E.On Ltd

Coastal Processes Scoping Zone EON02, South Coast

Date:	**November 2008**
Project Ref:	**R/3802/2**
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ABP mer
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Executive Summary

The proposed zone EON02 is located in the Eastern English Channel, along a stretch of coast extending from east of the Isle of Wight to Dungeness. Whilst the tidal regime exhibits relatively high energy, the wave regime is not as energetic as other sites around the UK coast. Surface sea bed sediments are predominately sands and gravels, with a proportion of fines observed in the east. Information regarding mobile bed forms is absent from the west, with small and medium scale features present in the east. This zone has a high proportion of marine aggregate developers present, which will need consideration when examining potential in-combination effects.

It is likely that measures will need to be in place to minimise scour effects following turbine installation. Further, planning will be required during the construction and de-commissioning phases to ensure the potential for sediment plume release and any over-lapping with plumes released by other sea bed users is minimal. For example, such activities could be restricted to neap tides, when the tidal energy is lower.

Abbreviations

ABPmer	ABP Marine Environmental Research Ltd
BODC	British Oceanographic Data Centre
CCO	Channel Coastal Observatory
CD	Chart Datum
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
EA	Environmental Assessment
EA	Environment Agency
EECMHM	Eastern English Channel Marine Habitat Map
EIA	Environmental Impact Assessment
E.On	E.On Ltd
EON02	pre-selected zone on South Coast
ES	Environmental Statement
gmS	gravely muddy Sand
gS	gravely Sand
(g)S	slightly gravely Sand
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
msG	muddy sandy Gravel
ODN	Ordnance Datum Newlyn
OWF	Offshore Wind Farm
SG	sandy Gravel
SEA	Strategic Environmental Assessment
smG	sandy muddy Gravel
ssc	suspended sediment concentration
UKHO	United Kingdom Hydrographic Office

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1. Introduction

The Crown Estate is progressing with plans for a third seabed leasing round for wind farm development in order to assist in the delivery of the Government's requirements for increasing offshore wind capacity; Round 3. This has led to those energy companies interested in entering the process, to develop strategies which will enable them to secure the licence for sea bed areas for offshore wind developments. One such company, E.On Ltd (E.On), has begun an initial site selection process for this purpose. This initial selection led to the identification of six zones for potential development. An integral part of refining the site selection further is the description of coastal processes within each zone to (i) develop an understanding of each site; and (ii) identify any risks which may result in the zone being unsuitable for development, in terms of coastal processes. ABP Marine Environmental Research Ltd (ABPmer) has been commissioned to undertake the identification of the coastal processes within the pre-selected zones.

This report details the coastal processes appropriate to zone EON02, South Coast. Due to the large extent of this zone, 1,976 km^2, combined with the timescales available and the current stage in the selection process, the information is provided at a generic, broad-scale level. In addition to identifying the coastal processes of relevance to the zone, this report also provides a qualitative description of any risks which may have 'show-stopping' consequences. The sources of data and scope of this study has largely been informed by the document: Guidelines for the use of metocean data through the life cycle of a marine renewable energy development (Cooper *et al* 2008).

2. Study Area

Zone EON02 is located along the south coast of England within the English Channel. The English Channel has two open entrances, with the wider, more exposed, into the North Atlantic and the narrower entrance to the North Sea present via the Straits of Dover. The Channel decreases both in width and depth from west to east:

- Widths decrease from, approximately, 160km to 35km from the west to eastern entrance; and
- Depths reduce from, approximately, 100m to less than 40m from west to east.

The English Channel is a relatively shallow shelf sea, fully exposed to hydrodynamic conditions originating from the North Atlantic. It is predominately covered by gravel populations in the deeper waters, with sand sized material located in the shallower waters (nearshore and within the Dover Straits) (James *et al*., 2007). The sea bed has both negative and positive morphological features.

More specifically, EON02 is located in the Eastern English Channel, offshore from a stretch of coastline which extends from east of the Isle of Wight to Dungeness. The proposed zone is located in shallow water depths, ranging from 11m to 64m, with relatively gentle sea bed slopes. The location of this zone is shown in Figure 1. The proposed zone is in close proximity to other marine applications, most notably aggregate extraction licence areas. Further, the shoreline immediately landward of the EON02 is, in places, designated and has coastal defences. These are of primary importance for cable landfall.

