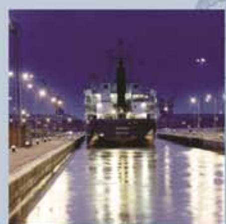
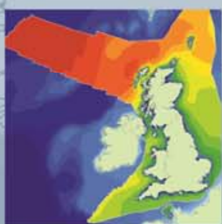
E.ON Climate and Renewables UK Ltd

Rampion Wind Farm: Coastal Processes Baseline Assessment

Report R.1853

November 2011

Creating sustainable solutions for the marine environment


E.ON Climate and Renewables UK Ltd

Rampion Wind Farm:
Coastal Processes Baseline Assessment

Date: November 2011

Project Ref: R/3953/4

Report No: R.1853

Version	Details of Change	Authorised By	Date
1	Draft	A M Bakare	07.10.2011
2	Final	C L Hinton	30.11.2011

Document Authorisation		Signature	Date
Project Manager:	C L Hinton	CHinton	30.11.2011
Quality Manager:	A M Fulford		30.11.2011
Project Director:	W S Cooper		30.11.2011

ABP Marine Environmental Research Ltd
Quayside Suite, Medina Chambers
Town Quay
SOUTHAMPTON
Hampshire
SO14 2AQ

Tel: +44(0)23 8071 1840
Fax: +44(0)23 8071 1841
Web: www.abpmer.co.uk
Email: enquiries@abpmer.co.uk

ABPmer is certified by:

Abbreviations

µm	micrometre(s)
ABPmer	ABP Marine Environmental Research Ltd
AWAC	Acoustic Wave And Current
BERR	The Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
BODC	British Oceanographic Data Centre
c.	circa
CCO	Channel Coastal Observatory
CD	Chart Datum
CEFAS	Centre for Environment, Fisheries & Aquaculture Science
CIRIA	Construction Industry Research and Information Association
CMACS	Centre for Marine and Coastal Studies
COWRIE	Collaborative Offshore Wind Research Into the Environment
CPA	Coast Protection Act
cSAC	Candidate Special Area of Conservation
CSM	Continental Shelf Model
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DTI	Department for Trade and Industry
EC&R	E.ON Climate and Renewables UK Rampion Offshore Wind Limited
EECHM	Eastern English Channel Habitat Map
EIA	Environmental Impact Assessment
EW	European Waters
FEPA	Food and Environmental Protection Act
GCR	Geological Conservation Review
gmS	Gravelly Muddy Sand
gS	Gravelly Sand
GW	Gigawatt(s)
H(max)	Maximum wave height
HAT	Highest Astronomical Tide
HMSO	Her Majesty's Stationary Office
HRA	Habitats Regulations Appraisal
Hs	Significant Wave Height
HSE	Health and Safety Executive
HW	High Water
IPC	Infrastructure Planning Commission
JNCC	Joint Nature Conservation Committee
km	kilometre(s)
LAT	Lowest Astronomical Tide
m	metre(s)
m/s	metres per second
MAFF	Ministry for Agriculture Farming and Fisheries

MALSF	Marine Aggregate Levy Sustainability Fund
MAREA	Marine Aggregate Regional Environmental Assessment
MCA	Maritime and Coastguard Agency
MCCIP	Marine Climate Change Impacts Partnership
mg/l	milligrams per litre
MHW	Mean High Water
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLW	Mean Low Water
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MMO	Maritime Management Organisation
msG	muddy sandy Gravel
MSL	Mean Sea Level
MW	Megawatt(s)
N/m^2	Newtons per square metre
N/A	Not Applicable
NAO	North Atlantic Oscillation
NERC	Natural Environment Research Council
NOC	National Oceanography Centre
NTSLF	National Tidal and Sea Level Facility
OBS	Optical Backscatter Sensor
ODN	Ordnance Datum Newlyn
OREIs	Offshore Renewable Energy Installations
OWF	Offshore Wind Farm
POL	Proudman Oceanographic Laboratory
PSA	Particle Size Analysis
Ramsar	Ramsar Convention
RBMP	River Basin Management Plan
REC	Regional Environmental Characterisation
RSL	Relative Sea Level
RSPB	Royal Society for the Protection of Birds
RYA	Royal Yachting Association
SAC	Special Area of Conservation
SCOPAC	Standing Conference on Problems Associated with the Coastline
SCREC	South Coast Regional Environmental Characterisation
SEA	Strategic Environmental Assessment
sG	sandy Gravel
smG	sandy muddy Gravel
SDCG	South Downs Coastal Group
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSC	Suspended Sediment Concentration
SSSI	Sites of Special Scientific Interest

Tp	Peak wave period
Tz	Zero crossing wave period
UK	United Kingdom
UKCIP	UK Climate Change Impact Programme
UKCS	UK Continental Shelf
UKHO	UK Hydrographic Office

Rampion Wind Farm:
Coastal Processes Baseline Assessment

Contents

Tables

Figures

1. Introduction

1.1 Study Description

ABP Marine Environmental Research Ltd (ABPmer) has undertaken a baseline assessment of coastal processes for the Rampion Wind Farm on behalf of E.ON Climate and Renewables UK Rampion Offshore Wind Limited (EC&R). The application site is located offshore from Brighton, in the eastern part of the English Channel (Figure 1). The wind farm application site and proposed cable corridor covers an area of approximately 271 km^2 and 77 km^2, respectively. The full description of the wind farm's characteristics, including details of all planned infrastructure, is given in the Project Description (Section 2a of the Environmental Statement (ES).

1.2 The Rampion Wind Farm Study Area

The Rampion study area includes the proposed Offshore Wind Farm (OWF) application site for development and a wider far-field region as defined below. The proposed OWF application site and cable corridor make up the near-field region of the study area. The lease area is located approximately, 13 km offshore within the English Channel and between two headlands; Selsey Bill and Beachy Head. The headlands are dominant geomorphological features that influence the hydrodynamic, sediment transport and morphodynamic regimes on the south coast of England and through this section of the English Channel. The headlands also form the limits of coastal sub-cell 4d and the landward boundary of the study area (Figure 1). The seaward extent of the study area is defined based on the occurrence of the Northern Palaeovalley offshore of the OWF application site (Figure 1).

It is important to complete an assessment of the coastal processes at the site, combining an understanding of the immediate development area and the associated coastline and offshore environment (Section 2.4). The coastline associated with this application site includes major coastal towns and working harbours, including Worthing, Shoreham-by-Sea, Brighton and Newhaven (Figure 1). Due to the occurrence of these towns, a '*Hold the line*' management strategy is in place as part of the Shoreline Management Plan (SMP) for the region, completed by the South Downs Coastal Group (SDCG) (1997; 2004).

The seabed within the study area, from the coastline to the offshore extent, is characterised by a relatively shallow and gently sloping seabed interspersed with deeper infilled palaeochannels cut into the Cretaceous and Tertiary solid geology along the proposed cable corridor. Within the OWF application site, the seabed is again gently sloping and interspersed with infilled palaeochannels in the north. In the southern area, part of the Northern Palaeovalley transects the site, so there are variable seabed gradients with deeper partially-filled and unfilled palaeochannels and palaeovalleys. Tidal flow through the area is from the southwest on the flood and northeast on the ebb tide. The flood flow is marginally stronger with higher current speeds on this tide and there is therefore a residual associated with this tide. The sediment transport varies from the nearshore to the offshore locations, presented further in Section 4. At the coastline, between the two headlands, there is a general trend of west to east wave driven shingle transport along the coastline, with fluvial flow causing localised variations.

Further offshore, there is an east to east-northeast transport pathway of sandy to gravel sediments, primarily moved by the tide leading to well-sorted distributions and bedform features. Available broad-scale data for the English Channel suggests that gravels, sandy gravels and sand are the dominant seabed sediments. These comprise the seabed deposits that make up the contemporary depositional environment and the palaeo-landscapes with a complex arrangement of infilled river channels.

2. Assessment Methodology

The baseline assessment is completed following best practice and current guidance for coastal process studies in relation to OWF developments as presented in the following documents:

- ‘Offshore wind farms: guidance note for Environmental Impact Assessment in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) requirements: Version 2’ (Department for Environment, Food and Rural Affairs (Defra), Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and Department for Transport (DfT), 2004) - current at the time of reporting;
- ‘Guidance on Environmental Impact Assessment in Relation to Dredging Applications’ (Office of the Deputy Prime Minister, 2001);
- ‘Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects’ (Cefas for MMO, 2011) –currently as draft (Judd, 2011);
- ‘Using the Rochdale Envelope. Advice note nine: Rochdale Envelope’ (IPC, 2011);
- ‘Nature Conservation Guidance on Offshore Wind Farm Development’ (Defra, 2005); and
- ‘Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment’ (COWRIE, 2009).

The purpose of the available generic guidance is to provide an overall consistency in approach and methodology to the identification and assessment of potential impacts. Using the recommended approaches, specific issues in relation to the Rampion Wind Farm application site have been determined during the Environmental Impact Assessment (EIA) scoping and consultation process (Section 2.4).

The interaction of any changes in the tidal, wave and sedimentological regimes may, consequently, result in changes to the morphodynamic regime. It is therefore recommended that the results from these assessments be investigated with regard to the morphological regime, with consideration to, for example, bed form changes.

2.1 Approach

The assessment of baseline coastal processes around the application site has been structured into three broad categories, namely:

- *Hydrodynamic regime:* water levels, currents and waves;
- *Sediment regime:* seabed sediment distribution, bedload and suspended load transport; and
- *Morphodynamic regime:* form and function of both the coast and offshore, the morphodynamic regime is defined as a response to both the hydrodynamic and sediment regime.

This baseline coastal processes assessment describes the natural variability of these regimes prior to the construction of the Rampion Wind Farm. This provides the reference condition and a basis to inform the assessment of the significance of any consequential changes to the baseline.

2.2 Spatial Scales

A consideration of the tidal, wave and sedimentological regimes is required over the following spatial scales as introduced in Section 1.2:

- Near-field (i.e. the area within the immediate vicinity of the turbine grid and along the cable corridor); and
- Far-field (i.e. the wider coastal environment in which effects of the wind farm could potentially result).

2.3 Temporal Scales

There are four main phases of development that require consideration in the coastal process part of the EIA. These are:

- Baseline;
- Construction;
- Operation; and
- Decommissioning.

In order to provide the context for the usage of this baseline report, a brief description of each phase is summarised in the following sub-sections.

2.3.1 Baseline

The baseline environment is not static and will exhibit some degree of natural change with or without the wind farm in place due to naturally occurring cycles and processes. Therefore, the baseline phase considers the ranges and interactions of naturally occurring coastal processes both prior to the installation of any wind farm infrastructure and over the lifetime of the development (in the absence of the proposed infrastructure). The baseline study also provides a condition against which the potentially modified coastal processes can be compared, throughout the lifecycle of the development. Consideration of any predicted naturally occurring variability or long-term changes to coastal processes within the lifetime of the array due to natural variability (e.g. seasonality, natural cycles or meteorology) and climate change (e.g. sea level rise) will also be included in this phase. For example, it is generally anticipated that climate change will result in global scale effects which will be represented at regional scales by the trends in rising mean sea level and increased storminess (Lowe *et al*., 2009). The baseline period is still to be determined in relation to the lease agreement.

This baseline assessment of the coastal processes has been developed through the analysis and interpretation of data and information from a variety of sources, including a programme of site surveys, pre-existing datasets and available literature sources. These are further detailed in Section 2.6. The impact assessment of the Rampion Wind Farm in relation to coastal processes is investigated at a later date but draws upon the conceptual understanding developed here.

2.3.2 Construction

Tidal and wave regimes

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

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

Sedimentological regime

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

- Installation of the structures; and/or
- Cable laying processes.

2.3.3 Operation

The operational phase of the OWF is expected to be 25 years in association with the lifetime of the turbines (Section 2a of the ES). The Crown Estate Lease area consented covers an area of approximately 271 km^2 within which the wind turbines will be installed. Changes to tide, wave and sediment transport regimes during the operational phase have the potential to be larger in magnitude and in temporal and spatial extent than during other phases.

Tidal regime

Potential effects may include changes to the naturally occurring water levels, current speeds and directions.

Wave regime

Potential effects may include changes to the naturally occurring wave heights, periods and directions.

Sedimentological regime

Effects upon the sediment regime during the operational phase of the modelling may occur due to the effects on the tidal and wave climate as above, potentially manifesting as:

- The alteration of suspended and/or bed load sediment transport pathways within both the near and far-fields;
- Scour around the turbine foundations and/or the cables, with the potential for the eroded material to be transported away from the application site; and
- Changes to the littoral drift processes along adjacent coastlines.

2.3.4 Decommissioning

Specific details of the decommissioning phase are presently unknown. However, it is expected that on expiry of the lease the developer will remove all structures and return the seabed to a usable state, in accordance with Department of Energy and Climate Change decommissioning guidelines (DECC, 2011).

It is assumed that the decommissioning phase will involve the removal and/or burial of any structures related to the wind farm development. Therefore, impacts upon tidal, wave and sedimentological regimes as a consequence of this phase will be comparable to those identified for the construction phase.

Post-decommissioning, the application site is expected to return to baseline conditions (allowing for some measure of climate change).

2.4 Consultation and Scoping of EIA Issues

The EIA Scoping report for the Rampion Wind Farm was submitted in September 2010 to statutory and non-statutory consultees and relevant parties (E.ON, 2010b). A number of issues and particular concerns to address in the EIA were raised by in the scoping responses (IPC, 2010). Those that are of direct relevance to the assessment of coastal processes are presented in Table 1.

Table 1. Coastal process issues and concerns expressed during the EIA consultation and scoping process

Coastal Process Issue	IPC	MMO	Brighton and Hove County Council	Natural England	Southern Water
Sediment dynamics		Scour and impact to sediment transport pathways and its effect on the coastline			
Hydrodynamics	Cumulative hydrodynamic impact				Altering hydrodynamics at the long sea outfalls and the dispersion of effluent
Sediment availability and transport pathways			Impact on marine aggregate extraction operations		

(Taken from IPC, 2010)

2.5 Coastal Processes Receptors

Waves and, tides are typically considered as pathways that can be altered by the presence of structures placed within the application area. As previously stated, alterations to the hydrodynamic regime may also result in changes to sediment transport pathways with the potential for a consequential effect on, for example, coastal morphology and seabed features. Coastal processes receptors occur within the application site and the wider far-field region.

The receptors that form the basis for exploring the potential impact of the proposed development are summarised in Table 2. These will be considered further within the Impact Assessment phase of works.

Table 2. Coastal process themes requiring consideration within this study

Receptor	Coastal Process Theme	Designation	Description
Seabed infrastructure including pipelines and cables	Hydrodynamics Sediment dynamics	None	This includes investigating current properties and the large-scale cumulative impact and the influence on scour and sediment transport pathways.
Aggregate sites	Sediment dynamics and transport pathways	None	Investigating the potential for plume interaction from aggregate activities during foundation installation works.
Coastline of Sub-Cell 4d	Sediment dynamics and transport pathways	None	The coastline of this Sub-Cell has a number of urban areas along the entire frontage; these are of high socio-economic value hence the "*Hold the Line*" policy that is prevalent along most of the frontage.
Pagham Harbour	Hydrodynamics Sediment dynamics	SPA (*) and Ramsar site	Changes to the coastal processes acting within the designated sites which could impact the habitats they support. The further assessment of effects on other EIA topics will be informed by these results, but will be reported in other chapters.
Beachy Head West	Hydrodynamics Sediment dynamics	rMCZ (**)	
Kingmere			
Offshore Overfalls			
East Meridian			
Pagham Harbour	Hydrodynamics Sediment dynamics	SSSI	
Bognor Reef			
Selsey, East Beach			
Felpham			
Adur Estuary			
Brighton to Newhaven Cliffs			
Climping Beach			
Seaford to Beachy Head			
Surfing Locations	Waves Hydrodynamics	None	Changes to the offshore wave climate due to the interruption of offshore swell wave transmission by turbine structures and the associated reduction in wave energy due to absorption, refraction and diffraction.

(*) Where SPA – Special Protection Area
(**) Where rMCZ – recommended Marine Conservation Zone
(***) Where SSSI – Site of Special Scientific Interest

2.6 Data Sources

As part of the planning, assessment and development of the proposed Rampion Wind Farm, a series of new data collection and historical data collation exercises have been undertaken. These have yielded a range of comprehensive datasets, including geophysical, benthic and metocean (meteorological and hydrodynamic) parameters (Table 3). The point-location or spatial coverage of the data collection is shown in Figure 3. Relevant information and knowledge from these surveys have been incorporated into appropriate sections of this report.

Table 3. Project specific data and information sources used in the baseline assessment

Survey/ Study	Date of Survey	Undertaken By	Description
Geophysical Surveys	04/05/2010-19/08/2010	Osiris Projects	High-resolution swath multibeam and single beam bathymetric survey, side scan sonar imaging, magnetometer and sub-bottom profiling.
Benthic Survey	03/2011-04/2011	EMU Ltd.	Baseline information on the benthic communities in and adjacent to the proposed wind farm application site has been collected. 52 grab samples are available from the application site. These samples have been used for particle size analysis (PSA) which provides a good indication of the seabed characteristics throughout the application site.
Metocean Surveys	L1: 01/11/2011-07/01/2011 L2: 01/11/2011-18/02/2011 Locations 3: 01/11/2011- 10/05/2011 (AWAC) 25/01/2011-10/05/2011 (wind)	EMU Ltd.	Provides data on waves, tides, water levels, suspended sediment concentrations (SSC) and wind. Waves: height, period and direction Currents: depth averaged and profiles of speed, direction Wind: speed and direction SSC: Temperature and turbidity (depth averaged and current profile).

Additional information has also been obtained from other sources to complement that obtained from the geophysical, geotechnical, benthic and metocean surveys described above. This additional data includes:

- British Geological Survey (BGS) 1:250,000 surface sediment maps, used to provide a more regional indication of the seabed material. This has been broadly verified within the application site using the grab samples provided by the benthic survey;
- UKCIP '09 (Lowe *et al.,* 2009) predictions of future changes to the hydrodynamic regime due to climate change;
- Wave observations from the Rustington wave buoy, Worthing Pier meteorological station and Arun Platform tidal gauge downloaded from the Channel Coastal Observatory (CCO);
- Wave observations from the Greenwich Light Vessel obtained from the Met Office; and
- Modelled wave data for a 10-year period out of the Seastates model (ABPmer, 2011c).

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

- Strategic Environmental Assessment Area 8 Superficial Seabed Processes and Hydrocarbon Prospectivity (Tappin *et al*., 2007);
- JNCC Coastal Directory Series: Coasts and seas of the United Kingdom. Regional Report 8 Sussex: Rye Bay to Chichester Harbour (Barne *et al*., 1998);

- Coastal flood boundary conditions for UK mainland and islands. Project SC060064/TR2: Design sea levels (McMillan *et al*., 2011a);
- Coastal flood boundary conditions for UK mainland and islands. Project SC060064/TR3: Design swell waves (McMillan *et al*., 2011b);
- The Eastern English Channel Marine Habitat Map. Science Series Technical Report 139 (James *et al*., 2007);
- The South Coast Regional Environmental Characterisation (James *et al*., 2010);
- The MALSF synthesis study in the central and eastern English Channel (James *et al*., 2011);
- Eastern English Channel Regional Environmental Assessment (Royal Haskoning, 2002);
- Extreme tidal water level estimations for different sites in the English Channel (ABPmer, 2004);
- Coastal processes scoping assessment for the EON02 zone, south coast (ABPmer, 2008a); and
- Sand banks, sand transport and offshore wind farms (Kenyon and Cooper, 2005);

3. Hydrodynamic Regime

3.1 Overview

The hydrodynamic regime encompasses the range of processes that together describe the physical marine environment in and around the application site, namely:

- Water levels;
- Currents;
- Winds (as a driving force for waves); and
- Waves.

These parameters are described in more detail in the following sub-sections. This information has subsequently been used to develop a conceptual understanding of the sedimentary and morphological regimes at the application site (see Sections 4 and 5).

The hydrodynamic regime has the potential to influence a number of the identified receptors. This includes the sediment availability and dynamics, as well as the flow patterns through the study area, particularly at the long sea outfalls for Southern Water. The influence of these elements on the receptors is considered in Section 6.

3.2 Water Levels

Marine water level measurements typically contain both a predictable astronomical tidal signal and a more random non-tidal signal, typically related to meteorological influences, which act to add a further influence to the tidal signal and observed properties.

Water levels through the study area are influenced by the location of a degenerate land-based amphidromic point, situated inland of Weymouth, which brings about a complex tidal pattern at the coastline. Tidal range increases in distance from the amphidrome meaning that tides increase in range in an easterly direction through this part of the English Channel. A mean spring tidal range of 4 m is observed on the western boundary of the far-field region, increasing to 6.5 m on the eastern boundary off Beachy Head. Within the OWF application site, locations L1 and L3 are in close proximity to the 5.5 m co-range line, while L3 occurs closer to the 6 m mean spring co-range line (Figure 4). This in turn means that within the near-field site there are expected differences in the water levels.

3.2.1 Sources of Water Level Data

Several sources of water level data are available from within the application site and far-field region. These datasets are listed in Table 4 and their locations are shown in Figure 3.

Table 4. Sources of water level data

Data Source	Latitude (°N)	Longitude (°W)	Period Analysed	Duration
NTSLF Newhaven tide gauge	50.79	0.06 E	Jan 2003 to Apr 2011	~ 8 years
CCO Arun platform tide gauge	50.77	0.49	Aug 2008 to Dec 2010	3 years
Rampion OWF AWAC L1	50.68	0.33	01/11/2010 to 06/01/2011	65 days
Rampion OWF AWAC L2	50.68	0.15	01/11/2010 to 08/02/2010	90 days
Rampion OWF AWAC L3	50.63	0.22	01/11/2010 to 10/05/2011	189 days
UKHO tide tables (Shoreham-by-Sea)	50.82	0.25	N/A	N/A
Published Storm Surge Statistics (Flather, 1987; Dixon and Tawn, 1997; McMillan *et al.*, 2011a)	N/A	N/A	N/A	N/A
Admiralty tidal co-range chart	Variable	Variable	N/A	N/A

NTSLF National Tide and Sea Level Facility
CCO Channel Coastal Observatory
UKHO United Kingdom Hydrographic Office

3.2.2 Astronomical Tidal Water Levels

The astronomical tide is harmonic and periodic, i.e. in this context the tide is repeatable and predictable, as described by the summation of a number of harmonic components of differing amplitude and phase.

Newhaven tide gauge (NTSLF)

The UK National Tide and Sea Level Facility (NTSLF) records tidal levels at 44 locations around the UK coastline. The closest observation site to the OWF application site is the station at Newhaven, which has been operational since 1990 (Figure 3). The tide level observations from the Newhaven gauge is downloaded from NTSLF at the National Oceanography Centre through the British Oceanographic Data Centre (BODC) data service. Data is obtained for the period between 2008 and May 2011, this predominantly coincides with the time frame for which data is available from the Arun Platform described below. Although data is available for this time frame, only the period for which survey data is available is assessed, i.e. 01/11/2010 to

10/05/2011. Water levels observed from the Newhaven gauge do not show any variation in the observed levels from the onshore gauge to the measurements within the OWF application site.

The observations for the same time period as the metocean site survey, confirm that the region is characterised by a macro tidal regime (maximum or typical tidal range between 4 and 6 m). This is based on a calculated mean spring tidal range of 5.9 m and a maximum normal tidal range of over 7 m. This relates to observations for the English Channel, where a high tidal range and complex regime exists (Pingree & Griffiths, 1979). In addition, water levels resonate as a standing wave within the English Channel due to the geometry and location the degenerate amphidromic point, which is located on land.

Arun Platform tide gauge

The Arun Platform is a meteorological station managed by Arun District Council (Figure 3). The tide gauge on the platform became operational in April 2008. Data is downloadable via the CCO data holdings, however there is no data available for the survey period, therefore there no comparison is available against the Newhaven and AWAC application site deployments.

Shoreham-by-Sea standard port

The nearest permanent standard port tide gauge to the application site is located at Shoreham-by-Sea (Figure 3). Astronomical tidal water level statistics for this location have been obtained from the Admiralty Tide Tables (UKHO, 2011) and are presented in Table 5. The measures from Shoreham-by-Sea are in agreement with the observations from other sources and also confirm that a macro tidal regime is present within the region.

Table 5. Astronomical tidal water level statistics

Water Level Statistic		Shoreham-by-Sea (m)	Rampion AWAC			Newhaven (m)
			L1 AWAC* (m)	L2 AWAC* (m)	L3 AWAC* (m)	
Highest Astronomical Tide	HAT	6.90	6.80	7.21	6.62	7.30
Mean High Water Spring Tides	MHWS	6.30	6.10	6.39	5.96	6.69
Mean High Water Neap Tides	MHWN	4.80	4.78	4.99	4.62	5.22
Mean Sea Level	MSL	3.40	3.38	3.54	3.21	3.56**
Mean Low Water Neap Tides	MLWN	1.90	1.99	2.08	1.81	2.10
Mean Low Water Spring Tides	MLWS	0.60	0.67	0.68	0.46	0.77
Lowest Astronomical Tide	LAT	0.00	0.00	0.00	0.00	0.16
Mean Spring Range	MHWS to MLWS	5.70	5.43	5.71	5.50	5.92
Mean Neap Range	MHWN to MLWN	2.90	2.79	2.91	2.81	3.12

Values in relation to CD.
* Taken from EMU (2011).
** Estimated using +3.4 level from the Shoreham standard port United Kingdom Hydrographic Office (UKHO, 2011).

Rampion AWAC deployments

AWAC instruments were deployed at three locations in the OWF applications site, two to the northern extent and one in the middle of the application site (Figure 3). Each deployment had a different temporal coverage due to varying deployment periods. A minimum of 65 days (~2 months) was obtained from L1, whereas a maximum of 189 days (~6 months) was obtained from L3.

Tidal properties observed from within the application site are included in Table 5. These are obtained from harmonic analyses of the observed water level time series from the study area as completed by EMU (2011). The observations follow the general trend in water levels as described from the co-tidal and co-range tidal information, where there is an increasing mean spring range from west to east (Table 5). In addition, the observations demonstrate that there is also a general trend of decreasing range moving offshore.

On a west to east axis and at the coastline, the range increases by approximately 0.2 m between Shoreham-by-Sea and Newhaven. Within the OWF site, there is also a small (~0.3 m) increase in the mean spring tidal range, with a larger range observed at L2, which is the furthest east. On a north to south axis comparing between the observations at Shoreham-by-Sea and L1, the mean spring range decrease by approximately 0.3 m by L1 (Table 5). However, assessment between the metocean survey locations shows the range observations at L3 are marginally larger compared with L1 (<0.1 m), but are less (by ~0.2 m) if compared with L2 (Table 5). This suggests the variability in the water levels is primarily driven by east to west co-range tidal variation. This also indicates that the range observed between the metocean survey locations is a realistic representation of the tidal variation across the site.

3.2.3 Non-Tidal Influences on Water Level

In addition to the astronomical tide, water levels may be influenced by meteorology. For example, higher than average atmospheric pressure causes the water level to be relatively depressed (negative surge) whilst low pressure causes water levels to be relatively elevated (positive surge). Either effect can be enhanced or reduced by the additional effect of winds if sufficiently strong and persistent enough, depending upon the direction, location and timing. Moving low pressure systems and associated strong and persistent wind fields may generate a strong positive surge, often referred to as a ‘storm surge’. The difference between the predicted astronomical tidal water level and that actually observed is termed the tidal residual.

National Tide and Sea Level Facility (NTSLF) surge observations (Newhaven)

The NTSLF tide gauge at Newhaven provides tide level observations at 15 minute intervals, data from January 2003 to April 2011 have been analysed in this study. In addition to the tidal levels, monthly average and extreme tidal levels and occurrences of positive and negative surge events are also recorded. A number of positive and negative surge events are observed from the tide gauge during the period of AWAC deployments. These are listed in Table 6, as measures above or below the expected tidal level.

Table 6. Positive and negative surge events observed for the NTSLF Newhaven tide gauge within metocean survey period (October 2010 to May 2011)

Negative Surge Events	Negative Surge Height (m)	Positive Surge Events	Positive Surge Height (m)
28/11/2010 05:00	-0.29	12/11/2010 17:00	0.70
01/12/2010 04:00	-0.32	16/12/2010 18:15	0.68
23/01/2011 11:15	-0.43	06/01/2011 11:00	0.37
04/02/2011 08:00	-0.37	04/02/2011 22:45	0.49
03/03/2011 21:00	-0.48	11/03/2011 05:00	0.28
13/04/2011 07:30	-0.21	30/04/2011 05:15	0.19

Published extreme water level statistics

Extreme water levels statistics are completed using a vertical datum of Ordnance Datum Newlyn (ODN) as opposed to the Chart Datum (CD) primarily used in navigation. On this basis the results presented in this section refer to ODN.

