Section 7

Description of the Physical Baseline Environment

7 DESCRIPTION OF THE PHYSICAL BASELINE ENVIRONMENT

7.1 INTRODUCTION

7.1.1 OVERVIEW

This section describes the existing physical environment of the Humber Gateway site and surrounding area. The physical features described in this section include the following:

- meteorology and climate (including a description of the wind climate and visibility characteristics), *Section 7.2*;
- chemical and physical oceanography (including a description of the water quality, waves, tides, bathymetry and sea level change), *Section 7.3*;
- coastal and marine geology and geomorphology (including a description of coastal features, seabed topography and shallow geology), *Section 7.4*; and
- coastal and seabed dynamics (including a description of coastal erosion and shoreline processes and sediment transport), *Section 7.5*.

As well as describing the preconstruction conditions, the baseline studies also include a consideration of natural changes (e.g. sea level rise) which may result over the operating period of the wind farm. This provides context for comparing natural changes against any introduced by the development.

7.1.2 SITE SPECIFIC SURVEYS

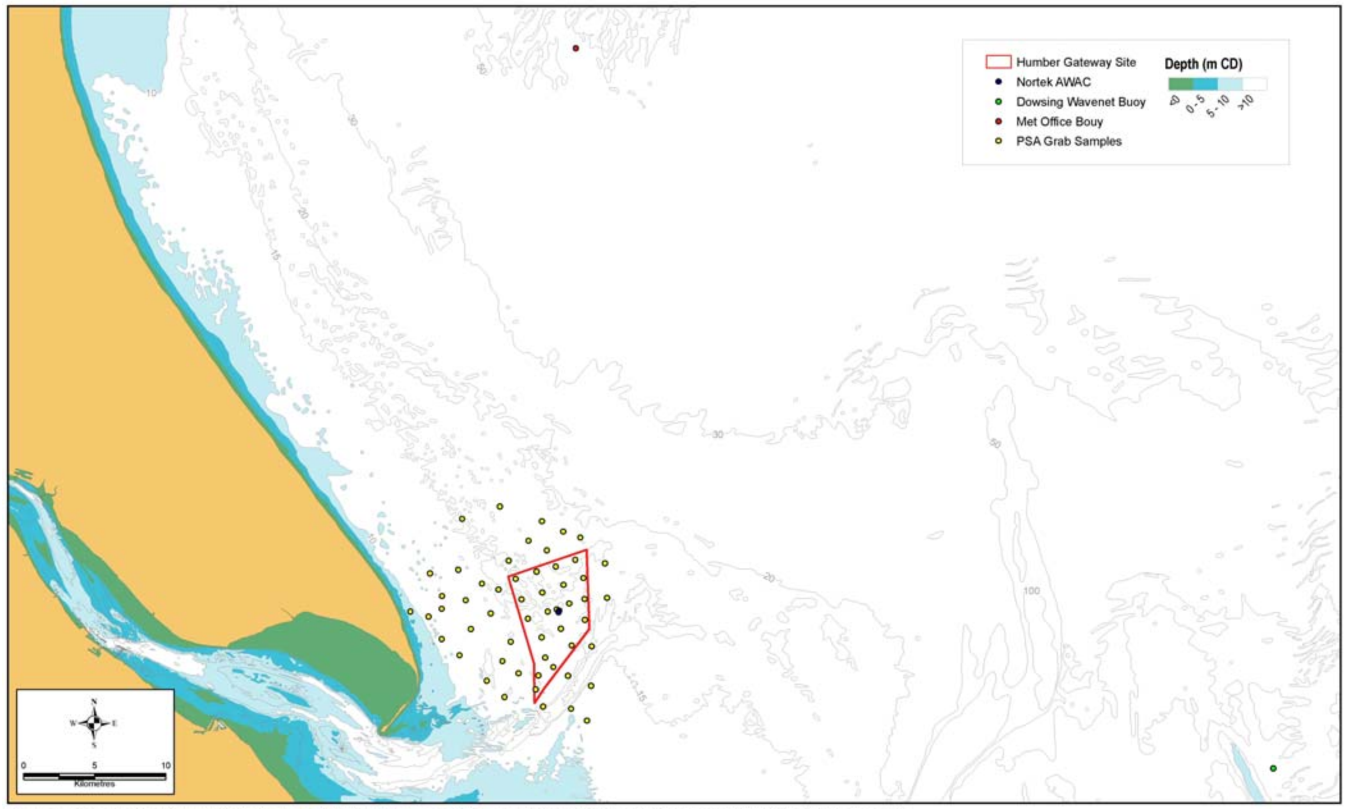
Metocean Survey

A survey was carried out between 26 March 2004 and 16 November 2004. A Nortek Acoustic Wave and Current Meter (AWAC) Buoy was deployed at a location central to the site, as illustrated in *Figure 7.1*, where the depth is approximately 11 m (above Chart Datum). It should be noted that due to the uniformity of the site and the absence of any major sand bodies, the data collected at this location are expected to be representative of the whole site. The results of the metocean survey are presented in full in *Appendix B1* and summarised in *Section 7.3.2*.

Geophysical Survey

The nature of the seabed in terms of bathymetry, geology, geomorphology and dynamics is critical to the understanding of the baseline environment, and a geophysical survey was undertaken between the 27 September and 26 November 2004 [1]. The survey was designed to provide detailed information on the bathymetry (*Section 7.3.3*), seabed morphology and obstructions (*Section 7.4.2*), shallow geology and seabed sediments (*Section 7.4.3*) within the Humber Gateway site and the areas of the two subsea cable route options, a northern and a southern option.

Figure 7.1 Location of Project Specific Surveys and Other Data Sources



Produced by ABPmer Ltd. © British Crown and SeaZone Solutions Limited, 2007. All rights reserved. Data License No. 122005.07. NOT TO BE USED FOR NAVIGATION. PROJECTION: British National Grid

[1] Titan Environmental Surveys Ltd, 2005. Humber Gateway Offshore Wind Farm Geophysical Survey. Report No: CS0114/R1/V2.

Benthic Survey

A benthic survey was undertaken during December 2004 [(1)]. A total of 55 grab samples were collected by use of a 0.1 m^2 Hamon Grab, of which 21 were located within the Humber Gateway site. The remaining 34 grab samples were located within the proposed cable route corridor options and wider areas *(Figure* 7.1). Particle Size Analysis (PSA) was undertaken using the grab sample data. The baseline report is presented in *Appendix C1 (Baseline Study of the Marine Ecology)* and the results that are relevant to the physical baseline are presented in *Section 7.4.3.*

Diver Survey

An additional survey was undertaken in December 2006 [(2)], in order to determine the sediment characteristics of some 'spiky features' identified from the geophysical survey within the nearshore cable route area. Particle size analysis was undertaken [(3)] and the results are discussed in *Section 7.4.3* as appropriate.

7.1.3 OTHER INFORMATION SOURCES

As well as the site specific survey reports, a significant amount of other information has been used to generate the physical baseline for the Humber Gateway site and surrounding area, including the following:

- *SeaZone charted vector and hydrospatial bathymetric data*. This data has been used to provide base mapping and to inform the far field model domain.
- *British Geological Survey (BGS) surface sediment information.* This data has been used to provide a more regional indication of the seabed material.
- *East Riding of Yorkshire Council*. Datasets obtained include cliff erosion rates along the Holderness Coast and beach profile data between Spurn Head and Mappleton, around 37 km to the north. This data has been used to calibrate the littoral drift model and provide a baseline against which to compare the effects of the wind farm.
- *WaveNet Data*. The Centre for the Environment, Fisheries and Aquaculture Sciences (Cefas) operates 'Wavenet' which is a strategic wave monitoring network for England and Wales. This provides a single source of real time wave data from a network of wave buoys located offshore from areas at risk from flooding. One such buoy is located 50 km to the east of the Humber Gateway site at 53°31.74'N and 001°3.21'E in approximately 22 m of water (above Chart Datum). 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 14 km from the Humber Gateway site at the entrance to the Humber Estuary. It should be noted that this recorder provides intermittent, although useful, 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.
- *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 years.
- *Cefas current meter data* from the iSEA website has been used to help calibrate current speeds within the hydrodynamic model.
- Current meter data from the British Oceanographic Data Centre (BODC), collected at alternate sites to the Cefas data, have also been used to help calibrate current speeds within the hydrodynamic model.
- *Ground conditions at Humber Gateway Wind Farm*, D'Olier 2006a [(4)].
- *Humber Gateway Wind Farm, The projected cable route 'spiky features',* D'Olier, 2006b [(5)].
- *Offshore Humber - Sites A, B, E. Geological Desk Study,* D'Olier, 2003 [(6)].

(1) Institute of Estuarine and Coastal Studies, 2005. Humber Gateway: Baseline Study of the Marine Ecology.
(2) Northern Divers, 2006. Humber Gateway Diving Inspection.
(3) Ambios Environmental Consultants Ltd, 2007. Laboratory Analyses Methodology. ERM Humber Gateway samples, February 2007.
(4) D'Olier, 2006a. Ground conditions at Humber Gateway Wind Farm.
(5) D'Olier, 2006b. Humber Gateway Wind Farm. The projected cable route 'spiky features'.
(6) D'Olier, 2003. Offshore Humber - Sites A, B, E. Geological Desk Study. For: Global Renewable Energy Partners (GREP A/S); Round II/Offshore Wind Farm Studies.

- Land Ocean Interaction Study (LOIS) reports [1].

7.1.4 Numerical Modelling

Numerical models have been developed by ABPmer to provide a baseline assessment of coastal processes within the study area. Technical details of these models, in addition to the proving techniques, are provided in *Appendix B2 (Coastal Processes Embedded Mitigation Assessment).*

7.1.5 Stakeholder Engagement

Key stakeholders were invited to respond to the *Humber Gateway Environmental Impact Assessment (EIA) Scoping Report* [2]. The responses received have been taken into consideration and have been a contributing factor in determining the scope of both the baseline studies and the assessment methodology. A full list of consultation responses is presented in *Appendix A*.

Stakeholders have raised the following key issues in relation to the physical baseline and assessment:

- the potential for the project to affect littoral drift leading to the exposure of coastal archaeological features;
- changes to shoreline processes which may impact Spurn Head and other coastal conservation sites;
- changes to turbidity during construction and operation;
- seabed scour, with the potential to expose ancient or remnant sub-seabed features and displace benthic features; and
- scour during construction and installation, potentially affecting seabed habitats.

[1] Land Ocean Interaction Study, 2000. Second Annual Meeting, Hull, pp. 155-156. LOIS Publication Number 323.
[2] Emu Ltd. 2004. Humber Wind Ltd, Proposed HOWF Offshore Wind Farm. EIA Scoping Report.

All survey methodologies described in *Section 7.1.2* have been developed in accordance with current guidance and best practice (Defra, Cefas and DfT [3], OfDPM [4] and Defra [5]). In addition, relevant stakeholders (e.g. Cefas, Defra and Natural England) were consulted and invited to provide comment on the scope of the metocean, benthic and geophysical surveys as appropriate. These comments were taken into account in agreeing the survey methodologies.

7.1.6 Study Area

Determining the Study Area

The main considerations in determining an appropriate study area were:

- to ensure that both stand-alone and cumulative impacts could be properly assessed;
- the spatial extent of the potential impacts on the receiving environment; and
- the nature of other users of the sea or the seabed in the area and their interaction with the physical environment and processes.

Two bathymetric depressions lie to the southwest of the site, New Sand Hole and Inner Silver Pit (*Figure 7.2*). New Sand Hole lies approximately 15 km east of the Spurn Head Peninsula and is approximately 10 km long, 1.5 km wide and has a maximum depth of 45 m below mean sea level [6]. It was agreed during consultation with the stakeholders that the extent of the surveys should focus on those sea users which are located within the same tidal elipse (i.e. the area delineated by the movement of water in one tidal cycle, since this is the area that could potentially be affected). It was agreed that any interactions with sea users outside of this area would have minimal impact. Similarly, Silver Pit acts as a major process divide within the area, thereby minimising the potential for impacts with any other offshore developments to the south of these features.

[3] Defra, Cefas and DfT, 2004. Offshore wind farms: guidance note for Environmental Impact Assessment in respect of FEPA and CPA requirements: Version 2.
[4] OfDPM, 2001. Guidance on Environmental Impact Assessment in Relation to Dredging Applications
[5] Defra, 2005. Nature Conservation Guidance on Offshore Wind Farm Development.
[6] Balson P S,1997. Predicting sediment yield from recession of the Holderness coast. In Land-Ocean Interaction Study – Second Annual Meeting, Hull, pp 152-154. Publication number 323.

Other users or potential users of the seabed [1] in the vicinity of the Humber Gateway site are described in *Section 9.6* and those that are located within the same tidal elipse are summarised in *Table 7.1* and shown in *Figure 7.2*.

Table 7.1 Seabed Users in the Study Area

Sub-Sea Cables and Pipelines	Aggregate Sites	Offshore Wind Farms
Amethyst to Easington pipeline	Area 102 (existing)	Westernmost Rough – at pre-planning stage
Ravenspurn to Easington pipeline	Area 448 (proposed)	
Rough to Easington pipeline	Area 449 (proposed)	
Langeled pipeline		
Amethyst to Easington power cable		

It should be noted that while *Figure 7.2* does not show the specific location of the Amethyst to Easington power cable, it is located approximately 50 metres to the north of the Amethyst to Easington pipeline.

Spatial Scales

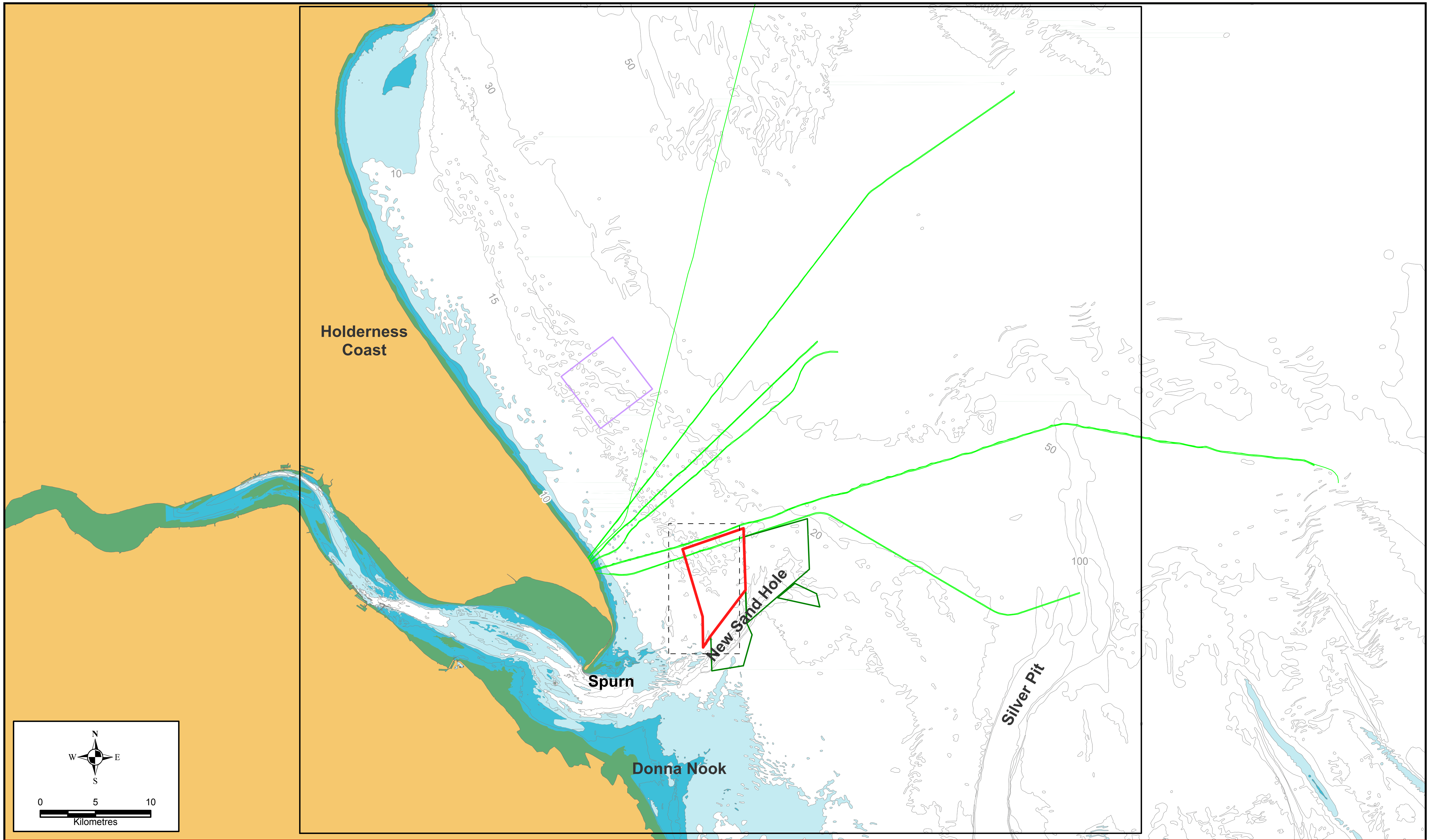
Within the baseline study area, two spatial scales are used, the far-field scale and the near-field. These spatial scales are shown in *Figure 7.2* and are used particularly in relation to the coastal process related topics.

The far-field scale is defined as the coastal area surrounding the development site where remote effects may occur. The boundaries to this area are as follows:

- 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.

The near-field scale is defined as the footprint of the entire Humber Gateway development that resides in the marine environment, including the turbines, foundations and cables.

[1] with the exception of commercial fisheries and commercial and recreational shipping where the use of the seabed is more general rather than defined by a boundary.