In part due to the interest in the English Channel by other marine users, it is a well studied area with numerous reports available which are of interest for coastal processes. The principal data sources which have been used within this study include:

- BODC database;
- Wavenet database;
- Channel Coastal Observatory (CCO) database;
- Marine Renewables Atlas;
- UKHO charts;
- BGS sediment data and associated reports (i.e. Graham *et al*., 2001);
- The Eastern English Channel Marine Habitat Map (James *et al*., 2007);
- Marine aggregate Environmental Assessments (EA) (i.e. EMU, 2007); and
- Journals, papers and reports.

3. Coastal Process Review

The following section provides a review of the coastal processes based upon currently available information.

3.1 Hydrodynamic Regime

The hydrodynamic regime is defined here as the behaviour of bulk water movements driven by the action of tides and non-tidal influences, such as meteorological conditions. The hydrodynamic regimes have been characterised in terms of water elevations and currents.

3.1.1 Water Levels

At present, the best available data source to define local tidal conditions along the south east coast is published by the United Kingdom Hydrographic Office (UKHO) through tide tables, Co-tidal Charts and Tidal Streams Atlases. Using a co-tidal chart (Chart 5058) it is possible to make a first order approximation of tidal conditions within EON02 by extrapolation from a standard port. For this area, the co-tidal relationship should always be referenced to Portsmouth. This is summarised in Table 1.

Table 1. Offshore tidal characteristics for EON02

Tidal Characteristic			Worthing West[1]	Worthing East[1]	Hastings[1]
Tide Level	Highest Astronomical Tide	HAT	5.0	6.5	8.4
	Mean High Water Springs	MHWS	4.6	6.0	7.7
	Mean High Water Neaps	MHWN	3.7	4.9	6.3
	Mean Sea Level	MSL	2.8	3.7	4.8
	Mean Low Water Neaps	MLWN	1.9	2.4	3.1
	Mean Low Water Springs	MLWS	0.8	1.0	1.3
	Lowest Astronomical Tides	LAT	0.1	0.1	0.2
Tidal Range	Extreme Difference	HAT - LAT	4.9	6.4	8.2
	Spring Range	MHWS – MLWS	3.8	5.0	6.4
	Neap Range	MHWN - MLWN	1.8	2.5	3.2

NB. All predicted heights are in metres above CD (2.73 m below ODN at Portsmouth).
1 Data derived from UKHO Co-tidal chart 5058 (1971) and Portsmouth standard Port data (UKHO, 2007). Figure 1 shows the extent of the three divisions of EON02, undertaken for ease of description only

Tidal parameters along the south coast adjacent to EON02 can be derived using the standard port of Shoreham and parameters outlined in UKHO (2007). Using this technique tidal parameters for Bognor Regis (approximately 18 km north of the western part of EON02), Shoreham (approximately 9 km north of the central part of EON02) and Eastbourne (approximately 13 km north of the eastern part of EON02). The locations of these points are shown in Figure 1 and tidal data for these locations are given in Table 2.

Table 2 Summary of coastal tidal data adjacent to EON02

Tidal Characteristic			Bognor Regis[1]	Shoreham[1]	Eastbourne[1]
Tide Level	Highest Astronomical Tide	HAT		6.9	
	Mean High Water Springs	MHWS	5.7	6.3	7.4
	Mean High Water Neaps	MHWN	4.3	4.8	5.4
	Mean Sea Level	MSL		3.4	
	Mean Low Water Neaps	MLWN	1.7	1.9	2.1
	Mean Low Water Springs	MLWS	0.5	0.6	0.7
	Lowest Astronomical Tides	LAT		0.1	
Tidal Range	Extreme Difference	HAT - LAT		6.8	
	Spring Range	MHWS – MLWS	5.2	5.7	6.7
	Neap Range	MHWN - MLWN	2.6	2.9	3.3

NB. All predicted heights are in metres above CD (3.27 m below ODN at Shoreham).
1 Secondary Port tidal parameters sourced from UKHO (2007) and derived from Shoreham Standard Port data

The Co-tidal chart (5058) for the British Isles shows that the tidal conditions in the eastern English Channel are governed by a degenerate tidal amphidrome (a nodal position with zero tidal influence) situated inland of Weymouth. The tidal wave travels in an anticlockwise direction around the amphidrome indicating that the tide travels in an easterly direction along the channel. The tidal range increases in distance from the amphidrome meaning that tides increase in range in an easterly direction through the study area, this is shown in both Tables 1 and 2.

3.1.1.1 Non-tidal influences

Superimposed on the regular tidal behaviour, various episodic non-tidal effects may be present, many of these originate from meteorological influences. Persistent winds can generate wind-driven currents, set-up water levels and develop sea states that lead to wind-wave generation. Atmospheric pressure variations can also raise or depress the water surface to generate positive or negative surges, respectively.