At a regional scale, the 2-year return period positive storm surge elevations within the English Channel is noted to be between 3 to 5 m (ODN). This increases to 4 to 5 m (ODN) for the 5, 10, 20 and 50-year return periods for the year 2000. In addition there are observed variations from west to east, where there are increasing extreme water levels in the same direction (ABPmer, 2008a). The increase in extreme water levels across this axis coincides with the observed increase in mean spring range from co-range observations and harmonic analyses of the metocean surveyed data from L1, L2 and L3 (Section 3.2.2).

These observations agree with other published studies characterising the spatial coherence of extreme water levels around the UK (McMillan *et al*., 2011a). Within the English Channel, the 2-year return period water levels increase from approximately 2 m (ODN) at Weymouth, to 4 m (ODN) at Newhaven, with the same rate of increase for the 5, 10, 20 and 50-year return periods (McMillan *et al*., 2011a).

The return period of extreme water levels calculated for Newhaven are assessed further as it is the closest available measurement to the OWF application site. The 2, 5, 10, 20, 25 and 50-year return period extreme water levels estimated by the Environment Agency coastal flood boundary condition (McMillan *et al*., 2011a) using data from 2008 are set out in Table 7. In addition the assessment for the same return period predicted for the years 2020 and 2060 by ABPmer (2004) is also given in Table 7. The values are set out as absolute levels and therefore include the tidal and surge components. The information indicates that the water levels associated with the assessed return periods are predicted to increase by 2060 by up to 0.4 m.

Based on the assessed statistics, the observed surge occurrences between 01/11/2010 and 10/05/2011 (Table 6) are less than the 2-year surge event.

Table 7. Extreme tidal level statistics at Newhaven for the year 2008 and predicted for 2060 for the 2, 5, 10, 20, 25 and 50-year return periods

Return Period (years)	2008* (m, ODN)	2060** (m, ODN)
2	3.88	4.30
5	4.03	4.48
10	4.13	4.44
25	4.27	-
50	4.37	4.56

* Taken from McMillan *et al*., (2011a).
** Taken from ABPmer (2004).

3.2.4 Future Changes to the Baseline

Mean sea level at the application site is likely to alter over the lifetime of the wind farm (which currently expected to have a operational period of 25 years). This change is generally accepted to include contributions from global eustatic changes in mean sea level and also as a result of regionally varying vertical (isostatic) adjustments of the land.

Information on the rate and magnitude of anticipated relative sea level change in the English Channel during the 21st Century is available from the UKCIP (United Kingdom Climate Change Impact Programme, http://www.ukcip.org.uk/) Summary predictions of 21st Century changes in relative sea level at the closest reported standard port to the application site (Shoreham-by-Sea) are presented in Table 8. These findings suggest that by 2050, relative sea level in the application site and surrounding area will have risen by 0.22 m based on the medium emissions scenario at the 50% percentile. As shown by the rate of increase in values in the table, the majority of predicted sea level rise occurs during the second half of the 21st Century when the rate of change is predicted to be greatest. It should be noted that such an increase in mean water level is significantly smaller than the tidal and non-tidal water level variations presently experienced at the application site.

Table 8. Summary statistics of 21st Century sea level rise at Shoreham-by-Sea, relative to 1990 levels

Year	Relative Sea Level Rise Based On Medium Emissions Scenario, 5% (m)	Relative Sea Level Rise Based On Medium Emissions Scenario, 50% (m)	Relative Sea Level Rise Based On Medium Emissions Scenario, 95% (m)
1990	0.00	0.00	0.00
2000	0.02	0.03	0.04
2010	0.03	0.06	0.09
2020	0.05	0.10	0.15
2050	0.11	0.22	0.33
2100	0.22	0.47	0.73

The UKCIP also includes projections of changes to storm surge magnitude in the future as a result of climate change (Lowe *et al*., 2009). For a ‘medium emissions’ scenario, the 1 in 50-year storm surge event will increase by 0.43 mm/yr (values apply until 2099), which is approximately equivalent to adding ±21.3 mm to the values in Table 6 over a 50-year lifetime for the wind farm. The resulting effect is evidently small in comparison to natural variability and would not constitute a measurable change.

3.3 Currents

The English Channel is a semi-enclosed sea that narrows towards the east. The main tidal wave that propagates through the Channel approaches from the west to east. Due to the narrowing in the central and eastern parts of the Channel, regional spatial variations in tidal velocities are observed. At a regional scale, annual mean spring peak current speeds taken from the Renewables Atlas (ABPmer *et al.*, 2008), show that large speed up to 2 m/s are observed between the Isle of Wight and Cotentin Peninsula. These then reduce eastwards to between 0.5 m/s to 1.25 m/s within the proximity of the OWF site. Further eastwards and towards the coastline, speeds reduce further to approximately 0.25 m/s before increasing again towards the Dover Strait (ABPmer, 2008b). The spatial variation in mean current speeds is demonstrated in Figure 4. There is also a variation in current speed between the flood and ebb tide, where marginally larger speeds are observed on the flood (Barne *et al*., 1998).

Pingree and Griffiths (1979), showed the importance of the M2 and M4 tidal constituents for generating tidal currents sediment dynamics in shallow water systems (i.e. generally less than 50 m), as present in the English Channel. The constituents in shallow water are 90º out of phase and result in opposing directions of tidally induces currents and sediment movement. In the English Channel this has the effect of generating currents that flow towards the east and west, which in turn induces the bedload parting that exists south of the Isle of Wight.

In addition to astronomically driven tidal currents, meteorological forcing may also cause an increase in locally observed current speeds. Of particular note in the English Channel are (i) currents associated with storm surges; and (ii) orbital currents associated with the passage of waves, both of which have the potential capacity to stir the seabed. This is mainly the case for the shallower areas of the Channel, with depths less than 18 m, identified from studies at the coastline of sub-cell 4d.

3.3.1 Sources of Current Data

Current data for the OWF application site and surrounding area are available from several sources. These datasets are listed in Table 9 and their locations are shown in Figure 3.

Table 9. Sources of current data

Data Source		Latitude (°N)	Longitude (°W)	Period Analysed	Duration
Rampion OWF AWAC L1		50.68	0.33	01/11/2010 to 06/01/2011	65 days
Rampion OWF AWAC L2		50.68	0.15	01/11/2010 to 08/02/2010	90 days
Rampion OWF AWAC L3		50.63	0.22	01/11/2010 to 10/05/2011	189 days
BODC Data Archive	49879	58.62	0.78	14/09/1984 to 01/10/1984	17 days
	49880	58.62	0.78	14/09/1984 to 01/10/1984	17 days
	100271	58.62	0.77	28/04/1985 to 18/05/1985	21 days
	100283	58.62	0.77	28/04/1985 to 21/05/1985	23 days
	49923	58.62	0.75	10/12/1983 to 17/12/1983	7 days
	49935	58.62	0.75	10/12/1983 to 17/12/1983	7 days
Totaltide (UKHO tidal diamonds)	SN158A	50.471	0.29	N/A (Representative spring and neap tidal cycle)	N/A
	SN007H	50.657	0.71		
	SN008B	50.735	0.34		
	SN008E	50.702	0.25		

3.3.2 Astronomical Tidal Currents

Rampion OWF AWAC deployments

The properties and validity of the metocean survey data outputs for currents was assessed prior to application in this baseline assessment, which is presented in ABPmer (2011a and 2011b). The properties of the currents interpreted for the site are shown in Figure 5 and Figure 6 and summarised below:

- Across the site, the dominant current speeds are consistently from the east-northeast and the reciprocal west-southwest, larger current speeds are observed in the south of the application site, compared with the northern locations;
- The tidal currents within the region are energetic as speeds are, with spring speeds in excess of 1 m/s;
- The highest current speeds are encountered at L3, in the south of the application site, reaching depth averaged peak speeds of ~ 1.25 m/s during spring tides;
- During spring tides, peak current speeds at L1 and L2, in the north of the application site are 1.04 m/s and 1.05 m/s respectively;
- During neap tides, depth averaged peak current speeds at all locations in the application site are typically half of that observed on spring tides, and range between 0.4 and 0.5 m/s;
- The observations show that there are marginally larger speeds on the flood tide showing that the site is flood-dominant, with an associated flood residual particularly under spring conditions; and
- The expected vertical profile in current speed for open water un-stratified flows is apparent at all the AWAC deployment locations, i.e. exhibiting a decrease in current speed towards the bed.

BODC data archive

The review of the BODC data is taken from ABPmer (2008a), who have previously completed an assessment on available current data. Results of analyses are presented in Table 10. Current data is only available from the western part of the far-field region off the Selsey Bill headland (Figure 3). On average speeds of <1 m/s are observed off the headland, although peak flow speeds of up to 1.6 m/s are also observed. In addition, marginally higher flow speeds are observed on the flood tide, indicating a flood dominant residual approximately eastwards (Table 10). Deployments at only one location (i.e. site B, BODC ID 100283 and 100271) are long enough to capture variation through a spring-neap cycle, which are therefore more representative values.

Table 10. Summary of BODC data and current properties

Site No.	BODC ID	Depth of Deployment (m)	Start Date	End Date	Depth Averaged Current Speed (m/s)	
					Peak Flood	Peak Ebb
A	49879	13	14/09/1984	01/10/1984	1.47	1.45
	49880	18	14/09/1984	01/10/1984	1.42	1.38
B	100283	18	28/04/1985	21/05/1985	1.57	1.50
	100271	26	28/04/1985	18/05/1985	1.44	1.42
C	49923	13	10/12/1983	17/12/1983	0.87	0.84
	49935	21	10/12/1983	17/12/1983	0.85	0.84

UKHO tidal data

There is no observational data of current speeds in close proximity to the OWF application site and the only information available is from tidal stream tables generated from modelled outputs. Due to the relatively simplistic data collection methods traditionally used, such model outputs can only be assumed to provide an indicative rate and direction of surface flow for a representative spring or neap tide.

The information on the flow speeds is available on UKHO Chart 1652: Selsey Bill to Beachy Head and UKHO Chart 2045: Outer Approaches to The Solent. These, and additional similar data sets can also be accessed using the UKHO 'Total Tide' software package. Four tidal diamonds that cover the axes of the OWF application site and which are in relatively close proximity (Figure 3) are used to assess the variation in current speeds through the tidal cycle across the site. The variation of flow at these locations is summarised in Table 11.

The tidal stream values indicate that peak flood speeds are again marginally larger that the peak ebb tide under spring conditions. However the same peak speeds are observed on the flood and ebb under neap conditions (Table 11). This further suggests there is a spring flood dominant residual through the study area. The current data collected during the metocean survey (Figure 5) is in good agreement with these values and observed patterns.

Table 11. Summary of tidal stream data from Admiralty Chart 1652 (A, D and H) and Chart 2045 (N)

Hours		Tidal Diamond A 50.657° N; 0.705° W			Tidal Diamond D 50.735° N; 0.342° W			Tidal Diamond H 50.702° N; 0.248° E			Tidal Diamond N 58.167° N; 3.10° W		
		Direction (°N)	Spring (m/s)	Neaps (m/s)	Direction (°N)	Spring (m/s)	Neaps (m/s)	Direction (°N)	Spring (m/s)	Neaps (m/s)	Direction (°N)	Spring (m/s)	Neaps (m/s)
Before HW Flood	-6	098	0.46	0.21	093	0.36	0.21	263	0.51	0.31	236	0.26	0.15
	-5	102	0.77	0.41	057	0.77	0.46	107	0.26	0.15	090	0.57	0.26
	-4	096	0.98	0.46	052	0.82	0.46	085	0.98	0.57	081	0.98	0.46
	-3	089	0.67	0.36	052	0.77	0.41	075	1.34	0.77	081	1.34	0.67
	-2	077	0.31	0.15	058	0.46	0.26	080	1.24	0.72	074	1.24	0.62
	-1	307	0.21	0.10	310	0.10	0.05	075	0.72	0.41	070	0.77	0.36
HW	0	272	0.72	0.36	267	0.36	0.21	107	0.10	0.05	063	0.21	0.10
After HW Ebb	1	268	0.98	0.46	250	0.62	0.36	263	0.41	0.21	267	0.41	0.21
	2	264	0.72	0.36	243	0.82	0.46	266	0.67	0.36	263	0.98	0.51
	3	281	0.36	0.21	238	0.72	0.41	254	1.03	0.51	260	1.27	0.67
	4	282	0.26	0.15	221	0.57	0.31	263	1.03	0.57	256	1.13	0.57
	5	329	0.10	0.05	191	0.41	0.26	263	0.93	0.51	253	0.82	0.41
	6	092	0.31	0.15	127	0.31	0.21	267	0.67	0.36	247	0.46	0.26

3.3.3 Non-tidal Influences

In addition to modifying water levels, storm surges may also modify the locally observed current speed from that expected from astronomical forcing alone. Because they are induced by meteorological forcing, surge currents are not directly related to the modified tidal range or the rate of water level change during the surge event. In addition to storm surges, individual storm waves can generate significant oscillatory currents through the water column and at the seabed.

Wave induced orbital currents

The currents generated in relation to the occurrence of waves are discussed as these have the potential to induce sediment mobility. Individual waves propagating through a fluid induce circular to elliptical movements through the water column. In shallow enough water which is less than the closure depth for waves, this motion extends to the seabed resulting in an oscillatory near-bed current. Wave induced currents oscillate at wave-period time-scales (order of seconds), typically with a symmetrical near-sinusoidal pattern unless in particularly shallow water. The amplitude of these oscillatory currents can be estimated as a function of wave height, period and the local water depth (Dean & Dalrymple, 1991) and are estimated in Table 12 for a series of extreme wave events. The return period wave conditions are estimated from the Seastates model output (ABPmer, 2011c) at locations north and south of the OWF application site and from a central point within the site (Figure 3).

Table 12. Maximum orbital current velocities (m/s) at the seabed associated with a series of low frequency, high magnitude storm events

	Return Period (years)	Significant Wave Height Hs(m)	Zero Crossing Wave Period Tz (s)	Orbital Velocity (m/s)
Seastates (nearshore) Depth=9.9m (CD)	2	4.18	7.14	1.52
	5	4.44	7.35	1.64
	10	4.64	7.51	1.74
	25	4.90	7.72	1.87
	50	5.09	7.87	1.96
Seastates (application site) Depth=33m (CD)	2	4.83	7.46	0.37
	5	5.10	7.67	0.43
	10	5.29	7.81	0.47
	25	5.47	7.94	0.51
	50	5.52	7.98	0.52
Seastates (offshore) Depth=54m (CD)	2	5.41	7.44	0.09
	5	5.60	7.57	0.11
	10	5.71	7.65	0.11
	25	5.83	7.73	0.12
	50	5.90	7.78	0.13

From Table 12 it is apparent that the highest nearbed orbital current amplitudes will be found in the shallower parts of the far-field study region. Here, current velocities are in excess of 1 m/s for a 1 in 2-year return period storm event and are approximately 2 m/s for a 1 in 50-year event, which could occur during the lifetime of the OWF. Orbital current speeds of this magnitude are considerably greater than observed peak spring tidal flow speeds (Section 3.3.2). Within the application orbital current speeds are considerably less and range between 0.4 m/s to 0.5 m/s for the 1 in 2-year to 1 in 50-year return period respectively. The implications of these findings for sediment mobility across the application site are discussed further in Section 4.6.

3.4 Winds

Although not part of the hydrodynamic regime, the wind regime is relevant to the generation of waves. The relationship between wave generation and meteorological forcing means that the wind and wave regimes are similarly episodic and exhibit both seasonal and inter-annual variation in proportion with the frequency and magnitude of changes in wind strength and direction. The relationship between the occurrence of wave events and the characteristic wave regime are discussed in Section 3.5.

3.4.1 Sources of Wind Data

Wind data is available from two locations within the study area, one of which was obtained as part of the metocean surveys within the application site and the other is within the far-field region (Table 13 and shown in Figure 3).

Table 13. Sources of wind data

Data Source	Latitude (ºN)	Longitude (ºW)	Period Analysed	Duration
Rampion OWF application site meteorological buoy	50.63	0.22	25/01/2011 to 10/05/2011	105 days
Worthing Pier meteorological sensor (CCO)	50.81	0.37	25/01/2011 to 10/05/2011 14/07/2010 to 13/07/2011	104 days 364 days

3.4.2 Wind Regime

Rampion Wind Farm meteorological station

The meteorological buoy was deployed at L3 within the OWF application area for the period between 25/01/2011 and 10/05/2011 (Figure 3). Two instruments were mounted on the buoy measuring wind speed and direction, gust speed, air temperature and pressure (EMU, 2011), one being the primary sensor and the other the secondary. Data is collected from this meteorological station at concurrent time scales to the AWAC instrument at location L3 and summarised in Figure 7. Data quality assessment by EMU (2011) showed that the sensors returned good quality data for all parameters, with good correlation between the primary and secondary sensors.

A frequency analysis of wind speed and direction based on the observed wind conditions are presented as a series of wind roses in Figure 7 and summarised in Table 14. The result shows that the most frequent wind direction is from the west-southwest (236˚ to 259˚), accounting for 12% of the record. Similar proportions are also observed from the west (79˚ to 101˚), west-northwest (56˚ to 79˚), and northwest (34˚ to 56˚), accounting for approximately 33% percentage of the record fairly evenly across the three sectors. Approximately 65% of the record contains wind speeds between 3 to 9 m/s, with the maximum occurrence at 5 to 7 m/s. The observed wind speeds are rarely less than 1 m/s (<2% of time) and only infrequently (<1% of time) exceed 15 m/s. Generally larger wind speeds are more frequent at this offshore location compared with the onshore observations at Worthing Pier.

Table 14. Summary of wind speed and direction frequency analysis at the OWF application site

Buoy Deployment	Dates of Deployment	Most Frequent Wind Direction and Percentage of Record	Most Frequent Wind Speed and Percentage of Record	Maximum Observed Wind Speed and Associated Direction Sector
Meteorological buoy Rampion OWF application site	25/01/2011 to 10/05/2011	WSW (12%)	5-7 m/s (24%)	16 m/s (SSW)
Worthing Pier meteorological buoy (CCO)	25/01/2011 to 10/05/2011	NNE (15%)	3-5 m/s (26%)	21 m/s (SW)
Worthing Pier meteorological buoy (CCO)	14/07/2010 to 10/05/2011	W (12%)	3-5 m/s (25%)	24 m/s (SSW)
Percentages are rounded to integers				

Worthing Pier Meteorological Station (CCO)

The meteorological station at Worthing Pier is managed by Worthing Borough Council, but the data is available from the CCO real-time observations data download. Data is obtained for a year from when the instrument was first installed. This includes the period between 14/02/2010 and 13/07/2010, which also covers the same deployment period for the meteorological buoy within the OWF application site. Therefore analyses of the wind properties from this station are carried out for the same period at the OWF application site and for the full annual record. The frequency analysis of the data obtained from is also presented as wave roses in Figure 7 and summarised in Table 14.

Table 14 shows that different dominant directions are observed for the subset of data covering the survey period only, compared with the full annual record. For the survey period, the dominant direction is wind blowing from the north-northeast. The next most dominant direction is from the southwest, which occurs approximately 12% of the time (Table 14). The dominant wind speed is between 3 to 5 m/s. The properties described for the survey period differ from the observed from the annual dataset. Generally most wind observations are in the north around to south, through the western sectors (Figure 8), while the dominant direction is from the west. This direction and proportion is similar to the observations from the application site. The dominant speeds are however the same as observed during the survey period.

3.5 Waves

The wave regime in the English Channel is the outcome of locally generated wind waves and swell waves. Wind waves are the result of the local transfer of wind energy to the water surface and swell waves are wind waves that would have been created as the result of a storm event and then propagated outside the area of generation.

Previous studies indicate that the English Channel is predominantly influenced by swell waves, which originate from the west and southwest, coming from the Atlantic. These are originally generated in open water in relation to storms and have significant wave heights in excess of 4 m over 50% of the time under winter conditions (Paphitis *et al*., 2010). As the swell waves propagate into the Channel, significant heights reduce to 2.4 m in the Western Approaches and reduce further to 0.9 into the eastern part of the Channel. Under summer conditions, wave heights are approximately half of winter conditions.

Wave action at the coastline typically has a controlling influence on erosion processes and littoral drift rates. The rates and directions of these processes are influenced by both the height and direction of the waves reaching the coast. (Sediment transport and littoral drift are considered further in Sections 4.5 and 5.2).

Under calm conditions with no storms (i.e. significant wave heights <0.5 m), waves are not seen to move large sediment volumes in the offshore environment, but have a limited sediment stirring effect for transport by currents. At the coast, under normal conditions, waves are again not seen to move large volumes of sediment. The occurrences of larger waves associated with storms have the potential to cause water movement at the seabed at the coastline and the

OWF application site. Focusing on the Eastern English Channel, Paphitis *et al*., (2010) showed that within this region and at the coastline, wave action with the potential to disturb seabed sediments occurs over 20% of the time on an annual time scale. Further offshore and towards the application site, this reduces to between 5 to 20% of time during the year. Further offshore in the middle of the Channel, this again reduces to less than 1% a year.

3.5.1 Sources of Wave Data

Wave data for the study area are summarised in Table 15, these are of varying quality and duration. The highest quality datasets are the observational wave records, e.g. those from the metocean deployments and Rustington Channel Coastal Observatory (CCO) and Greenwich Light Vessel Met Office wave buoys (Figure 3). The metocean survey wave records are only relatively short-term (less than 12 months) duration and as a result do not reliably reflect the longer term (> c.2 years) wave climate of the region if used alone. The wave records from the CCO and Met Office are from longer and ongoing deployments, which do not occur within the OWF application site or the near-field extents. Therefore these are used to primarily inform and characterise the longer term properties and far-field wave regime. Further information is derived from modelled outputs of wave conditions, which can be used to augment the information derived from observational wave records. These are useful as they can be used to characterise the wave regime at larger spatial and temporal scales. Data is derived from the Seastates model (ABPmer, 2011c) for the period between 2000 and 2009, at an offshore location, south of the OWF application site (Figure 3).

Table 15. Sources of wave data

Data Source	Latitude (°N)	Longitude (°W)	Period Analysed	Duration
Rampion OWF AWAC L1	50.68	0.33	01/11/2010 to 07/01/2011	65 days
Rampion OWF AWAC L2	50.68	0.15	01/11/2010 to 18/02/2010 except (21/12/2010 to 08/01/2011)	90 days
Rampion OWF AWAC L3	50.63	0.22	15/12/2010 to 10/05/2011	144 days
Rustington Directional Wave Buoy (CCO)	50.73	0.50	09/07/2003 to 31/12/2010	~8 years
Seastates (modelled data)	-	-	1999 to 2011	~13 years

3.5.2 Near-Field Wave Regime

The AWAC deployments provide the near-field description of waves within the OWF. These are used to characterise the short-term (less than 1 year) near-field wave climate at the application site as the observations only cover a two to four month time period.

The properties and validity of the metocean survey data outputs for currents were assessed prior to application in this baseline assessment, and are presented in ABPmer (2011a; 2011b). The assessments identified potential concerns with some of the wave data obtained from L3 during deployment one (01/11/2010-15/12/2010). The concerns related to the fact that exceptionally high wave heights were observed which were in turn associated with short wave periods. This is despite the deeper bathymetric depths that occur at the L3 survey location. For this reason, the data under question was removed from further analysis and is therefore not included in this baseline study.

Table 16. Summary of frequency analysis of observational wave records

Buoy/ Deployment	Dates of Deployment	Most Frequent Wave Direction and Percentage of Record	Most Frequent Wave Height and Percentage of Record	Maximum Observed Significant Wave Height and Associated Direction Sector	Most Frequent Mean Wave period and Percentage of Record	Peak Observed mean Wave Period and Associated Direction Sector
Rampion OWF AWAC L1	01/11/2010 to 07/01/2011	SW (39%)	0.5-1 m (49%)	3.75 m (S)	3-4 seconds (43%)	7.1 seconds (SW)
Rampion OWF AWAC L2	01/11/2010 to 18/02/2010	SW (32%)	0.5-1 m (53%)	4.08 m (SSW)	4-5 seconds (46%)	7.3 seconds (SW)
Rampion OWF AWAC L3	15/12/2010 to 10/05/2011	WSW (30%)	0.5-1 m (48%)	3.26 m (SW)	3-4 seconds (47%)	6.7 seconds (SW)
Rampion OWF AWAC L3	15/12/2010 to 10/05/2011	WSW (30%)	0.5-1 m (48%)	3.26 m (SW)	3-4 seconds (47%)	6.7 seconds (SW)
Rustington wave buoy (CCO)	01/11/2010 to 30/12/2010	SW (34%)	0.5-1 m (40%)	3.86 m (S)	3-4 seconds (37%)	7.8 seconds (SW)
Long term regime						
Rustington wave buoy (CCO)	09/07/2003 to 31/12/2010	SW (41%)	0.5-1 m (37%)	4.81 m (SSW)	3-4 seconds (46%)	10 seconds (SE, S, SW)
Seastates model output (offshore location)	01/01/2000 to 31/12/2009	WSW (39%)	0.5-1 m (36%)	5.61 m (SSW)	3-4 seconds (41%)	11 seconds (SW, WSW)
Percentages are rounded to integers						

A frequency analysis of wave heights and direction based on the observed wave conditions within the OWF area is presented as a series of wave roses in Figure 9 and summarised in Table 16. From these sources it is evident that:

- In the north of the application site at L1 and L2, the most frequent wave direction is from the southwest, with waves originating from this sector between 30% to 40% of the time;
- At the same locations wave heights of up to 4 m occur, although the most frequent wave heights are between 0.5 m to 1 m accounting for approximately 50% of all waves;
- In the south of the application site at L3, the dominants wave directions are from the west-southwest to southwest, with wave originating from these directions approximately 30% of the time at both sites;
- Again at this location, wave heights of up to 4 m occur, although the most frequent wave heights are between 0.5 m to 1 m accounting for approximately 50% of all waves;
- The largest significant wave height observed during the metocean survey was encountered at location L2 and was approximately 4.1 m. The larger waves observed during the survey period all approached from either the southwest or south-southwest; and

- The dominant wave direction and larger waves conform to the dominant swell direction of approaching waves into the English Channel.

A similar analysis was undertaken to define the relationship between the most frequent mean wave period and significant wave height, these wave statistics are shown in Table 16. In summary the frequency analysis shows:

- The most frequent mean wave periods are between 3 and 4 seconds, accounting for between approximately 43 and 47% of the records. These short wave-periods are indicative of wind waves and strongly suggest that the wave regime across the application site is dominated by waves of this type;
- Peak-mean wave-periods are approximately 7 seconds. These longer period waves typically approach from the southwest and although are longer are typically still within the range of wind waves and not necessarily characteristic of swell waves; and
- The OWF application site is therefore predominantly influenced by wind waves as these are the dominant occurrences, even with the event of longer period wind waves.

3.5.3 Far- Field Wave Regime

The wave records that are used to characterise the far-field wave regime are the Rustington (CCO) wave buoy and model outputs from the Seastates model for the offshore location. Analysis of wave properties for approximately the same period captured during the metocean survey is presented as a series of wave roses in Figure 9 and also summarised in Table 16. In addition, the full available dataset from these records are also evaluated to investigate long term regimes within the far-field extents (Figure 10). The results for the longer term assessment are also included in Table 16.

The longest assessed record is from the CCO Rustington Datawell Directional Waverider Buoy Mk III located approximately 11 km to the northeast of the application site, which was analysed for the period between July 2003 and December 2010 (Figure 10). The results show that the most frequent wave direction is from the southwest to south-southwest, which accounts for approximately 60% of the record. This is largely consistent with the metocean observations collected from locations L1, L2 and L3, despite the differing length of the records. The largest wave height observed in the ~8-year record at this site was 4.81 m which approached from the south-southwest.

Across the far-field region and into the application site, wave heights generally increase as they propagate to the coastline. This is in line with shoaling effects where the depths change from 49 m (CD) at L3 to 25 m (CD) at L1 and L2 and 10 m (CD) at the Rustington site, which is represented by increasing wave heights towards L1, L2 and the Rustington wave buoy (Figure 9 and Figure 10). Another spatial behaviour is the change in the direction of approaching waves between the site located further offshore (i.e. L3). At this location, waves predominantly approach from west-southwest to southwest, this together account for 60% of the record, with equal proportions from each segment. At the sites further onshore, the dominant wave direction is from the southwest, with at least 30% of the record for the different sites. This is again in line with the refraction of waves as they approach shallow water due to depth-limiting effects.

The analyses of the data within the OWF application site suggest the predominant occurrence of a wind wave regime. However, ongoing observations from the Rustington buoy confirm the occurrence of swell waves with peak periods of up to 10 seconds (Bovington & Amos, 2010). Therefore, there is the potential for swell waves in relation to storm events to exert an influence on the hydrodynamic and morphodynamic properties within the site due to the larger energy and forces.