KEY:

- Humber Gateway Site
- Far Field
- Near Field
- Pipeline
- Westernmost Rough Site
- Dredge Site

Depth (m CD)

<0 | 0 - 5 | 5 - 10 | 10 - 15

CLIENT: e·on

ABP mer marine environmental research

ERM

SIZE:

TITLE:

Figure 7.2
Key Bathymetric Features, Near and Far Field Study Areas and Other Developments in the Baseline Study Area

DATE: 30/11/07	CHECKED:	PROJECT: 3682
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DRAWING: Fig_EON_Key_bathy2.mxd

REV: 1

7.2 METEOROLOGICAL PARAMETERS

7.2.1 WIND DATA

Figure 7.3 presents wind frequency distributions at 53.529°N 0.797°E, in the vicinity of the Humber Gateway site. From the wind rose it can be seen that the most predominant wind speed for the study area is from the southwest and west. Peak wind speeds for the southern North Sea are predominantly in the range of 28.5 to 32.7 m s^{-1} (Beaufort Force 11).

7.2.2 VISIBILITY DATA

The study area is within the Humber Shipping Forecast area. The Meteorological (Met) Office issues a Shipping Forecast on behalf of the Maritime and Coastguard Agency (MCA) every day, which includes information on visibility. *Figure* 7.4 indicates the visibility records between 1999 and 2003 at Weybourne on the Norfolk coast. It is assumed that there will be no be significant differences between the Humber and Norfolk coastlines with regard to atmospheric visibility.

The coast in this area is characterised by visibility of 15 km or more for approximately 62% of the time (226 days per year) and visibility of less than 15 km for 38% of the time (138 days). For shorter distances, visibility is greater than 8.5 km for 81% of the time (288 days) and it is typically less than 8.5 km for 19% of the time (77 days).

Figure 7.3 Wind Rose for the Study Area (data from HSE, 2001[1])

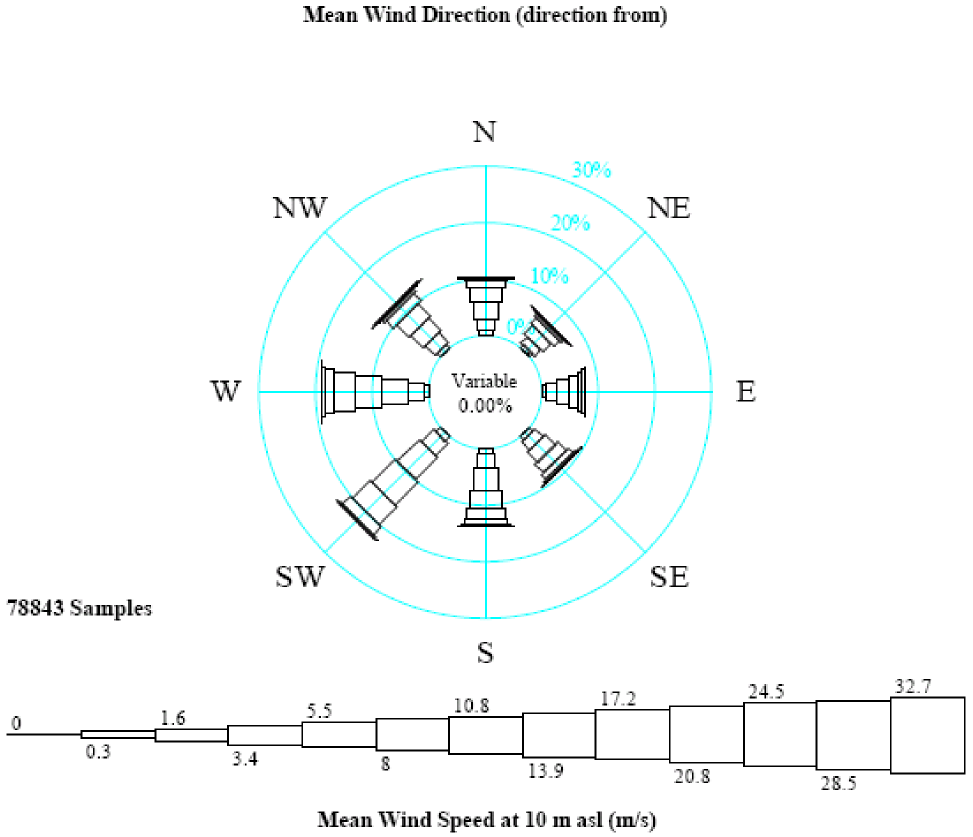
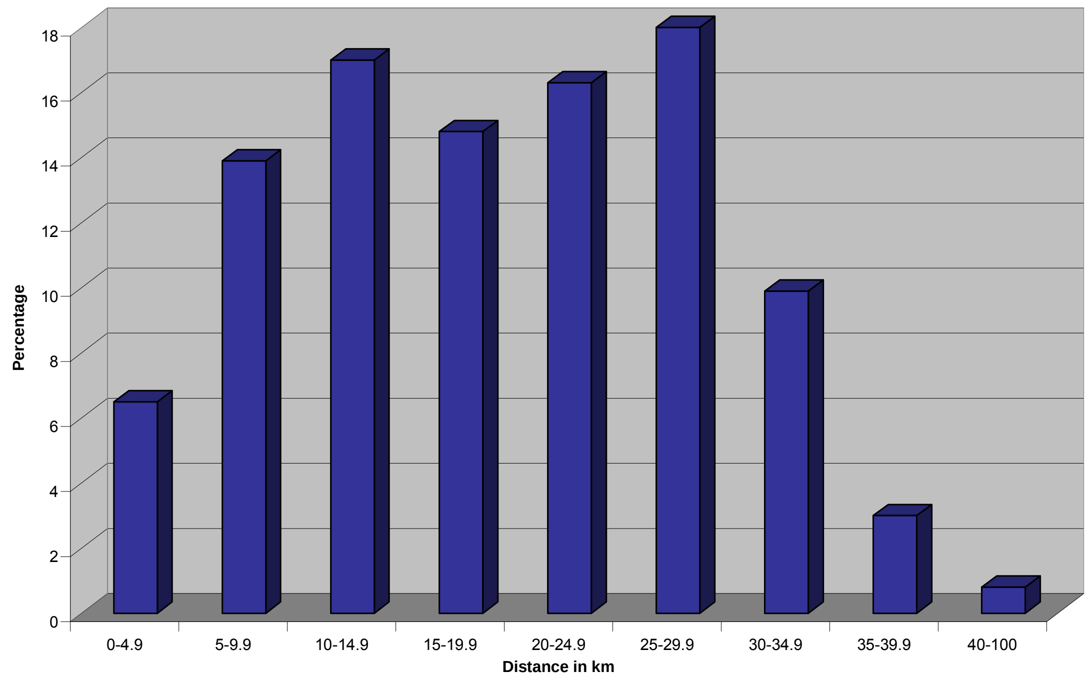


Figure 7.4 Met Office Visibility Data for 1999 - 2003 for Weybourne



(1) Health & Safety Executive, 2001. Wind and wave frequency distributions for sites around the British Isles. Fugro GEOS Offshore Technology Report 2001/030.

7.3 CHEMICAL AND PHYSICAL OCEANOGRAPHY

7.3.1 WATER QUALITY

Introduction

There is little detailed information regarding offshore water quality for the Humber Gateway development site and its surrounding waters because regulatory monitoring programmes tend to focus on inshore areas. Regional water quality is predominantly influenced by terrestrial run-off and riverine inputs from the coast. In particular, the Humber Estuary provides a significant input of nutrients, contaminants and debris flow to this area of the North Sea. This section describes the regulatory and policy context of water quality in the coastal area of Holderness and also describes the current understanding of existing baseline conditions.

Relevant Policies and Plans

The *Directive on Integrated Pollution Prevention and Control (IPPC) (96/61/EEC)* applies to many industries, including the energy industry, to ensure that companies bear the responsibility for preventing and reducing any pollution to air, soil or water that they may cause. In relation to the Humber Gateway project, this could involve the prevention of spills or releases of non-permitted substances or wastes into the marine environment, the use of Best Available Techniques throughout the construction, operation and decommissioning of the wind farm, and the implementation of appropriate monitoring.

The Dangerous Substances Directive (67/464/EEC) aims to improve water quality by limiting the types and quantities of certain substances that are permissible for release into the aquatic environment. Monitoring is carried out by the Environment Agency and the results are compared to Environmental Quality Standards set for freshwaters and coastal/estuarine waters. There were no monitoring sites in England or Wales that failed water quality standards for dangerous substances in 2005 [(1)].

The UK has signed up to the *North Sea Conference* and the *Convention for the Protection of the Marine Environment of the North-East Atlantic* (known as the OSPAR Convention). The objective is to reduce the load of contaminants released into the North Sea and target reductions were set in 1995 for a number of contaminants such as heavy metals, nitrates, and phosphates. Most of these target reductions have been met, with the main exceptions of zinc and nitrogen [(2)].

The Water Framework Directive (2000/60/EEC) addresses the water quality of inland, estuarine, groundwater and coastal surface waters, up to limit of one nautical mile offshore. Monitoring of the aquatic environment started in 2006 by the Environment Agency with a view to ensuring a *'good ecological status'* of all surface water bodies by 2015. Chemical and biological Environmental Quality Indicators (EQI) will be used in the move towards this objective, and a programme of measures will be implemented by the Environment Agency in order to improve surface waters that do not meet the required status.

The Bathing Waters Directive (76/160/EEC) sets mandatory and guideline water quality standards for microbiological parameters and also certain physical parameters (such as visible oils). These standards apply to certain designated coastal waters in the interest of public health and are monitored annually by the Environment Agency. There are 32 designated bathing beaches from Flamborough Head to Great Yarmouth [(3)] as identified under the *EC Bathing Water Directive (76/160/EEC).*

The Shellfish Waters Directive (79/923/EEC) is implemented in the UK through the *Shellfish Waters (Shellfish) (Classifications) Regulations 1997*. Mandatory and guideline water quality standards are set under this legislation in order to protect the health and growth of bivalve and gastropod molluscs such as mussels, oysters, clams, cockles, whelks and winkles. The objective is to ensure that the quality of edible shellfish species and shellfish products can be maintained for safe human consumption. The Regulations do not apply to crustacean shellfish such as crabs or lobsters.

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(1) Environment Agency, 2005. State of the Marine Environment Report.

(2) Environment Agency, 2007. Environmental Facts and Figures. Available online from http://www.environment-agency.gov.uk/yourenv/eff/1190084/water/1182267/1182529/?version=1&lang=_e [Accessed 16/07/07].

(3) Crumpton C A and Goodwin M J, 1995. Chapter 9.6 Water quality and effluent discharges. In: Coasts and seas of the United Kingdom. Region 6 Eastern England: Flamborough Head to Great Yarmouth, ed. by Barne J H, Robson C F, Kaznowska S S, Doody J P, and Davidson N C, pp 195-200. Peterborough, Joint Nature Conservation Committee.

However, there are no designated shellfish waters immediately adjacent to the Humber Gateway site [(1)]. The nearest designation is located on the southern side of The Wash, which has no potential for any exchange of water body from the development site.

Existing Conditions

Temperature

The waters of the east coast of Britain usually reach their warmest temperatures in August. The mean surface water is between 13 and 15ºC in the summer months (June to September) [(2)] with temperatures increasing to the south (based on data for August). The highest recorded summer surface water temperature was reported in the North Sea Pilot as 20ºC [(3)]. The region's winter sea surface temperatures are amongst the coldest in the UK, with the lowest mean temperatures ranging between 5ºC to 6ºC in February and early March. Mean minimum daily temperatures can fall to 1°C.

Both coastal and offshore waters tend to be well mixed with only occasional vertical stratification occurring in the summer months. The mean sea surface temperature at Spurn Point has risen by 0.17ºC in the past decade [(4)].

Turbidity

A survey conducted on behalf of E.ON in 2004 showed that turbidity fluctuated between around 50 to 200 mg l^{-1}, depending on depth, sea state and tides with a maximum of 700 mg l^{-1}, recorded during a period of heavy rain [(5)]. The Southern North Sea Sediment Transport Study Phase 2 [(6)] reported background turbidity levels in this area to be in the regions of 8 to 128 mg l^{-1} in summer and 4 to 256 mg $^{-1}$ in winter. This highest value of 256 mg l^{-1} relates to a very narrow band along the coastline north of Spurn Head.

Suspended sediment concentrations have also been measured as part of the Humber Gateway field surveys, showing a range of 50 to 200 mg l^{-1} over the site.

Sources of the fine particulate matter that contribute to the region's high levels of turbidity include the Humber Estuary plume and sediment drift resulting from the rapid and persistent cliff and beach erosion along the coast from Bridlington to Spurn Head. Maximum winter concentrations are approximately twice those found during the summer months. This is the result of higher storm event frequency and higher rainfall leading to greater run-off and river discharges.

Dissolved Oxygen

The Holderness coastal and offshore waters demonstrate average levels of dissolved oxygen for North Sea coasts. There have been no records of depressed oxygenation as a result of algal blooms [(7)].

Consented Discharges

There are a number of consented discharges to tidal and nearshore waters located along the coastline adjacent to the Humber Gateway site.

Withernsea was designated as a High Natural Dispersion Area during the implementation of the *EC Urban Waste Water Treatment Directive in 1994* due to characteristics of the currents and tidal regimes in the area. In line with changes in waste water treatment and the consequential improvements to sewage effluents as directed by EC legislation and standards, this designation was removed in 2005. However, the designation highlights the high dispersal rates that exist in the region.

[(1)] Defra, 2004. Water quality - sewage treatment in the UK: Sensitive areas July 2003. Available online from http://www.defra.gov.uk/environment/water/quality/uwwtd/sensarea/05.htm [Accessed 16/07/07].
[(2)] Lee A J and Ramster J W, 1981. Atlas of the seas around the British Isles. Lowestoft, Ministry of Agriculture, Fisheries and Food.
[(3)] Hydrographer of the Navy, 1991. North Sea (West) Pilot – East coasts of Scotland and England from Rattray Head to Orford Ness. Second Edition.
[(4)] IACMST Inter-Agency Committee on Marine Science and Technology; UK Marine Waters 2004 – Marine Processes and Climate, Sea Temperature. Available online at http://www.oceannet.org/medag/reports/IACMST_reports/MCP_report/ch_temp/MCPreport_temp_tab1.htm [Accessed 13/10/07].
[(5)] Institute of Estuarine and Coastal Studies, 2005. Humber Gateway: Baseline Study of the Marine Ecology.
[(6)] HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier, 2002. Southern North Sea Sediment Transport Study: Phase II.
[(7)] Crumpton C A, and Goodwin M J, 1995. Chapter 9.6 Water quality and effluent discharges. In: Coasts and seas of the United Kingdom. Region 6 Eastern England: Flamborough Head to Great Yarmouth, ed. by Barne J H, Robson C F, Kaznowska S S, Doody J P, and Davidson N C pp 195-200. Peterborough, Joint Nature Conservation Committee.

Bathing Water Quality

The closest designated Bathing Waters to the Humber Gateway development site are located on the Holderness Coast at Hornsea and Withernsea. There are five Bathing Waters designated around the southern side of Flamborough Head but it is unlikely that the development will impact water quality at these sites due to the southerly direction of the coastal currents. There are also Bathing Water designations at Cleethorpes and Mablethorpe on the Lincolnshire coast. In 2006, Anglian Water reported 100% compliance with the mandatory coliform standards set in the *Bathing Water Directive* (1) following routine water quality monitoring of the beaches that fall into its jurisdiction, including those at Cleethorpes and Mablethorpe. The Holderness sites also achieved 100% compliance in 2005 and 2006 (2).

Beach quality has been described as generally poor in a national context (3) primarily as a result of beach litter such as plastics, fishing gear, and sewage debris (4).

7.3.2 WAVES

Overview

Within the southern North Sea, two mechanisms restrict the size of the waves. First, the location of storm tracks passing over the area ensures that the winds do not always blow over the longest available fetch (the linear distance over which the wind is blowing over the sea). Secondly, there are further restrictions to wave growth imposed by the complex shallow water bathymetry. The wind is responsible for the generation of most of the surface gravity waves (wind-waves and swell) which are nearly always present.

(1) Anglian Water, 2006. Environment Report 2006. Available online from http://www.anglianwater.co.uk/assets/environment/Enviro%20Report%202006.pdf [Accessed 16/07/07].
(2) Defra, 2006. News release 481/06 of 9 November 2006 – 2006 mandatory compliance results for bathing waters in the UK. Available online from http://www.defra.gov.uk/environment/water/quality/bathing/pdf/summary-tables2006.pdf [Accessed 16/07/07].
(3) Crumpton C A, and Goodwin M J, 1995. Chapter 9.6 Water quality and effluent discharges. In: Coasts and seas of the United Kingdom. Region 6 Eastern England: Flamborough Head to Great Yarmouth, ed. by Barne.
(4) Beachwatch, 2006. The annual MCS UK beach litter survey report. Available online http://www.adoptabeach.org.uk/downloads/beachwatch/BWFullReport.pdf [Accessed 16/07/07].

The wind factors affecting wave development are wind speed, fetch and duration (the time for which the wind has been blowing over the fetch). Wind speed and duration are generally quite independent of location. Fetch, on the other hand, is very dependent on location. In the North Sea the fetch is quite limited compared to the open North Atlantic. However, the effective fetch may be limited, even from the north, by the location of the storm tracks that pass mostly from west to east throughout the area.

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 Humber Gateway site is open to offshore waves that are generated within the northern North Sea. The wave regime has been characterised in terms of offshore waves and within-site and nearshore waves.

Wave Data

Wave data from the following three locations (shown in *Figure 7.1*) have been incorporated into this assessment.

- Dowsing WaveNet buoy;
- Met Office Wave Data; and
- Nortek AWAC.

