.50 - 1.75		0	1.3	3.8	2.4	2.3	1.1	0.4	0.4	0.3	0.3	0.2	0.1		0	12.6	34.6
1.25 - 1.50		0.1	2.8	3.1	2.4	1.7	0.9	0.4	0.4	0.4	0.3	0.3	0.1	0	0	12.9	47.5
1.00 - 1.25		0.4	4	2.5	2.4	1.4	1	0.5	0.3	0.2	0.3	0.1	0.1	0.1	0	13.3	60.8
0.75 - 1.00	0	2.4	4	2.3	2	1.6	1	0.7	0.5	0.4	0.3	0.2	0	0	0	15.4	76.2
0.50 - 0.75	0.2	2.8	1.9	1.8	1.3	0.7	0.6	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0	10.9	87.1
0.25 - 0.50	1.1	2.8	2.6	1.7	1.3	0.7	0.5	0.5	0.3	0.2	0	0.1	0	0	0	11.8	98.9
0.00 - 0.25	0	0.2	0.3	0.2	0.2	0.1	0.1	0	0	0	0	0	0	0	0	1.1	100.0
Total %	1.3	8.7	17.1	19.9	17	13	7.8	4.3	3.5	3.2	2.2	1.3	0.4	0.2	0.1	100.0	

Table A3. Wave frequency table for Met Office data; wave height versus direction

Direction (ºN)	0 - 30	30 - 60	60 - 90	90 - 120	120 - 150	150 - 180	180 - 210	210 - 240	240 - 270	270 - 300	300 - 330	330 - 360
Wave Height (m)	Values are expressed in percentage units											
0.0 - 0.5	4.64	0.66	0.63	0.53	0.81	0.57	0.53	0.60	0.54	0.30	0.11	0.51
0.5 - 1.0	11.89	1.79	1.87	2.14	2.02	1.72	2.77	2.79	2.50	1.63	0.70	1.31
1.0 - 1.5	9.38	1.59	1.46	1.65	1.27	1.64	2.27	2.15	1.66	1.27	0.89	1.18
1.5 - 2.0	4.05	0.89	0.85	0.75	0.78	1.27	1.92	1.42	0.95	0.64	0.48	1.13
2.0 - 2.5	1.73	0.52	0.56	0.77	0.45	1.03	0.89	0.51	0.35	0.20	0.24	0.88
2.5 - 3.0	0.81	0.33	0.33	0.31	0.22	0.39	0.37	0.16	0.06	0.11	0.16	0.54
3.0 - 3.5	0.35	0.08	0.17	0.14	0.14	0.13	0.07	0.02	0.01	0.03		0.53
3.5 - 4.0	0.18	0.06	0.02	0.06	0.04	0.10	0.01					0.36
4.0 - 4.5	0.19	0.02	0.02	0.01		0.01	0.01					0.05
4.5 - 5.0	0.09		0.01									0.01
5.0 - 5.5	0.02		0.01									0.01
5.5 - 6.0	0.01											
	NNE	NE	ENE	ESE	SE	SSE	SSW	SW	WSW	WNW	NW	NNW
Total %	33.34	5.94	5.93	6.36	5.73	6.85	8.85	7.65	6.08	4.19	2.57	6.51

Table A4. Wave frequency table for Met Office data; wave height versus period

Wave Period (s)	3.0 - 3.5	3.5 - 4.0	4.0 - 4.5	4.5 - 5.0	5.0 - 5.5	5.5 - 6.0	6.0 - 6.5	6.5 - 7.0	7.0 - 7.5	7.5 - 8.0	8.0 - 8.5	8.5 - 9.0	9.0 - 9.5	9.5 - 10	10 - 10.5	10.5 - 11	11 - 11.5	11.5 - 12
Wave Height (m)	Values are expressed in percentage units																	
0.0 - 0.5	3.459	3.146	1.599	0.961	0.348	0.324	0.217	0.127	0.096	0.069	0.041	0.014	0.007	0.014	0.003	0.003	0.003	0.003
0.5 - 1.0	1.426	14.265	9.575	4.097	1.988	0.896	0.400	0.179	0.127	0.083	0.055	0.014	0.010	0.017	0.003	0.003		
1.0 - 1.5	0.338	0.596	9.186	9.637	3.511	1.747	0.765	0.310	0.148	0.114	0.031	0.024	0.014		0.000			
1.5 - 2.0	0.017	0.052	0.114	4.700	7.391	1.509	0.679	0.455	0.141	0.048	0.007	0.000	0.007		0.003			
2.0 - 2.5		0.014	0.000	0.034	2.688	4.259	0.768	0.255	0.065	0.034	0.007	0.007						
2.5 - 3.0					0.031	0.965	2.357	0.407	0.028	0.003	0.000	0.000						
3.0 - 3.5						0.003	0.462	1.041	0.179	0.000	0.000	0.000						
3.5 - 4.0							0.024	0.172	0.593	0.024	0.000	0.003						
4.0 - 4.5								0.010	0.083	0.200	0.003	0.000						
4.5 - 5.0									0.003	0.034	0.079	0.000						
5.0 - 5.5										0.007	0.024	0.003						
5.5 - 6.0												0.010						
Total %	5.241	18.072	20.473	19.429	15.956	9.703	5.671	2.956	1.464	0.617	0.248	0.076	0.038	0.031	0.010	0.007	0.003	0.003