A summary of the return period wave conditions for locations onshore and offshore from the OWF application site is provided in Table 12. A difference is observed between the two locations, where marginally larger wave heights and zero-crossing wave period are estimated for the same offshore location at the same return period. For example the significant wave height associated with the 2-year return period at the nearshore location is 4.18 m, compared with 5.41 m at the offshore location. The same pattern in observed for all the return periods.

3.5.4 Future Changes to the Baseline

There is evidence to suggest that longer-term changes in storminess have taken place across northwest Europe (e.g. Alexandersson *et al*., 2000). These changes may be related to long-term changes in the strength of the North Atlantic Oscillation (NAO), a hemispheric meridional oscillation in atmospheric mass with centres of action near Iceland and over the subtropical Atlantic (Visbeck *et al*., 2001). Longer-term trends in storminess across north and north-western Europe are summarised in Figure 11 (Matulla *et al*., 2007). Storminess was relatively high during the late 19th and early 20th century, followed by a decrease up until about 1970. A subsequent rise in the late 20th century can be clearly identified although most recent years have seen a decline in storminess (Figure 11). These findings are broadly consistent with published investigations into 21st century wave climate changes which are applicable to the English Channel (HSE, 2001; 2005; McMillan *et al*., 2011b).

Modelling as part of UKCIP (Lowe *et al*., 2009) currently gives the most up-to-date projection of the likely future wave climate. Changes in climate over the 21st century may include changes in mean wind speed and direction which will in turn affect the wave regime. The UKCIP indicates that in the English Channel in the vicinity of the study area, mean annual maxima significant wave heights between 1960 and 1990 and 2070 and 2100 will increase by 0.5 to 1 m.

4. Sediment Regime

4.1 Overview

The seabed within the study area is characterised by a relatively shallow and gently sloping seabed interspersed with deeper infilled, partially-infilled and unfilled palaeochannels and palaeovalleys cut into the solid geology. These are infilled to varying thicknesses with alluvium characteristic of a historic fluvial source. Sediment availability on the seabed away from the palaeochannels and palaeovalleys is sparse, with relatively thin sediment cover (BGS, 1989; 1990; 1995).

Previous understanding of regional scale sediment transport pathways is obtained from work completed by Kenyon (1970) and Stride (1982). These show that the dominant transport paths through the English Channel are predominantly governed by tidal conditions (Figure 12). A bedload parting or divergence exist between the Isle of Wight and the Conetentin Peninsula in France and a convergence zone occurs further east off Dungeness, extending to the French coast (Grochowski *et al.*, 1993b).

In the vicinity of the OWF application site and the associated far-field region the dominant transport pathway is eastwards (Figure 12). This direction relates to the dominant flood residual observed and discussed in Section 3.3.2. At a local level, differences occur in the dominant hydrodynamic forcing factor along with the available sediment. This brings about a difference in the sediment regime at the coast and offshore locations. It is therefore on this basis an assessment of the sediment regime is discussed.

The sediment regime and geological properties within the OWF application site and far-field region has been considered in the following sections:

- The composition and distribution of seabed sediments across the application site and the wider far-field study area;
- The composition of the sub-strata across the application site and the wider far-field study area;
- Sediment transport pathways in the vicinity of the application site in the form of a conceptual understanding of the sediment regime; and
- The key process controls on sediment mobility and thresholds of sediment motion.

4.1.1 Nearshore Regime

At the coastline of sub-cell 4d, there is an eastward net longshore transport pathway from Pagham Harbour towards Shoreham-by-Sea and on to Beachy Head (Figure 12). This is evident from the up-drift accumulations of sediment in between groynes along the sub-cell frontage. Therefore in the nearshore environment, particularly at the coastline, the movement is primarily wave induced as the tidal currents are not sufficient to move shingle sized sediment (SCOPAC, 2004). Observations from coastline studies identify that transport rates are spatially variable in relation to available energy and sediment availability and sinks. Higher transport rates are observed to the west in line with the incident wave approach and the annual average spring peak currents (Figure 4). In addition to the net longshore drift, there is also a small onshore feed of shingle in relation to wave conditions, which has been identified from field studies (SCOPAC, 2004). However this can not be a continuous feed, as the assessment of the wave conditions in Section 3.5 shows that waves with enough energy to disturb the seabed occur only 20% of the time.

No large scale bedforms are observed in relation to the coastline or nearshore zone, which is taken to be the seabed up to the wave closure depth.

4.1.2 Offshore Regime

The presence of large scale bedform features varies from the central to Eastern English Channel. The common presence of longitudinal gravel furrows and areas of gravel and sand waves in the central part of the channel, west and south of the Isle of Wight reduce towards the eastern regions. In the eastern part of the channel, large areas of the seabed are observed to have little sediment cover, with the occurrence of sand ribbons and patches (Figure 13). The thickness of sediment cover then increases further eastwards with the more frequent occurrence of sand waves and megaripples. Models of maximum bed stress presented in UKSeaMap for the English Channel show that the bed shear stress varies across the channel. In the central region, south of the Isle of Wight high values for the bed shear stress are observed which reduce to moderate levels towards the western extents and in the eastern extents of the channel (Conner *et al*., 2006).

As previously mentioned, a major bedload parting zone exists, extending across the English Channel from the Isle of Wight to the Cotentin Peninsula in northern France. To the west of the bedload parting, offshore sediments are moved westwards and east of the parting, sediments move eastwards (Figure 12). Net sediment transport through the far-field study area is eastwards to north-eastwards, with localised variation in relation to the occurrence of sand banks (Kenyon & Cooper, 2005). At the coastline, the littoral drift direction is also towards the east with a progressive reduction in transport rates for a mean grain size of 200 μm as water depths increase (SCOPAC, 2004). The sediment distribution through the region is predominantly of sand size and above with large patchy gravel areas. The predominance of the coarser sediments, in addition to the relative absence of fines, suggests a strong tidal regime, whereby the residual tidal current is the main transport mechanism for sand size grains through the region, with contribution from waves in maintaining the movement of suspended sediments. Supplies of new sedimentary material from the land are mainly through the Rivers Arun, Adur and Ouse, while waves cause the onshore transport of shingle (SCOPAC, 2004).

4.2 Sources of Sediment and Geological Data

Key sediment and geological data for the application site is available from several sources which are summarised in Table 17, some of which are also illustrated in Figure 3:

Table 17. Sediment and geological data available from the study area

Data Source	Reference
Rampion application site benthic particle size analysis grab survey	EMU (2011)
Rampion application site geophysical survey	Osiris Project (2010a; 2010b; 2010c)
BGS seabed sediment maps	BGS (1988; 1989; 1990; 1995)
MALSF Central and Eastern English Channel synthesis	James *et al*., (2011)
MALSF South Coast REC	James *et al*., (2010)
MALSF Eastern English Channel Marine Habitat Map	James *et al*., (2007)
Geology of the English Channel	Hamblin *et al*., (1992)
SCOPAC Sediment Transport Study	SCOPAC (2004)
South Coast MAREA Sediment Transport Study	HR Wallingford (2010)
South Coast Seabed Mobility Study	HR Wallingford (1993)

4.3 Seabed Sediments: Composition and Distribution

The present day English Channel has a diversity of physical and geological features (Figure 14). The geomorphology of the English Channel in particular is characterised by the presence of a network of drowned palaeovalleys and channels formed within the last 10,000 years during the Holocene transgression (Velegrakis *et al.*, 1999; Velegrakis, 2000; Gupta *et al.*, 2007; *Paphitis et al.*, 2010). These in turn contribute to the two characteristically different types of deposits that occur within the region (Velegrakis *et al.*, 1999; Velegrakis, 2000). The modern sediments are controlled by the present hydrodynamic regime and form a thin veneer of sediment over areas of exposed bedrock. The older sediments are those that make up the palaeovalley and channel infill, which are considered to have been deposited under completely different hydrodynamic conditions. The modern sediments are respectively finer compared to the infill deposits, whereas the infill deposits relate to the fluvial characteristic of the palaeo-environment prior to submergence and are therefore coarser. The thickest deposits, up to 90 m, are also located within palaeovalleys and channels (BGS, 1989; 1990).

Based on the Folk (1954) classification, the sediments that occur in this region are composed of muddy sandy Gravel (msG), sandy Gravel (sG), gravely Sand (gS), slightly gravely Sand ((g)S), gravely muddy Sand (gmS) and sandy muddy Gravel (smG) as identified from BGS (1989; 1990). Gradistat analyses (Blott and Pye, 2001) of the grab samples obtained by EMU (2011), identified muddy sandy Gravel (msG), gravely muddy Sand (gmS), gravely Sand (gS), slightly gravely Sand ((g)S) and sandy Gravel (sG). The surveyed grab sample data is presented in Figure 15, overlying the BGS Wight and Dungeness – Boulogne seabed sediment maps BGS (1989; 1990). Geophysical data obtained by the site specific surveys completed by Osiris has also been used to infer the nature of the seabed across the application site and is shown in Figure 15.

According to grab samples (Figure 15) and seabed type maps from BGS the application site can be expected to be dominated by gravelly sand (gS) and slightly gravelly sand ((g)S). This is agreement with the benthic grab samples obtained within the OWF application site. Twenty-four of the 52 grab samples are from within the application site of which 38% (9 out of 24) comprise slightly gravelly sand and 25% (6 out of 24) are gravelly sand. Evaluating the full dataset of sediment grab samples obtained from within and in close vicinity to the application site, the dominant sediment is sandy gravel with 33% (17 out of 52). If this is compared directly with the BGS sediment data for the same extents, the dominant sediment is gravelly sand. The majority of the samples collected from the application site were found to have a bimodal grain size distribution, with sand and gravel as the modal sediment. In addition over 80% of the samples were poorly to very poorly sorted.

Dominant modal particle sizes are variable across the application site, ranging from 38,500 µm (pebble gravel) to 152.5 µm (fine sand). However, almost every sample contained a modal peak at approximately 302 µm (medium sand), indicating that this is the most common sediment type in this area. Detrital carbonate sediments, (which comprise mainly of shell fragments) in the benthic grab samples are commonly less than 10%, therefore these make only a small contribution to the sediment deposits (EMU, 2010). In terms of the modern Holocene sediments, there is considered to be a fining trend from the coast through to the offshore environment in the Eastern English Channel. The coastline is noted as being made up of shingle and gravel sized material, which reduce to sands further offshore (SCOPAC, 2004; Paphitis *et al*., 2010). Scatter plots investigating the association between sediment size and depth, did not show any correlation within the far-field region (Figure 16). This is considered to relate to the known diversity of sediment deposits in relation to present and past hydrodynamic regimes as the PSA results suggest that both modern sediments and infill deposits have been collected. Instead the scatter plots confirm that within the context of the OWF application site depths of up to 20 m (CD) are dominated by fine sand (215 µm) and with increasing depth up to 60 m (CD), medium sand (302 µm) becomes more dominant. Finally the occurrence of gravel deposits is not necessarily depth dependent, but more the spatial location of the deposit. This is because gravel size material is noted across all depths (Figure 16).

Side scan sonar evidence was collected for the proposed cable corridor and the northern half of the OWF application site. The discrete grab sample data obtained was used in conjunction with an interpretation of the side scan sonar evidence to infer the distribution of the sediment deposits across the site. This showed that the dominant sediment types are typically gravelly sand with bedforms, interspersed with areas of sandy gravel and slightly gravelly sand (Figure 15). The interpreted deposits are broadly arranged into east-northeast to west-southwest orientations, which is predominantly in line with the morphology and orientation of the palaeochannels through the study site. Based on the interpreted distribution of seabed sediments, gravel areas primarily occur along the same orientation as described above, in the north and central part of the OWF application site. However, using the grab sample data, gravel is mainly observed in the samples that are obtained beyond the extent of the application site (Figure 15).

The BGS was recently commissioned by Defra to produce a digital data layer (map) of the distribution of hard substrate at, or near (~ <0.5 m), the seabed surface across all areas of the United Kingdom Continental Shelf (UKCS) (Gafeira *et al*., 2010). The map indicates that the majority of the OWF application site, particularly for the locations outside of the palaeovalleys and channels, is characterised by a hard seabed substrate. Across much of this area the surficial sediments are noted as being <0.5 m, which agrees with previous published work discussed above.

4.4 Sediment Sub-Strata: Composition and Distribution

The discussion on the composition and distribution of the sub-strata and solid geology across the study area is based primarily on the interpretations from geophysical survey completed by Osiris (2010a; 2010b; 2010c). Due to the presence of a complex network of palaeochannels within the near-field area, the sediment thickness varies across the site for the same deposit (Figure 14). Therefore the discussion focuses around the occurrence of the geological features and the associated deposits in relation to the features.

The solid geology across the study area comprises of Cretaceous and Tertiary deposits. The Cretaceous deposits comprise older Upper Cretaceous Chalk beds with bands of flints. The Tertiary deposits include sand, gravels and clays with occasional limestone bands (for the younger Eocene and Palaeocene deposits). The Tertiary sequences sub-crop beneath seabed sediments within the study area at varying depths. This occurs along the proposed cable corridor window and the northern extent of the OWF application site. Sub-bottom measurements across these areas indicate that bedrock is present within 2.0 m of the seabed (Osiris, 2010b; 2010c). There is no geotechnical data identifying the outcrop of the chalk deposits, although the BGS (1989; 1990) indicate that such bedrock is present in the eastern extents of the application site.

A number of geological features cross the OWF application site, which relate to the palaeochannel and palaeovalley systems (Figure 17). Of significance is a distinctive 10 m to 14 m high escarpment which crosses the site, where the top escarpment occurs at approximately 30 m (CD) and the base lies between 42 m and 46 m (CD). This feature is also demonstrated in the surveyed bathymetry for the OWF application site (Figure 18). Four approximately north to south running large palaeochannels with widths between 350 m and 2 km wide and depths of up to 34 m are observed within the application site. Two of these also run through the proposed cable corridor. The palaeochannels within the application site primarily occur to the north of the escarpment, with the outcrops of bedrock also occurring in the areas between these palaeochannels, although southern extensions of the palaeochannels are also observed south of the escarpment (Figure 17). The central channel is interpreted to be the Palaeoarun system, and is the offshore extension of the contemporary Arun River (Paphitis, 2010; Gupta *et al*, 2004; Antoine *et al.*, 2003). The other palaeochannels are then considered to relate to the contemporary Adur, Ouse and Cuckmere Rivers which drain southwards along a similar axis to the palaeochannels (Antoine *et al.*, 2003). The observed palaeochannels are considered to be infilled with varying sediment types ranging from soft silty clays to silts, sands, gravels and localised peat deposits. Acoustic blanking is present within large sections of the palaeochannels, also suggesting the presence of biogenic gas associated with organic materials. Other geological features present north of the escarpment include buried channel features which are much narrower and shallower than the previously described palaeochannels (Osiris 2010b).

The area south of the escarpment is observed to have greater thicknesses of Holocene sediment, varying between 2 m and up to 36 m thick. In addition to the north to south running palaeochannels, there is also a deep buried channel running perpendicular to the palaeochannels described above. This deep buried channel feature extends through the central region of the application area. The occurrence of this buried channel is at 20 m sediment thickness depth (or isopachyte) and is infilled by up to 36 m of sands and gravels. Therefore the feature is considered to be a branch of the Northern Palaeovalley that transects the English Channel south of the OWF application site (Osiris 2010b).

4.5 Conceptual Understanding of the Sediment Regime

Factors that significantly control the sediment regime within the far-field study area are the sediment sources for transport and deposition and the hydrodynamic conditions. Sediment sources dictate the type and volume of sediment available and the mechanism required for transport.

The two primary mechanisms of sediment transport within the OWF application area and wider far-field region are:

- **Bed-load transport.** This mechanism refers to all sedimentary grains that move, roll or bounce (saltation) along the seabed as they are transported by currents, waves or the combination of both factors. This mode of transport is principally related to coarser material (sands and gravels); and
- **Suspended-load transport.** This mechanism refers to particles of sediment that are carried above the seabed within the water column.

These two mechanisms of transport can be variably controlled or dominated by different processes (e.g. currents, waves or some combination of the two), which can also vary spatially in relation to conditions at the coastline and offshore contexts. The sediment transport regime within the application site and across the far-field region varies from the coastline to offshore locations. This is due to the dominant hydrodynamic forcing conditions across the two environments. The differences between the contexts are important for understanding the relationship between the proposed OWF and receptors as the coastline. For this reason the evaluation of the sediment transport regime is discussed in terms of the coastline and offshore conditions.

4.5.1 Nearshore Sediment Transport

Along the coastline, there is a dominant west to east net drift. Locally, existing broad-scale mapping suggests gravels, sandy gravels and sand are the expected dominant sediments that make up the seabed at the coast. The coastline along this frontage is also defended with a series of hard structures, which results in the observable sediment accumulation updrift of the structures.

The drift direction at the coastline is predominantly influenced by the wave conditions, which originates from the west-southwest to southwest (Figure 10). This is because the tidal currents are generally not strong enough to move gravels observed at the coastline. Although, there is the recognition that current flow speeds increase towards the Dover Straits in the eastern extents of the English Channel (HR Wallingford, 2003). Sediment is transported at the coastline primarily as bedload transport in relation to the wave conditions. Studies by SCOPAC (2004) indicate an onshore and littoral drift of shingle due to waves and wave-assisted kelp rafting. Although there is the potential for suspended sediment transport, this has not been quantified as the dominant sediment is coarser sand and shingle which would need much more energetic tidal conditions to keep such sediments in suspension.

Within the shoreward far-field region, the sediment transport rates are seen to be variable in relation to the amount of energy and sediment available and the presence of barriers to flow, such as groynes or harbour sinks (SCOPAC, 2004). No large scale bedform features are observed at the coastline, although there is the known abundance of shingle for transport.

4.5.2 Offshore Sediment Transport

The known transport pathways through the far-field study region are primarily to the east and east northeast in relation to the tidal currents (Paphitis *et al*., 2010; Barne *et al*., 1998; Tappin *et al.,* 2007; Brampton *et al*., 1998). This is also confirmed through numerical modelling (HR Wallingford, 1993; 2010; Grochowski *et al*, 1993a; 1993b) and field studies (SCOPAC 2004).

The tide dominance leads to the formation of well-sorted distributions and tide-dominant bedform features. This includes sand banks and areas of sand and gravel waves and megaripples (Figure 13) as identified by BGS (1989; 1990) and outputs from the South Coast Regional Environmental Characterisation (James *et al.*, 2010). Geophysical survey completed by Osiris (2010b; 2010c) also identifies large areas of sand waves and megaripples, where the crests are aligned to the northeast, thereby indicating a transport pathway in this direction (Figure 19). The dominance of tidal activity and the availability of finer sand and silt sediments do suggest that the dominant transport mechanism in the offshore region is through suspended sediment transport. However, the presence of bedforms and the described asymmetry also confirms the occurrence of bedload transport (Stride, 1982; Belderson, *et al*., 1982; Kenyon & Cooper, 2005) within the OWF application site and the far field region. Therefore the properties and evidence for these two modes of transport are discussed further below.

A review of sediment composition from the OWF application site confirms sediment is available locally for transport, although this is recognized to be a thin veneer.

Suspended load transport

The level of suspended sediment concentration (SSC) is used as an indication of suspended sediment transport. Regional scale assessments of SSC has been carried out by Eggleton *et al*., (2011) using satellite remotely sensed images calibrated against six SmartBuoys around the UK. These were used to create a suspended particulate matter map for the UK continental shelf. The assessment carried out by Eggleton *et al*., (2011) measured turbidity near the surface of the water column, which differs from the metocean study that derives measures near the seabed. Therefore whilst the values are not directly comparable, they can still be used to discuss the relative abundance of suspended sediment transport within the study area. Values taken from the turbidity map show the SSC values to range between 5 to 10 mg/l during winter months and generally <3 mg/l during the summer period. This is broadly consistent with the findings described from the project specific survey, which were predominantly through the winter months as presented below.

Within the OWF application area, the level of SSC has been calculated from Optical Backscatter Sensors (OBS) and Acoustic Backscatter Sensor (ABS) deployed as part of the metocean survey. Only the values from the OBS measures are discussed as these are provided as a single value representative at a single depth in the water column (EMU, 2011). The OBS unit was mounted on a frame 0.5 m above the seabed and recorded water turbidity by measuring the backscatter intensity from a pulse of light emitted into the adjacent water. The raw units of turbidity measurement were calibrated to a suspended sediment concentration in a laboratory using artificial suspensions of the locally present sediments. The procedures used are described in EMU (2011), it is relevant to note that the resulting SSC measures are outputs of regression functions based on data obtained across the UK and are not site specific. These therefore have associated confidence limits but are not available at the time of writing.

The resulting SSC values are indicative of the concentrations approximately 0.5 m above the seabed and the sediment being transported under suspended load. The values are not considered to be representative of bedload transport that may also exist within the study region. A subset of measurements between 18/11/10 and 20/12/10 are presented in Figure 20 and Figure 21 for locations L1 and L2 respectively. Wave data is not available for the same period at L3, as described in Section 3.5.2. Therefore measurements between 07/01/11 and 06/02/11 are used for this location. Hydrodynamic data collected during the same time interval are also shown to demonstrate the relationship between the forces potentially driving sediment resuspension and the resulting SSC. This is used to provide an insight into the relationship between tidal state, event occurrences and sediment movement within the application site.

Table 18, which sets out the percentage of turbidity observations within 5 mg/l bands shows that SSC turbidity values generally remains low across the application site. Values of 5 to 10 mg/l are commonly observed across the three metocean survey locations, although values exceeding 10 mg/l also frequently occur. The shallower sites at L1 and L2 generally have lower turbidity measurement values in comparison to the offshore site at L3, which has a lower percentage up to 20 mg/l, with more infrequent occurrences of high turbidity measures (Table 18).

Table 18. OBS estimated suspended sediment concentrations approximately 0.5 m above the seabed

Turbidity (mg/l)	L1 (%)	L2 (%)	L3 (%)
0-5	9.24	27.26	14.23
5-10	62.48	50.48	35.30
10-15	24.43	13.31	15.57
15-20	2.36	3.88	4.76
20-25	0.76	1.83	2.88
25-30	0.31	0.98	3.29
30-35	0.18	0.76	3.86
35-40	0.14	0.72	3.84
40-45	0.04	0.38	2.88
45-50	0.07	0.35	2.86
50-55	-	0.03	2.23
55-60	-	0.01	1.53
60-65	-	0.01	1.01
65-70	-	-	0.66
70-75	-	-	0.68
75-80	-	-	1.00
80-85	-	-	1.21
85-90	-	-	0.71
90-95	-	-	0.82

The significance of the above results is considered to relate to the dominant forcing factor at the sites and the sediment availability as described in Section 4.3. Across all three sites, there is a general temporal trend whereby fluctuation in current flow speeds with respect to the spring-neap cycles correspond with similar variation in SSC, (Figure 20, Figure 21 and Figure 22). This is particularly the case for location L3, where for example spring-neap variations in flow speeds as well as the flood and ebb variability of the tide are represented in the SSC values (Figure 22). The close agreement with current speeds observed at L3 is not repeated at the shallower locations L1 and L2. At these sites, there is agreement between the SSC and the spring-neap cycles as described for L3. However at shorter time scales, particularly in relation to storm events there is a divergence from this pattern. This would suggest that other factors contribute to the sediment concentration values although the tides are the dominant mechanism. A comparison of the SSC observations with wave conditions (with the aim of including the occurrence of storm events) was also completed. The results presented in Figure 20, Figure 21 and Figure 22 for L1, L2 and L3 respectively also show that the SSC is significantly increased during periods of increased wave activity, particularly at locations L1 and L2. This is illustrated for L1 and L2 for the period between 04/12/10 and 08/12/10 which is during the spring tidal flows. Prior to this period, SSC values between 5 to 15 mg/l are observed, with an increase in wave heights in excess of 3 m, the SSC increases to between 30 to 35 mg/l (Figure 20). Following the peak associated with the storm event, SSC gradually decreases (as the sediment settles out of suspension) to the baseline condition which is controlled by the ambient regional tidal regime. This is also repeated at location L2 for the same event (Figure 21). A similar behaviour observed particularly during neap flow conditions and the turning tide is also explained by the wave characteristics at the sites.

The response of the SSC levels to changing wave conditions is not repeated to the same magnitude at L3. At this site two wave events with significant wave heights in excess of 3 m occur between 07/01/11 and 15/01/11. However these are not seen to change the SSC levels beyond the influence of the tidal regime (Figure 22). The analyses confirm that tidal currents with a small contribution from wave conditions are the major influence on the net movement of seabed sediments in the shallower locations at L1 and L2. Whereas at deeper sites represented by location L3, only tidal conditions are the dominant factor.

Due to the seasonal nature of the frequency and intensity of storm events, levels of SSC will likely follow a broadly seasonal pattern with higher values observed more frequently during late spring, winter and early autumn months. It is also possible that seasonal blooms of marine plankton may also contribute to apparent seasonality in measurements of total turbidity, but this is not directly associated with the resuspension of (inorganic) sediments.

Bedload transport

The evidence for bedload transport is primarily the presence of bedforms within the OWF application site and the far field region and in the asymmetry of the features. The features are aligned in relation to tidal flow conditions indicating that these are active features that are still evolving in relation to the tidal currents.

4.6 Process Controls on Sediment Mobility

An assessment has been made of sediment mobility within (and nearby to) the application site by identifying the modal sizes of available sediments (from the grab sample data) and calculating the bed shear stresses required to initiate transport (using standard methods described in Soulsby, 1997). The potential for mobility due to currents and waves is calculated based on the time series current and wave observations from the AWAC site surveys as introduced in Section 3.3.1and Section 3.5.1 respectively.

Table 19 provides a summary of the modal grain size classes used for the analysis of sediment mobility, their frequency of occurrence and critical shear stress values for transport.

Table 19. Summary of the main sediment types within (and nearby to) the application site including associated theoretical bed shear stress thresholds for mobility

Common Modal Size (μm)	Size Class (Wentworth)	Number of Occurrences in 52 Samples	Threshold Bed Shear Stress for Mobility (N/m²)
> 38500	Pebble gravel	0	33.49
6000 - 38500	Granule gravel	4	4.92
3000 - 6000	Very coarse sand	3	2.02
750 - 3000	Coarse sand	1	0.35
302.5 - 750	Medium sand	19	0.20
187.5 - 302.5	Fine sand	22	0.17
47.5 - 187.5	Very fine sand	3	0.10

4.6.1 Potential Mobility Due to Tidal Currents

The regional tidal current regime has been described in more detail in Section 3.3. Here, tidal current time series from the three metocean survey locations are used to assess the potential for local sediment transport. These have been used to calculate an equivalent bed shear stress time-series (due to currents only) using all available data from each location (Figure 3).

The calculated bed shear stress values are plotted in Figure 23 and compared to the threshold values for mobility of the sediment grain sizes listed in Table 19. Figure 23 shows that mobilisation events (when the critical bed shear stress values are exceeded) occur frequently for grain sizes up to course sand through most states of the tide. The proportion of the time series during which each sediment fraction is potentially mobilised is examined further in Table 20. The assessment of current properties (see Section 3.3.2) identified that current speeds in excess of 1 m/s are observed on the spring tide, and typically half of spring conditions on the neap tides. However, there is also the potential for the occurrence of current speeds between 1.5 to 2 m/s, in relation to the 2-year to 50-year return period wave conditions. Therefore there is a strong potential for the mobilisation of sediment grains that would not ordinarily be disturbed under normal tidal conditions, as demonstrated below.

It is apparent from Table 20 that tidal currents provide a great potential for mobilising sediments across the application site, with sufficient strength to mobilise up to medium sand (302.5 μm) at nearly all states of the tide. Coarse sand (750 μm) sediments are also mobilised although this is limited to peak spring conditions only. There is an overall dominance towards spring conditions, where sediment is always mobilised. These predictions of spatial and temporal variations in sediment mobility are considered further in Section 5.4 and have been used to enhance the conceptual understanding of the seabed morphology across the application site.

Table 20. Estimated potential sediment mobility (due to tidal currents only) at four locations across the application site

Location (Depth and Bed Sediment Size)		Sediment Fraction						
		Coarse Silt (47.5µm)	Fine Sand (187.5µm)	Medium Sand (302.5µm)	Coarse Sand (750 µm)	Very Coarse Sand (3000 µm)	Granule Gravel (6000 µm)	Pebble Gravel (38500 µm)
L1 (28 m (CD); d50 bed of 284.6µm)	Mobility Summary	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile during all states of spring tides	Not mobile	Not mobile	Not mobile
	Mobility % time	59%	43%	37%	13%	0%	0%	0%
L2 (24 m (CD); d50 bed of 257.6µm)	Mobility Summary	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile only during peak spring tides	Not mobile	Not mobile	Not mobile
	Mobility % time	47%	29%	22%	7%	0%	0%	0%
L3 (45 m (CD); d50 bed of 338.2µm)	Mobility Summary	Mobile at nearly all states of the tide, except at the lowest neaps	Mobile during spring tides and peak neap conditions	Mobile during spring tides and peak neap conditions	Mobile during all states of spring tides	Not mobile	Not mobile	Not mobile
	Mobility % time	59%	43%	37%	16%	0%	0%	0%

It is important to note that the calculated bed shear stress is sensitive to the 'roughness' of the seabed with coarser grained and/or more rippled surfaces inducing greater flow turbulence and hence bed shear stress than a fine grained and/or flat surface for the same flow speed. It is for this reason that a slightly larger mobility percentage time is observed for coarse sand sediment size at L3 (Table 20), despite the deeper depths. This is in addition to the higher current flow speeds that also occur at the location (Figure 6). In terms of both grain size and the potential for the development of megaripple and sand wave bedforms, there is known to be variability within the application site (Figure 13, Figure 15 and Figure 19). This variation might result in a high degree of spatial variability in the inferred bed shear stress across the application site. Therefore, for the purposes of the present study, the seabed is assumed to be flat at the scale of a few meters (i.e. without very small bedforms).