Figure 7.5 shows the wave rose for the Dowsing WaveNet buoy. It indicates that the majority of waves are from the north northwest direction. The primary direction for waves, over 25% of all records, are events from north northwest (between 330 and 360 ºN). The largest wave heights (class 5.75 to 6 m) occur from the north northeasterly sector (between 000 and 030ºN).

The most frequent wave period is in the range 5 to 6 seconds, accounting for more than 19% of all records. The most common wave height is between 0.75 to 1 m, accounting for over 15% of all records. The largest waves are in the class 4.50 to 4.75 m and are generally associated with longer wave periods (10 to 12 seconds).

A comparative analysis has been undertaken with the Met Office wave data presented in *Figure 7.6.* The Met Office wave rose indicates that the primary direction for waves are events from a north northeasterly direction (between 000 and 030 ºN) which account for over 33% of all records. The largest wave heights (class 5.50 to 6.00 m) occur from the north northeasterly sector (between 000 and 030ºN).

Figure 7.5 Wave Rose from Dowsing Wavenet

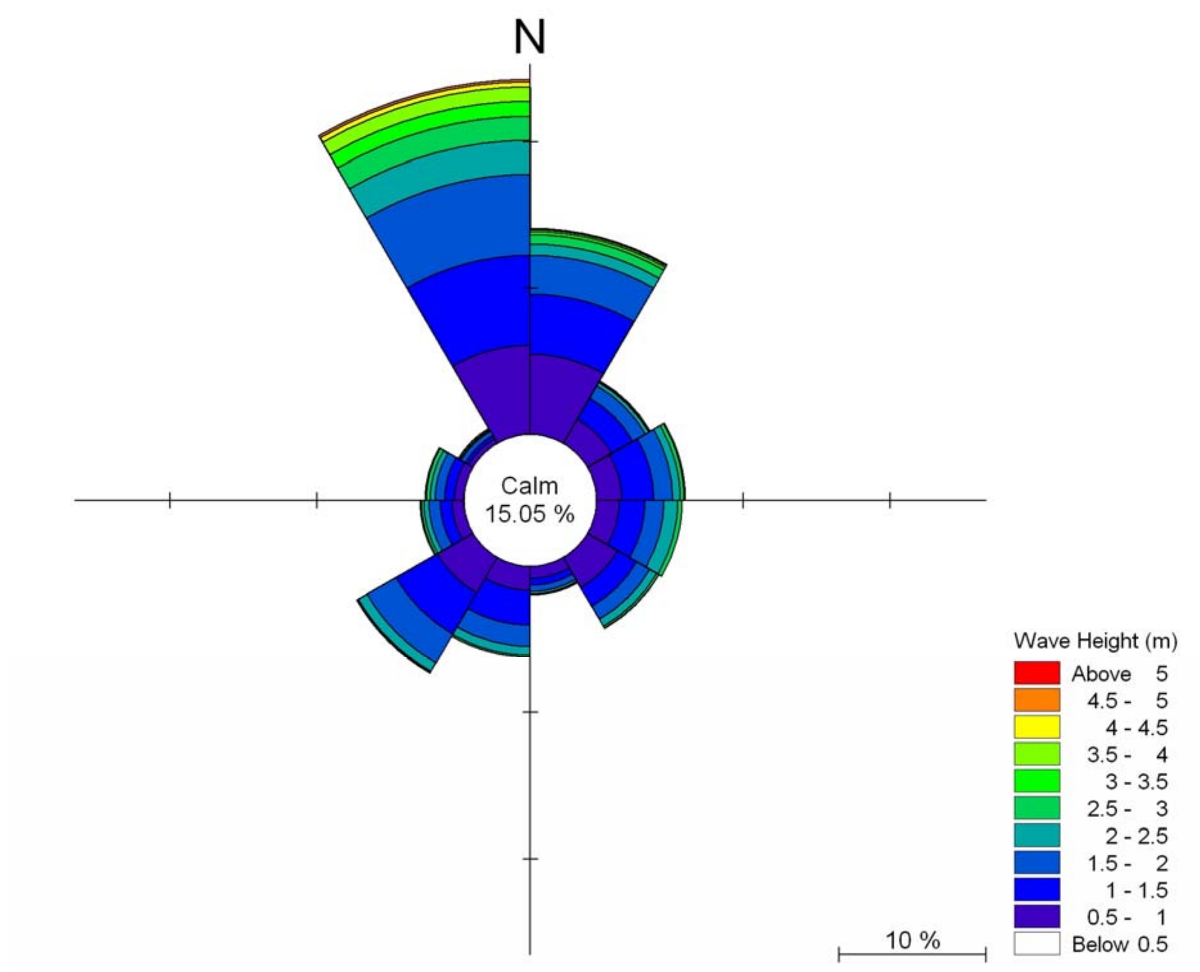
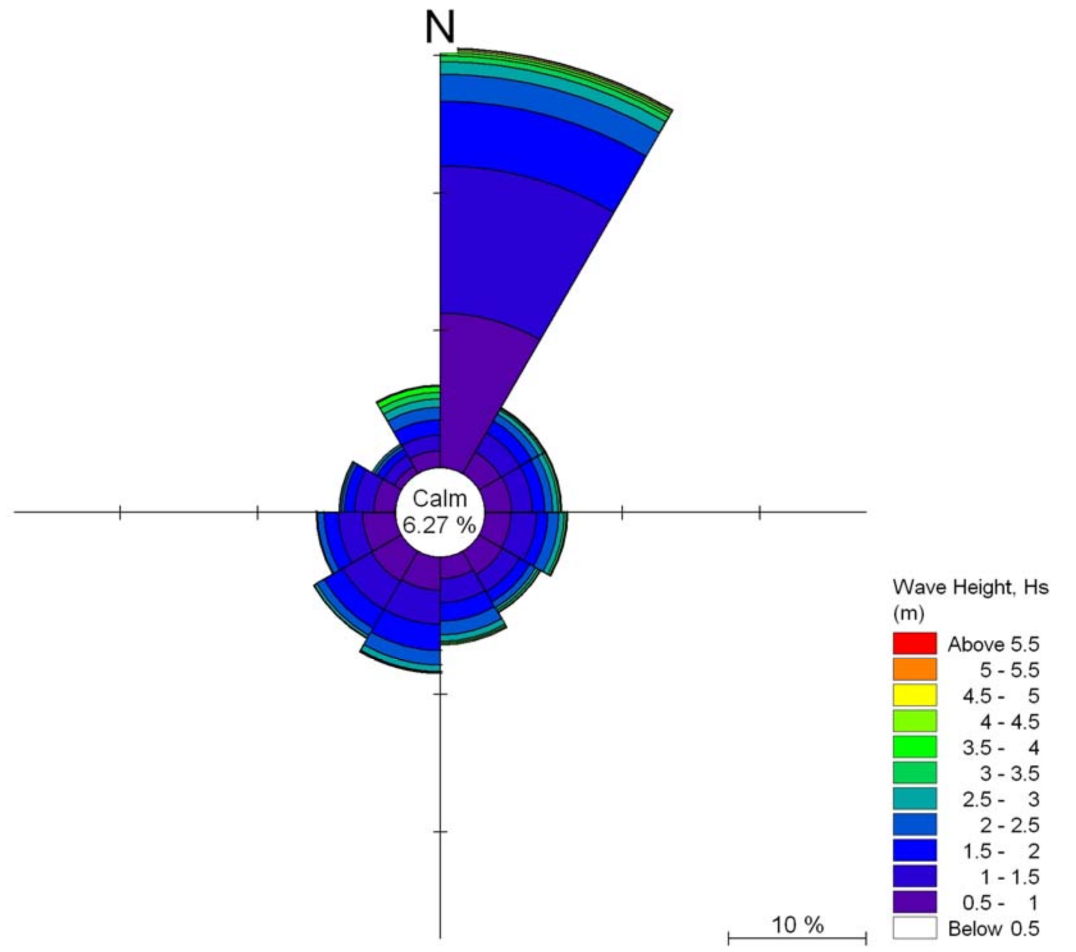


Figure 7.6 Wave Rose from Met Office Wave Data



An analysis of significant wave height against peak wave period shows that the most frequent wave period is between 4 to 5 seconds, accounting for more than 39% of all records. The most common wave height is 0.5 to 1 m which accounts for over 33% of all records. The largest waves are in the class 5.50 to 6 m and are generally associated with the longer wave periods (8 to 9 seconds).

The wave data provided from the Met Office was used to derive different extreme wave characteristics and used as input conditions for the numerical modelling (*Table 7.2*).

Table 7.2 Extreme Wave Characteristics for Different Return Periods

Return Period (Years)	330^{0} N		000^{0} N		030^{0} 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

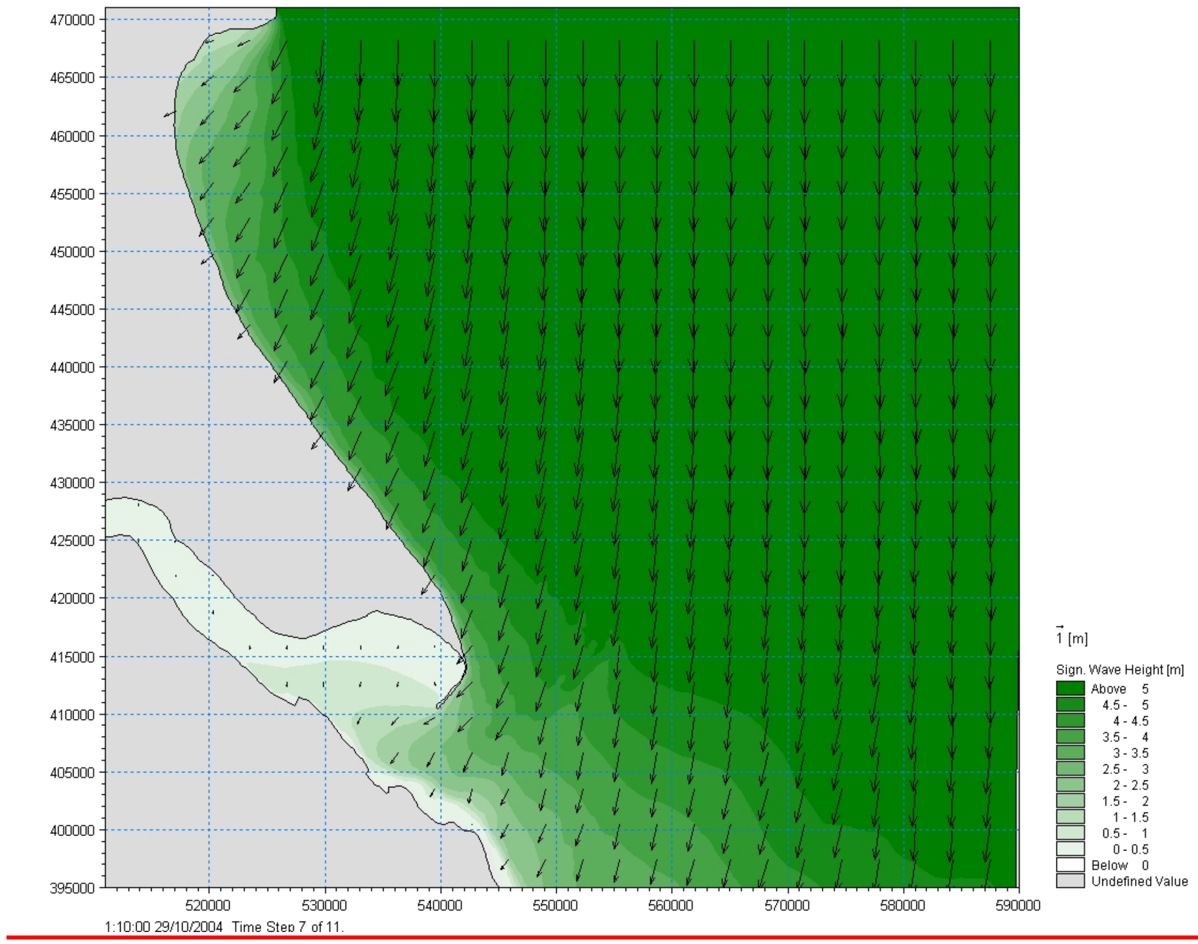
The wave conditions experienced over the far-field, as illustrated using numerical modelling output, are shown in *Figure 7.7* for the greatest wave conditions (the 1 in 50 year return period from the north).

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

- shoaling and refraction (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.

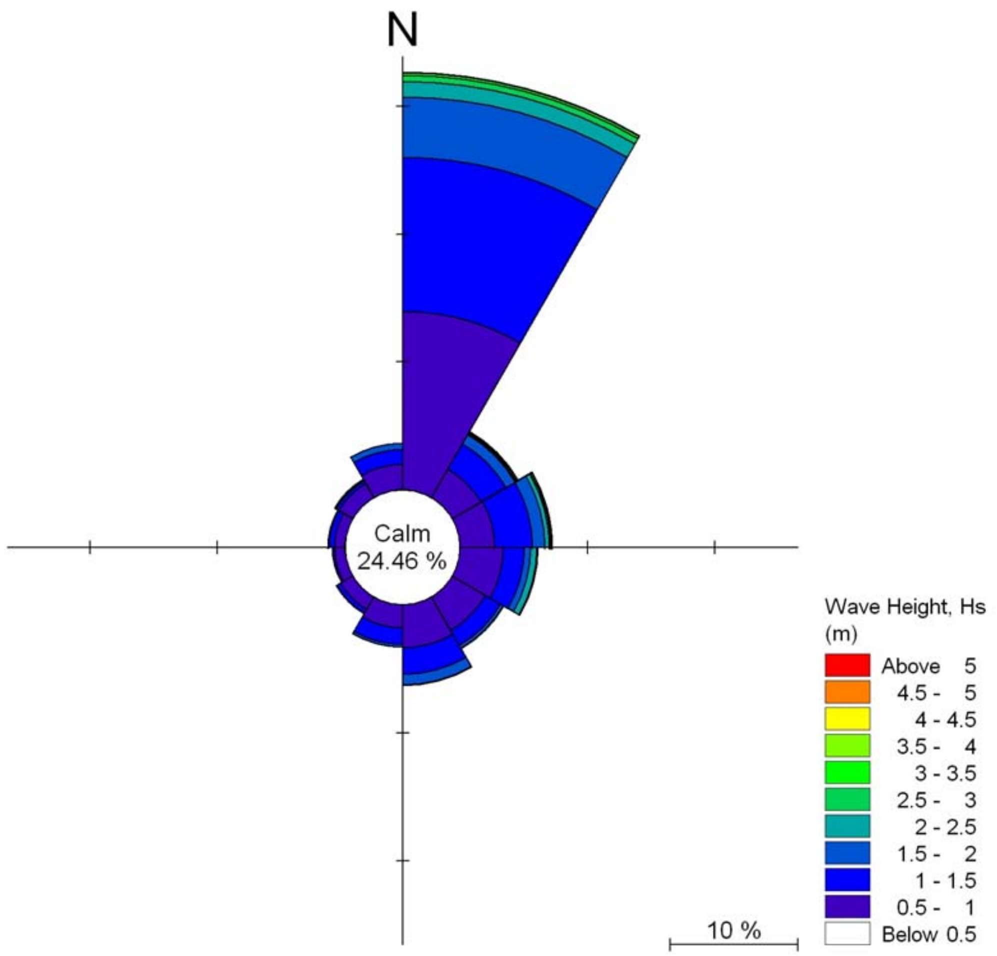
Figure 7.7 Baseline Conditions for the 1 in 50 Year Return Wave Period from 000°N



The wave data collected at the Nortek AWAC site covers the period from 26 March 2004 to 16 November 2004 and is presented as a wave rose in *Figure 7.8*. The wave roses show a dominant wave direction from the north northeast. From a consideration of wave height versus direction, for a period excluding winter, the prevailing directions for waves are the following:

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

Figure 7.8 Wave Rose from Nortek AWAC



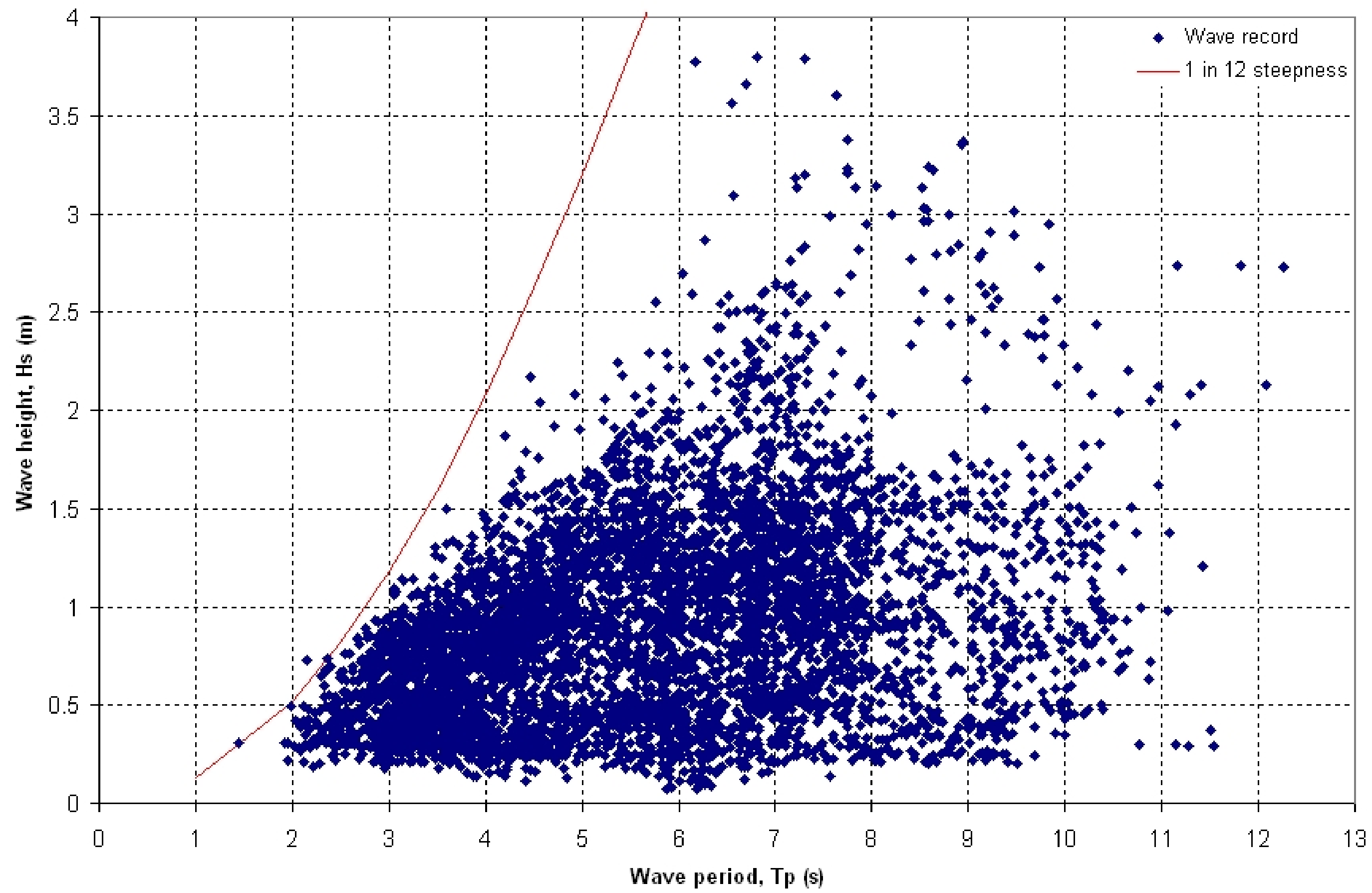
Largest wave heights (class 3.75 to 4 m) occur from the north northeasterly sector (between 000 and 030 ºN) with a frequency of occurrence of 0.04% and from the east northeasterly sector (between 060º and 090º N) with a frequency of occurrence of 0.02%, during the survey period.