Surges are formed by rapid changes in atmospheric pressure with an inverse relationship. During a positive surge, low atmospheric pressure raises the water surface and during a negative surge, high atmospheric pressure depresses the water surface. These effects can cause water levels to fluctuate considerably above or below the predicted tidal level. Whilst positive surges may have implications for structural design and the assessment of impacts on coastal processes, negative surge events may also need to be taken into consideration when assessing conditions that may be experienced during installation.

A comprehensive analysis of extreme water levels using tidal records was undertaken by ABPmer (2004) along the south coast of England. Extreme water levels were calculated by fitting distributions to the time-series of annual maximum water levels. The 2060 predictions were based on a assumed rise in mean sea level of 6mm per year from the year 2000 onwards. The results of relevance to this study are summarised in Tables 3 and 4.

Table 3 Extreme water level predictions at locations relevant to EON02 for the year 2000

Station	Return Period (years)								
	2	5	10	20	50	100	200	500	1000
	Metres to Ordnance Datum Newlyn								
Littlehampton	3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3
Shoreham	3.9	4.0	4.1	4.1	4.2	4.3	4.3	4.4	4.4
Newhaven	3.9	4.0	4.1	4.1	4.2	4.3	4.3	4.4	4.4
Pevensey	4.4	4.5	4.6	4.7	4.8	4.9	4.9	5.0	5.1
Rye	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.3

Table 4 Extreme water level predictions at locations relevant to EON02 for the year 2060

Station	Return Period (years)								
	2	5	10	20	50	100	200	500	1000
	Metres to Ordnance Datum Newlyn								
Littlehampton	3.8	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7
Shoreham	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.7	4.8
Newhaven	4.3	4.4	4.4	4.5	4.6	4.6	4.7	4.7	4.8
Pevensey	4.8	4.9	5.0	5.1	5.2	5.2	5.3	5.4	5.5
Rye	4.9	5.1	5.2	5.3	5.4	5.5	5.5	5.6	5.7

3.1.1.2 Future sea level rise

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

Future sea level rise results from the net effect of global change and the local change in land levels due to glacial rebound and subsidence. The guidance for coastal management in the south of the UK is summarised in Table 5.

Table 5. Future sea level rise guidance for the study area

Region	Assumed Vertical Land Movement (mm/yr)[1]	Net Sea Level Rise (mm/yr)[2]				Previous Allowances[3]
		1990-2025	2025-2055	2055-2085	2085-2115	
East of England, East Midlands, London, SE England (South of Flamborough Head)	-0.8	4.0	8.5	12.0	15.0	6mm/yr constant

1 Vertical land movement from Shennan and Horton (2002).
2 Global mean sea level rise projections up to the 2080s were taken from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) High estimates. Global mean sea level rise projections for the 2110s were extrapolated from the 2020s, 2050s and 2080s.
3 Updated figures now reflect an exponential curve, and replace the previous straight line graph representations.

(Source: Defra, 2006)

3.1.2 Tidal Currents

3.1.2.1 BODC data

A review of the BODC data archives indicated that the study area has poor data coverage, with current meter data only in the vicinity of the western part of EON02 (Figure 1). The results of these deployments are summarised in Table 6.

Table 6. Summary of BODC current data in the vicinity of EON02

Site No.	BODC ID	Depth of Deployment (m)	Start Date	End Date	Current Speed (m/s)		
					Minimum	Maximum	Average
A	49879	13	14/09/1984	01/10/1984	0.012	1.571	0.703
	49880	18	14/09/1984	01/10/1984	0.012	1.439	0.645
B	100283	18	28/04/1985	21/05/1985	0.011	1.646	0.718
	100271	26	28/04/1985	18/05/1985	0.011	1.359	0.531
C	49923	13	10/12/1983	17/12/1983	0.012	0.934	0.465
	49935	21	10/12/1983	17/12/1983	0.012	0.844	0.423

3.1.2.2 UKHO

Tidal stream data is available on UKHO Charts 1652: Selsey Bill to Beachy Head and 536: Beachy Head to Dungeness, and includes details at various locations for tidal streams to assist navigation. Such data provides an indicative value of surface flow through the tide and is quoted relative to high water at Dover. Of these data there are a number of tidal stream locations in close proximity to EON02.

From Chart 1652, Diamond C is within the western part of EON02 and Diamond D is situated within the central part of EON02, towards the north of the site (Figure 1). The variation of flow at these locations through a tidal cycle is summarised in Table 7 and Figure 2.