Figure 23 provides information on the duration of exceedance of various mobilisation thresholds, however, it is important to note that these episodes of exceedance may not be of equal duration on both the ebb and flood tide. Indeed, any asymmetry in the tide (both in terms of the duration of the ebb and flood and the magnitude of peak flows) will result in variations in the direction of sediment transport for different sized sediment particles. Relating the potential for sediment mobility with the identified current properties described for the study region (Section 3.3.2), it is likely that there is predominant sediment mobility under spring flood conditions. This is because there are marginally larger current speeds and with an associated residual under the spring flood flow.

To investigate the effect of asymmetry further, progressive vector analyses have been undertaken using current data obtained from the three metocean survey locations. Spatial variation in residual flow and residual sediment displacement patterns over a 14-day spring-neap tidal cycle is used. This is applied with a coarse silt sediment size, which is seen to be mobile for long periods of time. The evaluated progressive vector is shown in Figure 24. The residual sediment displacement (the net advective pathway), which illustrates the net transport pathway driven by current, when speeds are above the threshold for sediment mobility is also estimated and illustrated in Figure 24. The absolute magnitude of residual sediment displacement can not be directly applied as an indicator of sediment transport volume. Instead it serves to describe the proportion of time sediment would be mobilised for transport and in which direction. Over the assessed 14-day period, the threshold for mobility is frequently exceeded (as shown in Figure 24). The net direction can be used together with the relative magnitude to draw a qualitative comparison between the different sites.

Residual tidal flow is broadly towards the northeast to east-northeast across the site, based on the values from the metocean survey. This means that finer material held in suspension will generally be transported east-northeast, which follows the path of the deep palaeovalley through the application site. The observed residual direction and east-northeast trend in predicted sediment displacement is consistent with published information on the direction of net sediment transport in this region (e.g. Figure 12). This pattern can be readily explained as a result of the relatively higher peak flood current speeds, which lead to a longer net duration of eastward flowing currents (see Section 3.3.2).

4.6.2 Potential Mobility Due to Waves

The regional wave climate has been discussed in more detail in Section 3.5. Significant wave heights are generally less than 4 m across the site as represented through the approximately 6-month metocean survey period. Present understanding of wave-dominant transport is considered to differ between the nearshore and offshore environments (see Section 4.5). Secondary information indicates that the dominant transport mechanism in the nearshore is due to waves, with tidal dominance in the offshore environment (HR Wallingford, 2003; SCOPAC, 2004). Therefore within the OWF application site there is considered to be an existing but limited influence from waves, represented through the SSC measures (see Section 4.5.2).

The spatial variations in sediment mobility due to waves only across the application site is summarised in Table 21. In comparison to tidal currents, the near bed orbital current velocities associated with the observed are not enough to cause significantly higher bed shear stresses and therefore sediment mobility. This is demonstrated through the proportion of sediment moved, whereby generally sediment would only be mobilised only 1 % of the time due to the influence of waves only. Also only coarse silt would be mobilised compared with tidal conditions that mobilised coarse sand for over 10 % of the observation period.

A representation of the bed shear stress in relation to waves is set out in Figure 23. For reference the associated bed shear stress in relation to currents over the same time periods is also included. Conceptually waves have the capacity to stir the bed, resulting in the increased mobility or suspension of finer sediment for transport by currents. However in this instance, Figure 23 would suggest that waves only stir or move sediment for a small proportion of time and overall have a limited influence in relation to tidal currents. In the instance that waves have the capacity to mobilise sediment, these occur as isolated events, with a limited duration, which is also identified through the SSC observations discussed in Section 4.5.2. For the assessed time period the percentage mobility time (Table 21) is less than what Paphitis *et al*., (2010) identified on an annual time scale (see Section 3.5). Whereby, the occurrence of waves with the potential to disturb seabed sediments within the study area occurs approximately 5 to 20% of time during the year.

Table 21. Spatial variation in sediment mobility due to waves at the metocean survey locations across the application site

Location (Depth and Bed Sediment Size)		Sediment Fraction					
		Coarse Silt (47.5µm)	**Fine Sand (187.5µm)**	**Medium Sand (302.5µm)**	**Coarse Sand (750 µm)**	**Very Coarse Sand (3000 µm)**	**Granule Gravel (6000 µm)**
L1 (28 m (CD); d50 bed of 284.6µm)	Mobility Summary	Mobile under isolated event	Not mobile	Not mobile	Not mobile	Mobile	Mobile
	Mobility % time	0.53%	0.36%	0.03%	0%	0%	0%
L2 (24 m (CD); d50 bed of 257.6µm)	Mobility Summary	Mobile under isolated event	Not mobile	Not mobile	Not mobile	Not mobile	Mobile
	Mobility % time	1.31%	0.86%	0.80%	0.58%	0%	0%
L3 (45 m (CD); d50 bed of 338.2µm)	Mobility Summary	Mobile under isolated event	Not mobile	Not mobile	Not mobile	Mobile	Mobile
	Mobility % time	0.01%	0%	0%	0%	0%	0%

Overall, tidal currents associated with spring and tidal flows generate the same or much larger shear stresses during the spring-neap tidal cycles, which have a longer duration to the sporadic wave events. This also shows that in the long term the influence of wave events are of a much lower significance to mobilise sediment. This observation is the same across the three metocean survey sites. Therefore, the combined effect of currents and waves are not investigated further.

5. Morphodynamic Regime

5.1 Overview

The discussion of the morphodynamic regime does not differentiate between the nearshore and offshore regimes as implemented in the previous section as these are linked into a single system. The contemporary morphology within the OWF application site and far-field region is considered, as well as the natural evolution of the morphodynamic regime over the next 25 to 50 years in relation to the operational period of the OWF. The seabed morphology and its potential evolution are evaluated alongside knowledge of the local and regional hydrodynamic and sediment transport regimes as defined in the previous sections.

The data sources used to characterise the morphological features and morphodynamic regime are as previously identified in Table 17.

5.2 Coastal Characteristics

The coastline associated with the OWF application site and far-field region are heavily defended due to dense urban development, where currently a “hold the line” policy is in place for much of sub-cell 4d. It is the information available from the SMP (SDCG, 1997; 2004), work completed by SCOPAC (2004) and research related papers that are used to describe the nearshore properties, particularly at the coast.

The coastline of sub-cell 4d can be described according to its solid geology and its degree of exposure to climatic and tidal influences. It is characterised by low-lying land with associated sandy/gravelly beaches and coastal plains in the west and chalk cliffs to the east (Figure 1). The low-lying lands to the west, extending from Selsey to Shoreham-by-Sea are currently below high water. Eastwards between Brighton and Beachy Head, the beach is backed by chalk cliffs, which are part of the South Downs chalk ridge. South flowing rivers dissect the chalk ridge, cutting deep channels into the chalk that are subsequently filled with alluvium (Anotine *et al*., 2003). These rivers are the Arun, Adur, Ouse and Cuckmere Rivers and are considered to be associated with north to south running palaeochannels which connect with the Northern Palaeovalley within the English Channel (Anotine *et al*., 2003; Gupta *et al*., 2004; Gupta *et al*., 2007). The sediment sinks within this sub-cell are the tidal inlet at Pagham Harbour in the west, which acts as a transport discontinuity causing a partial barrier to longshore transport. Further east is the spit associated with Shoreham-by-Sea, which acts as an absolute boundary to drifting of coarse sediments. Generally it is only the southwest facing coastline that is susceptible to the sporadic occurrence of storm events (Paphitis *et al*., 2010).

In the nearshore environment, there is a wide shelf along the coast of this sub-cell, where the 20 m depth contour is 15 to 20 km offshore. This region is characterised by north to south orientated infilled palaeochannels. Away from the palaeochannels, the seabed gently undulates with an overall gradient of less than 0.5º away from the isolated rock ridges and described palaeochannels.

The cross-shore sediment profile characteristic for this sub-cell is a low-lying coastal plain or chalk cliff, with a beach shingle frontage to depths greater than 10 m. Further away from the coast, the shingle deposits fine up to sandy deposits characteristic of the permanently sub-tidal environment. The described deposits are characteristic of a historic fluvial source and inputs from the backing cliffs (Anotine *et al*., 2003; Gupta *et al*., 2004). These sources are predominantly closed now with the construction of cliff facing and the reduction in the size of the fluvial input. Evidence of the once dominant fluvial sediment inputs are the large north to south dissecting palaeochannels infilled with alluvium, observed within the English Channel (*Paphitis et al.*, 2010; James *et al.*, 2011; James *et al.*, 2010; James *et al.*, 2007). The fining of deposits offshore is representative of the winnowing of finer grains in relation to hydrodynamic processes at the coast and into the offshore environment. The contemporary dominant regime at this sub-cell, from the coast to the offshore environment varies with depth. In locations less than 18 m onshore shingle creep in relation to wave conditions is prevalent (SCOPAC, 2004) (see Section 4.5.1). At greater depths, only sand size material is transported and these predominantly follow the net flood dominant residual flow and sediment transport path to the east-northeast.

Changes to the baseline wave and current regime have the potential to strongly influence the susceptibility of the coastal morphology and the littoral sediment transport identified in the nearshore environment. Increased wave activity would increase the onshore feed of shingle and potentially from greater depths, although this is considered to be a finite source (SCOPAC, 2004). At the same time, increased wave activity could also increase the offshore and alongshore erosion of the coastline frontage.

5.3 Seabed Morphology

Within the English Channel, seabed topography and sediment substrate are variably influenced by the structure and composition of underlying bedrock, the configurations and composition of geological features originating from former terrestrial and marine environments. These morphological states, combined with the sediment input from fluvial and anthropogenic sources and the interactions with near bed tidal and wave induced currents, bring about the contemporary morphodynamic regime within the application site.

The seabed morphology in terms of the geological and sedimentary features has been assessed. These have previously been analysed within the geophysical survey report by Osiris, (2010b; 2010c) in relation to the cable corridor and OWF application site. These are in turn summarised here and at the time of writing, Osiris has completed surveys for section 1 (cable corridor) and section 2 (approximately the northern half of the OWF application site). Only the properties for these sections are considered here. Additional data sources, including the bathymetric output from the SCREC (James *et al.*, 2010) and BGS (1989; 1990), have also bee used.

Cable route

Maximum seabed depths across this section are up to 23 m (CD), observed in the extreme southwest corner, while the shallowest depths occur inshore and are inter-tidal. For most of the section, particularly in the sub-tidal areas, the seabed gently dips towards the south-southeast with gradients <0.5°, except around the shallow and narrow rock ridges that occur tin the central and southern areas. Geophysical evidence indicates that the bedrock is present within 2 m of the seabed for much of the section, comprising of rocks from different geological epochs and confirming the occurrence of a relatively thin veneer of mobile seabed sediment.

Also present within the section are a network of steep-sided buried palaeochannels, characteristic of the approximate north to south trending palaeochannels that are known to occur in the study area. These features have varying widths and depths, with observed widths up to 1.5 km, depths in excess of 10 m and steep sides with gradients >10°. The features are interpreted to be infilled with alluvium, including silts, sands, clays and peat deposits, indirectly represented through gas blanking.

Bedform features present within this section are rock outcrops, rock ridges and megaripples. The rock ridges and outcrops occur in the central and southern part and are representative of more resistant bed underlying the Eocene limestone geology. A large number of boulders also occur around these features. Poorly defined gravel and sand megaripples also occur across the section, where these are orientated approximately north-northeast to south-southwest and are generally less than 0.5 m high.

A number of wrecks and outfall pipelines are also identified within this section, particularly in the northern areas.

OWF application site

The geophysical interpretation provide by Osiris, (2010b; 2010c) is used to summarise the properties of the OWF application site. Seabed depths across this section range from 18 m (CD) in the northwest corner of the application site to 61.3 m (CD) in the extreme southwest corner of the assessed section 2 area. The depth observed in the southwest corner of section 2 is most likely representative of the deepest depth across the OWF application area. This is because the Osiris survey just captures the northern extent of the Northern Palaeovalley as it transects the study area (Figure 14 and Figure 17).

A distinctive 10 to 14 m high escarpment runs through the application area, this feature may relate to the Northern Palaeovalley further south of the application site, however this has not been proven. The western extent of the escarpment has a southwest to northeast orientation and turns west to east through the central and eastern parts of the area. The top of the escarpment is roughly at 30 m (CD) and extend down to 42 m to 46 m (CD), with seabed gradients of 6° to 9° to the west and east of the escarpment. In the central part the escarpment is much less steeper with gradients between 0.8° to 1° and is approximately 8 m high. The aforementioned escarpment provides a natural division for which the study area is described.

The area north of the escarpment is described as having bed depths between 18 m and 42 m (CD). The morphology is irregular and undulating, with a number of shallow rocky ridges that are 1 m to 3 m high. Gradients of up to 4° are identified on the edges of the rocky ridges but are generally less than 1°. To the eastern extents of the application area, there are outcrops of more resistant beds, which have localised steep edges and 2 m height above the surrounding seabed, which is at 25 m to 28 m (CD). The rest of the northern area is generally undulating with a south or south-southeast inclination.

The area south of the escarpment is described as having bed depths approximately between 29 m and 60 m (CD). Immediately south in the central part of the area, there is a dipping plateau feature which extends from 35 m to approximately 45 m (CD), with an average gradient of 0.1°. The feature is over 8 km long with widths between 0.9 km and 1.8 km, narrowing towards the northeast. A number of long and narrow sand and gravel ridges are observed on the plateau, running from southwest to northeast. The ridges are between 35 m to 90 m wide and are less than 1 m high.

South of the plateau is a large area of seabed characterised by the presence of sand and gravel waves, which are orientated north-northwest to south-southeast and with a height of over 8 m. The sand waves are asymmetrical in profile with steeper sides (up to 14°) facing the east-northeast, this indicates a transport direction of east-northeast based on a prevailing current direction from the west-southwest. This observation agrees with the net sediment pathway calculated from the progressive vectors for the tidal currents (see Section 4.6.1 and Figure 24). Further south of these bedforms, the seabed deepens to the observed maximum in the southwest extent of section 2, i.e. greater than 6 m (CD). Further east of the bedform features there is isolated deep seabed scour orientated northeast to southwest and a base depth of 56 m (CD).

East-northeast of the deep scour and south of the escarpment is an undulating area of shallow scouring. A large number of megaripple bedforms are evident with heights between 0.5 m and 3 m and have the same orientation as the larger sand wave bedforms to the southwest. Further south and east of the scour, the seabed shallows to between 29 m and 38 m (CD), with another area of large sand and gravel waves and associated megaripples. These features have the same orientations, but are smaller in size, with heights between 2.5 m and 5.5 m. These are again asymmetrical in profile with the same gradients as the larger features indicating a migration direction to the east-northeast.

There are a number of wrecks across the surveyed sections of the OWF application area, which have varying degrees of scour associated to the wrecks. Of significance is the large wreck of the *Pagentrum*, which has large areas of associated scour northwest and southeast of the wreck, which is seen to influence nearby bedforms.

The descriptions presented by Osiris (2010b; 2010c) provide a useful and extensive picture of the variability of the morphology for the Osiris survey section 2. For southern half of the application area (i.e. section 3, which currently does not have any available geophysical information), it is expected that the identified sand and gravel wave bedforms will continue in this region. Larger areas of plateaus and deeps are also theorised to occur here as the Northern Palaeovalley transects the OWF application area in this region.

Review of the bathymetry output from the SCREC indicates the seabed potentially shallows again in the eastern area of section 3, with a further hard substrate ridge as described for the area south and east of the deep scour (see above). This area is also likely to have a similar depth of between 30 m to 40 m (CD) and is most likely representative of the outcrops of more resistant beds in the eastern extents of the application are as described for section 2. This ridge is on the same line and orientation that BGS (1989; 1990) and SCREC identify with a sandbank, therefore there is likely to be such a bedform on top of the geological feature. Isolated areas of resistant bed are likely to occur moving further south into the southern to southeastern extents of the application area.

5.4 Conceptual Understanding of the Morphodynamic Regime

The OWF application site is located off the coast of sub-cell 4d in the south coast of England, between the headlands of Selsey Bill in the west and Beachy Head to the east. It is located in open water within the semi-enclosed English Channel. The solid geology across the site and assessed far-field region is characterised by primarily sub cropping Tertiary and Cretaceous sediments of sand, gravels and clays with occasional limestone bands. To the east of the application site and towards Beachy Head the solid geology is made up of Upper Cretaceous chalk with flints.

Geophysical surveys within the application site and the far-field region, from the site specific, SCREC, EECHM and DTI SEA surveys identified bedforms indicative of transport regimes within the region. These also identified the presence of large scale geological features and a relatively thin veneer of seabed sediment with areas of exposed bedrock across the region. The Holocene sediment sequence across this region is characterised by loose sand and gravels, which form the thin veneer of sediment over the bedrock. In addition to the exposed bedrock, there are a number of palaeochannels that dissect the region in a north to south axis. These palaeochannels are partially to completely unfilled with alluvium associated with the fluvial characteristics of the region and the subsequent submergence (Velegrakis *et al.*, 1999; Velegrakis, 2000; Gupta *et al.*, 2007). There is also a large palaeovalley, namely the Northern Palaeovalley which runs on an approximately east to west axis. This palaeovalley is predominantly unfilled so that the deepest depths within the region are identified here. Due to morphology of the geological landscape, these features are likely to exert an influence on the tidal flow properties through the region. These features are not considered to still be active, therefore the shape or form of the features are not likely to be influenced by hydrodynamic regime over the next 50-years. The only aspect that could evolve in time is the deposition of contemporary sediment infill within the palaeochannels and palaeovalleys.

The PSA based on the collected grab samples shows that the dominant sediment is gravelly sand, the associated dominant mode across all the sites is 302 μm, which relates to a medium sand. There is therefore a significant potential for sediment movement because the modal sediment size is mobile approximately 40% of time across the surveyed locations, based on the bed shear stress from the observed tidal currents. Investigations completed as part of this assessment identify flood dominant tidal flows particularly under spring conditions. This dominance in relation to the potential for sediment mobility showed that sediments up to coarse sand can be transported, although not at all states of the tide. This in turn leads to an eastwards (between the northeast and east-northeast) dominant transport direction in response to the tidal regime. This dominance is also represented by the asymmetry of the bedforms identified in the geophysical survey within the OWF application site. The bedform observations confirm a transport direction to the east-northeast, again in relation to the tidal characteristics. This is because the crests and stoss side of the sand and gravel waves and megaripples are aligned perpendicular to the dominant flow, where the transport direction is parallel to the same flow (Belderson, *et al*., 1982). The fact that the bedforms are aligned in relation to tidal flow conditions indicates that these are active features that are still evolving in relation to the tidal currents. Although a migration rate for the bedform features is not available, it is anticipated that within the 50-year assessment time frame, the features will continue to migrate in relation to the tidal flow.

The offshore environment in depths greater than 18 m is not considered to provide a significant feed to the nearshore and the coastline. This is because sand is the dominant sediment offshore and previous studies do not identify any onshore movement of sediment from these depths. Instead what is identified is a small onshore feed of shingle from depths less than 18 m based on wave conditions (SCOPAC, 2004), particularly during storms (Paphitis *et al*., 2010). This feed is only observed to occur where potentially mobile shingle exists, which in itself is a finite resource as re-supply from further offshore is unlikely due to limited gravel mobility at greater depths. Other sediment sources to the coastline are fluvial and estuarine inflow, which are generally not influenced by offshore hydrodynamic conditions. The sand present in the offshore environment, instead moves along the sediment transport path, towards the east-northeast in relation to the dominant tidal flows as described above. Over the next 50-years, this behaviour is not expected to vary significantly from what has been described. The factors that would alter the rate of evolution are an increase in storminess and more energetic storm wave activity to transport shingle onshore.

6. Summary

This report provides a baseline assessment of coastal processes in the Rampion Wind Farm application site and surrounding far-field region. This has primarily been achieved on the basis of data collected during targeted metocean and geophysical survey campaigns and data and information from previously published studies. Overall the findings of the baseline can be summarised as follows:

6.1 Hydrodynamic Regime

Water Levels:

- The application site is situated within a macro-tidal setting and is characterised by a mean spring tidal range of just under 6 m and a maximum astronomic range (HAT to LAT) of approximately 7 m;
- Storm surges may cause short term modification to predicted water levels and under an extreme (1 in 50-year return period) storm surge, water levels may be above 4.2 m within the English Channel;
- It is probable that relative sea levels will rise in this region during the course of the 21st Century and by 2100 is likely to be approximately 0.5 m higher across the application site based on a medium scenario at the 50 percentile; and
- Climate change may be expected to slightly increase the mean water level over the lifetime of the proposed development; however, the tidal range about the new mean level will likely have little effect due to the large tidal range.

Currents:

- Information available on the strength of tidal currents in this region shows that recorded (depth-averaged) peak spring current speeds are around 0.5 m/s to 1.25 m/s through the, application site;

- Both storm waves and storm surges may cause short term modification of astronomically-driven tidal currents. During a 1 in 2 year storm event, orbital currents at inshore areas are likely to approach 1.5 m/s, but are considerably less (<0.1 m/s at offshore locations). Within the application site, a 1 in 2 year storm event generates orbital currents speeds that are still less than the current speeds associated with peak spring tidal flows;
- Tidal currents play a critical role in driving sediment transport through the process of longshore drift, at the coastline, through the OWF application site and in the offshore environments;
- Residual tidal currents (over a period of days to weeks) are directed east-northeast towards the Dover Strait; and
- Climate change is not expected to have any effect on the local tidal current regime (currents are largely controlled by the corresponding tidal range) over the lifetime of the proposed development.

Waves:

- The wave regime in the English Channel includes both swell waves generated elsewhere in the Atlantic and propagates into the Channel, as well as locally generated wind waves;
- The wave regime in the vicinity of the application site is primarily characterised by locally generated wind waves due to the largest occurrence of significant wave heights less than 0.5 m and wave periods between 3-4 seconds;
- Longer period waves (i.e. approximately 7 seconds) can be identified within the observational wave records collected from within and nearby to the application site, however these are still characteristic of a wind wave regime;
- Despite the dominance of wind waves, there is still the potential for the occurrence of swell waves and storm events as observed from ongoing wave observations at the Rustington buoy;
- However, the occurrence of swell and storm waves that have sufficient capacity to stir the seabed are infrequent;
- The wave climate provides a limited contribution to the sediment transport regime that occurs through OWF application site and offshore areas, as it only predominantly facilitates transport in the nearshore area; and

- Climate change is predicted to cause variability in the inter-annual wave climate over the lifetime of the proposed development; however, historical trends have shown that this variability may include both increases and decreases in mean storminess on decadal timescales.

6.2 Sediments

- Sediments across the OWF application site are characteristics of two very different deposition regimes. The Holocene seabed sediments generally consist of sand, gravelly sand and sandy gravel. The sediments associated with the palaeochannels are also sands and gravels but from a fluvial origin;

- A modal peak grain size at 302 μm (medium sand) is common across the application site. Other modal peak grain sizes were observed, ranging from 38,500 μm (pebble gravel) to 152.5 μm (coarse silt). The proportion of shell in sediment samples from and nearby to the application site are generally less than 10% (EMU, 2010);
- Across much of the application site, surficial sediments are primarily made up of the Holocene deposits, which form a relatively thin veneer of sediments (~0.5 m) over bedrock;
- Sediment thicknesses vary across the application site and far-field region. The thickest deposits occur in relation to the large-scale palaeochannels and palaeovalleys present, whereby infilled palaeochannels have thicknesses up to 90 m;
- The available evidence suggests that (bedload) material is travelling east-northeast further towards the Eastern English Channel. In the offshore environment, tidal currents are the primary agent for mobilising sediment through bedload and suspended load transport. As wave conditions alone do not have sufficient strength to mobilise large sediment volumes for transport;
- The effect of tidal currents on sediment transport can be seen to mobilise sediment sizes up to medium sand at nearly all states of the tide. Coarse sand is generally mobilised under peak spring conditions only. The combination of tidal currents and wave induced currents only has a limited effect on sediment transport as these occur over a short period;
- Across the application site, suspended sediment concentrations are typically between 5-10 mg/l across the site. However, during periods with larger significant wave heights, near bed current speeds can be increased due to the influence of waves stirring of the seabed, causing a short-term increase in concentrations as observed at the shallower sites (L1 and L2). Coarser sediments may be transported a short distance in the direction of ambient flow or down-slope under gravity before being deposited. Finer material that persists in suspension will eventually be transported in the direction of net tidal residual flow, i.e. to the east-northeast; and
- The influence of climate change on the offshore environment is not expected to have any effect on the type or distribution of sediments within the extent of and over the lifetime of the proposed development.

6.3 Morphology

- The morphology of the OWF application site is characterised by the presence of multiple geological features. These include a number of north to south running palaeochannels, a large approximately east to west orientated escarpment through the central region of the site and a deep east to west palaeovalley considered to be part of the northern palaeovalley system;
- The bathymetry within the application site is characterised by water depths between 18 m and 61 m (CD). The shallowest depths occur in the northwest corner, while the greatest depths are observed in the western extents, in relation to where the northern palaeovalley system crosses the application site;
- Bedforms identified within the application site have been considered alongside the findings from the sediment mobility analysis as well as published literature from this region to develop a conceptual understanding of the morphological regime. Particular

attention has been focused on ascertaining those mapped bedforms which are considered to be active;

- Active seabed bedforms are primarily controlled by the tidal flows through the region. Small and large sediment waves and megaripples orientated perpendicular to the main axis of tidal flow are present across the central axis of the site;
- The majority of the coastline is heavily defended resulting in limited sediment input from the coastal cliffs. Therefore ongoing sediment sources would be from fluvial and estuarine inputs and sediment recharge on associated beaches and nearshore zone; and
- Climate change is not expected to have any effect on the form or function of the identified bedforms and morphology over the lifetime of the proposed development.

7. References

ABPmer, 2004. English Channel Extreme Tidal Level Review. ABP Marine Environmental Research Ltd, Report No. R.1085.

ABPmer, 2008a. Coastal Processes Scoping Zone EON02, South Coast. ABP Marine Environmental Research Ltd, Report No. R.1476.

ABPmer, 2008b. English Channel and Southern North Sea Model Calibration. ABP Marine Environmental Research Ltd, Report No. R.1205.

ABPmer, 2011a. Initial review of Emu AWAC data. Report 3953/02/09/03/2011.

ABPmer, 2011b. Review of Emu AWAC data. Report 3953/02/01/07/2011.

ABPmer, 2011c. SEASTATES. The metocean forecasting service from ABPmer. Technical note available at http://www.seastates.net/.

ABPmer, Met Office and POL, 2008. Atlas of UK Marine Renewable Energy Resources: Atlas Pages. A Strategic Environmental Assessment Report, March 2008. Produced for BERR. Report and associated GIS layers available at: http://www.renewables-atlas.info/.

Alexandersson H., Tuomenvirta H., Schmith T., Iden K. 2000. Trends of storms in NW Europe derived from an updated pressure data set. Climate Research, 14, 71-73.

Antoine, P., Coutart, J. P., Gibbard, P., Hallegouet, B., Lautridou, J. P. and Ozouf, J. C., 2003. The Pleistocene rivers of the English Channel region. Journal of Quaternary Science, 18 (3-4), 227-243.

Barne, J. H., Robson, C. F., Kaznowska, S. S., Doody, J. P., Davidson, N. C. and Buck, A. L., 1998. Coasts and seas of the United Kingdom. Region 8 Sussex: Rye Bay to Chichester Harbour. Peterborough, Joint Nature Conservation Committee. (Coastal Directories Series.)

Belderson, R. H., Johnson, M. A., Kenyon, N. H. 1982. Bedforms. In Stride, A. H. (ed) Offshore tidal sands. Processes and deposits. Chapman and Hall, London, 27-57.

Blott, S. J. and Pye, K. 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, 26, 1237-1248.

Bovington, J. and Amos, D., 2010. Strategic Regional Coastal Monitoring Annual Report 2010 - Beachy Head to Selsey Bill. Project Report AR 62.