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 7.9* 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 shows:

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

Figure 7.9 Nortek AWAC Wave Scatter Diagram (March to November 2004)



Some caution should be expressed when considering the above results since the short-term deployment may not necessarily be representative of longer-term conditions. Analysis of the longer-term offshore wave record from WaveNet has therefore been compared with the Nortek data collected within the Humber

Gateway site. The data sets overlap sufficiently to enable a direct comparison to be made.

Figure 7.10 shows a comparison in recorded wave heights, periods and directions between the two wave climate records. Over the data period, there is a very high level of similarity between the two and across the three parameters, indicating a common behaviour in the wave regime from offshore to nearshore. There are slight differences 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.

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. During the survey period (March to November 2004), the maximum wave height at Dowsing was 4.24 m, which represents 0.5% exceedance of all wave data presently available from Dowsing. The equivalent height at Humber Gateway site was recorded as 3.77 m. *Table 7.3* summarises the percentage frequency exceedances of different wave height values.

Figure 7.10 Comparison of Metocean Data between Nortek AWAC and Dowsing

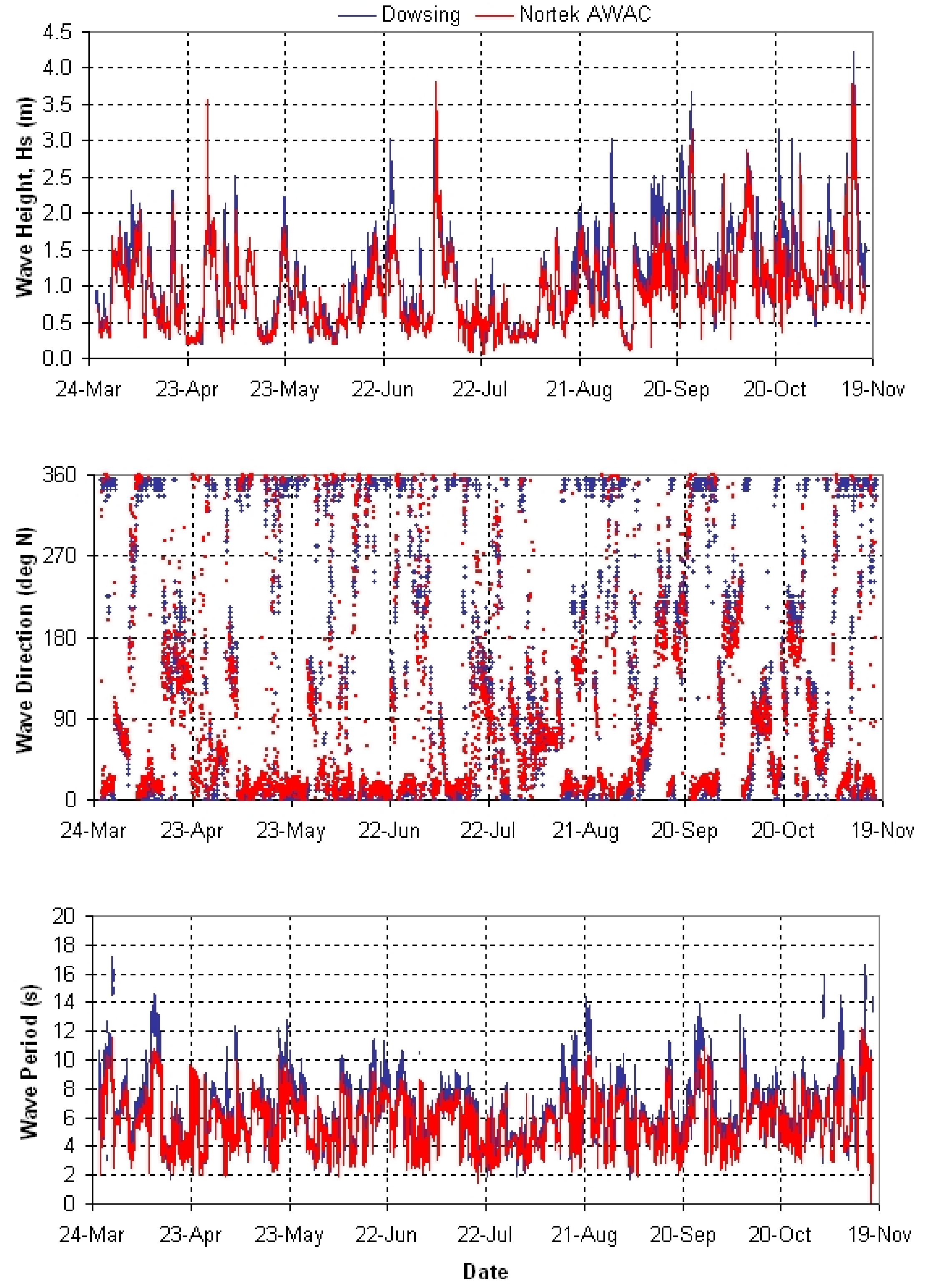


Table 7.3 Wave Exceedance at Dowsing and Nortek AWAC

Exceedance (%)	Dowsing Wave Height (m) (October 2003 to November 2004)	Exceedance (%)	Nortek AWAC Wave Height (m) (March to November 2004)
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
1.0	3.80	1.0	2.61
5.0	2.71	5.0	1.83
10.0	2.32	10.0	1.57
50.0	1.21	50.0	0.85

Sea Levels

Tides

The tidal regime can be defined 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:

- water elevations (due to tidal patterns, non-tidal influences and sea level rise); and
- 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 operational life of the scheme (i.e. 40 years). This definition provides the appropriate context for comparing scheme-related changes against the natural variability within the coastal system.

The tidal oscillations within the North Sea and along the Holderness Coast propagate across the shelf edge, entering the North Sea both across the northern boundary and through the English Channel. Semi-diurnal tides 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 seabed [(1)].

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^{-1} compared with the oscillatory tidal currents which typically exceed 1 m s^{-1}), the resulting net currents are persistent and account for approximately 50% of the water transport in the western North Sea [(2)].

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 5.5 m along the Holderness coast, and increasing into the Humber Estuary.

Table 7.4 presents astronomical tidal characteristics from the Admiralty Tide Tables for Spurn Head, being the nearest standard port to the Humber Gateway site at a distance of approximately 10.5 km.

Table 7.4 Summary Tidal Data for Spurn Head (m above Chart Datum)

Tidal Data		Spurn Head (53°35'N, 0°07'E)
Highest Astronomical Tide	HAT	7.70 m
Mean High Water Springs	MHWS	6.90 m
Mean High Water Neaps	MHWN	5.50 m
Mean Sea Level	MSL	4.07 m
Mean Low Water Neaps	MLWN	2.70 m
Mean Low Water Springs	MLWS	1.20 m
Lowest Astronomical Tide	LAT	0.20 m
Extreme Difference	-	7.50 m
Spring Range	MHWS – MLWS	5.70 m
Neap Range	MHWN – MLWN	2.80 m

NB. Predicted heights are in metres above Chart Datum (3.9 m above Ordnance Datum Newlyn)

Water level information was recorded within the Humber Gateway site using the Nortek AWAC between 25 October and 14 November 2004. It demonstrates that

[(1)] Vincent P & Le Provost C, 1988. Semidiurnal tides in the northeast Atlantic from a finite element numerical model. Journal of Geophysical Research, Volume 93 (C1), 543 - 555.
[(2)] OSPAR Commission, 2000. Quality Status Report 2000: Region II - Greater North Sea. London: OSPAR Commission.

the tidal range is, for neap and spring tides, in the order of 2 m and 7 m respectively. The rate of exchange of tidal water is higher during a spring tide and a larger tidal volume is exchanged between high and low waters than during neaps for an equivalent tidal period (around 12.5 hours). This feature of the tidal regime is important in influencing rates of sediment transport.

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. The main axis for tidal flows is to the south during the flood phase (*Figure 7.11a*) and to the north during the ebb phase (*Figure 7.11b*). Generally, the significance of such non-tidal effects is more likely to be evident during neap tides when the tidal flows are at their weakest. Current speeds are typically low, with the average speed being of the order of 0.55 m s^{-1}. Maximum and minimum speeds recorded were 1.27 m s^{-1} and 0.07 m s^{-1}, respectively.

Superimposed on the regular tidal behaviour, various random non-tidal effects may be present. Persistent winds can generate wind-driven currents, influence 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.

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* (1) 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 (2) which includes an estimate of the marginal extremes in water levels for the closest site at Easington (approximately 8 km west of the Humber Gateway site).

Hydrodynamic conditions used within the engineering feasibility study (3) indicate that the 50 year maximum return period water level is 7.3 m LAT (Lowest Astronomical Tide), where LAT is approximately equal to Chart Datum (*Table 7.5*).

Table 7.5 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 3.9 m (above Chart Datum)
Taken from: ABP R&C, 1999 (1)

Climate Change

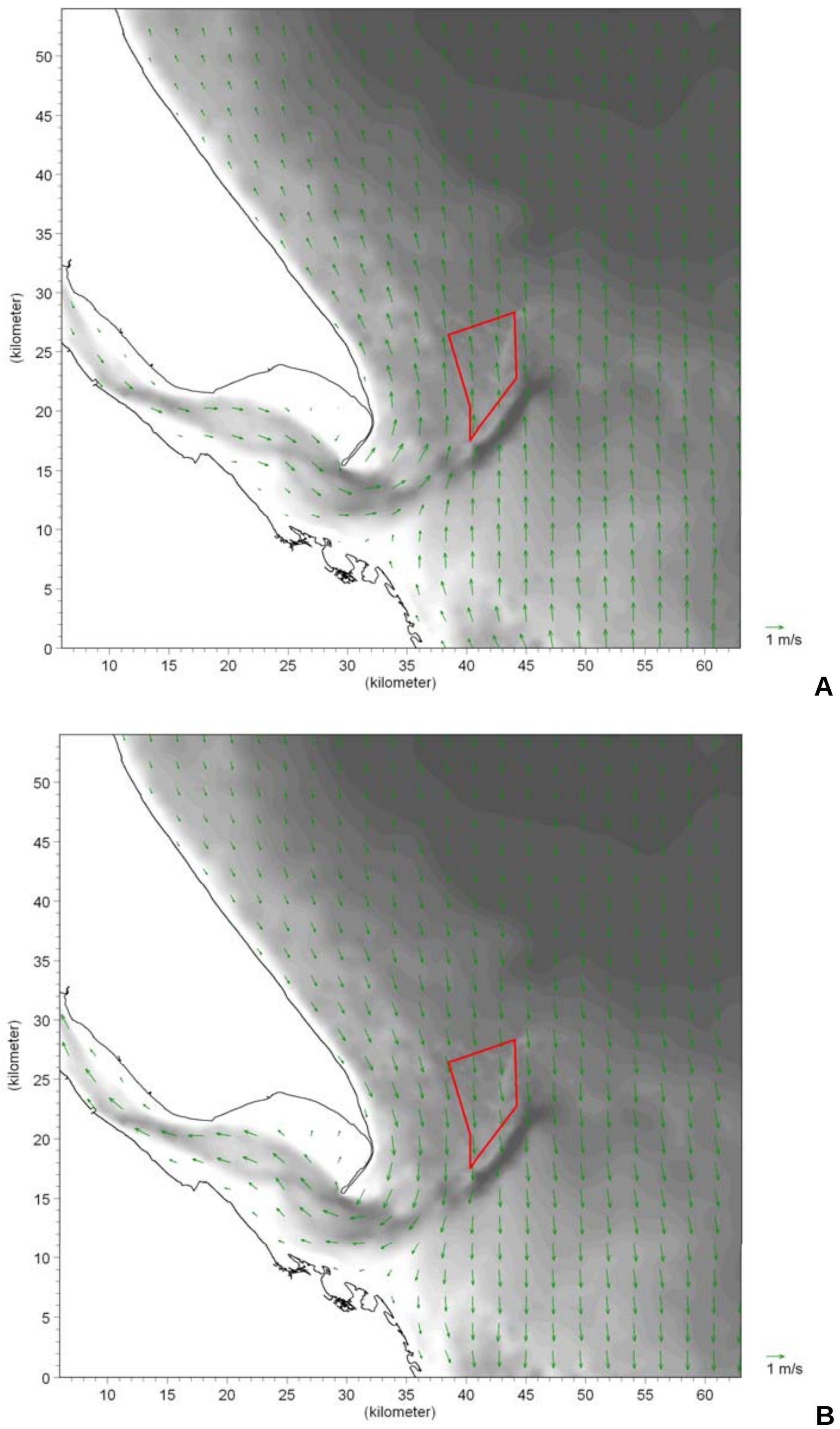
Past and anticipated future changes in relative sea level in the study area will be the result of the interaction between a number of mechanisms, as follows:

- *eustatic changes* - changes in absolute water elevation tend to be relatively uniform geographically and can be caused by glacio-eustacy (ice melt) or thermal expansion (changes in water volume due to warming); and
- *local changes* - changes (both positive and negative) in the elevation of the land surface, 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 4 mm y^{-1} to 2025 and then 8.5 mm y^{-1} from 2025 to 2055 (4). This assumes a vertical land movement of -0.8 mm y^{-1}.

(1) HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier, 2002. Southern North Sea Sediment Transport Study: Phase II.
(2) ABP R&C. 1999. The Humber Tidal Database and Joint Probability Analysis of Large Waves and High Water Levels, Main Report, 41pp and Data Report (Annex 1), ABP Research & Consultancy Ltd Report for the Environment Agency.
(3) SLP Consulting Engineers Limited, 2006. Humber Wind Limited, Humber Offshore Wind Development, Engineering Feasibility Study.
(4) Defra, 2006. FCDPAG3 Economic appraisal, supplementary note to operating authorities – Climate change impacts.

Figure 7.11 Current Direction for Spring Tide (a) Peak Flood and (b) Peak Ebb



7.3.3 BATHYMETRY AND SEA LEVEL CHANGE

Bathymetry - Wider Area

The bathymetry of the wider study area is shown in *Figure 7.1*, and is based on Admiralty chart data and previous reports [(1)]. This shows that shoreward of the 12 nm UK territorial limit the water depth decreases from approximately 35 m to a nearshore shallow sloping platform with a water depth of approximately 9.5 m to 12 m (extending to approximately 1 to 1.3 km from the coast). Seabed slopes are gentle and gradients are typically less than 1°, although gradients increase as the nearshore area is approached. Two bathymetric depressions lie to the southwest of the site, New Sand Hole and Inner Silver Pit. New Sand Hole, approximately 10 km long, 1.5 km wide and a maximum depth of 45 m below mean sea level, lies approximately 15 km east of the Spurn Head Peninsula [(2)].

Humber Gateway Site and Cable Route Areas

A geophysical survey was carried out between 27 September and 26 November 2004 [(3)] to determine the bathymetry, seabed features and sub-bottom geological profile of the Humber Gateway area [(3)].

The bathymetry within the Humber Gateway site is typically flat and was shown to be between 16 and 21 m deep. *Figure 7.12* provides an indicative snapshot of the seabed, showing some minor topographical features across the site. The area is subject to strong metocean conditions which have swept mobile sediments into the nearshore areas to form large offshore banks [(4)]. Variation in depth is generally within +/- 2 m of the 15 m contour, with localised variations of up to +/- 4 m[(5)].