Table A5. Wave frequency table for Nortek AWAC Buoy - Significant wave height versus direction (March to November 2004)

Direction (ºN)	0 - 30	30 - 60	60 - 90	90 - 120	120 - 150	150 - 180	180 - 210	210 - 240	240 - 270	270 - 300	300 - 330	330 - 360
Wave Height (m)	Values are expressed in percentage units											
0.00 - 0.25	1.13	0.89	0.53	0.39	0.21	0.11	0.00	0.05	0.05	0.07	0.05	0.34
0.25 - 0.50	8.13	3.26	2.46	1.93	1.10	0.76	0.39	0.48	0.43	0.37	0.28	0.81
0.50 - 0.75	6.87	1.24	1.26	1.47	1.36	1.38	0.60	0.48	0.34	0.48	0.73	1.17
0.75 - 1.00	7.14	1.33	1.47	1.95	1.65	1.98	1.19	0.66	0.48	0.37	0.55	0.81
1.00 - 1.25	6.29	1.65	1.45	0.89	0.90	1.31	0.78	0.30	0.11	0.28	0.14	0.46
1.25 - 1.50	5.81	0.66	1.52	0.74	0.48	0.78	0.57	0.02	0.05	0.14	0.09	0.71
1.50 - 1.75	3.63	0.48	0.74	0.34	0.21	0.44	0.14	0.02	0.05	0.07	0.11	0.37
1.75 - 2.00	1.06	0.35	0.23	0.19	0.02	0.39	0.04	0.02	0.00	0.02	0.02	0.12
2.00 - 2.25	0.74	0.07	0.27	0.25	0.02	0.04	0.02	0.02	0.02		0.02	0.02
2.25 - 2.50	0.48	0.04	0.09	0.21	0.02	0.00						
2.50 - 2.75	0.28	0.04	0.09	0.09	0.04	0.02						
2.75 - 3.00	0.21	0.07	0.02	0.02								
3.00 - 3.25	0.18	0.07	0.04									
3.25 - 3.50	0.04		0.02									
3.50 - 3.75	0.02		0.04									
3.75 - 4.00	0.04		0.02									
	NNE	NE	ENE	ESE	SE	SSE	SSW	SW	WSW	WNW	NW	NNW
Total %	42.1	10.1	10.2	8.5	6.0	7.2	3.7	2.0	1.5	1.8	2.0	4.8

Table A6. Wave frequency table for Nortek AWAC - Wave height versus period (March to November 2004)

Wave Period (s)	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	Total %	Exceedance %
Wave Height (m)	Values are expressed in percentage units												
3.50 - 3.75					0.0	0.1	0.0					0.1	0.1
3.25 - 3.50					0.0	0.0	0.0					0.0	0.1
3.00 - 3.25					0.0	0.0	0.0					0.0	0.1
2.75 - 3.00					0.0	0.0	0.0					0.0	0.1
2.50 - 2.75					0.0	0.2	0.0					0.2	0.3
2.25 - 2.50					0.0	0.4	0.0					0.4	0.7
2.00 - 2.25		0.0	0.1	0.0	0.1	0.8	0.0					0.9	1.6
1.75 - 2.00				0.0	0.7	1.2	0.4	0.0				2.3	3.9
1.50 - 1.75			0.0	0.3	2.2	3.4	2.1	0.3	0.0			8.5	12.4
1.25 - 1.50		0.0	0.2	1.4	7.2	3.3	2.1	0.3	0.4	0.3	0.0	15.3	27.7
1.00 - 1.25		0.0	0.8	2.8	3.9	2.1	2.6	0.2	0.2	0.8	0.0	13.4	41.1
0.75 - 1.00	0.0	0.1	2.6	5.1	2.2	0.9	0.6	0.1	0.6	1.0	0.0	13.2	54.3
0.50 - 0.75	0.1	0.9	7.0	3.5	1.3	0.3	0.7	0.4	2.2	0.8	0.0	17.3	71.6
0.25 - 0.50	0.1	4.8	6.3	2.1	2.1	1.0	2.1	3.1	3.1	0.4	0.3	25.5	97.1
0.00 - 0.25	0.0	0.2	0.2	0.1	0.2	0.1	0.7	0.9	0.7	0.0	0.0	2.9	100
Total %	0.2	6.0	17.1	15.4	19.9	13.9	11.3	5.3	7.2	3.3	0.3	100.0	

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