Brampton A.H., Evans C.D.R., and Velegrakis A.F., 1998. Seabed Sediment Mobility Study - West of the Isle of Wight. CIRIA, Project Report 65, 218pp.

British Geological Survey, 1988. Dungeness - Boulogne Sheet 51°N 00°W 1:250 000 Solid Geology Series.

British Geological Survey, 1989. Dungeness - Boulogne 51°N 00°W sea bed sediments and Quaternary geology, 1:250,000 geological map.

British Geological Survey, 1990. Wight 50°N 02°W sea bed sediments and Quaternary geology, 1:250,000 geological map.

British Geological Survey, 1995. Wight Sheet 50°N 02°W 1:250 000 Solid Geology Series.

Connor, D. W., Gilliland P., Golding, N., Robinson, P., Todd, D., & Verling, E., 2006. UKSeaMap: The mapping of seabed and water column features of UK seas. Peterborough, Joint Nature Conservation Committee.

COWRIE, 2009. Coastal Process Modelling for Offshore Wind Farm Environmental Impact Assessment.

Dean RG., Dalrymple. 1991. Water Wave Mechanics for Engineers and Scientists. Advanced Series on Ocean Engineering - Vol. 2. World Scientific Publishing Co. 353pp

DECC, 2011. Decommissioning of offshore renewable energy installations under the Energy Act 2004. Guidance notes for industry. Department of Energy & Climate Change https://www.og.decc.gov.uk/EIP/pages/files/orei_guide.pdf

Department for Environment, Food and Rural Affairs (Defra), Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and Department for Transport (DfT), 2004. 'Offshore wind farms: guidance note for Environmental Impact Assessment in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) requirements: Version 2'.

Department for Environment, Food and Rural Affairs (Defra). Nature Conservation Guidance on Offshore Wind Farm Development.

Dixon, M.J. and Tawn, J.A. 1997: Spatial analyses for the UK coast: Proudman Oceanographic Laboratory report POL 112

E.ON Climate and Renewables, 2010a. Rampion Offshore Wind Farm - Project Design Statement. Version 1.0 Draft.

E.ON Climate and Renewables, 2010b. Rampion Offshore Wind Farm - Scoping Report. September 2010.

Eggleton, J., Dolphin, T., Ware, S., Bell, T., Aldridge, J., Silva, T., Forster, R., Whomersley, P., Parker, P., Rees J., 2011. Natural Variability of Turbidity in the Regional Environmental Assessment (REA) Areas. Project 09-P114. Cefas, Lowestoft, 41pp.

EMU, 2010. South Coast Marine Aggregate Regional Environmental Assessment Volume 1: Introductions and Baselines. Report Number J/1/06/1165.

EMU, 2011. Rampion Offshore Wind Farm Metocean Survey and Assessment. Survey report for E.ON Climate and Renewables UK Rampion Offshore Wind Limited. Report 11/J/1/01/1743/1156.

Environment Agency, 2009. River Basin Management Plan (RBMP): South East River Basin District Annex D: Protected area objectives. Available from http://www.environment-agency.gov.uk/research/planning/124978.aspx

Flather, R.A., 1987. Estimates of extreme conditions of tide and surge using a numerical model of the north west European Continental Shelf. Estuarine Coastal and Shelf Science 24, 69-93.

Folk, R.L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology 62 (4), 344-359

Gafeira, J., Green S., Dove, D., Morando, A., Cooper, R., Long, D. and Gatliff R. W. 2010. Developing the necessary data layers for Marine Conservation Zone selection - Distribution of rock/hard substrate on the UK Continental Shelf. MB0103 Marine Biodiversity R&D Programme. Contract administered by Defra.

Grochowski, N. T. L., Collins, M. B., Boxall, S. R. and Salomon, J. C., 1993a. Sediment transport predictions for the English Channel using numerical models. Journal of the Geological Society, 150, 683-695.

Grochowski, N. T. L., Collins, M. B., Boxall, S. R., Salomon, J. C., Breton, M., and Lafite, R., 1993b. Sediment transport pathways in the Eastern English Channel. Oceanologica Acta, 16, (5-6), 531-537.

Gupta, S., Collier, J. S., Palmer-Felgate, A. and Potter, G., 2007. Catastrophic flooding origin of shelf valley system in the English Channel. Nature, 448, 342-346.

Gupta, S., Collier, J. S., Palmer-Felgate, A., Dickinson, J., Bushe, K. and Humber, S., 2004. Submerged Palaeo-Arun River: Reconstruction of Prehistoric Landscapes and Evaluation of Archaeological Resource Potential. Integrated projects 1 and 2. 504pp

Hamblin RJO., Crosby A., Balson PS., Jones SM., Chadwick RA, Penn IE., Arthur MJ., 1992. United Kingdom Offshore Regional Report: The Geology of the English Channel. (London: HMSO for the British Geological Survey.)

HR Wallingford, 1993. South Coast Seabed Mobility Study. Report EX 2795. July 1993.

HR Wallingford, 2003. The Physical Environment and the effects of Dredging: East Channel Region. Report EX 4731.

HR Wallingford, 2010. South Coast Dredging Association MAREA: Tidal Flows and Sediment Transport Study. Technical Note DDR4323-05.

HSE, 2001. Wind and wave frequency distributions for sites around the British Isles. Prepared by Fugro GEOS for the Health and Safety Executive. Offshore Technology Report 2001/030.

HSE, 2005. Wave Mapping in UK Waters. HSE Research Report Number RR392.

Infrastructure and Planning Commission, 2010. Scoping Onion - Proposed Rampion Offshore Wind Farm. October 2010.

Infrastructure Planning Commission (IPC), 2011. Using the Rochdale Envelope. Advice note nine: Rochdale Envelope. 10pp

James, J W C, Pearce, B, Coggan, R A, Arnott, S H L, Clark, R, Plim, J F, Pinnion, J, Barrio Frójan, C, Gardiner, J P, Morando, A, Baggaley, P A, Scott, G, Bigourdan,N., 2010. The South Coast Regional Environmental Characterisation. British Geological Survey Open Report OR/09/51. 249 pp.

James, J. W. C., Pearce, B., Coggan, R. A., Leivers, M. Clark, R. W. E., Plim, J. F., Hill, J. M., Arnott, S. H. L., Bateson, L., De-Burgh Thomas, A., Baggaley, P. A., 2011. The MALSF synthesis study in the central and eastern English Channel. British Geological Survey Open Report OR/11/01. 158pp

James, J. W. C.; Coggan, R. A.; Blyth-Skyrme, V.J.; Morando, A.; Birchenough, S. N. R.; Bee, E.; Limpenny, D. S.; Verling, E.; Vanstaen, K.; Pearce, B.; Johnston, C. M.; Rocks, K. F.; Philpott, S. L. and Rees, H. L., 2007. The Eastern English Channel Marine Habitat Map. Science Series Technical Report, Cefas Lowestoft 139. 191pp.

Judd 2011. Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects. DRAFT. Cefas contract report: ME5403 - Module 15.

Kenyon N. H. and Cooper W. S. 2005. Sand banks, sand transport and offshore wind farms. DTI Strategic Environmental Assessment Area 6 technical report.

Kenyon, N.H., 1970. Sand ribbons of the European tidal seas. Marine Geology 9: 25-39.

Lowe J, Howard T, Pardaens A, Tinker J, Holt J, Wakelin S, Milne G, Leake J, Wolf J, Horsburgh K, Reeder T, Jenkins G, Ridley J, Dye S, Bradley S., 2009. UK Climate Projections Science Report: Marine and coastal projections. Met Office Hadley Centre: Exeter.

Matulla, C., Schöner, W., Alexandersson H., von Storch H., Wang XL., 2007. European storminess: late nineteenth century to present. Climate Dynamics, DOI 10.1007/s00382-007-0333-y.

McMillan, A., Batstone, C., Worth, D., Tawn, J., Horsburgh, K. and Lawless, M., 2011a. Coastal flood boundary conditions for UK mainland and islands. Project SC060064/TR2: Design sea levels. Environment Agency, Flood and Coastal Erosion Risk Management Research and Development Programme.

McMillan, A., Johnson, A., Worth, D., Tawn, J., Hu, K., 2011b. Coastal flood boundary conditions for UK mainland and islands. Project SC060064/TR3: Design swell waves. Environment Agency, Flood and Coastal Erosion Risk Management Research and Development Programme.

Office of the Deputy Prime Minister, 2001. Guidance on Environmental Impact Assessment in Relation to Dredging Applications, HMSO, London.

Osiris Project, 2010a. E.ON Climate and Renewables Rampion Offshore Wind Farm Definitive Geophysical Survey, Volume 1 - Operations Report. Report C10011.

Osiris Project, 2010b. E.ON Climate and Renewables Rampion Offshore Wind Farm Definitive Geophysical Survey, Volume 2 - Section 1 Report. Report C10011.

Osiris Project, 2010c. E.ON Climate and Renewables Rampion Offshore Wind Farm Definitive Geophysical Survey, Volume 3a - Section 2 Report. Report C10011.

Paphitis, D., Bastos, A. C., Evans, G. and Collins, M. B., 2010. The English Channel (La Manche): evolution, oceanography and sediment dynamics - a synthesis. In, Whittaker, J. E. and Hart, M. B. (eds.) Micropalaeontology, Sedimentary Environments and Stratigraphy: A Tribute to Dennis Curry (1912-2001). London, GB, Geological Society of London, 99-132.

Pingree, R. D. and Griffiths, D. K., 1979. Sand transport paths around the British Isles resulting from M2 and M4 tidal interactions. Journal of Marine Biological Association UK, 59, 497-513.

Royal Haskoning and Posford Haskoning, 2002. Eastern English Channel Regional Environmental Assessment.

Soulsby, R., 1997 Dynamics of Marine Sands. Thomas Telford. pp249.

South Downs Coastal Group (SDCG), 1997. South Downs Shoreline Management Plan: Selsey Bill to Beachy Head.

South Downs Coastal Group (SDCG), 2004. Beachy Head to Selsey Bill Shoreline Management Plan First Review.

Standing Conference on Problems Associated with the Coastline. (SCOPAC). 2004. South and East Isle of Wight. http://www.scopac.org.uk/scopac_sedimentdb/sow2/sow2.htm. Accessed on August 2011.

Stride, A. H., 1982. Offshore Tidal Sands: Processes and Deposits. Chapman and Hall, London 222 pp.

Tappin, D. R., Mason, T. and Rocks, K., 2007. DTI Strategic Environmental Assessment Area 8 Geology. Superficial Seabed Processes and Hydrocarbon Prospectivity. British Geological Survey Commissioned Report, CR/07/075.

UKCIP (United Kingdom Climate Change Impact Programme, http://www.ukcip.org.uk/).

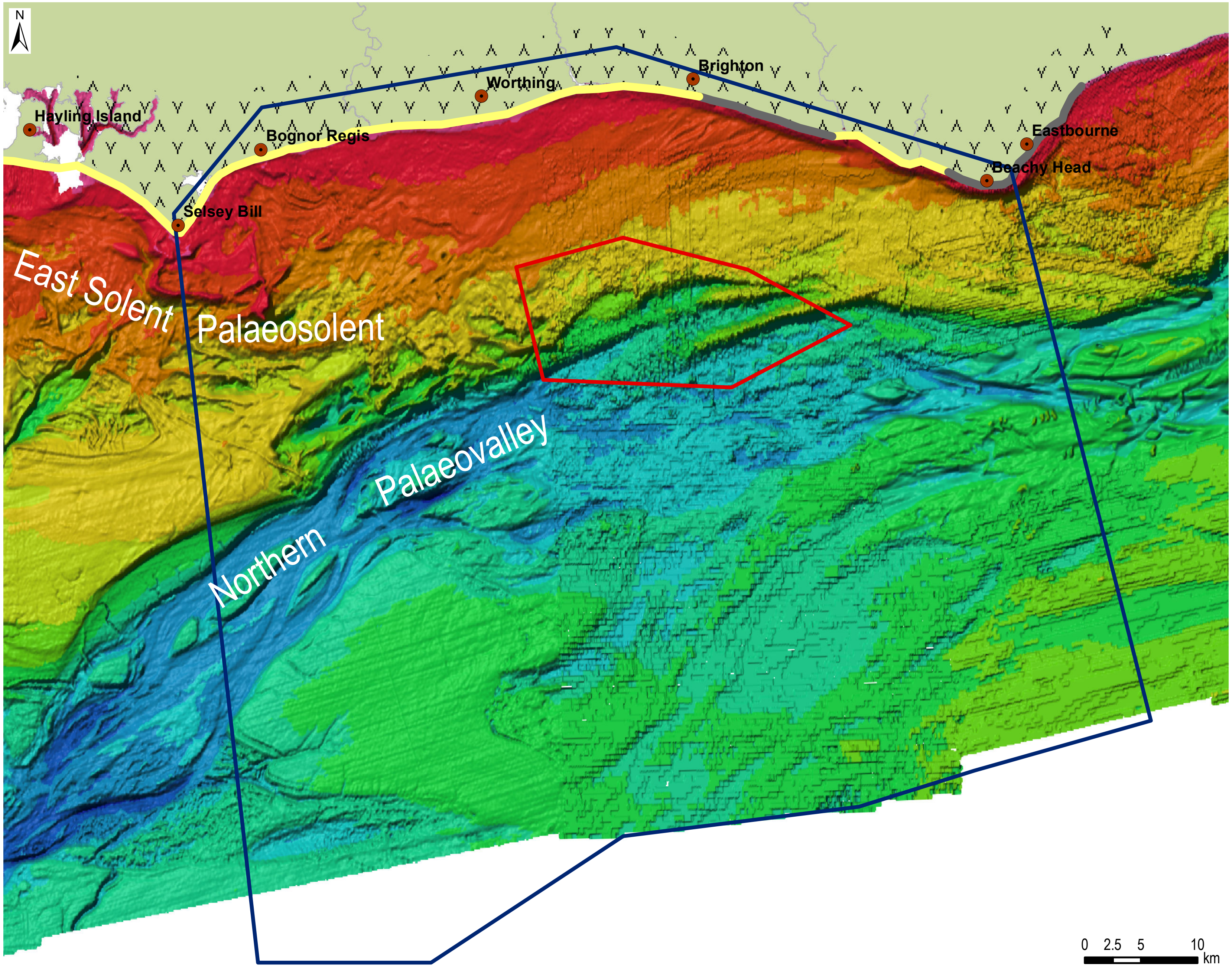
United Kingdom Hydrographic Office, 2011. Admiralty Tide Tables, Volume 1. Taunton: United Kingdom Hydrographic Office.

Velegrakis A.F., 2000. Geology, Geomorphology and Sediments of the Solent System, in: Collins M.B., and Ansell K., (Eds). Solent Science - A Review, Amsterdam: Elsevier Science, 21-43.

Velegrakis, A. F., Michel, D., Collins, M. B., Lafite, R., Oikomomou, E. K., Dupont, J. P., Huault, M. F., Lecouturier, M., Salomon, J. C. and Bishop, C., 1999. Sources, sinks and resuspension of suspended particulate matter in the Eastern English Channel. Continental Shelf Research, 19, 1933-1957.

Visbeck M., Hurrell JW., Polvani L. and Cullen HM., 2001. The North Atlantic Oscillation: Past, present and future. Proceedings at the 12th Annual Symposium on Frontiers of Science: Vol. 98, 12876-12877.

Figures



Rampion OWF application area
Far field study boundary
Place names
Cliffs (soft), with sandy/gravelly beaches
Lowlands, with sandy/gravelly beaches
Soft mesozoic/cenozoic rocks

Depth (m)
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-70
-80
-90
-100

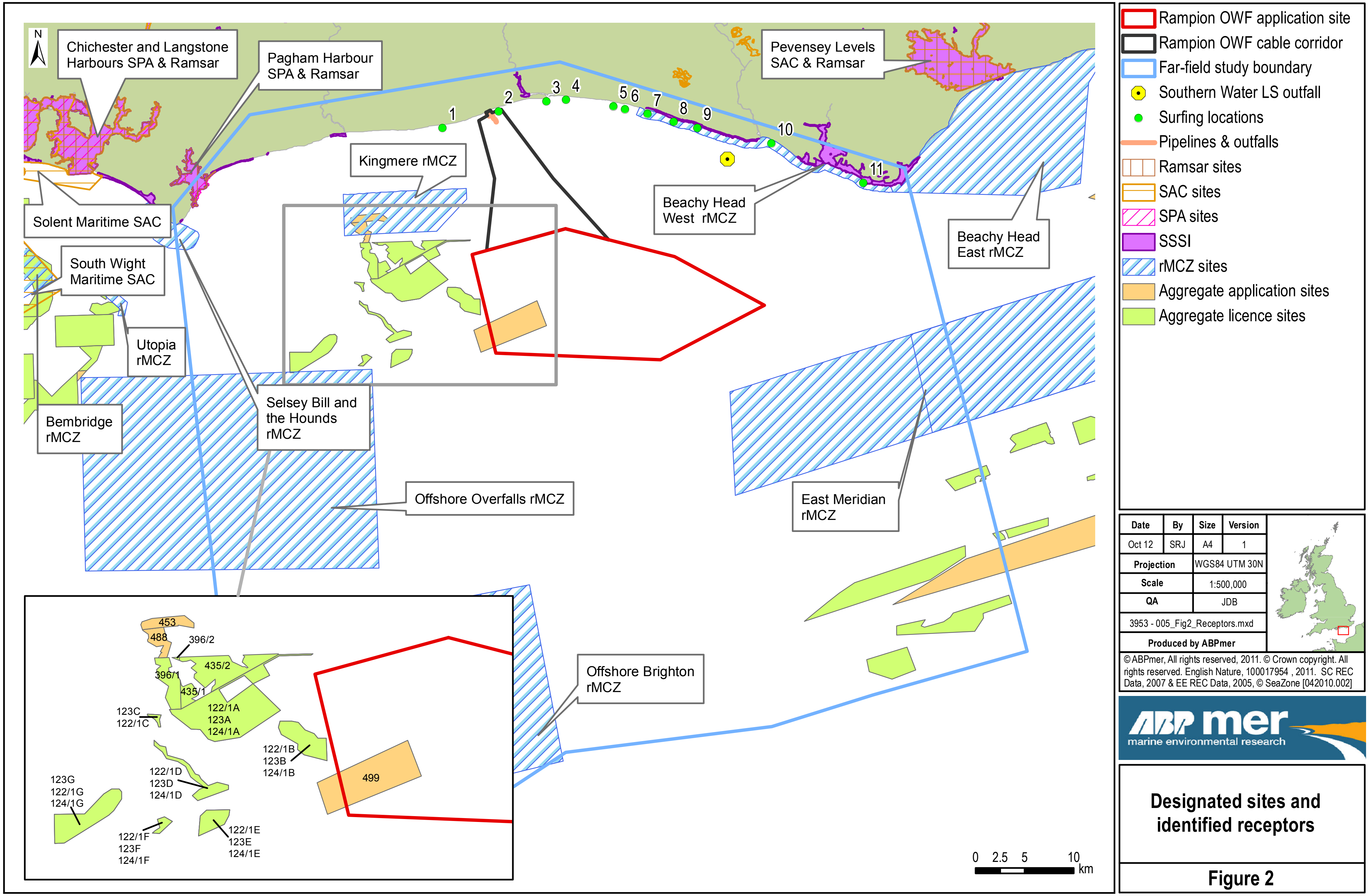
Date	By	Size	Version
Aug 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:500,000	
QA		FMM	
3953 - Fig_Study_Area.mxd			
Produced by ABPmer Ltd			

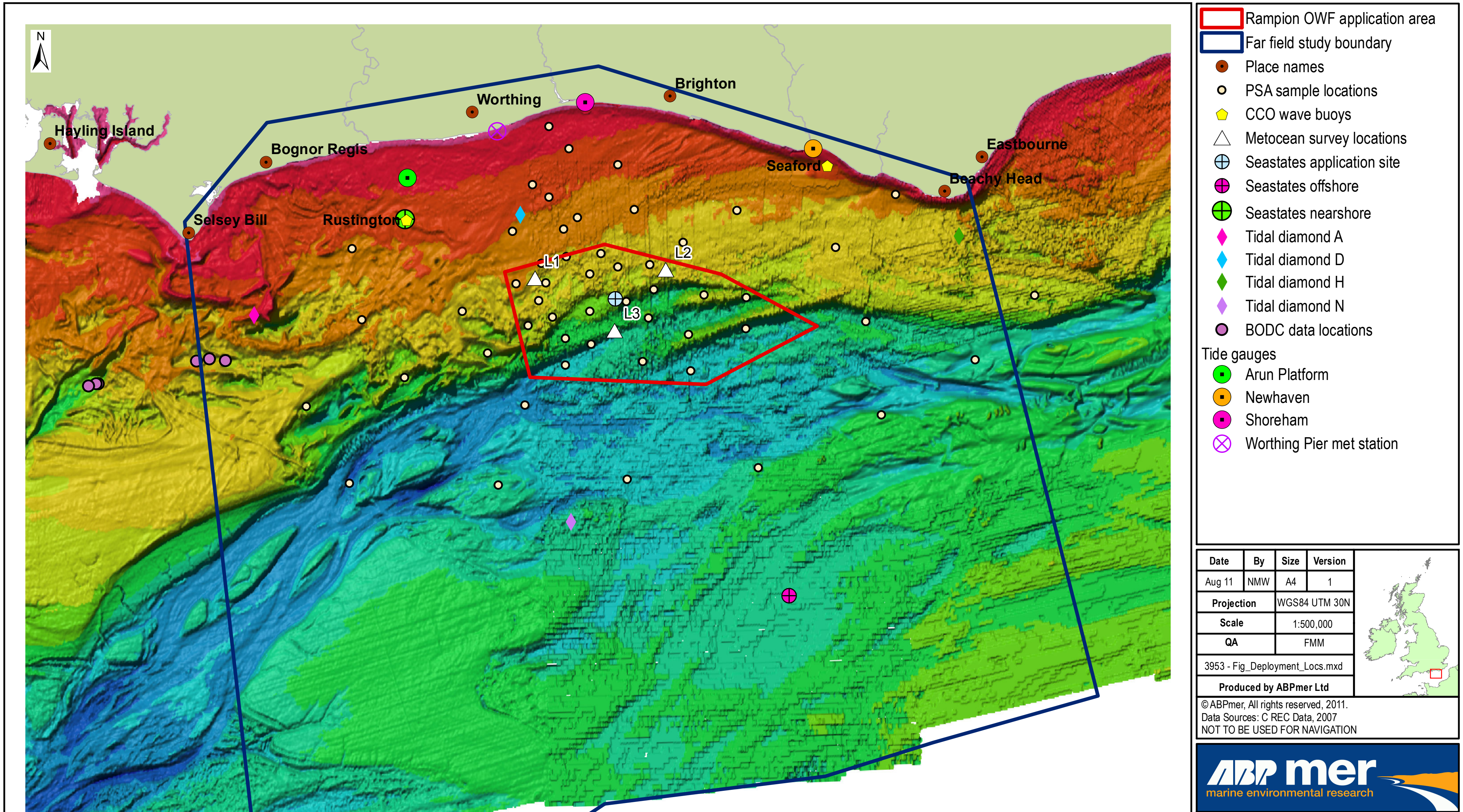
Data Sources: South Coast REC Data (2007)
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Study area including coastal characteristics of the sub-cell 4d: Beachy Head to Selsey Bill

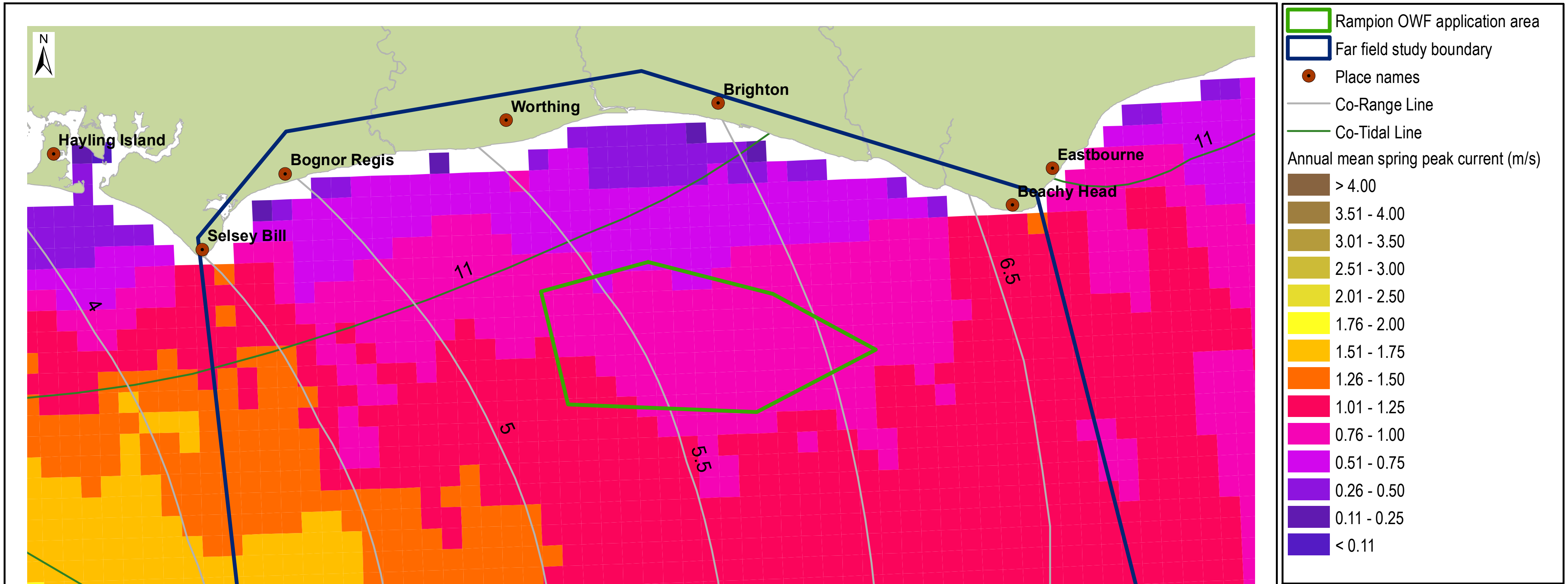
Figure 1


N
Chichester and Langstone Harbours SPA & Ramsar
Pagham Harbour SPA & Ramsar
Pevensey Levels SAC & Ramsar
Kingmere rMCZ
Solent Maritime SAC
South Wight Maritime SAC
Utopia rMCZ
Bembridge rMCZ
Selsey Bill and the Hounds rMCZ
Offshore Overfalls rMCZ
Beachy Head West rMCZ
Beachy Head East rMCZ
East Meridian rMCZ
Offshore Brighton rMCZ
1
2
3
4
5
6
7
8
9
10
11
453
488
396/2
435/2
396/1
435/1
122/1A
123A
124/1A
123C
122/1C
122/1B
123B
124/1B
499
123G
122/1G
124/1G
122/1D
123D
124/1D
122/1F
123F
124/1F
122/1E
123E
124/1E
0 2.5 5 10 km
Rampion OWF application site
Rampion OWF cable corridor
Far-field study boundary
Southern Water LS outfall
Surfing locations
Pipelines & outfalls
Ramsar sites
SAC sites
SPA sites
SSSI
rMCZ sites
Aggregate application sites
Aggregate licence sites
Date | By | Size | Version
Oct 12 | SRJ | A4 | 1
Projection | WGS84 UTM 30N
Scale | 1:500,000
QA | JDB
3953 - 005_Fig2_Receptors.mxd
Produced by ABPmer
© ABPmer, All rights reserved, 2011. © Crown copyright. All rights reserved. English Nature, 100017954 , 2011. SC REC Data, 2007 & EE REC Data, 2005, © SeaZone [042010.002]
ABP mer
marine environmental research
Designated sites and identified receptors
Figure 2