The survey area including the periphery was shallowest in the southeast (13.2 m), in an area of sandwaves, and deepest in the northeast (23 m). The seabed was dominated by a veneer, typically of a few centimetres of sandy

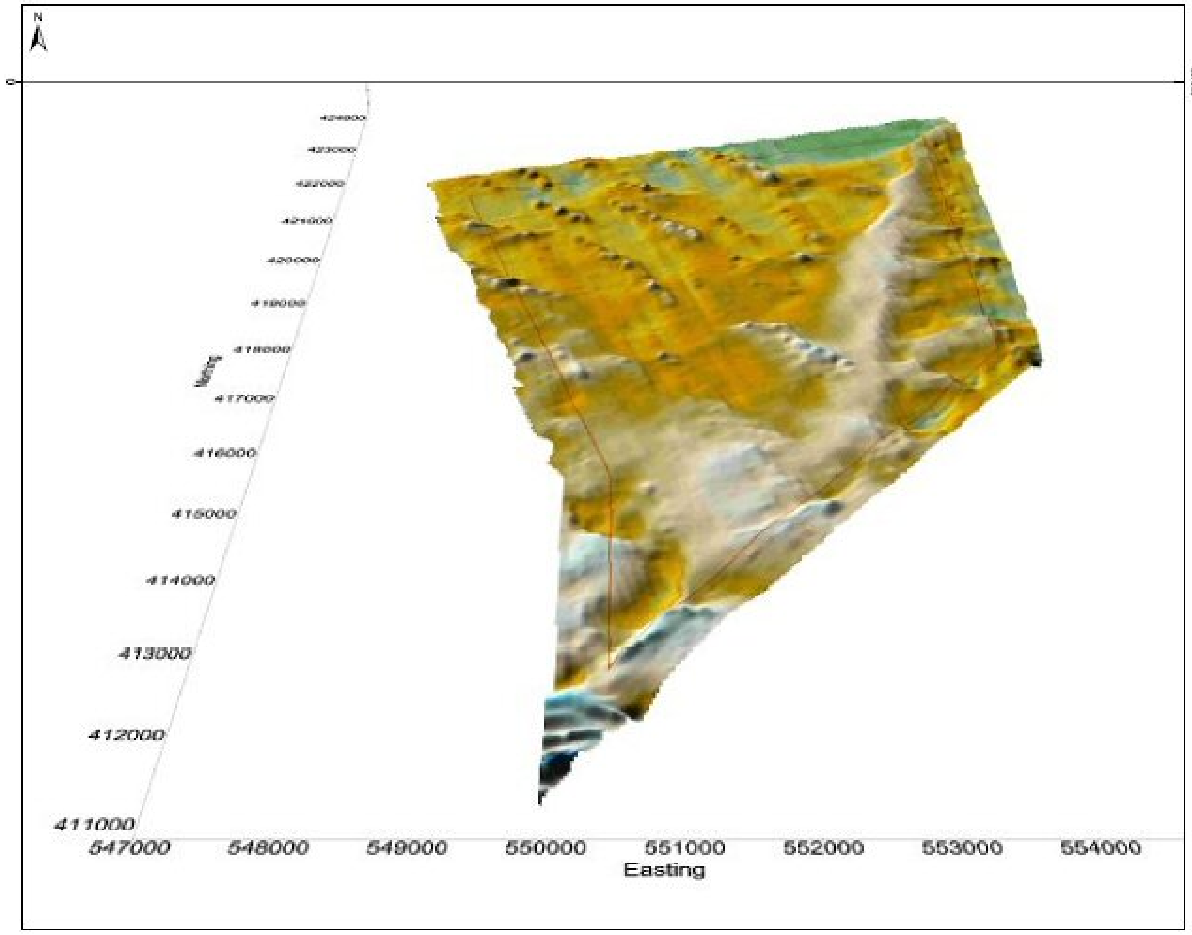
[(1)] British Geological Survey, 1992, The Geology of the southern North Sea, United Kingdom Offshore Regional Report. HMSO.
[(2)] Balson P S,1997. Predicting sediment yield from recession of the Holderness coast. In Land-Ocean Interaction Study – Second Annual Meeting, Hull, pp 152-154. Publication number 323.
[(3)] Titan Environmental Surveys Ltd, 2005.Humber Gateway Offshore Wind Farm Geophysical Survey. Report No: CS0114/R1/V2.
[(4)] British Geological Survey, 1990. Spurn, Sheet 53N 00, Seabed Sediments and Solid Geology, Natural Environment Research Council.
[(5)] D'Olier, 2003. Offshore Humber – Sites A, B, E. Geological Desk Study. For: Global Renewable Energy Partners (GREP A/S); Round II/ Offshore Wind Farm Studies.

gravel and gravely sand with numerous pebbles, cobbles and small boulders. This veneer was primarily derived as erosion products of the underlying Pleistocene age Bolders Bank Formation made up of boulder clay. This material has been formed into localised northwest to southeast trending 'gravel ridges' identified on the bathymetric chart, which are likely to contain abundant pebbles, cobbles and coarser material [(1)].

The bedrock is usually overlaid with gravel (5 mm) and boulders (greater than 256 mm) [(2)] which are rarely moved by the currents and tides. Most transport of sediments occurs closer to the coast, moving towards the Humber Estuary and The Wash. As a result of this lack of movement the erosion of the near shore seabed is estimated to be much slower than at the coast (circa 2 cm yr^{-1}).

The bathymetry of the two options for the cable route corridors was typically flat except for the presence of low gravel ridges, apart from a zone close to shore where very steep ridges of exposed boulder clay were present. Along the cable routes the gradients were initially shallow (1˚) but rapid gradient increases are observed close to shore, between 10˚ and 20˚ along the southern and northern cable routes respectively.

Figure 7.12 Indicative Snapshot of Seabed Bathymetry



[(1)] Titan Environmental Surveys Ltd, 2005.Humber Gateway Offshore Wind Farm Geophysical Survey. Report No: CS0114/R1/V2.

[(2)] D'Olier, 2003. Offshore Humber – Sites A, B, E. Geological Desk Study. For: Global Renewable Energy Partners (GREP A/S); Round II/ Offshore Wind Farm Studies.

7.4 COASTAL AND MARINE GEOLOGY AND GEOMORPHOLOGY

7.4.1 COASTAL GEOLOGY

The Holderness Coast stretches for over 50 km 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 38 m high, comprising glacigenic sediments.

At the end of the last ice age the Holderness Coast was formed from glacial till, deposited from the retreating icecap. It is comprised chiefly of boulder clay, consisting of mud (72%), sand (27%) and pebbles and boulders (1%). These materials show a low degree of cohesion and result in a highly eroding coastline.

The soft Holderness cliff and associated landforms are of geological interest and there are two geological Sites of Special Scientific Interest (SSSI) along the Holderness Coast (Dimlington Cliffs SSSI and Humber Estuary SSSI).

7.4.2 SEABED TOPOGRAPHY

Overview

With the exception of the southern edge, the Humber Gateway site is not covered by any extensive areas of mobile sediment. Instead, transitory sand ribbons and patches occur across the site. The sands thicken and become more extensive to the south and east, with mobile sediments occurring in the southern corner of the site.

Contemporary Morphology

The geophysical survey [(1)] indicated a bathymetric rise or ridge running from the southern central part of the survey area, along a south southwestern to north northeastern axis. There are several ridges, of a maximum height of 3 m, orientated west southwest to east northeast on the eastern flank of this feature. To the west of this feature there are several gravel ridges, of a maximum height of 3.5 m, orientated northwest to southeast. This latter feature is shown in *Figure 7.13*. It is suggested that these ridge features consist of englacial debris carried to the seabed by faulting along inclined shear planes during the periods of glacial depositional activity [(2)]. The presence of the coarser material has rendered the features resilient to erosion.

Sand waves with heights exceeding 5 m were noted in the south of the development site, and are illustrated in *Figure 7.14*. The orientation of these bed forms indicates a north to south sediment transport direction. These features suggest that the surface sediment has a mobile nature. D'Olier [(2)] reported that localised, thin and transitory sand ribbons and sand patches were located on the seabed. 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 / southeasterly sediment transport direction.

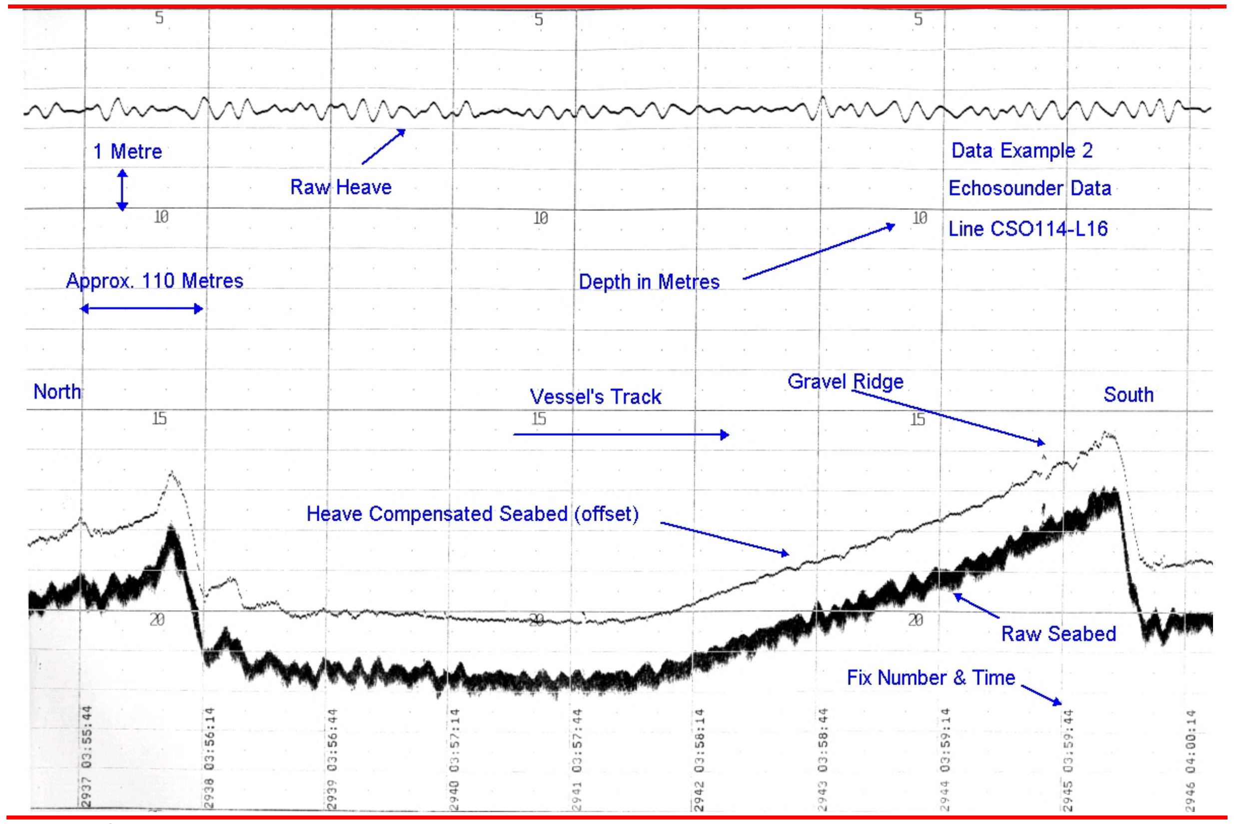
In addition to the seabed features described in *Section 7.3.3*, steep, near vertical ridges of boulder clay, typically between 1 and 3 m high are present between the gently undulating offshore seabed and the beach, indicating potential severe erosion activity from the shore out to approximately 1 km from the beach [(1)]. A diver survey carried out across the cable route corridor confirmed the occurrence of these structures and also indicates the presence of clay mounds (known locally as mud huts) along the cable route [(3)].

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.

(1) Titan Environmental Surveys Ltd, 2005. Humber Gateway Offshore Wind Farm Geophysical Survey. Report No: CS0114/R1/V2.

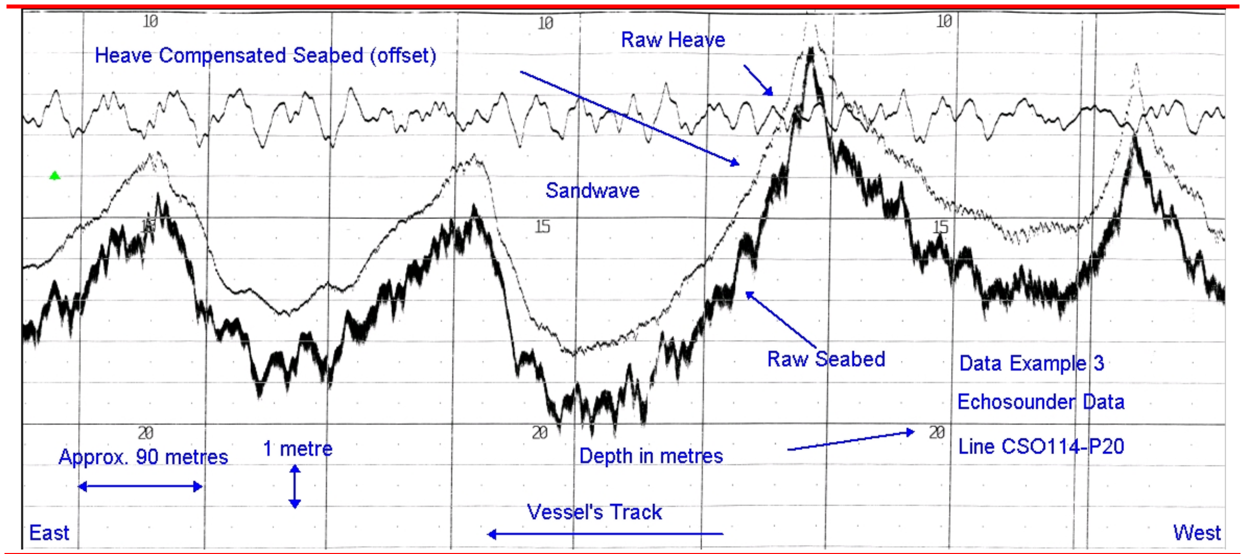
(2) D'Olier, 2003. Offshore Humber - Sites A, B, E. Geological Desk Study. For: Global Renewable Energy Partners (GREP A/S); Round II/Offshore Wind Farm Studies.
(3) Northern Divers (Engineering) Ltd, 2006. Humber Gateway Diving Inspection.

Figure 7.13 Gravel Ridges Observed from the Bathymetry Survey



Source: Titan

Figure 7.14 Sand Waves Observed from the Bathymetry Survey



Over the past 4,000 years, the predominant process has 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.

The geological sequence underlying the area is made up of the successions listed in *Table 7.6*.

Table 7.6 Geological Sequence on the Humber Gateway Site

Age	Formation	Description	Comments	Thickness (m)
Late Pleistocene	Botney Cut	Beds of very soft to soft clays silts and fine sands interspersed with sand and gravel layers.	Offshore equivalent to Dimlington Silts.	< 8
	Bolders Bank	Consists of calcareous, gravely sandy clay with chalk erratics and coarser elements. Contains approximately 10% cobbles and boulders.	Offshore equivalent to Basement Till. Chaotic, poorly bedded seismic character.	< 25
Upper Cretaceous	Chalk	Buried by up to 25 m of overlying sequence, Channels often identified within the layer, Erosion of this layer may have lead to the identified sink hole features.	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 18 m).	-

Details are taken from: D'Olier, 2003 (1); and Titan Environmental Surveys Ltd, 2004 (2)

(1) D'Olier, 2003. Offshore Humber - Sites A, B, E. Geological Desk Study. For: Global Renewable Energy Partners (GREP A/S); Round II/Offshore Wind Farm Studies.
(2) Titan Environmental Surveys Ltd, 2004. Humber Gateway Offshore Wind Farm Geophysical Survey. Draft Report No: CS0114/R1/V1.

Seabed Features and Obstructions

The seabed consists of the same material as the soft glacial cliffs of the Holderness Coast, characterised by relatively hard boulder clay substratum with patchy deposits of sand, shingle and pebbles and the occasional lag boulder.

The geophysical survey report indicated that the survey sites outside the Humber Gateway site (closer to the shore) had a higher degree of siltation, presumably due to the Humber plume (*Section 7.5.1*). Further offshore, within the wind farm site, seabed sediments were cleaner and the underlying veneer of stones and cobbles often formed a more solid pavement with areas of larger boulders mixed within it.