Data and deployment locations within and nearby to the OWF application site

Figure 3

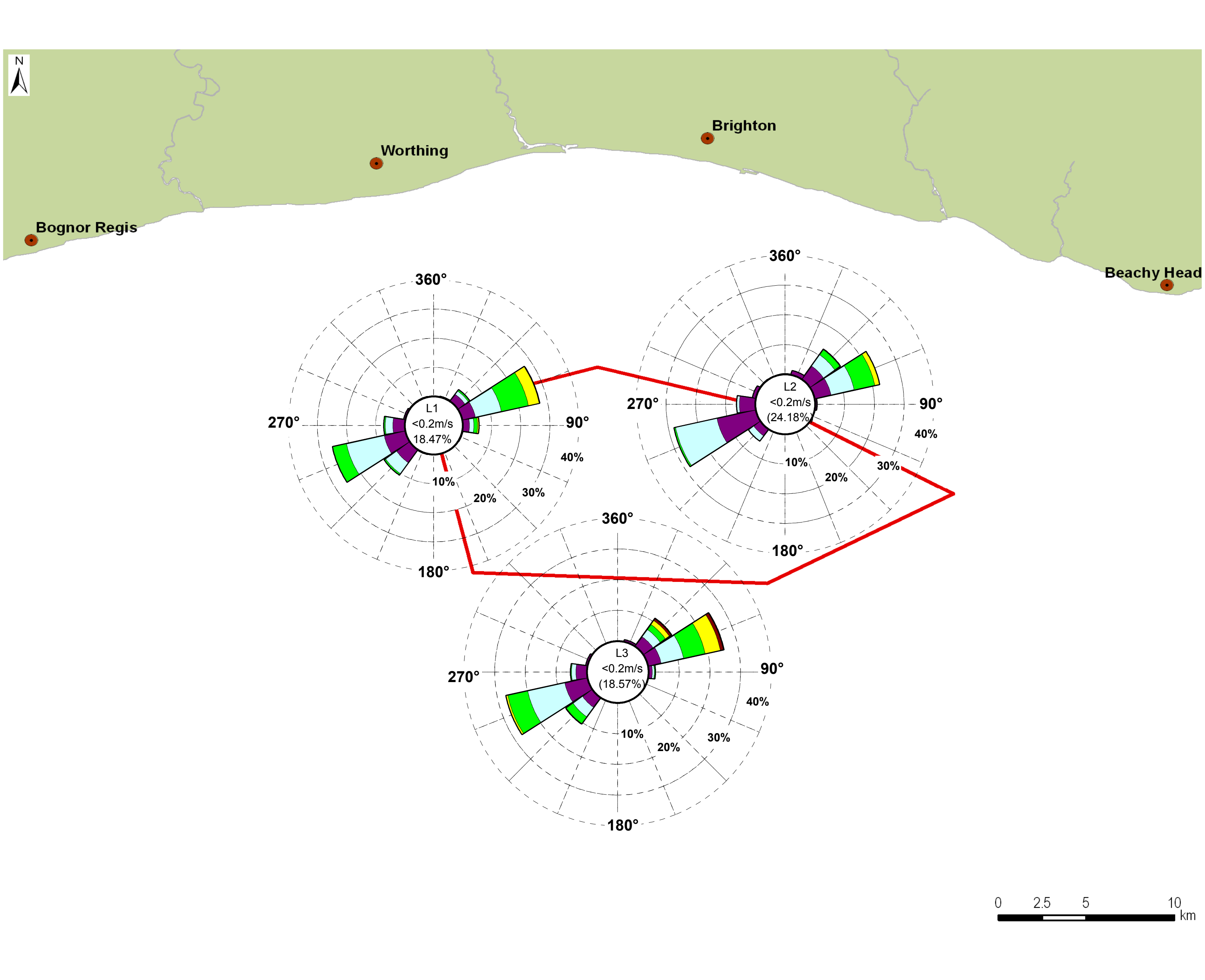


Date	By	Size	Version
Aug 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:500,000	
QA		FMM	
3953 - 004Fig5_Spring_Currents.mxd			
Produced by ABPmer Ltd			

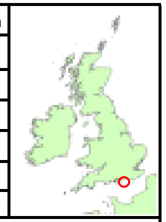
ABP mer
marine environmental research

Annual mean spring peak current speeds from the Renewables Atlas (ABPmer *et al.*, 2008)

Figure 4

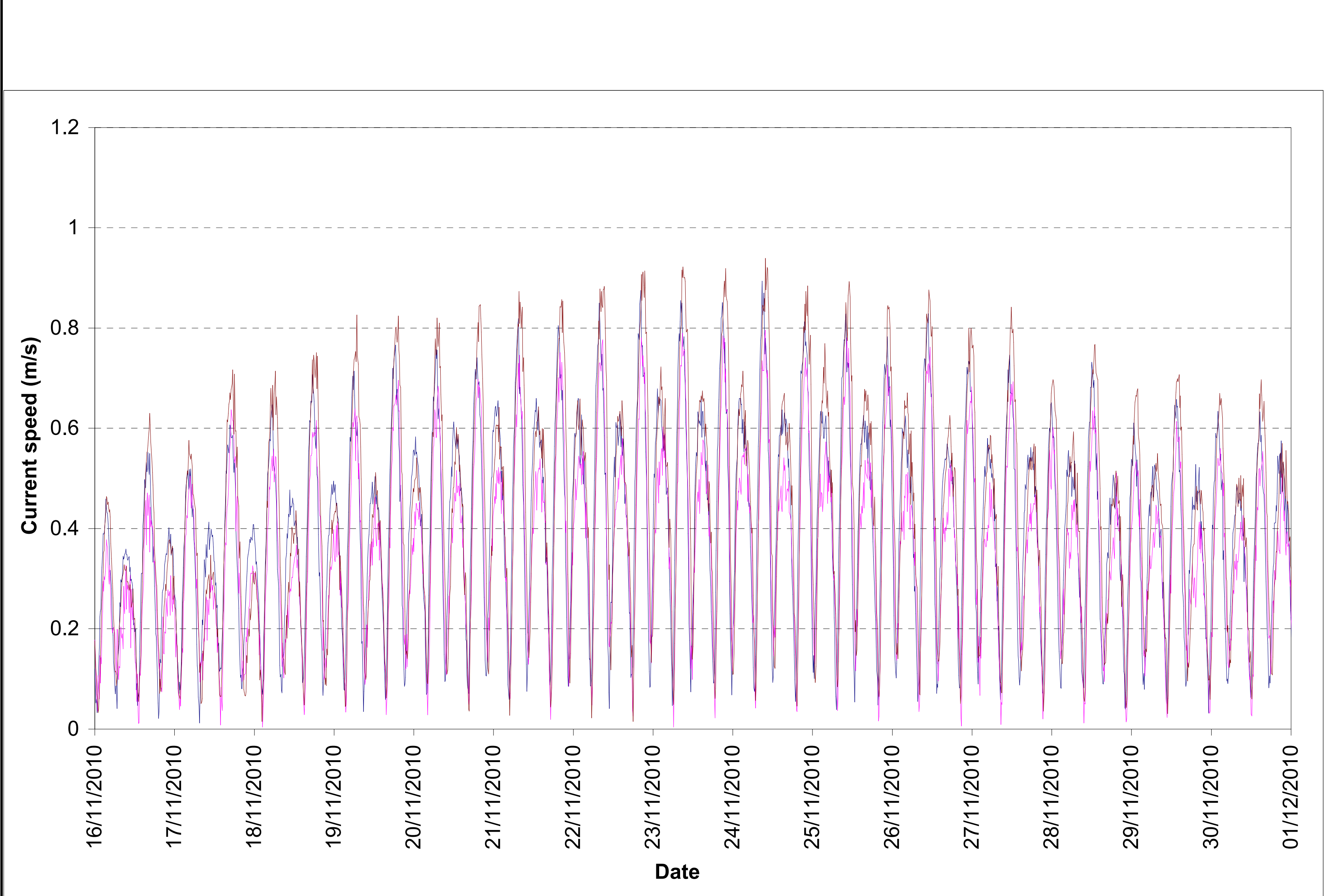


Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_F6-12.xls			
Produced by ABPmer Ltd.			



Observational Current Records from within and nearby to the OWF Application Site

Figure 5

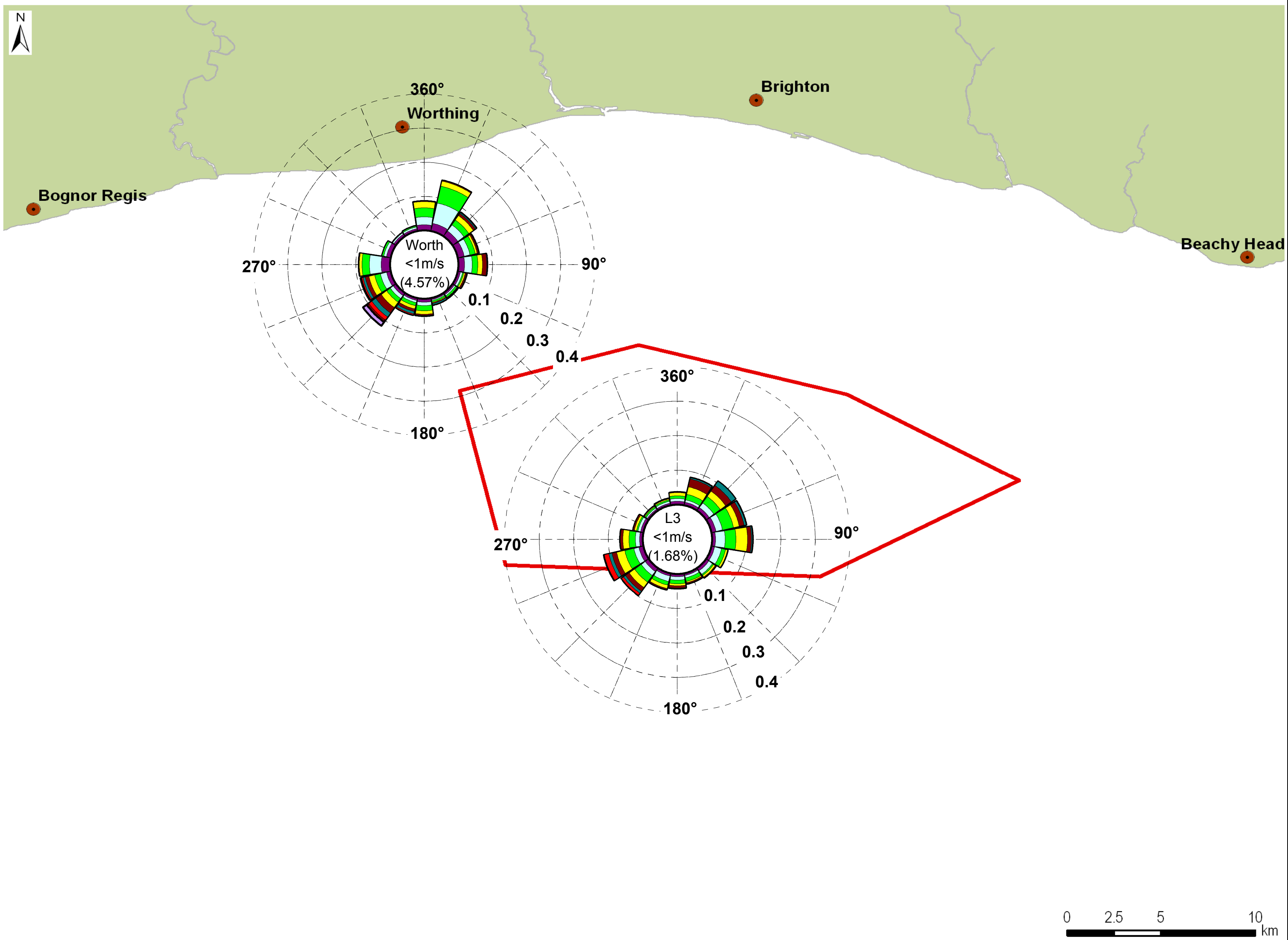


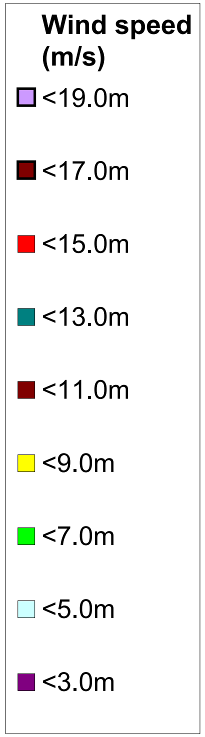
Date	By	Size	Version
Oct 11	AMB	A4	1
Projection	n/a		
Scale	n/a		
QA	NMW		
ReportFigures_F6-12.xls			
Produced by ABPmer Ltd.			

ABP mer
marine environmental research

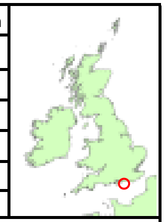
Variation in Current Velocity Across the Application Site

Figure 6



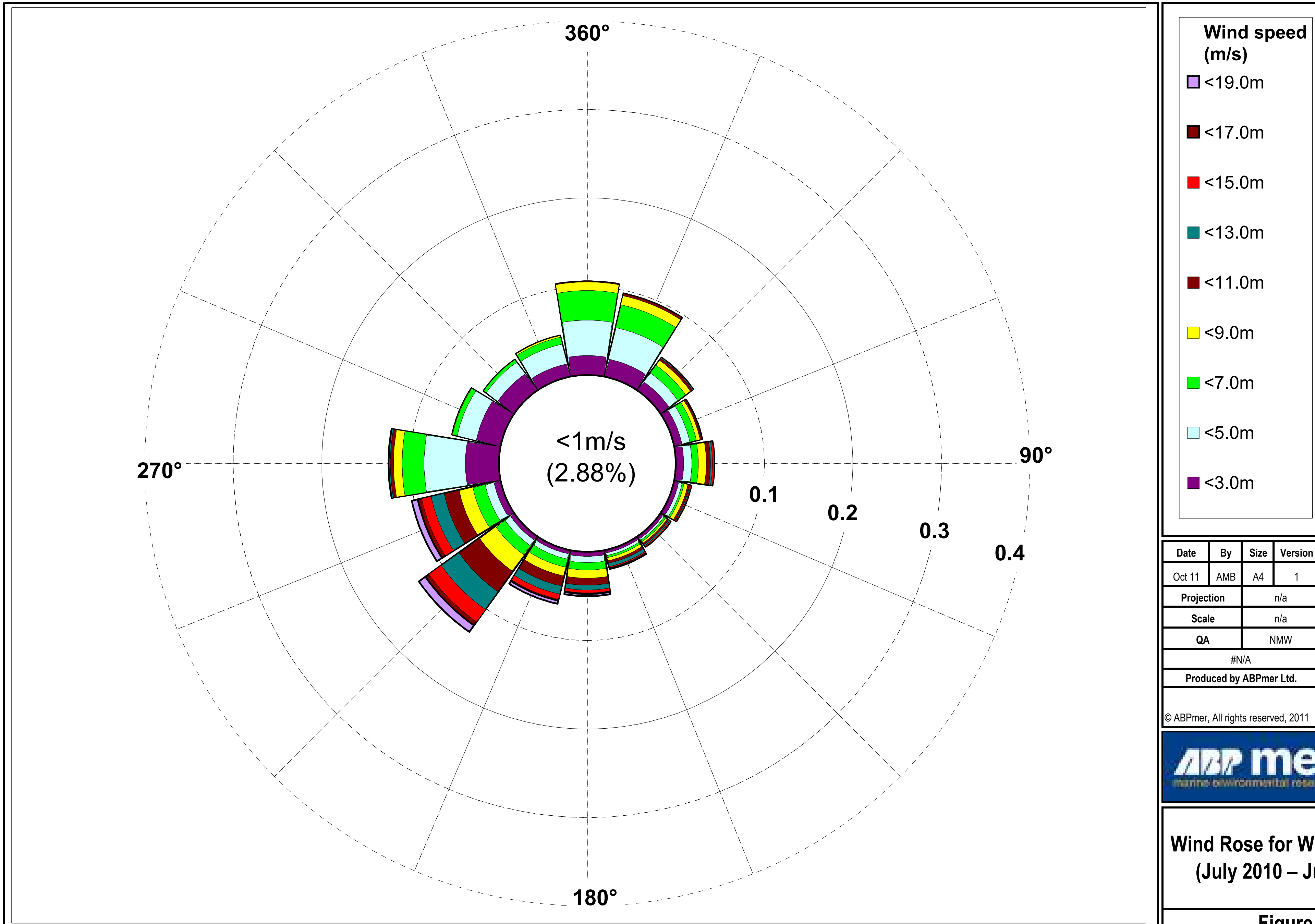


Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_F6-12.xls			
Produced by ABPmer Ltd.			



Wind Roses from Observational Records within and nearby to the OWF Application Site

Figure 7

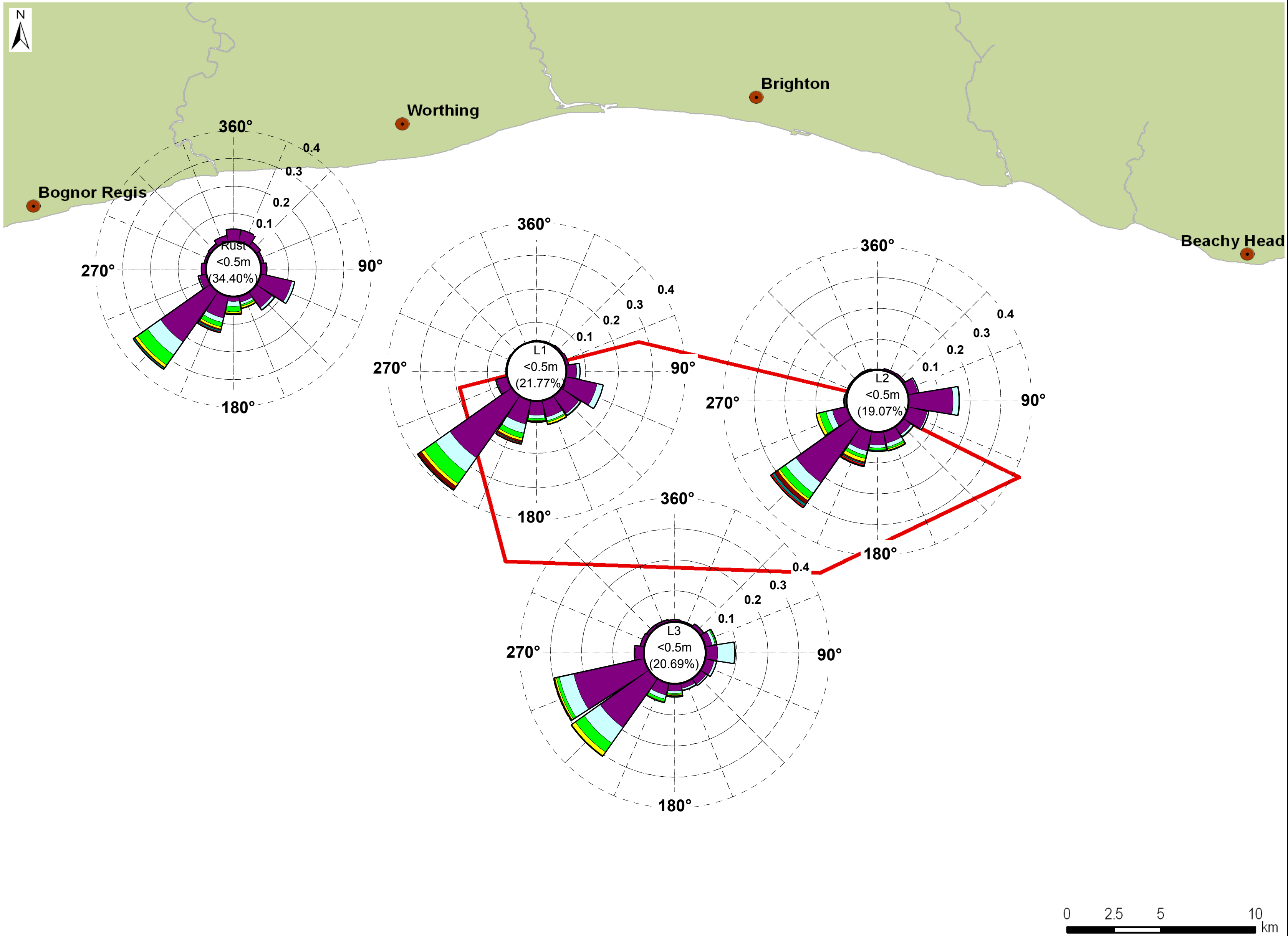


Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
#N/A			
Produced by ABPmer Ltd.			

ABP mer marine environmental research

Wind Rose for Worthing Pier (July 2010 – July 2011)

Figure 8



Significant wave height (m)

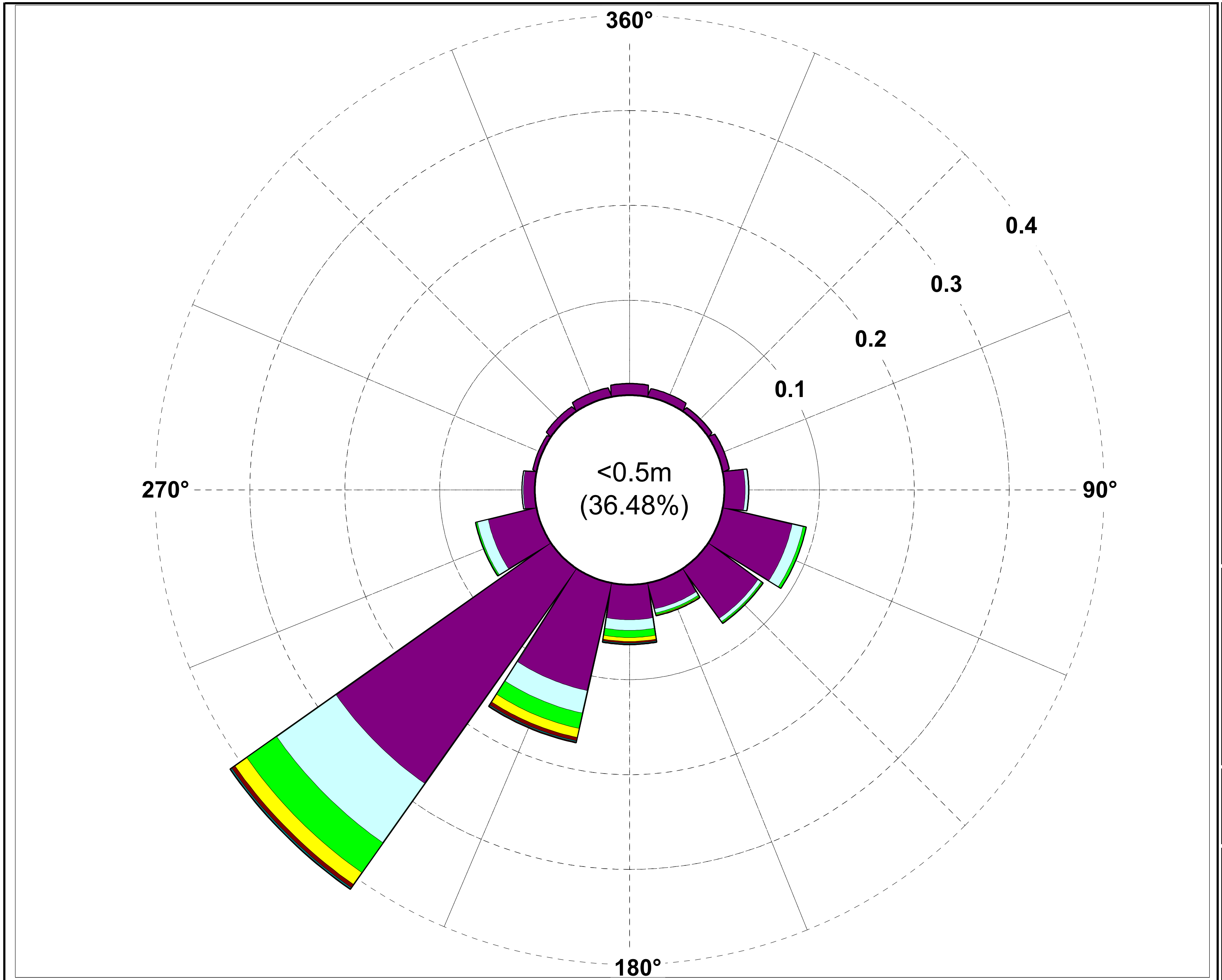
- <5.0m
- <4.5m
- <4.0m
- <3.5m
- <3.0m
- <2.5m
- <2.0m
- <1.5m
- <1.0m

Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_F6-12.xls			
Produced by ABPmer Ltd.			

ABP mer
marine environmental research

Wave Roses from Observational Records within and nearby to the OWF Application Site

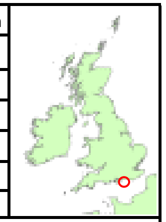
Figure 9



Significant wave height (m)

- <5.0m
- <4.5m
- <4.0m
- <3.5m
- <3.0m
- <2.5m
- <2.0m
- <1.5m
- <1.0m

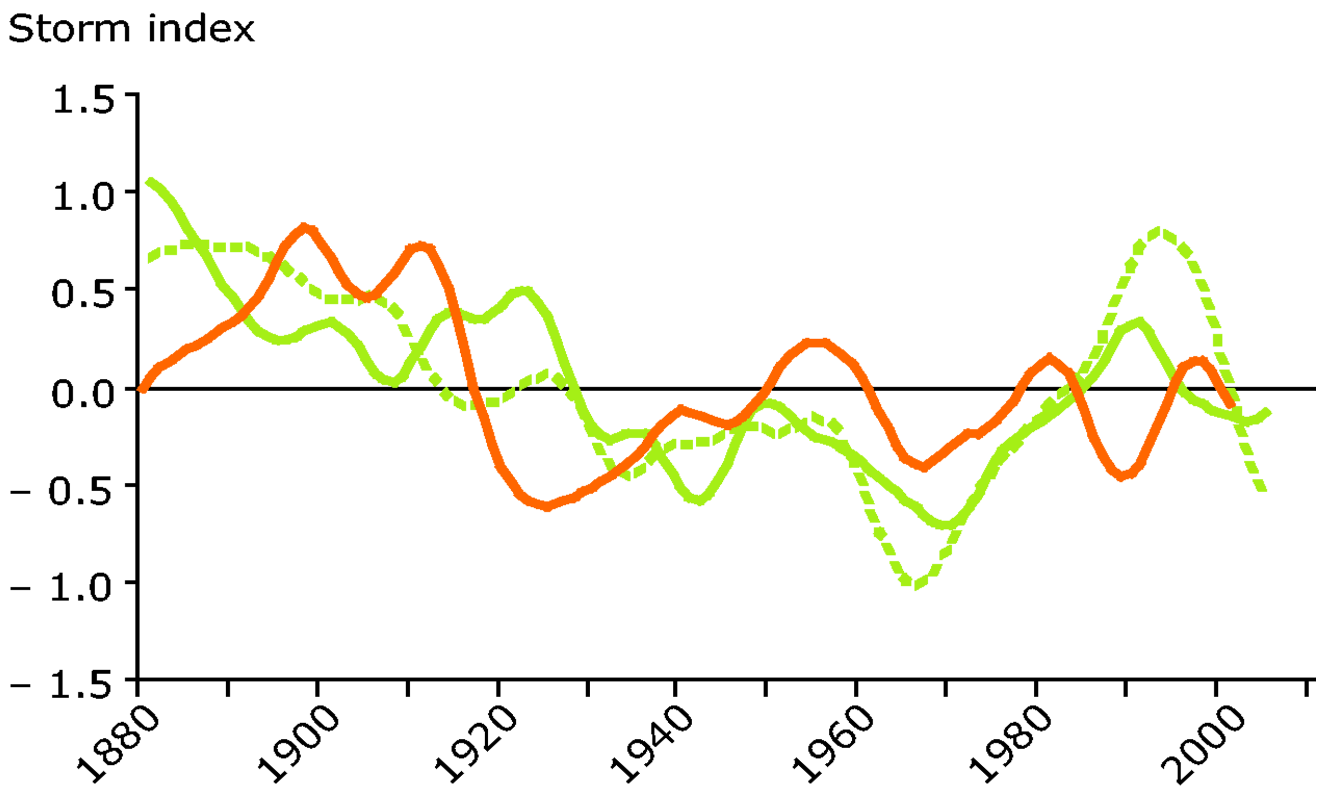
Date	By	Size	Version
Oct 11	AMB	A4	1
Projection	n/a		
Scale	n/a		
QA	NMW		
ReportFigures_F6-12.xls			
Produced by ABPmer Ltd.			



ABP mer
marine environmental research

Wave Rose for Rustington (CCO) Wave Buoy (July 2003 – December 2010)

Figure 10



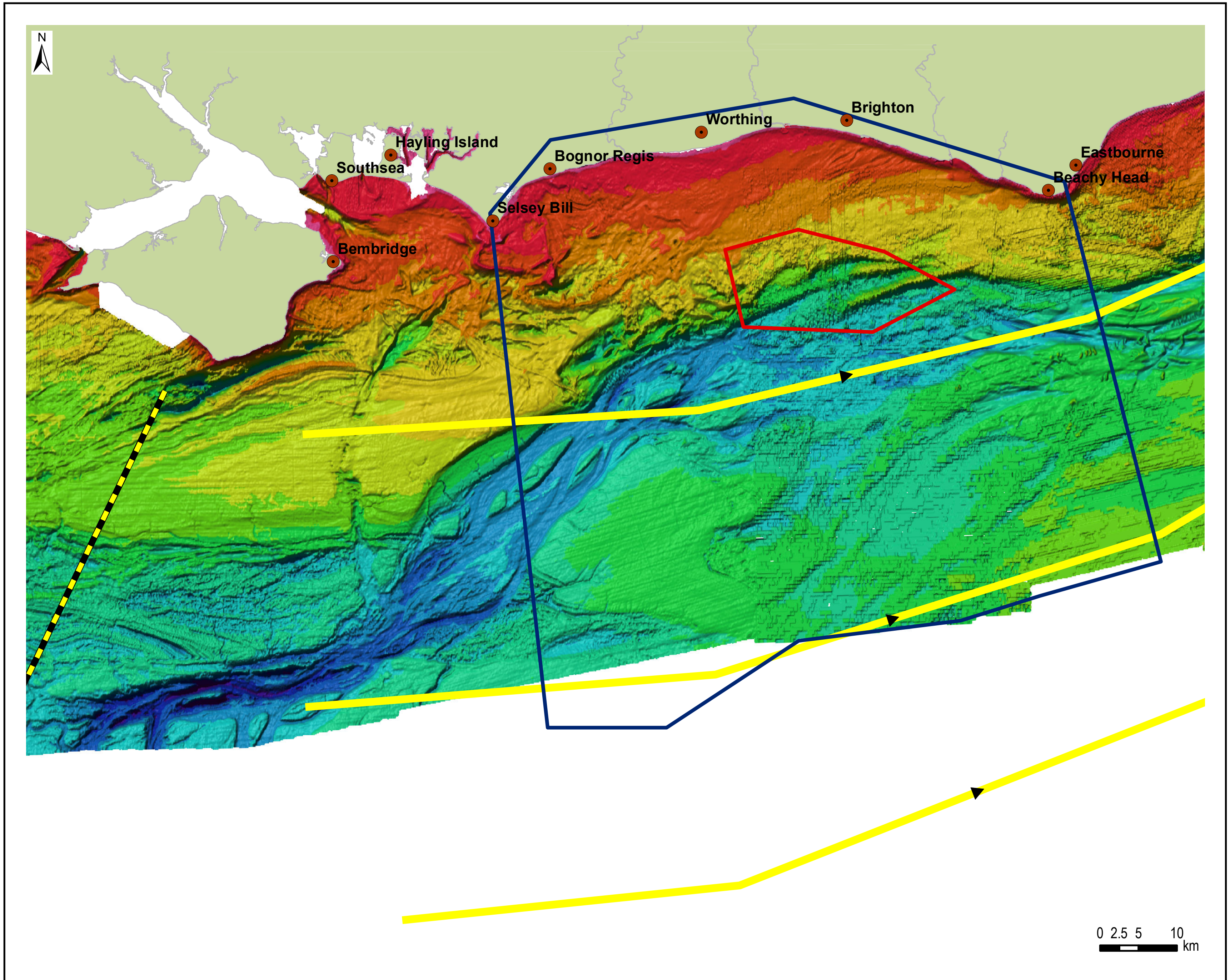
North-western Europe
North Europe
Central Europe

Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_F6-12.xls			
Produced by ABPmer Ltd.			

ABP mer
marine environmental research

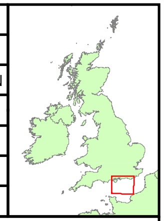
Storm Index for Various Parts of Europe 1881 - 2005

Figure 11



Rampion OWF application area
Far field study boundary
Place names
Sediment transport type
Type
Sediment transport path
Bed-load parting

Date	By	Size	Version
Sept 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:700,000	
QA		FMM	
3953 - Fig_transport_paths.mxd			
Produced by ABPmer Ltd			

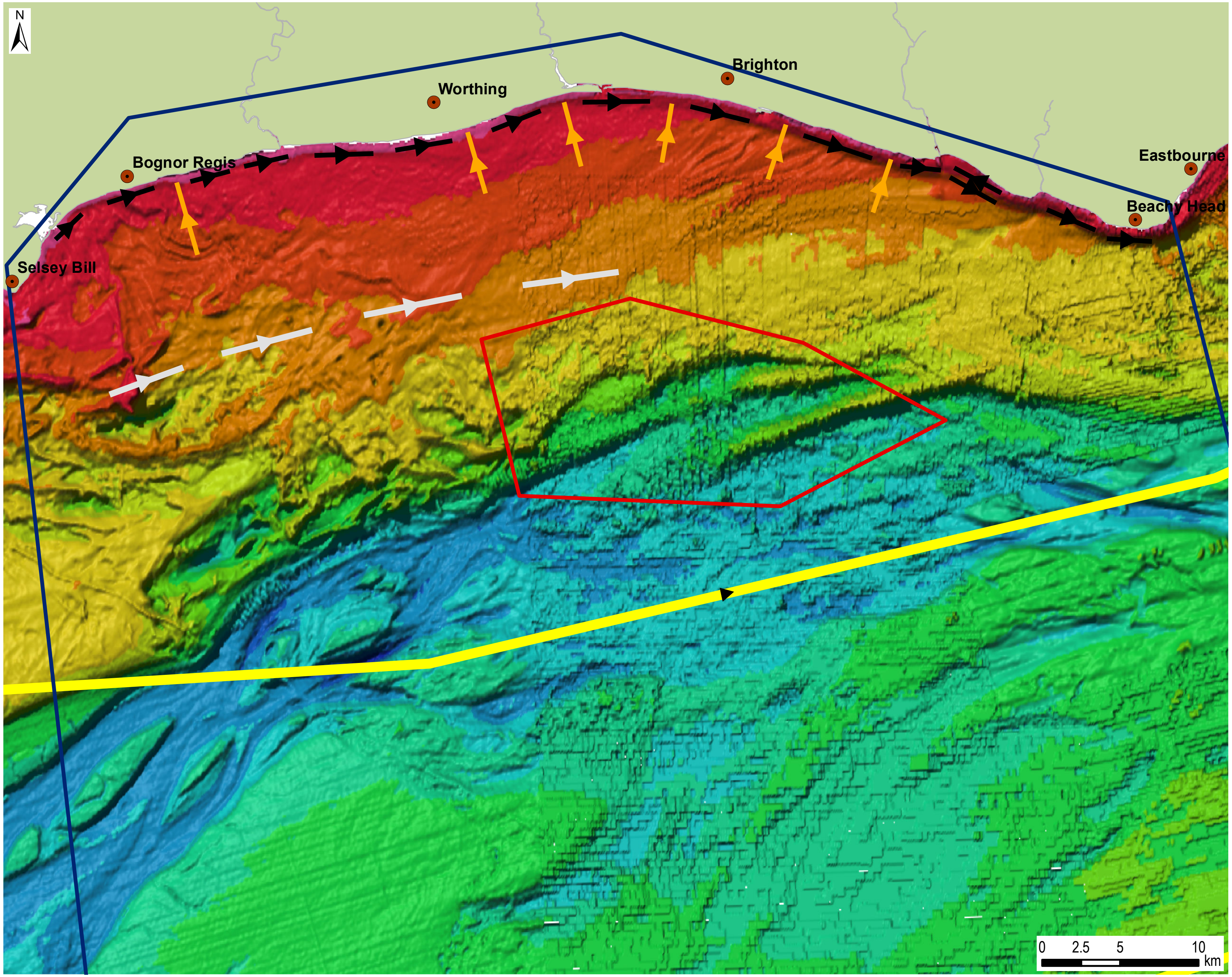


Data Sources: C REC Data, 2007, SCOPAC (2004) NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Offshore sediment transport pathways through the study area adapted from SCOPAC (2004)

Figure 12a



Rampion OWF application area
Far field study boundary
Place names
Sediment transport path
Shingle and sand littoral drift
Shingle and sand, wave driven nearshore and offshore zone transport
Sand offshore transport

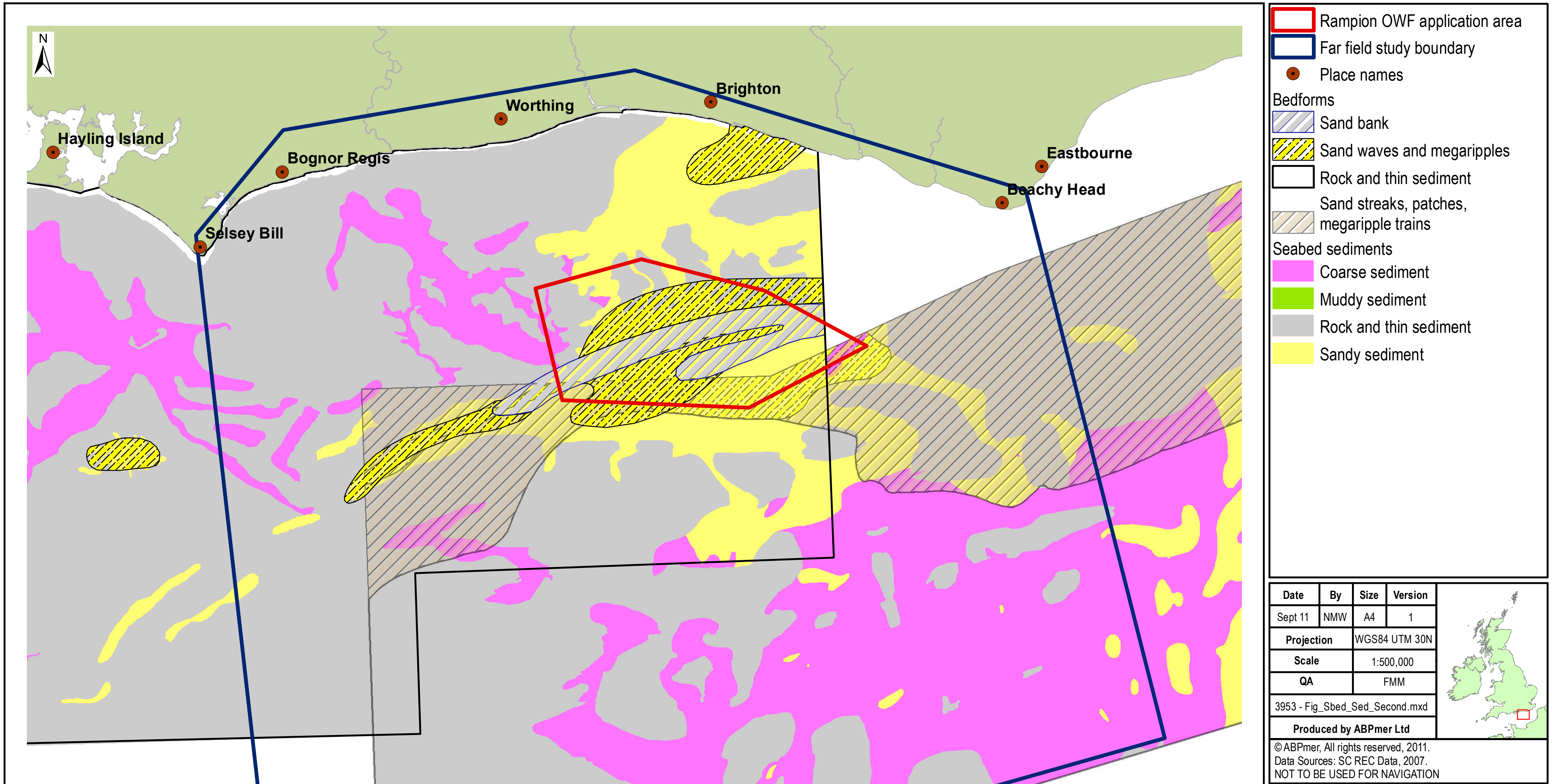
Date	By	Size	Version
Sept 11	NMW	A4	1
Projection	WGS84 UTM 30N		
Scale	1:360,000		
QA	FMM		
3953 - Fig_transport_paths.mxd			
Produced by ABPmer Ltd			

Data Sources: C REC Data, 2007, SCOPAC (2004)
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Nearshore sediment transport pathways through the study area adapted from SCOPAC (2004)

Figure 12b



Date	By	Size	Version
Sept 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:500,000	
QA		FMM	

3953 - Fig_Sbed_Sed_Second.mxd

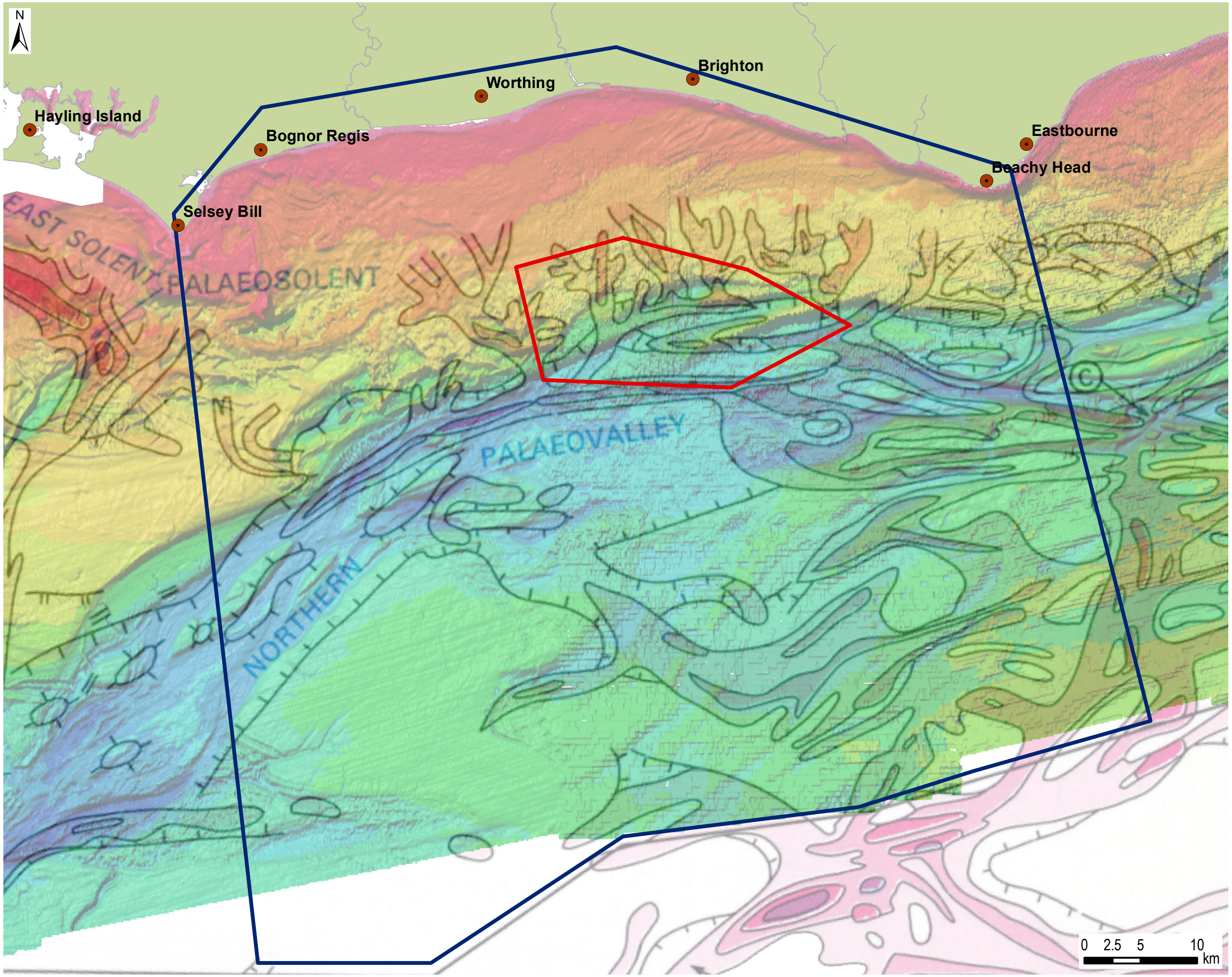
Produced by ABPmer Ltd

Data Sources: SC REC Data, 2007.
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Observed seabed sediments and distribution within the study area from the SCREC and EECHM

Figure 13



Rampion OWF application area
Far field study boundary
Place names

Date	By	Size	Version
Aug 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:500,000	
QA		FMM	

3953 - Fig_Geological_Features.mxd

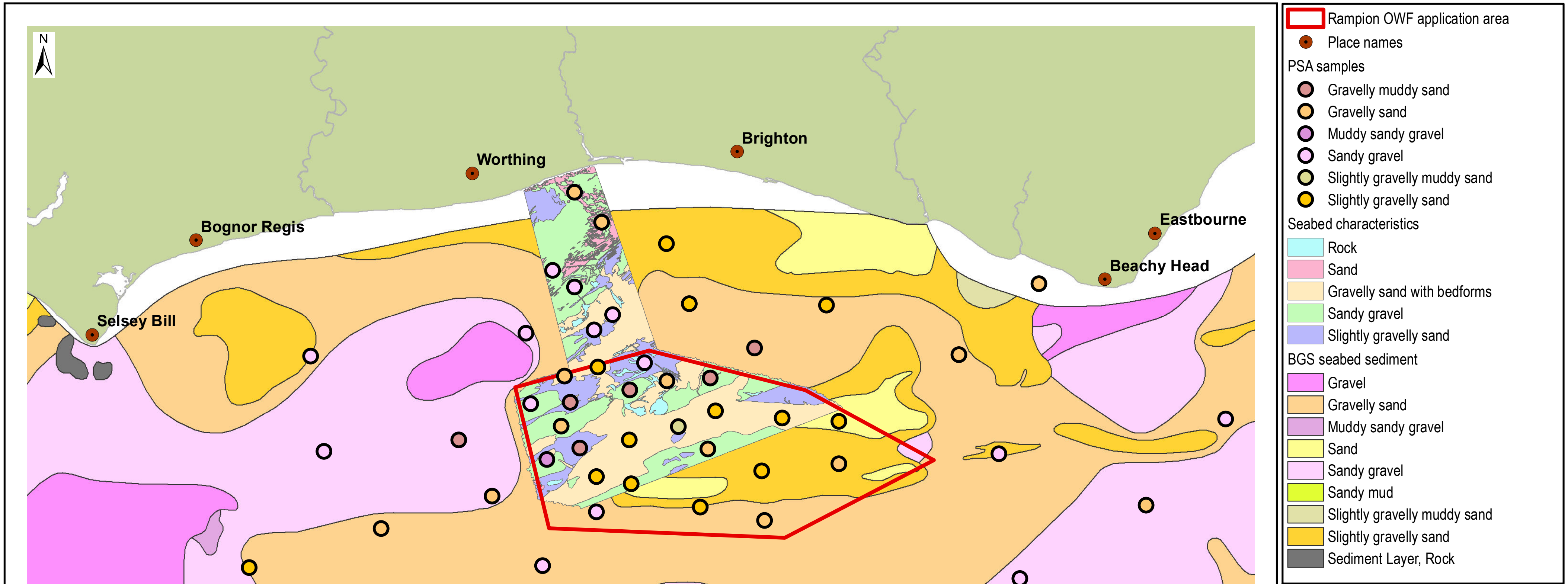
Produced by ABPmer Ltd

Data Sources: SC REC Data, 2007.
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Geological features and relative sediment thickness within and nearby to the OWF application site

Figure 14



Date	By	Size	Version
Sept 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:400,000	
QA		FMM	

3953 - Fig_Seabed_Sed_Prim.mxd

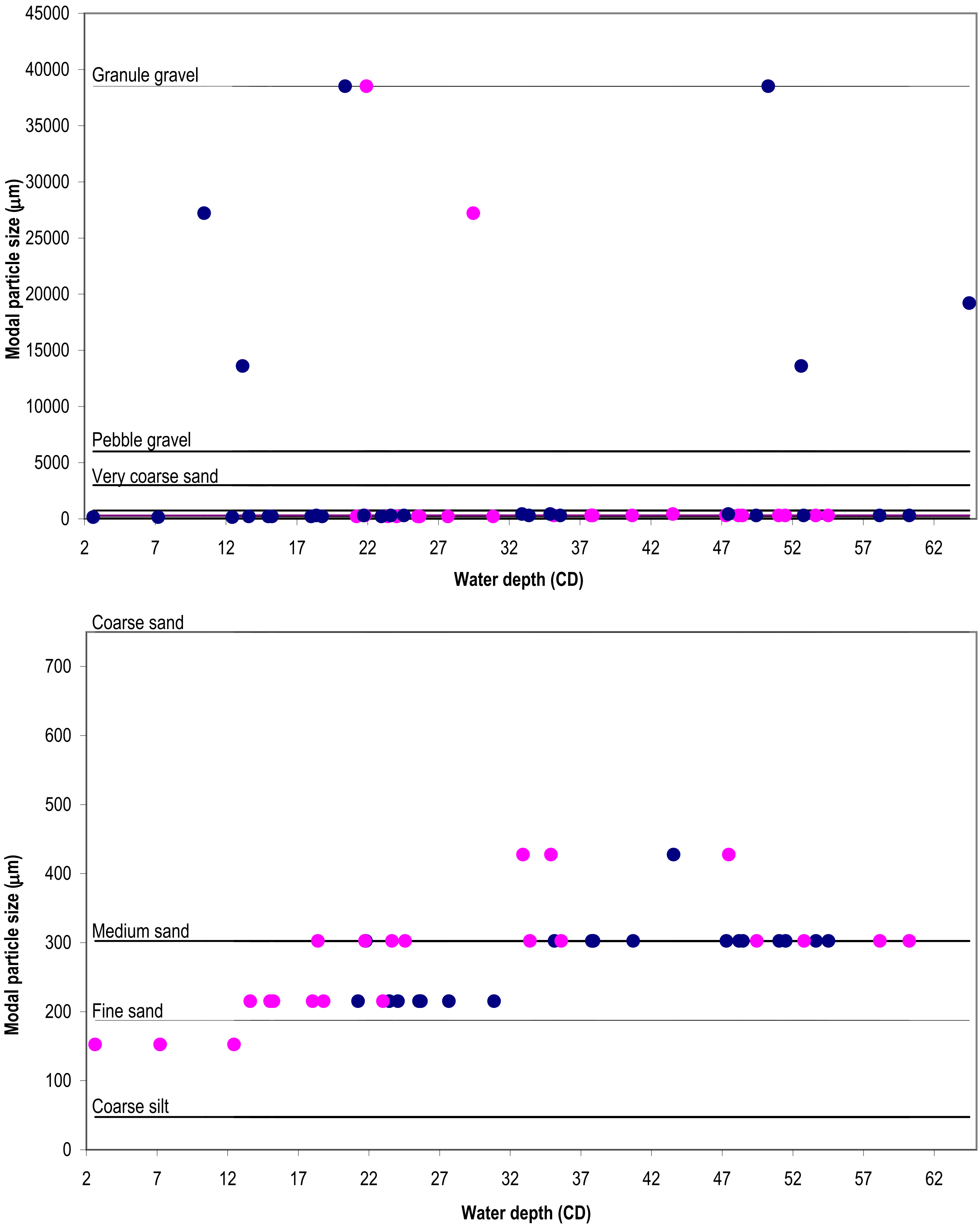
Produced by ABPmer Ltd

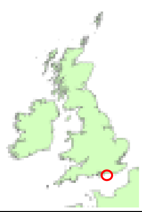
Data Sources: OSIRIS (2011) © SeaZone Solutions Limited, 2011, [04210.002]

ABP mer
marine environmental research

Seabed sediments interpreted from obtained grab samples and Osiris (2011) geophysical surveys

Figure 15





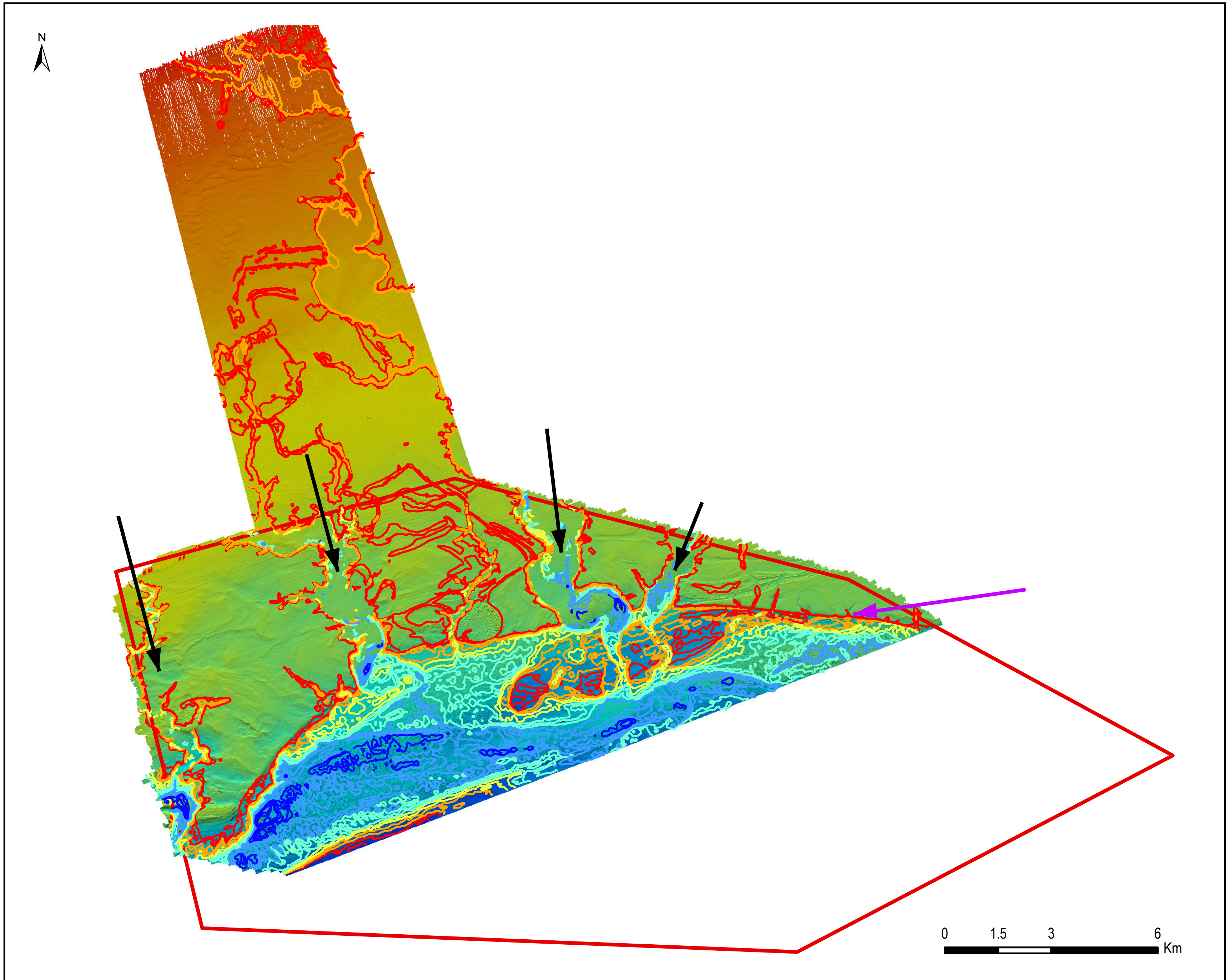
Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_Fig24-25.xls			
Produced by ABPmer Ltd.			