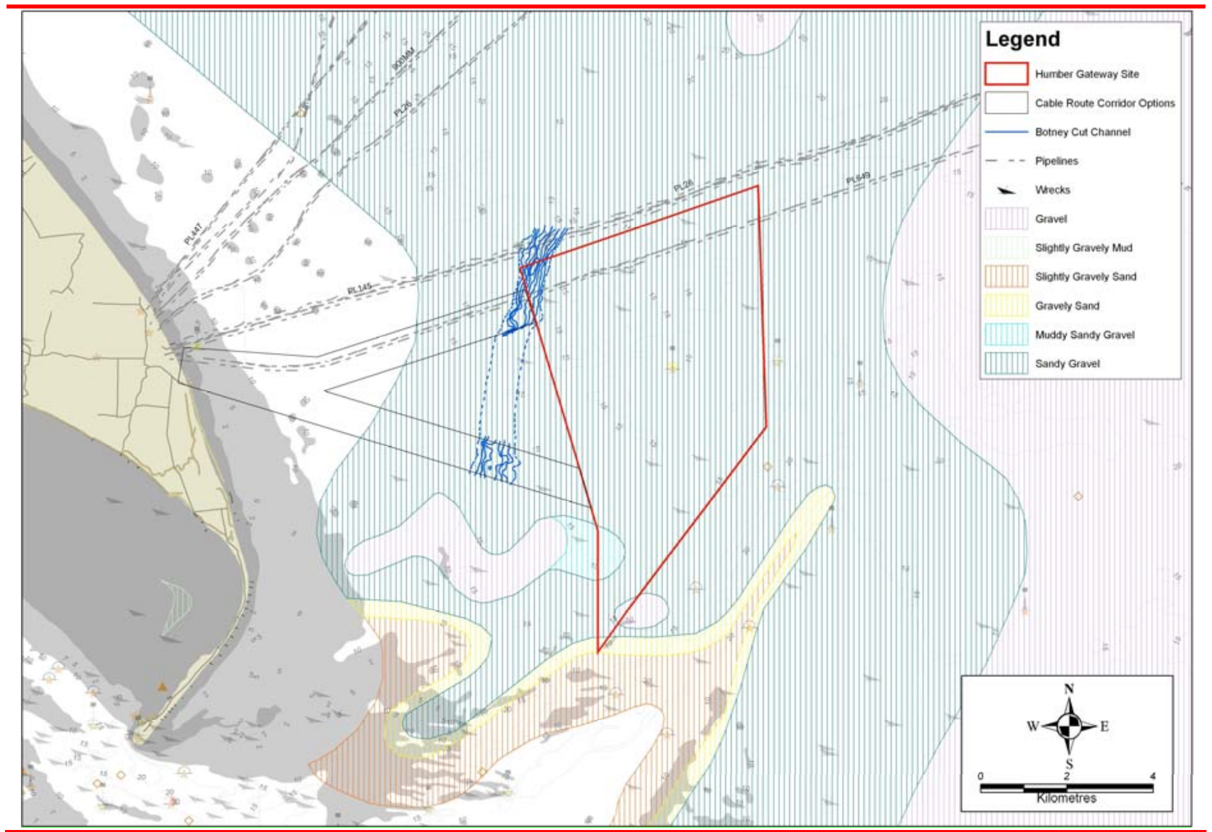
The seabed characteristics within the cable route areas generally consist of a thick layer of boulder clay interspersed with numerous small boulders. A thin layer of mobile beach sand is present at the shoreward end of both cable route corridors, with sand transport from north to south along the coast.

Seabed features and obstructions are shown in *Figure 7.15*.

Human activities in the wider area include fishing activity, marine aggregate dredging, shipping activity, sub-sea cables and pipelines and wrecks. These activities all result in some interaction with the seabed and subsequently there is the potential for anthropogenic seabed features or seabed scarring.

Scarring indicates fishing activity is most prominent in the north and west of the site. In addition, marine aggregate dredging occurs adjacent to the Humber Gateway site at Aggregate Site 102 (*Figure 4.1*) and there are also disposal sites and other offshore wind farm developments further afield. The northern margin of the Humber Gateway site is crossed by the Amethyst to Easington pipeline and power cable and a single charted wreck is located within the southern cable route corridor (*Figure 7.15*).

Figure 7.15 Seabed Features and Obstructions



7.4.3 SHALLOW GEOLOGY

Overview

The shallow geological sequence across the Humber Gateway site is dominated by the Bolders Bank formation over a thick sequence of Upper Cretaceous Chalk bedrock (1). The Bolders Bank formation was deposited during late Pleistocene (Weichselian) times. The formation is a tillite consisting of calcareous, gravely sandy clay with erratics, predominantly of chalk. This can be divided into two units; a lower lodgement till thought to be analogous Basement Till and an overlying water lain ablation till, which is better bedded and sorted, and may be Withernsea Till. There may also be thin pockets and lenses of silt found,

(1) Titan Environmental Surveys Ltd, 2005.Humber Gateway Offshore Wind Farm Geophysical Survey. Report No: CS0114/R1/V2.

analogous to the soft, laminated water lain silts of the Dimlington Silts identified onshore [(1)].

Well bedded glaciomarine muds overlay the Bolders Bank Formation in the far northwest corner of the site. These were deposited at the very end of the last ice age in latest Weichselian times in glacially produced scaphiform valleys. In this case, the valley trends north northeast to south southwest crossing the offshore end of the northern cable route and the southern cable route.

The base of the Bolders Bank Formation / Top Chalk is typically identified as a moderate to high amplitude, gently undulating seismic reflector. This is possibly due to weathering of the chalk by periglacial streams during the period of lowered sea-level during the last ice age or fluvial/marine eroded features during periods of higher sea level. In other areas, weathering and erosion of the chalk may have given rise to potential sink hole features and linear subsidence features. The same erosive and associated Quaternary subsidence process may be responsible for the thickening of the till to the southwest. The till is generally between 15 and 18 m thick, except where sink hole and other erosion features have produced local sharp increases in thickness [(2)].

Sediment Structure

As previously described, sediments from the Humber Gateway site and surrounding study areas were collected and Particle Size Analysis (PSA) was undertaken [(3)(4)].

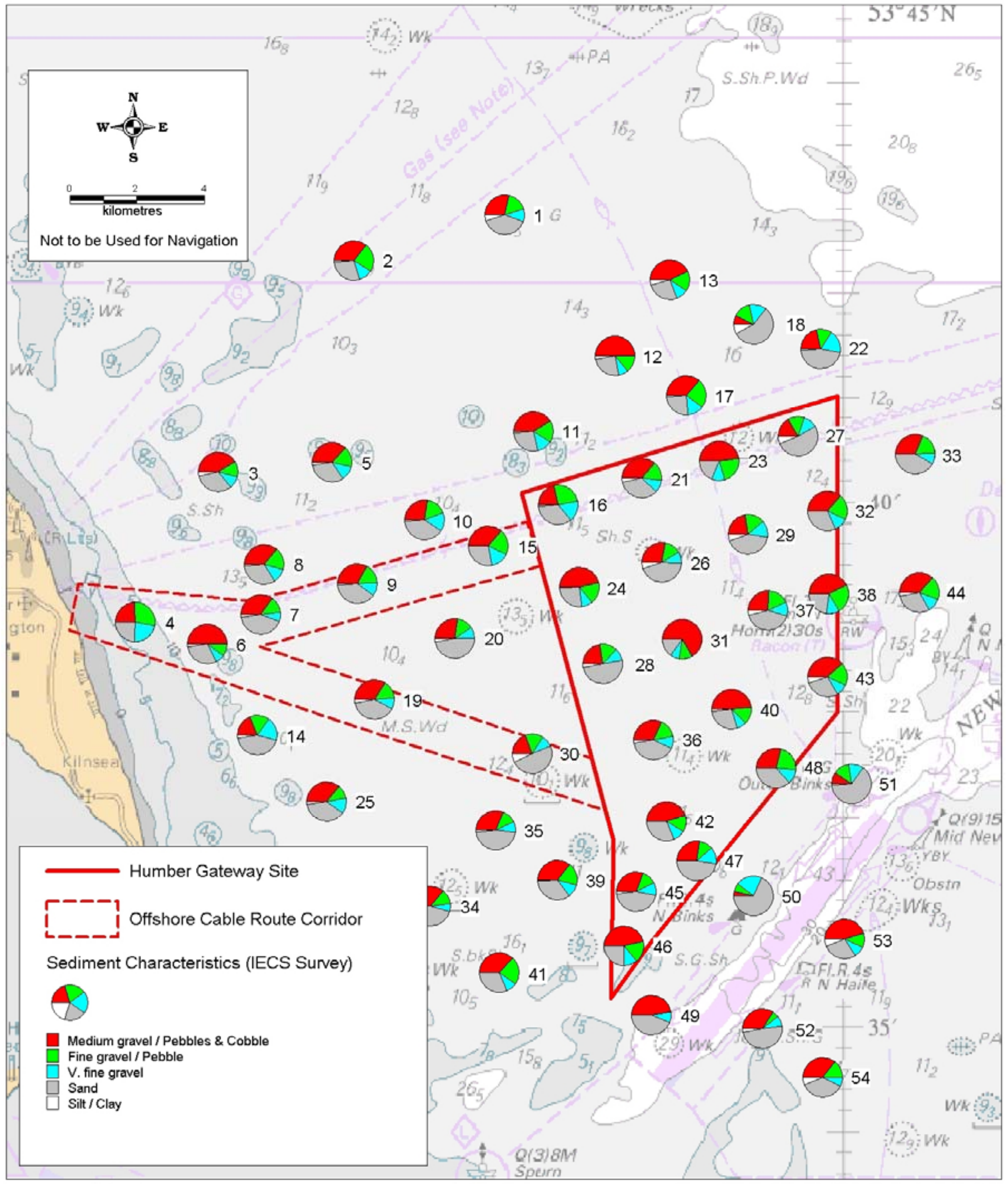
The results of the PSA indicated that sediment characteristics were highly variable across the site, although the sediments were generally composed of coarse sands and gravels. The highly variable sorting coefficient indicates poorly sorted sediments composed of a range of particle sizes with no particular areas of extensive homogenous substrata. All sites contained a relatively high proportion of gravel (*Figure 7.16*).

Gravel content ranged from 32% to 85%. The minimum sand content was generally found in sediments with the highest gravel content. Both silt and organic content were extremely low at all sites with the highest organic content values corresponding to sediments with the highest silt content. Organic content at the majority of stations was less than 2%, the minimum being 0.9%. According to nomenclature used by Folk [(5)], the sediments at the majority of the stations are classed as sandy gravel with muddy sandy gravel found at 13 stations and gravel being found at two stations (*Figure 7.16*).

In addition, a PSA carried out [(6)], on sediments sampled from the nearshore 'spiky features' indicated that these features were composed of gravels and sands.

[(1)] British Geological Survey, 2005. The geology of the southern North Sea, United Kingdom Offshore Regional Report. HMSO.
[(2)] Titan Environmental Surveys Ltd, 2005.Humber Gateway Offshore Wind farm Geophysical Survey. Report No: CS0114/R1/V2.
[(3)] Institute of Estuarine and Coastal Studies, 2006. Baseline Study of the Marine Ecology of the Humber Gateway Offshore Wind Farm.
[(4)] ABPmer, 2007. Humber Gateway Offshore Wind Farm Coastal Processes Baseline Assessment.
[(5)] Folk R L. 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature: J Geol. 62: 344-359.
[(6)] Ambios Environmental Consultants Ltd, 2007. Laboratory Analyses Methodology. ERM Humber Gateway samples.

Figure 7.16 Sediment Characteristics (IECS Survey)



Sediment Quality

Due to the presence of a number of disposal sites in the vicinity of the Humber Gateway project, understanding of background levels of Polycyclic Aromatic Hydrocarbons (PAHs), metals and other contaminants (oil and grease, air dried solids, polychlorinated biphenyls (PCBs), stones, selenium and boron) is required. Concentrations of PAH compounds were below the generally accepted detection limit of 0.35 mg kg^{-1}. However, these compounds readily bind to organic matter and are generally found in higher concentrations in areas where the particle size is small and the silt and organic content of the sediment are high. Given the coarse nature of the sediments and the low organic content (generally less than 2%), PAH compounds are not expected to be present in high concentrations. It is noteworthy that sediment samples were taken from the surface (top 10 cm) and provide no indication of contaminant levels at depth.

There are currently no direct standards for UK marine sediments. As a result, standards used in the Netherlands by VROM (Verantwoordelijk voor Wonen, Ruimte en Milieu) [(1)] and Environment Canada were used to make direct comparison and provide an indication of the potential levels of contamination. The determinants examined are standards used to indicate contamination from PAHs, heavy metals and other contamination caused by human activity. These activities include discharge and dumping or disposal of waste carried out at sea.

With the exception of nickel, concentrations of all metals were considered to be low, being either below both the Canadian Sediment Quality Guidelines (SQG) and the Probable Effects Levels (PEL) [(2)] or below the limit of detection. The mean nickel concentration (across the whole area) was 11.18 mg kg^{-1}, below the SQG and values used by VROM. Furthermore, the maximum nickel concentration of 16.5 mg kg^{-1} at ST4 was slightly higher than the SQG but lower than the VROM concentration. Thus, the potential for pollution by this substance is considered low. No standards were available for PCBs although concentrations of similar compounds were below the limit of detection. Concentrations of oil and grease ranged from 39 to 80 mg kg^{-1} (mean of 55), and the boron concentration ranged from 4.2 to 18.1 mg kg^{-1} (mean of 9.2).

[(1)] Grimwood M J & Dixon E 1997. Assessment of risks posed by List II metals to Sensitive Marine Areas (SMAs) and adequacy of existing environmental quality standards (EQSs) for SMA protection. Report to English Nature.
[(2)] Canadian Council of Ministers of the Environment. 2001. Canadian sediment quality guidelines for the protection of aquatic life. Summary tables. Updated in Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

7.5 COASTAL AND SEABED DYNAMICS

7.5.1 PATHWAYS

The sediment transport regime can be divided into two main parts:

- that which is mobilised as bed load; and
- that which is transported within the water column as suspended load.

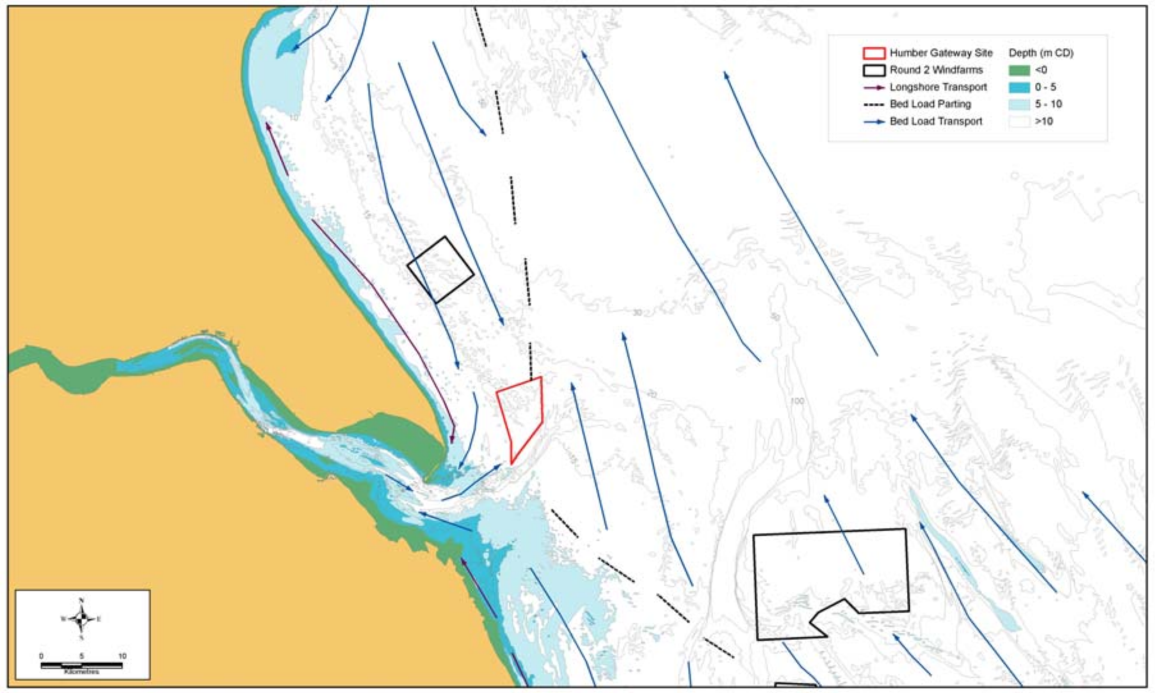
The Greater Wash area has been the subject of many studies investigating the sediment transport regime, including the *Southern North Sea Sediment Transport Study, Phases I and II* [(1)] and *Sand Banks, Sand Transport and Offshore Wind Farms* [(2)].

Sediment transport pathways as inferred using bedform indicators and numerical modelling from the Southern North Sea Sediment Transport Study [(3)] are shown in *Figure 7.17*. This figure shows that:

- in the nearshore zone, and up to 7 km 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 Humber Gateway site, the transport is to the south;
- to the west of Silver Pit transport is to the north;
- to the east of the 40 m contour, transport is typically of a variable direction; and
- storm surge induced transport is to the south, shoreward of the 40 m contour.

[(1)] HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier, 2002. Southern North Sea Sediment Transport Study: Phase II.
[(2)] Kenyon N H & Cooper W S, 2005. Sand banks, sand transport and offshore wind farms.SEA6 Technical Report for the Department of Trade and Industry.
[(3)] HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier, 2002. Southern North Sea Sediment Transport Study: Phase II.

Figure 7.17 Sediment Transport Pathways



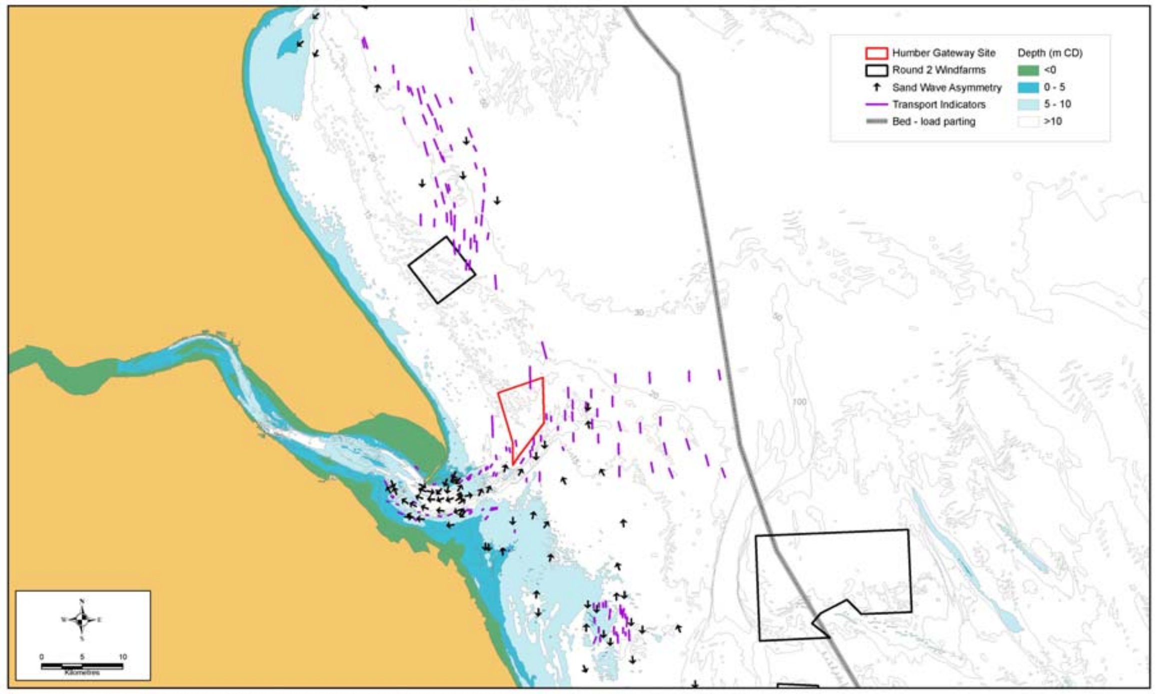
Produced by ABPmer Ltd. © British Crown and SeaZone Solutions Limited, 2007. All rights reserved. Data License No. 122005.07. NOT TO BE USED FOR NAVIGATION. **PROJECTION**: British National Grid

HR Wallingford et al [(3)] 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 in the form of ribbons or streaks, or rippled sand patches. Some of the sand which enters the estuary is deposited in the sand flat system.