● Modal particle size for grab samples within the OWF application site

● Modal particle size for grab samples nearby to the OWF application site

Relationship between Modal Grain Size and Water Depth within and nearby to the OWF Application Site

Figure 16



Rampion OWF application area

Paleochannel

Escarpment

Isopachs
Thickness (m)

0.00 - 4.00

4.01 - 8.00

8.01 - 12.00

12.01 - 18.00

18.01 - 24.00

24.01 - 36.00

Depth mLAT

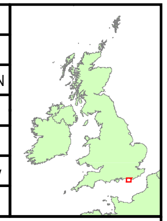
-5.00

-18.33

-41.67

-65.00

Date	By	Size	Version
Sept 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:52,000,000	
QA		FMM	
3953 - Fig_Geological_Feat_Primary			
Produced by ABPmer Ltd			

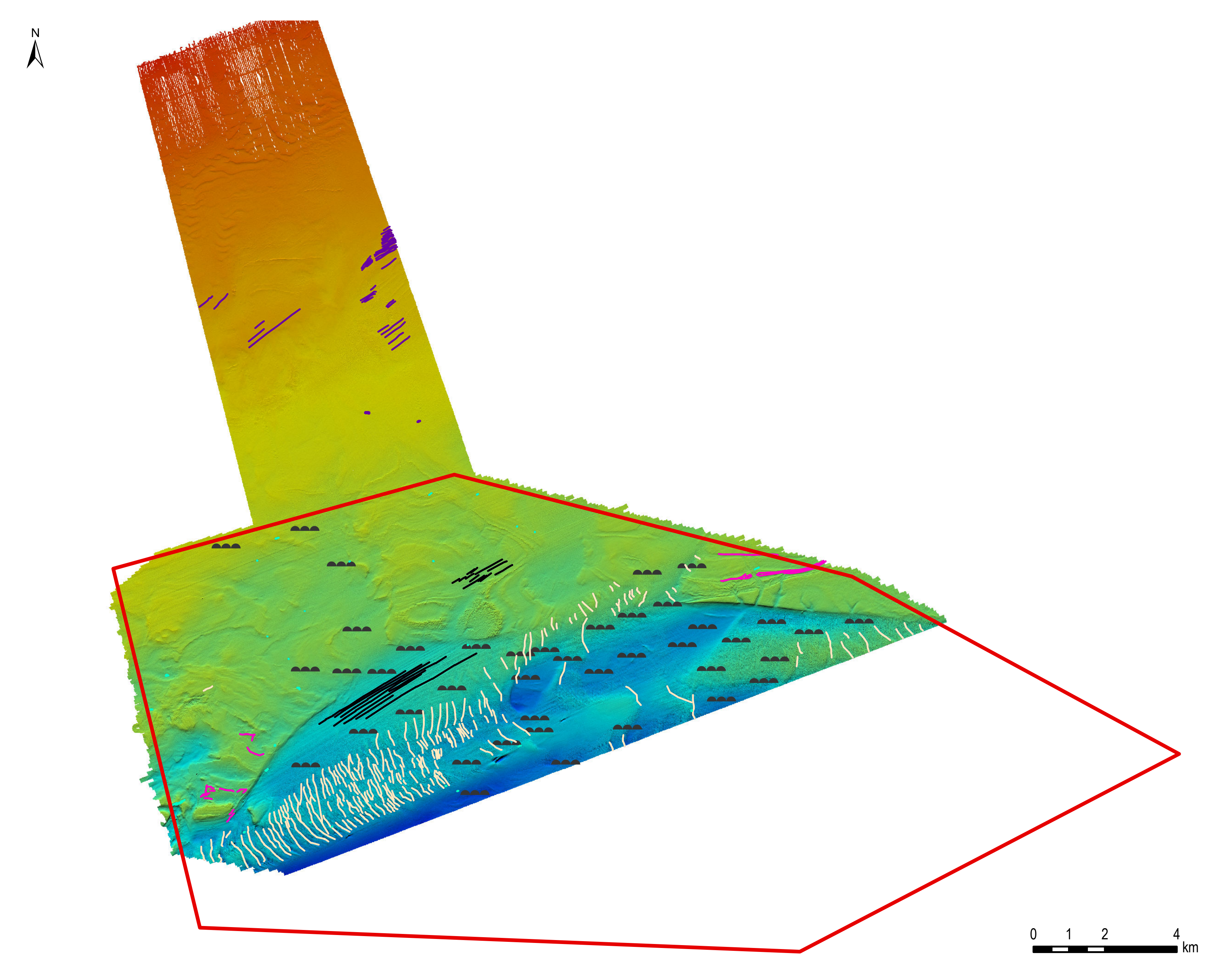


Data Sources: SC REC Data, 2007 & EE REC Data, 2005
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Isopachyte of significant geological features within the OWF application site

Figure 17



Rampion OWF application area

Seabed features

- Gravel streaks
- Linear sonar targets
- Rock ridges
- Sandwave crests
- Linear seabed features
- Megaripples

Depth mLAT

-5.00

-18.33

-41.67

-65.00

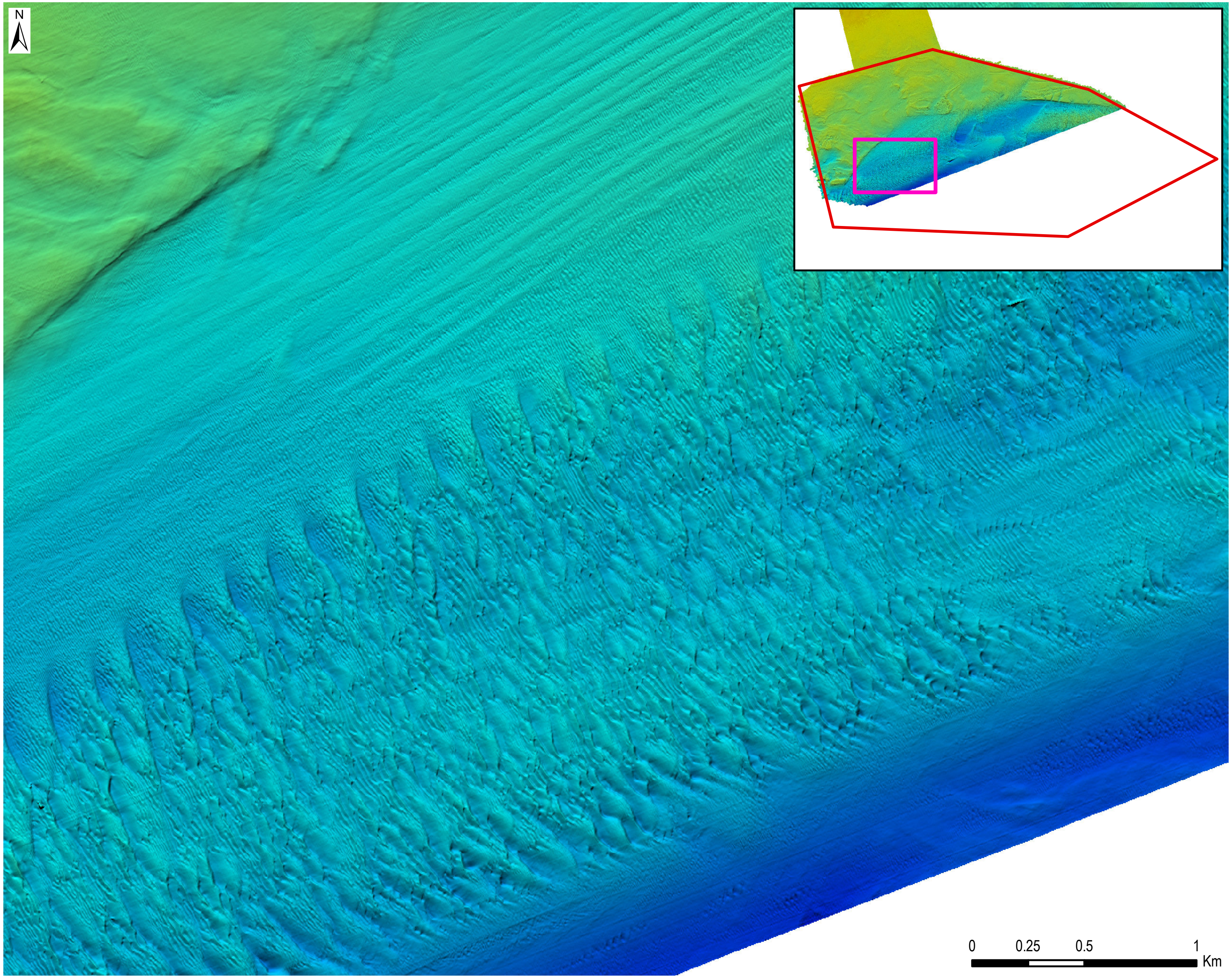
Date	By	Size	Version
Sept 11	NMW	A4	1
Projection	WGS84 UTM 30N		
Scale	1:152,000		
QA	FMM		
3953 - Fig_Bathy_Primary.mxd			
Produced by ABPmer Ltd			

Data Sources: SC REC Data, 2007
NOT TO BE USED FOR NAVIGATION

ABP mer
marine environmental research

Swath bathymetry and morphological features within the OWF application site

Figure 18



Rampion OWF application area

Depth mLAT

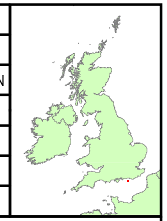
-5.00

-18.33

-41.67

-65.00

Date	By	Size	Version
Sept 11	NMW	A4	1
Projection		WGS84 UTM 30N	
Scale		1:25,000	
QA		FMM	
3953 - Fig_Bathy_Zoom_Prim.mxd			
Produced by ABPmer Ltd			



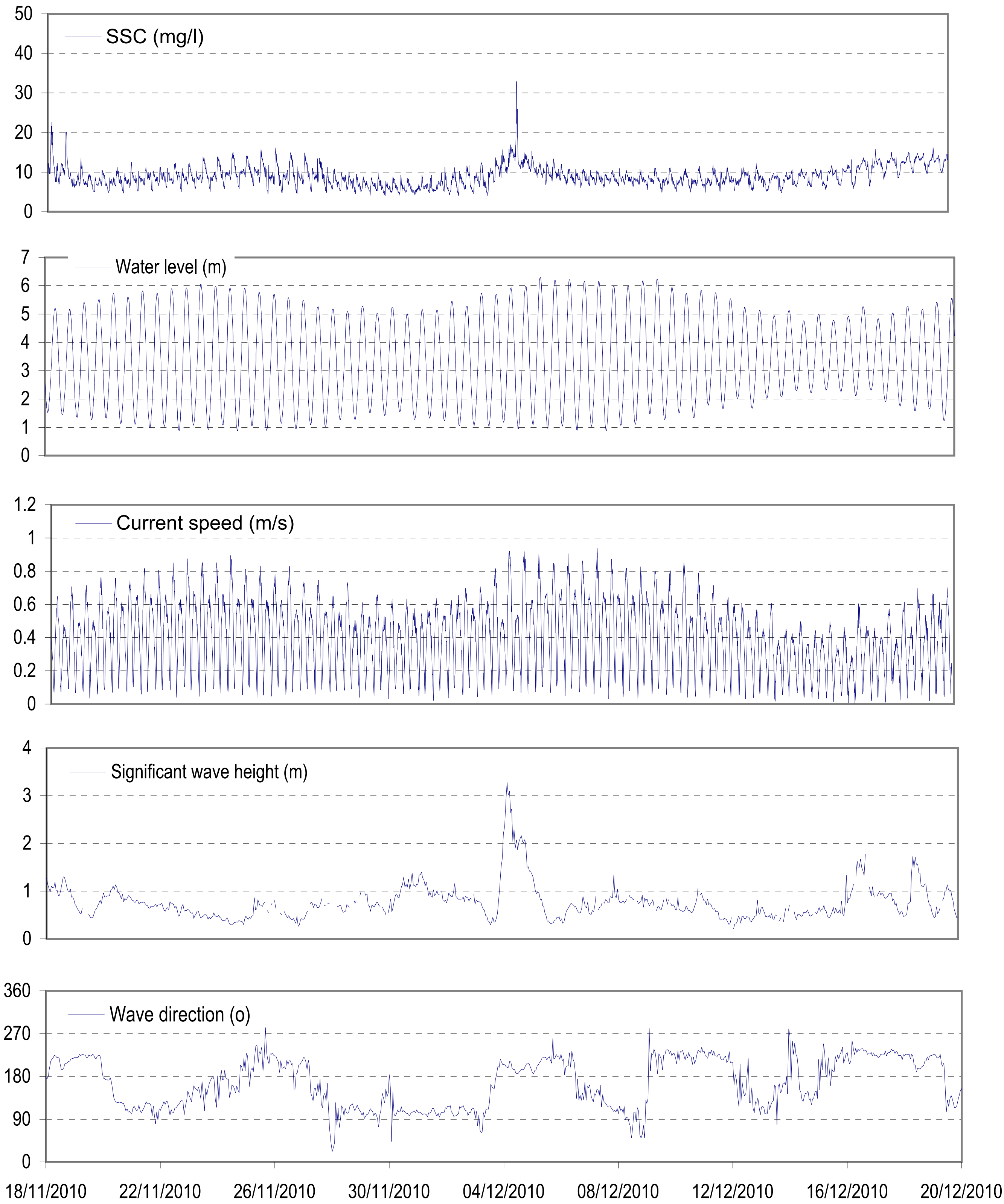
Data Sources: SC REC Data, 2007 & EE REC Data, 2005

NOT TO BE USED FOR NAVIGATION

ABP mer marine environmental research

Bedforms within the OWF application site

Figure 19

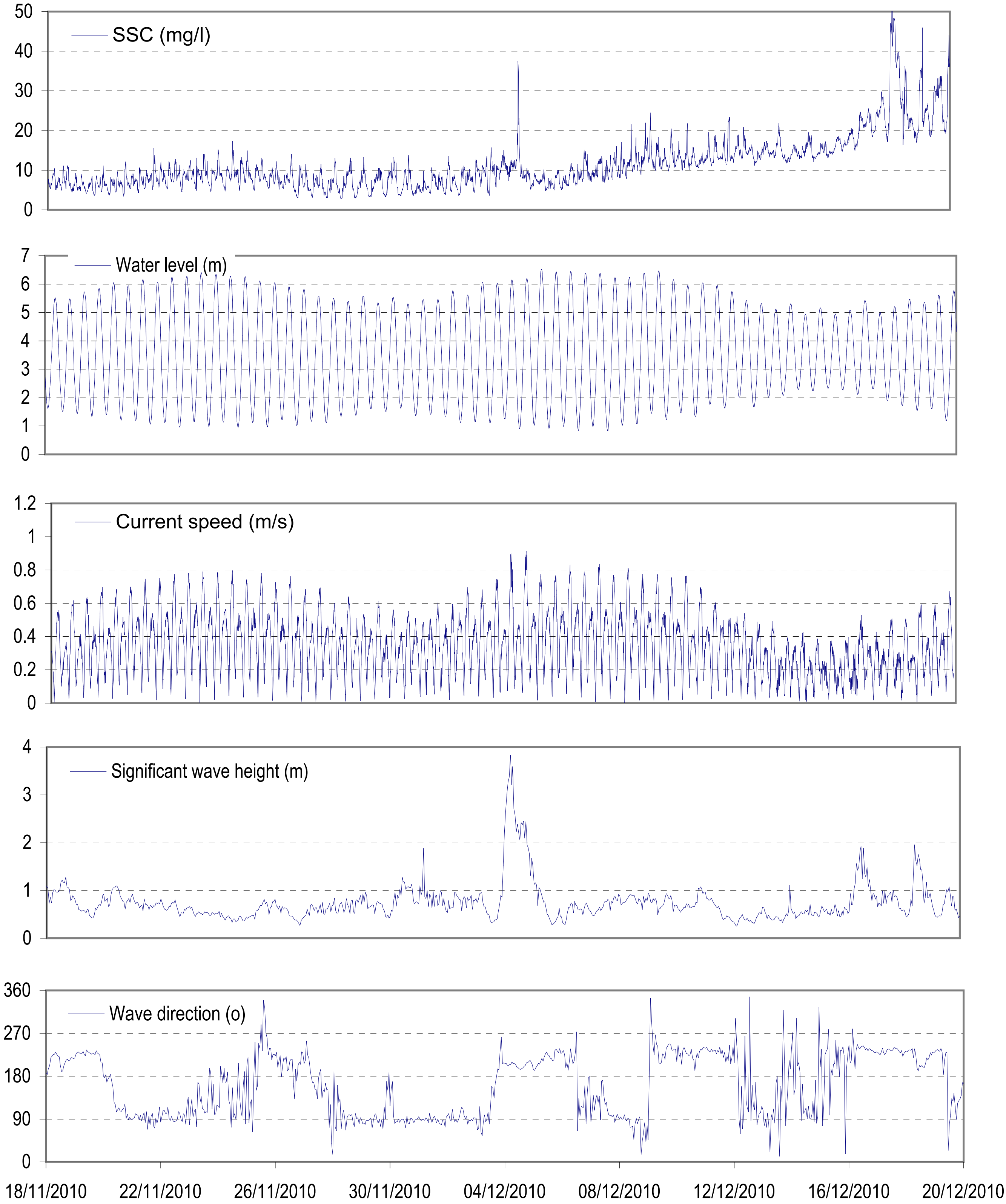


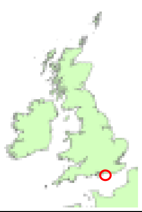
Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_Fig21-23.xls			
Produced by ABPmer Ltd.			

ABP mer marine environmental research

Relationship Between Suspended Sediment Concentrations and Selected Hydrodynamic Variables, Location L1

Figure 20



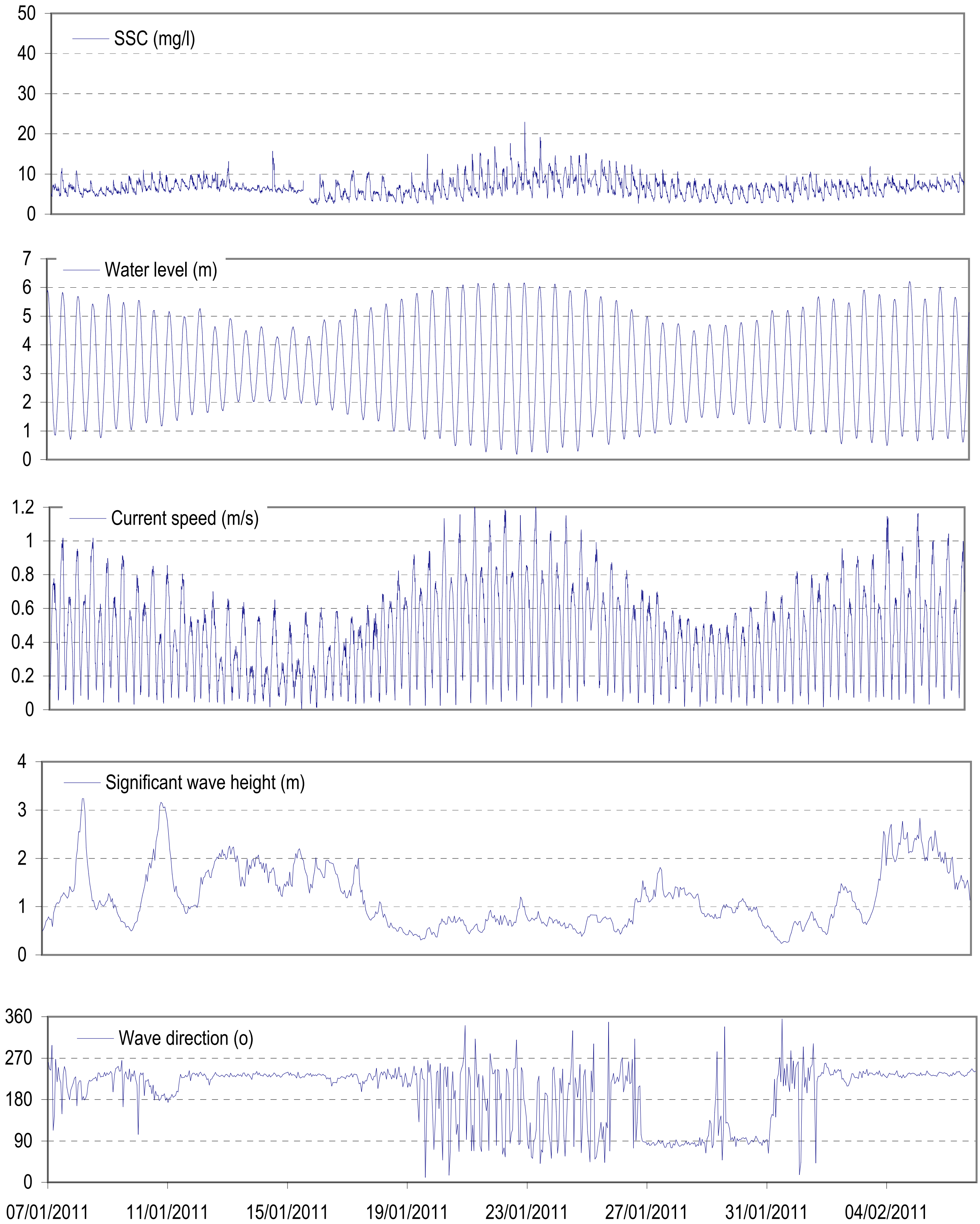


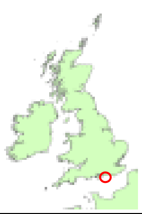
Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_Fig21-23.xls			
Produced by ABPmer Ltd.			

ABP mer
marine environmental research

Relationship Between Suspended Sediment Concentrations and Selected Hydrodynamic Variables, Location L2

Figure 21



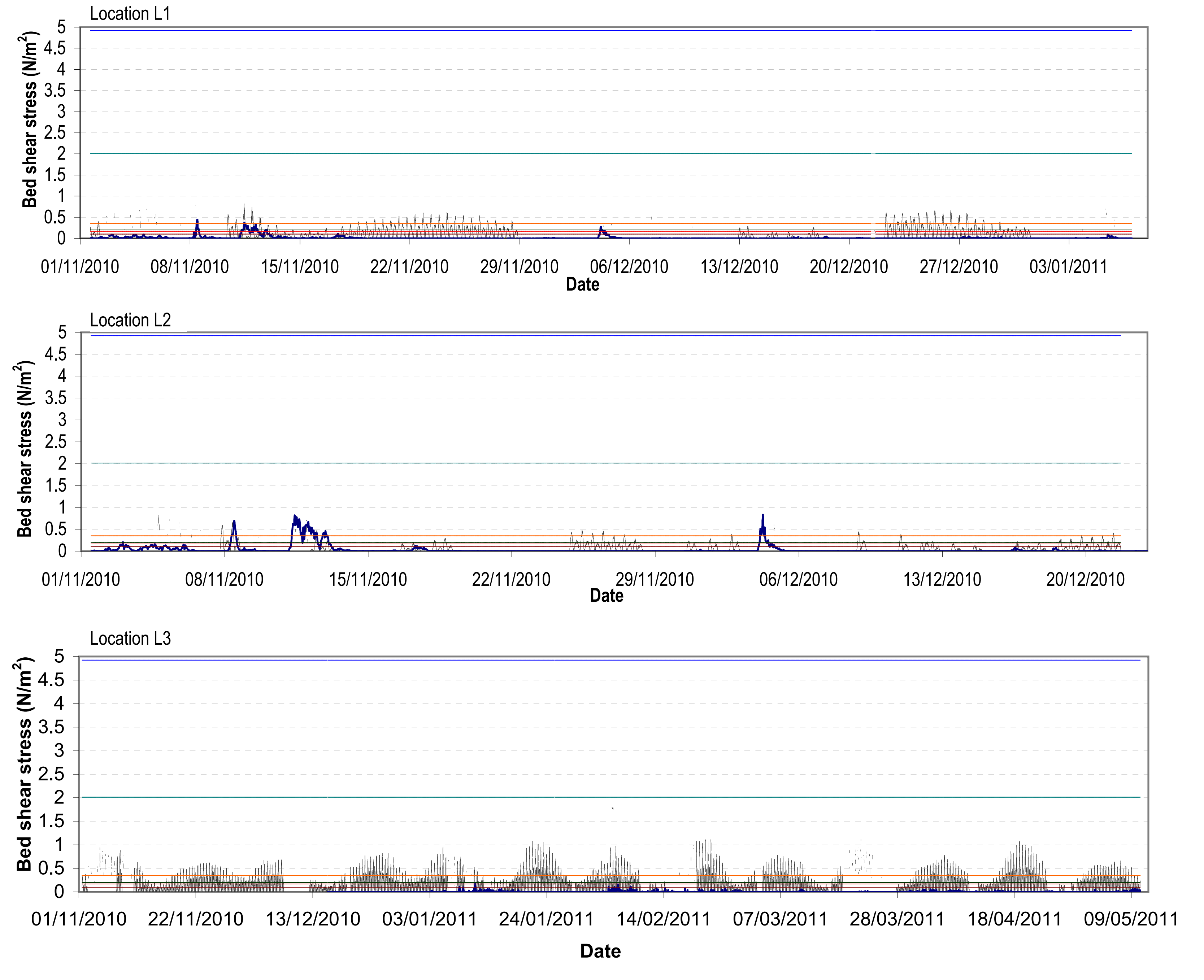


Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_Fig21-23.xls			
Produced by ABPmer Ltd.			

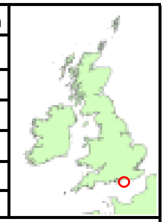
ABP mer marine environmental research

Relationship Between Suspended Sediment Concentrations and Selected Hydrodynamic Variables, Location L3

Figure 22



Date	By	Size	Version
Oct 11	AMB	A4	1
Projection	n/a		
Scale	n/a		
QA	NMW		
ReportFigures_Fig24-25.xls			
Produced by ABPmer Ltd.			

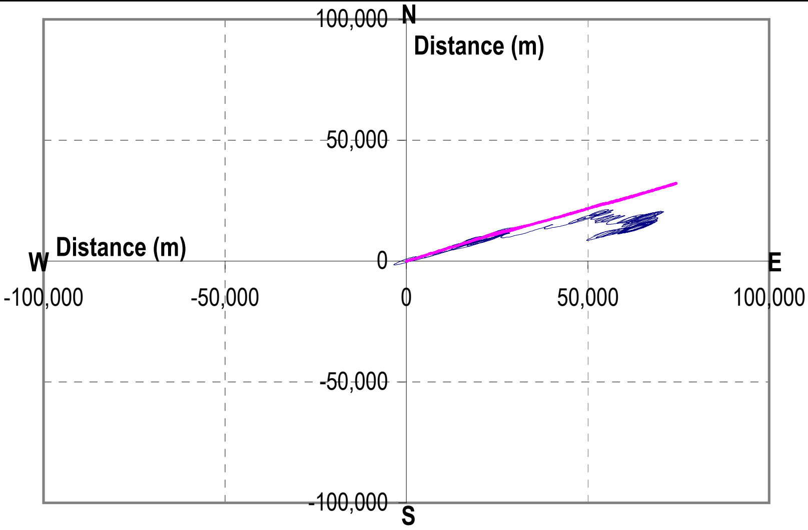


ABP mer
marine environmental research

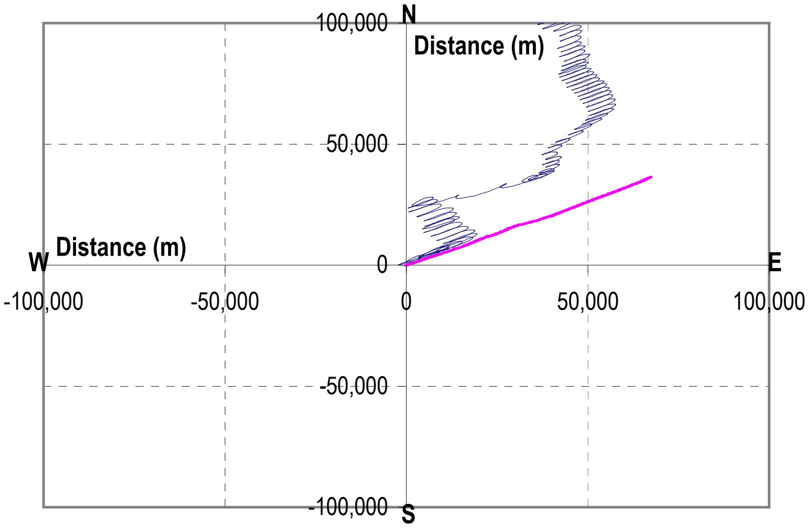
Tide and Wave Induced Bed Shear Stress and Mobility Thresholds at the Metocean Surveyed Locations

Figure 23

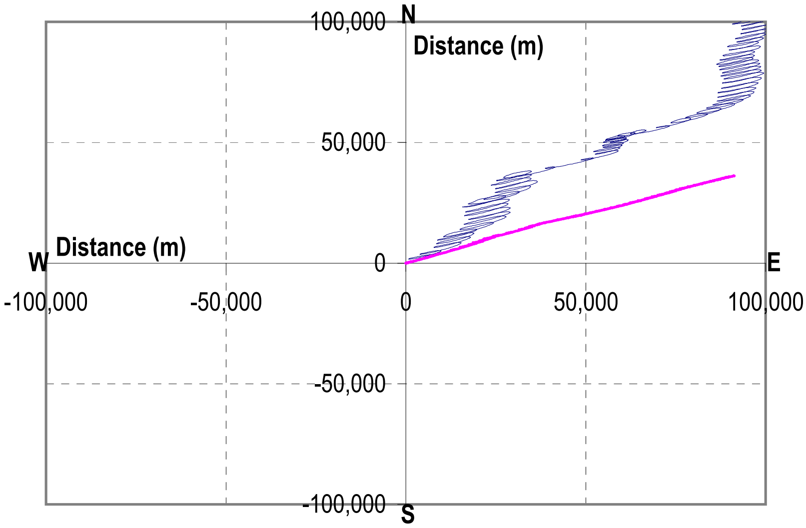
Location L1

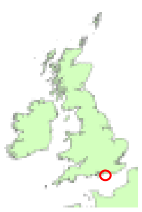


Location L2



Location L3





Date	By	Size	Version
Oct 11	AMB	A4	1
Projection		n/a	
Scale		n/a	
QA		NMW	
ReportFigures_Fig24-25.xls			
Produced by ABPmer Ltd.			

Net Potential Advection

Coarse Silt Sediment net pathway

ABP mer
marine environmental research

Progressive Vector Analysis Demonstrating Residual Flow and Projected Displacement of Fine Sediment after 30-Days

Figure 24

ABP Marine Environmental Research Ltd (ABPmer)
Quayside Suite, Medina Chambers, Town Quay, Southampton SO14 2AQ

T +44 (0)23 80 711840
F +44 (0)23 80 711841
E enquiries@abpmer.co.uk

www.abpmer.co.uk

Creating sustainable solutions for the marine environment