Revised sand transport pathways within the Greater Wash have been published based upon existing and new data. These are illustrated in *Figure 7.18* which 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 Humber Gateway site; and
- to the east of the bedload parting zone, sand is transported in a northerly direction.

Figure 7.18 Sandwaves and Sediment Transport



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Finer material suspended from the erosion of the Holderness Coast is transported to the south towards the Humber Estuary, where muds are transported out of the Humber to form a plume which moves offshore to the southeast towards the southern North Sea. This plume can be observed from satellite images and is shown in *Figure 7.19*. The majority of the suspended load from this plume is deposited beyond UK Territorial Waters [(1)]. Within the study area, muddy material is deposited within the Humber Estuary and within the Outer Silver Pit [(2)], where there is evidence of some re-working of the deposited sediment [(3)].

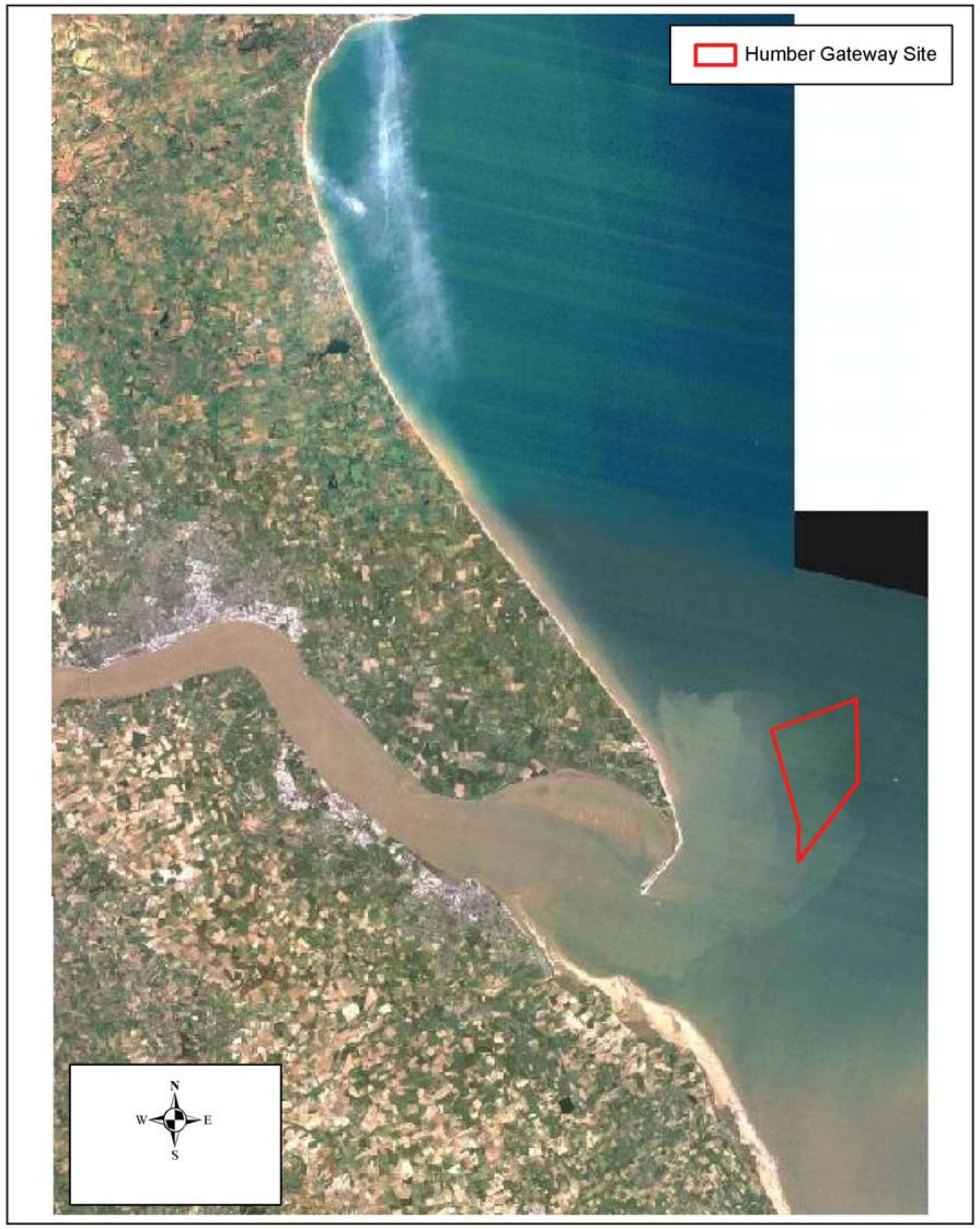
Regional measurements have been made of suspended sediment concentrations (SSCs) by Cefas as part of the Southern North Sea Sediment Transport Study [(4)].

[(1)] Defra, 2002. Futurecoast.
[(2)] Proctor R, Holt J T and Balson P S, 2001. Sediment deposition in offshore deeps of the Western North Sea: Questions for models. Estuarine and Coastal Shelf Sciences 53, 4, 553-567.
[(3)] Eisma, D & Irion G, 1988. Suspended matter and sediment transport. In: Salomons, W, Bayne B L, Duursma E K, Forstner U (Eds). Pollution of the North Sea, An Assessment. Springer, Berlin pp. 20 - 35.
[(4)] HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier., 2002. Southern North Sea Sediment Transport Study: Phase II.

These indicate that the summer and winter SSCs within the study area are in the range of 8 to 128 mg l^{-1} and 4 to 256 mg l^{-1} respectively. Note that the lower values are typically located over the Humber Gateway site, whilst the higher SSCs are for the nearshore zone.

These concentration ranges have been confirmed by further studies in the area in 2004 and are 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 seabed.

Figure 7.19 Landsat Image of Suspended Sediment Plume



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7.5.2 SEDIMENT TRANSPORT

Overview

The contemporary sediment regime is comprised of:

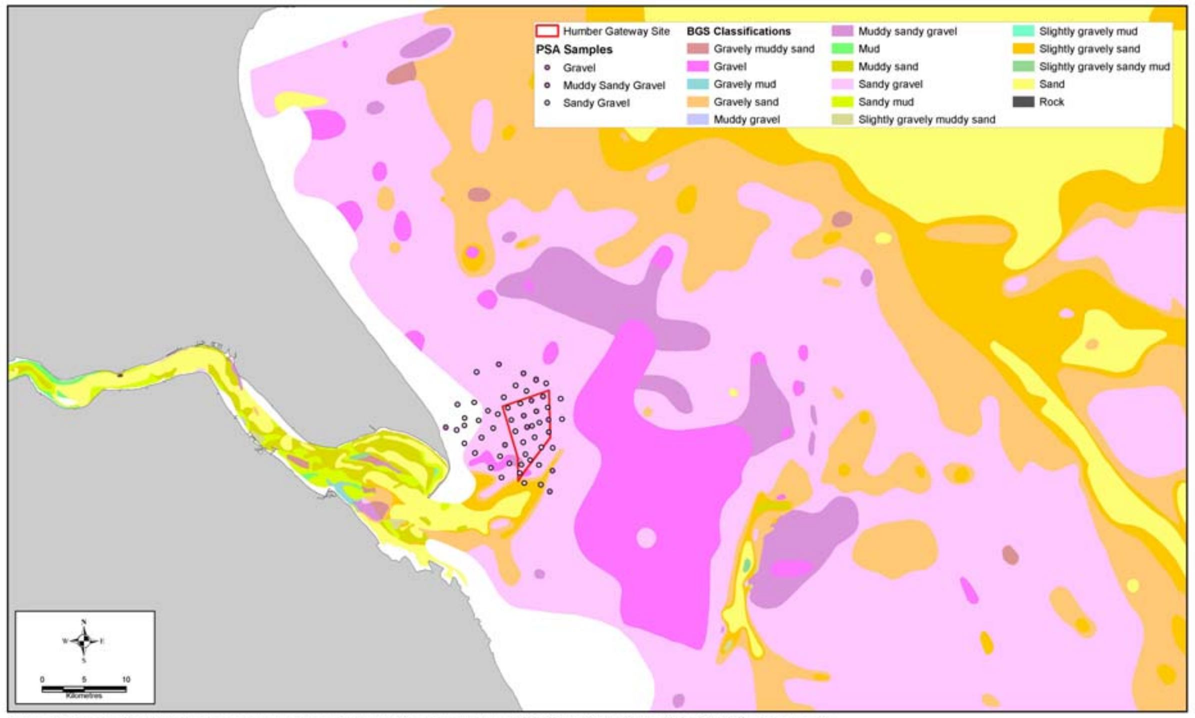
- seabed surface sediments (bed load);
- sediments suspended in the water column; and
- sources and sinks of material.

The behaviour of these sediment populations is dependant upon their respective response to the hydrodynamic forcing conditions (e.g. waves and 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 and the sediment will fall out of suspension when shear stresses then fall below this threshold. The size of materials will determine the time that sediments remain in the water column. 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 British Geological Society regional sediment coverage map which includes the location of the Humber Gateway site is shown in *Figure 7.20*. 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 southeastern fringe of the site.

Figure 7.20 Bed Sediment Composition



Previous investigations by D'Olier [(1)] reveal that the majority of the site is not covered by any extensive areas of mobile sand, hence bedrock is usually found at the seabed. 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 sediments pass on south towards the Humber Estuary, the Lincolnshire coast and The Wash.

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, 200,000 $m^3 y^{-1}$ and 350,000 $m^3 y^{-1}$ between Hornsea and Easington. The estimated drift rate into Spurn Point is around 125,000 $m^3 y^{-1}$ [(2)] [(3)], 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.

[(1)] D'Olier, 2003. Offshore Humber - Sites A, B, E. Geological Desk Study. For: Global Renewable Energy Partners (GREP A/S); Round II/Offshore Wind Farm Studies.
[(2)] Valentin, 1954 in HR Wallingford et al., 2002. Southern North Sea Sediment Transport Study: Phase II.
[(3)] HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier., 2002. Southern North Sea Sediment Transport Study: Phase II.

Sediment transport within the nearshore zone is controlled by wave forcing. Fine sediment originating from the Holderness cliffs is typically suspended when the significant wave height is greater than 1 m [(4)]. 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 [(5)]. 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 Humber Gateway site by identifying the modal sizes of all available sediments, derived from Hamon Grab survey data, and calculating the combined wave and tide bed shear stresses required to initiate transport (using standard methods) [(6)].

It can therefore be concluded that:

- coarse sand (750 µm) is responsive on spring tides and only during peak flows on neap tides - the percentage of time these events occur is around 50%;
- larger granule sized gravel (2,400 µm) appears to be limited to peak events on spring tides only - the percentage of time these events occur is around 13%; and
- the limit of sediment mobility is reached at a sediment size of around 4,800 µm (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 [(7)] [(1)].

[(4)] Prandle D, Hargreaves J C, McManus J P, Campbell A R, Duwe K, Lane A, Mahnke P, Shimwell S, & Wolf J, 2000. Tide, wave and suspended sediment modelling on an open coast -Holderness. Coastal Engineering, 41, 237 -267.
[(5)] McCave I N, 1987. Fine sediment sources and sinks around the East Anglian Coast (U.K.). Journal of the Geological Society, London, 144, 149 - 152.
[(6)] Soulsby R, 1997. Dynamics of marine sands. A manual for practical applications. Thomas Telford.
[(7)] British Geological Survey. 1990. Spurn, Sheet 53N 00, Seabed Sediments and Solid Geology, Natural Environment Research Council.

The mean grain size for sediments across the Humber Gateway site is equivalent to pebble gravel. Pebble gravel is not within the 'live bed' regime, in response to local wave and tidal conditions.

7.5.3 COASTAL EROSION AND SHORELINE PROCESSES

Holderness Coast

Most of the 50 km length of the Holderness Coast consists of cliffs up to 38 m 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 (1). However, some regions of the coast may experience erosion rates of up to 20 m per annum (2). Further, the nearshore seabed also experiences erosion of the order of 2 m per annum (2). Analysis of a monitoring programme along part of the Holderness Coast suggest that the erosive behaviour follows a cyclical pattern of three to five years, within which the erosion rates respond to the prevailing weather conditions, for example in response to storm events (2).

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 northeast (for approximately 25% of the time). The dominant longshore transport direction along the coast is to the south (3).

The sediment supply to the North Sea is dominated by the inputs from the east coast of England, most notably from the Holderness Coast. 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.

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. Spurn Head has, over a significant number of years, been subjected to a variety of processes that have seen it grow longer, breached and subsequently re-formed further west (4). It is suggested that it is only as a result of human intervention, that the present spit has remained in its location for such a long period of time.

There is debate concerning whether or not Spurn Head is an example of a spit (5). The tidal range of the Humber Estuary is too large for the normal development of a spit (6 m, compared to the 2 to 4 m range present at all other spits around the UK) and tidal currents are too fast to normally 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. Gravely sands are located to the north of The Binks and sands to the south, whilst within the Humber, mud and muddy gravely sediment predominate.

The Centrica, BP Easington and Dimlington Gas Terminals are located approximately 1 km to the north of the cable landfall and collectively cover an area of 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 immediately to the north of the cable landfall.

A number of ecological and geological designated sites are located along the Holderness Coast and are described in *Section 8.2.* The nearest designated site of geological interest is Dimlington Cliffs Site of Special Scientific Interest (SSSI) which is nationally important for its geological features. This site is located approximately 1.3 km to the north of the boundary of the northern cable route corridor. The cliffs are important for their Quaternary stratigraphy showing a sequence, from the base of the cliffs upwards, of pre-late Devensian Basement Till, organic silts and sands (Dimlington silts), Late Devension Skipsea and Withernsea Tills.

(1) Land Ocean Interaction Study, 2000. Second Annual Meeting, Hull pp. 155-156. LOIS Publication Number 323.

(2) Institute of Estuarine and Coastal Studies, 2007. Preliminary assessment of the cable landfall, Humber Gateway Wind Farm. 15 March 2007 (Draft). Report No. ZBB645-D-2006.

(3) Balson P S, 1997. New Sand Hole and the former course of the Humber. In: LOIS: Land-Ocean Interaction Study - Second Annual Meeting, Hull, pp. 155-156. LOIS Publication Number 323.

(4) HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier., 2002. Southern North Sea Sediment Transport Study: Phase II.

(5) IECS, 1994. Preliminary Assessment of the Cable Landfall, Humber Gateway Wind Farm.

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 which has shown that the convergence of tidal currents has resulted in sediment deposition such that the lower foreshore has undergone substantial accretion [(1)]. 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 0.045 M tonnes per annum of fine sediments are transported from the Lincolnshire coast to the North Sea [(2)] . This feature is designated as a Lincolnshire Wildlife Trust Nature Reserve, which is 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 scheme in the UK [(1)]. In contrast, the coastline to the south of Skegness and in the approaches to The Wash includes features associated with deposition such as spit features, sand banks and the sand dunes that 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.

Humber Estuary

The Humber Estuary is characterised as a single spit enclosed estuary. It is a tidally-dominated estuary, although there are significant freshwater inputs [(3)]. The tidal asymmetry is ebb dominant and the cross sectional area ratio suggests that the estuary is sediment dominated. Sediment eroded from the Holderness Coast enters the estuary and it is suggested [(4)] that the estuary could be a strong sink for sediment, both coarse and fine. The Humber has a high suspended sediment concentration which is transported beyond the mouth on the ebb tide.

A sand bank feature composed of gravely sands with high sand waves, locally known as The Binks, is located at the mouth of the estuary. Part of this feature is dry at Low Water. 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 [(4)].

Erosion at Easington

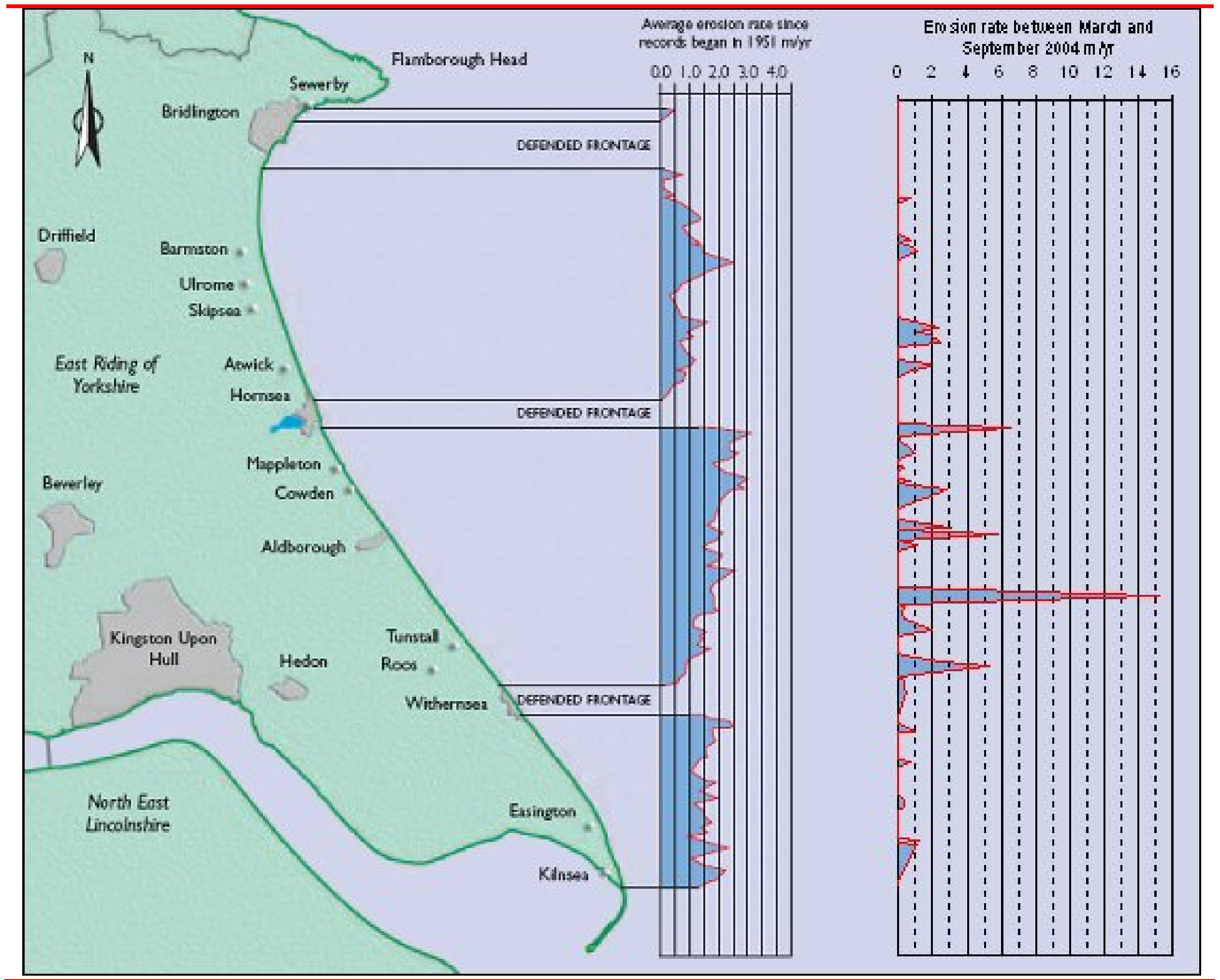
The recent *Humber Estuary Coastal Authorities Group Shoreline Management Plan (SMP)* [(5)] indicates that there is an offshore and residual longshore movement of sediment south of Easington. Wave action moves sand in a net southerly direction, whilst muds and clays in suspension move south and offshore. Larger cobbles remain and accumulate. At Spurn Head, sediments move offshore or continue on to the Humber Estuary and then to beaches to the south.

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, the normal annual variations in erosion rates are averaged and eventually converge towards a more reliable annual value (although these values may not, of course be representative of short term erosion rates nor are they necessarily indicative of erosion rates in the future)

Figure 7.21 illustrates that between Easington and Spurn Point, average cliff erosion rates have varied between 0.86 and 4.15 m y^{-1} 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 1.2 m.

(1) HR Wallingford, Cefas/UEA, Posford Haskoning and D'Olier, 2002. Southern North Sea Sediment Transport Study: Phase II.
(2) ABP R&C, 1996. Southern North Sea Sediment Transport Study: literature review and conceptual transport model. ABP Research & Consultancy Ltd, Research Report No. R.546.
(3) Townend I, Whitehead P A, 2003. A preliminary net sediment budget for the Humber Estuary. Science of the total environment, vol. 314-16, 755-767.
(4) Defra, 2002. Futurecoast.
(5) Posford Duvivier, 1998, Volume 1.

Figure 7.21 Average Erosion Rates along the Holderness Coast



Further analysis of the cliff erosion rates [1] has been used to derive values for the present, predicted and worst case scenarios for the East Riding of Yorkshire Council (ERoY) erosion monitoring posts located within the landfall window for the preferred cable route to the north (*Table 7.7*). The landfall location is covered by monitoring posts 108 to 110 shown in *Figure 7.22*.

The average erosion rate at the cable landfall location is likely to be between 1.5 and 2 m y^{-1} based on continued erosion at the current rate. This would result in a total predicted loss of between 53 and 61 m over 40 years. However, using an erosion rate of 5.6 m y^{-1} as the worst case scenario, the potential loss could be as high as 224 m over 40 years.

Table 7.7 Present, Predicted and Worse Case Scenario Erosion Rates

Erosion Post	Present Rate of Erosion (m y^{-1})	Predicted Loss Over Next 40 Years (m): At present erosion rate	Predicted Loss Over Next 40 Years (m): At worst future erosion rate
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: (-) no further erosion predicted as cliff line now defended

(Taken from: IECS, 2007)[1]

Shoreline Management

The *Humber Estuary Coastal Authorities Group Shoreline Management Plan (HECAG SMP)* was first developed in 1998, and sets out a strategy to guide future coastal defence decisions. An evaluation has been undertaken of the strategic coastal defence policy options. These options comprise of:

- do nothing;
- hold the existing defence line by maintaining or changing the standard of protection;
- advance the existing defence line; or
- retreat the existing defence line.

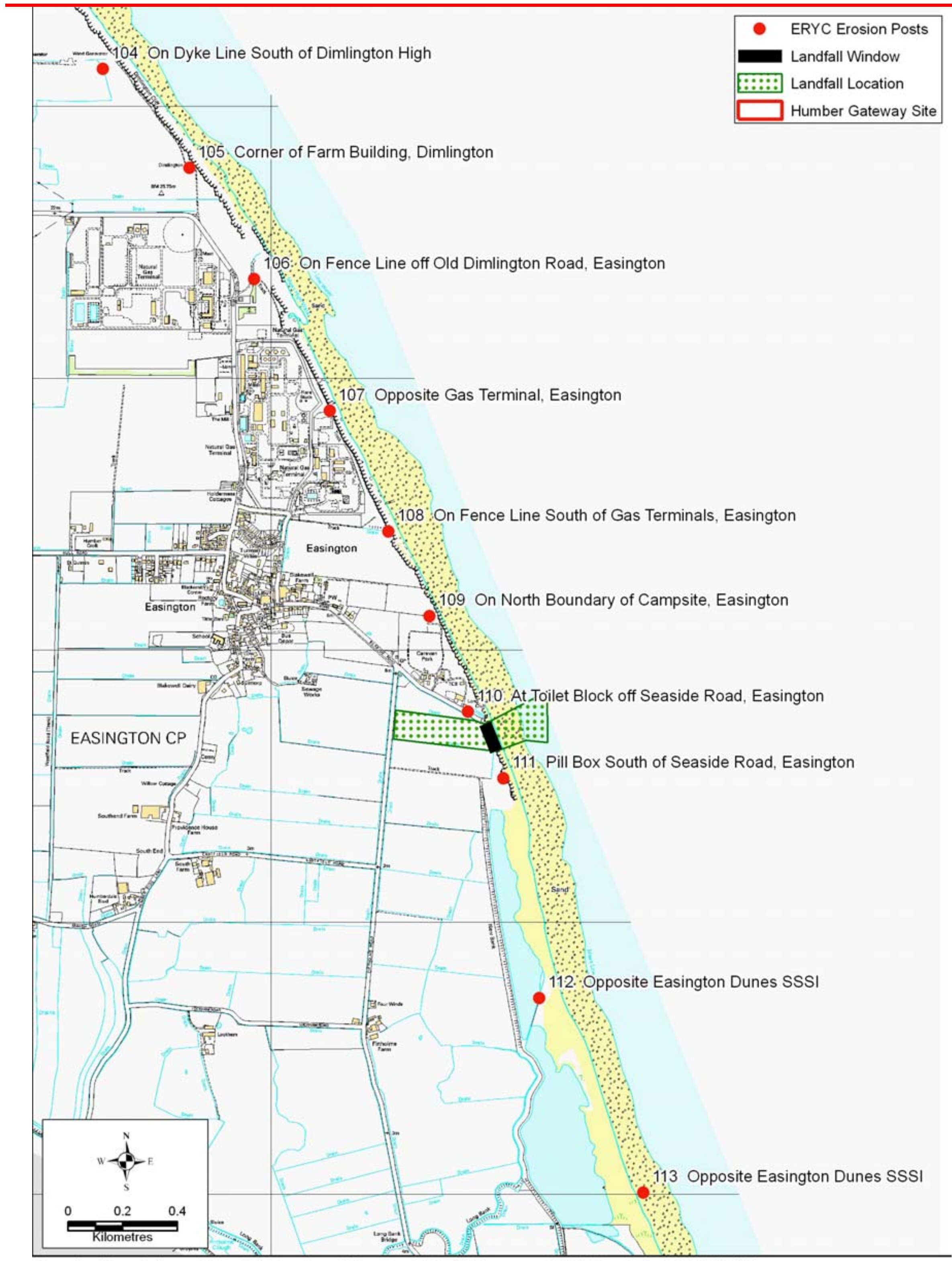
The 110 m cable landfall window is located within Management Unit 12 of the SMP which is located to the south of the Easington Gas Terminals extending to the top of the neck of the Spurn peninsula. The boulder clay cliffs are eroding at a long term average rate of between 0.94 m to 5.6 m a year. There are currently

(1) Institute of Estuarine and Coastal Studies, 2007. Preliminary assessment of the cable landfall, Humber Gateway Wind Farm. 15 March 2007 (Draft). Report No. ZBB645-D-2006.

no coastal defence structures within this management unit [1], the current option being to do nothing and review the management strategy where protection against flooding is required.

The preferred Humber Estuary management option is to continue maintaining defences until 2035, with some realignment in the long-term.

Figure 7.22 Monitoring Post Locations along the Easington Coast



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PROJECTION: British National Grid

[1] Humber Estuary Coastal Authorities Group (HECAG) Shoreline Management Plan, East Riding of Yorkshire Council, 1998.

7.6 SUMMARY

7.6.1 METEOROLOGICAL PARAMETERS

The prevailing wind for the study area is southwesterly and westerly where peak wind speeds are in the range of 28.5 to 32.7 m s^{-1} (Beaufort Force 11). Good visibility of 15 km or more occurs approximately 62% of the time, whilst poor visibility below 8.5 km occurs in the region of 19% of the time.

7.6.2 CHEMICAL AND PHYSICAL OCEANOGRAPHY

Physical water quality parameters in the vicinity of the Humber Gateway site are summarised as follows.

- Mean surface water temperature in summer is between 13 and 15˚C, whilst winter surface water temperature is in the range of 5 to 6˚C. Coastal and offshore waters are generally not stratified. Mean surface water temperature has risen by 0.17˚C at Spurn Head in the past decade.
- Mean surface water salinity is 34.5 in summer and 34.25 psu in winter. Mean bottom water salinity is marginally lower, in the range of 34.0 to 34.2 psu.
- Turbidity has been recorded as ranging between 4 to 256 mg l^{-1} with winter concentrations of suspended sediment commonly reaching levels twice those of the summer months. Ambient suspended sediments concentrations are generally a function of occasional fluxes across the site derived from alternative sources, such as the Humber Estuary plume and coastal erosion.
- The North Sea is well oxygenated with average levels of dissolved oxygen for North Sea coastal waters found in the study area.

In terms of the chemical and microbiological water quality parameters, the region's designated bathing waters achieved 100% compliance with the *EC Bathing Water Directive (76/160/EEC)* in 2005 and 2006.

The wave climate in the vicinity of the Humber Gateway site is summarised as follows.

- The dominant wave direction is from the north northeast (42% occurrence).
- The largest waves originate from the north northeast.
- The most common wave period is in the range 5 to 6 s (19% occurrence).
- The most common wave height is in the range 0.25 to 0.5 m (25% occurrence).
- The largest waves are in the class 3.50 to 3.75 m, and are generally associated with the mean wave period in the range 6 to 7 s.

The tidal regime in the vicinity of the Humber Gateway site is summarised as follows.

- The tidal range is in the order of 2 m for neap tides, and 7 m for spring tides.
- The maximum tidal current recorded during a storm event was in the order of 1.5 m s^{-1}.

The bathymetry in the vicinity of the Humber Gateway site is summarised as follows.

- The bathymetry ranges from 16 m to 21 m (ODN) within the site.
- The 12 nm UK territorial limit reaches depths of approximately 35 m.
- The nearshore area extends to approximately 1.3 km at depths of 9.5 to 12 m.
- There are two bathymetric depressions, south of the site, that reach a maximum depth of 45 m.

7.6.3 COASTAL AND MARINE GEOMORPHOLOGY

Seabed topography in the vicinity of the Humber Gateway site is summarised as follows.

- There is little topographic variation with seabed gradients typically less than 1˚.
- Bedforms (sand waves and sand ribbons) are localised within the site. Close to the shore, low gravel ridges are present.
- There is a bathymetric rise that runs from the centre to the south southwest with 3 m high ridges along its eastern flank.

- Sand waves exceeding 5 m in height orientated north-south are present to the south of the study site.

- Steep ridges of boulder clay reaching 1 to 3 m height and clay mounds are present in the nearshore area, up to 1 km from the shore.

Seabed geology and the type and distribution of seabed sediment in the vicinity of the Humber Gateway site are summarised as follows.

- The general seabed surface sediment type across the site is classified as sandy gravel, with occasional gravels and occasional muddy sandy gravel. It forms a veneer of a few decimetres to centimetres depth across the site. This layer is an erosional product of the underlying shallow geological sequence dominated by the Bolders Bank formation over a thick sequence of Upper Cretaceous Chalk bedrock [(1)].

- At sites with muddy sandy gravel, the mud content is generally very low and is always less than 5.6%.

- The Bolders Bank Formation was deposited during the late Pleistocene (Weichselian) times. The formation is a tillite consisting of calcareous, gravely sandy clay with erratics, predominantly of chalk and can be divided into two units, a lower lodgement till thought to be analogous Basement Till and an overlying better bedded, more well sorted, water lain ablation till which may be Withernsea Till. There may also be thin pockets and lenses of silt found, analogous to the soft, laminated water lain silts of the Dimlington Silts identified onshore [(2)].

- The proposed two options for cable routes are characterised by a thick layer of boulder clay interspersed with small boulders.

7.6.4 COASTAL AND SEABED DYNAMICS

Sedimentary transport pathways in the vicinity of the Humber Gateway site are summarised as follows.

- Bedload sediment transport in the nearshore zone and up to 7 km offshore moves in a generally southerly direction.

- A bedload parting zone runs through the site with a southerly sediment transport direction on the western shoreward side of this partition, and a northerly sediment transport direction to the east.

- Sands eroded from the Holderness Coast enter the Humber Estuary along the shoreline from the north. Some of this sediment is deposited in the sand flat system.

- Muds and sands move out of the Humber Estuary through the central channel of the estuary, forming a plume that moves offshore to the southeast. This plume is understood to be mostly deposited beyond UK territorial waters and is visible in satellite images.

- Beyond depths of 40 m, bedload sediment transport directions are variable.

Coastal erosion and shoreline processes in the vicinity of the Humber Gateway site are summarised as follows.

- The cliffs of the Holderness Coast are subject to severe erosion and rapid recession, typically in the region of 1 to 3 m per year but with extreme events of up to 20 m per year.

- Erosional rates respond to prevailing weather conditions, storm events, waves and tidal forces with waves compromising cliff stability via undercutting. Wave direction is predominantly from the northwest carrying material away from the coast, with longshore transport occurring to the south.

- The estimated longshore drift rate into Spurn Point is around 125,000 $m^3 y^{-1}$.

- Large-scale long-term sediment transport follows the meteorologically driven anti-clockwise flow of the southern North Sea.

- The nearshore seabed is undergoing erosion of around 2 m per year.

- There are few areas of mobile sands on the seabed across the site with the only significant area existing in the southern corner of the study area. Fine particles originating from the eroded Holderness cliffs are typically suspended when wave heights exceed 1 m.

- The limit of mobility rests with pebble gravel sediments of around 4,800 µm. Sediments of this size are limited to bedload with all larger cobbles and boulders remaining immobile.

- The Humber Estuary is a sediment-dominated Type 4a single spit enclosed estuary due to the presence of Spurn Head, a sandy peninsula that extends

[(1)] Titan Environmental Surveys Ltd, 2005.Humber Gateway Offshore Wind farm Geophysical Survey. Report No: CS0114/R1/V2.
[(2)] British Geological Survey, 2005. The geology of the southern North Sea, United Kingdom Offshore Regional Report. HMSO.

from the north out into the Humber Estuary. There are linear sand bank features, sand flats, and intertidal mudflats.

- Easington lagoons are located to the south of the landfall. The site consists of a range of coastal habitats and the area has received a number of conservation designations.

- Donna Nook on the Lincolnshire coast acts as a sediment sink for fine grained sediments eroded from the Holderness cliffs. Approximately 0.045 M tonnes of fine sediments are transported from the Lincolnshire coast into the North Sea each year.

- The coastline between Mablethorpe and Skegness has undergone erosion and now has coastal defences in place along some reaches. Significant beach recharge has also occurred here.

- The Humber Estuary Coastal Authorities Group Shoreline Management Plan has evaluated strategic coastal defence policy options and has opted to continue maintaining defences on line until 2035, with some realignment in the long term.