Table 7. Summary of tidal stream data from Chart 1652

Hours		Tidal Diamond C 50º36'.5N 0º41'.2W			Tidal Diamond D 50º44'.1N 0º20'.5W		
		DirectionºN	Spring (m/s)	Neaps (m/s)	DirectionºN	Spring (m/s)	Neaps (m/s)
Before HW	-6	72	0.5	0.3	93	0.4	0.2
	-5	72	1.2	0.6	57	0.8	0.5
	-4	72	1.5	0.7	52	0.8	0.5
	-3	72	1.2	0.6	52	0.8	0.4
	-2	72	0.7	0.4	58	0.5	0.3
	-1	72	0.1	0.1	310	0.1	0.1
HW	0	252	0.5	0.3	267	0.4	0.2
After HW	1	252	1.1	0.6	250	0.6	0.4
	2	252	1.3	0.6	243	0.8	0.5
	3	252	1.1	0.6	238	0.7	0.4
	4	252	0.8	0.4	221	0.6	0.3
	5	252	0.4	0.2	191	0.4	0.3
	6	72	0.2	0.1	127	0.3	0.2

From Chart 536, Diamond D and E are situated within the eastern part of EON02. The tidal flows at these locations are plotted in Figure 3 and summarised in Table 8.

Table 8. Summary of tidal stream data from Chart 536

Hours		Tidal Diamond D 50º42'.7N 0º27'.0E			Tidal Diamond E 50º48'.4N 0º45'.7E		
		DirectionºN	Spring (m/s)	Neaps (m/s)	DirectionºN	Spring (m/s)	Neaps (m/s)
Before HW	-6	248	0.4	0.2	220	0.6	0.3
	-5	67	0.3	0.2	227	0.5	0.3
	-4	68	1.0	0.5	233	0.2	0.1
	-3	68	1.3	0.8	37	0.4	0.2
	-2	68	1.2	0.7	41	0.5	0.3
	-1	68	0.6	0.3	46	0.4	0.3
HW	0	67	0.1	0.1	42	0.4	0.2
After HW	1	248	0.5	0.3	48	0.3	0.2
	2	247	0.7	0.4	56	0.2	0.1
	3	248	0.9	0.5	183	0.1	0.1
	4	248	0.9	0.5	209	0.2	0.1
	5	248	0.8	0.5	216	0.5	0.3
	6	249	0.6	0.4	221	0.6	0.3

3.1.2.3 Marine Renewables Atlas

In addition, current data calculated throughout the water column is available from the Marine Renewables Atlas (ABPmer *et al*, 2008), the tidal current data is presented as a series of grid cells. The data within EON02 can be summarised as follows:

- At mid-water depth the averaged peak spring current ranges between 1.63 and 0.43m/s;
- At mid-water depth the averaged peak neap current ranges between 0.87 and 0.23m/s;
- At the near bed the averaged peak spring current ranges between 1.33 and 0.33m/s;
- At the near bed averaged peak neap current ranges between 0.71 and 0.18m/s.

Data from the grid cell located to the west, east, seaward and landward parts of the EON02 zone have been presented as current speeds with water depth for both springs and neaps (Figure 4a-d).

Spatial variation of the current speeds across EON02 is observed. As shown in Figure 5 and 6, higher speeds are located towards the western part of the site as opposed to the central and eastern parts.

3.1.3 Waves

Waves result from the transfer of wind energy to the water surface. The amount of wind energy transfer and wind-wave development is a function of the available fetch distance across which the wind blows, wind speed, wind duration and the original state of the sea. The longer the fetch distance, the greater the potential there is for the wind to interact with the water surface and generate waves. In shallower water, depth becomes an additional limiting factor on the size of the waves.

Since wind-waves originate from meteorological forcing, the wave regime is highly episodic and exhibits strong seasonal variation. In deep water, waves will move across the sea surface without any influences from the seabed. However, as waves move into shallower water the orbital motion of the wave through the water column eventually reaches the seabed where frictional drag changes the shape of the wave and refraction, shoaling (wave steepening) and eventually wave breaking will occur as the waves move into progressively shallower water.

Within the eastern English Channel the largest fetch is from the west and south west which also coincides with the dominant wind directions. Waves can also be generated from the south and east but as the fetch is limited these will be of a short period and generally of a smaller size.

Site specific information on wave data has been collated to characterise the local wave climate and to identify requirements for any additional data collection to support the detailed needs of this project. The available wave data is as follows:

- Hastings wave buoys from WaveNet;
- Hayling Island, Pevensey Bay and Rustington wave buoys from the Channel Coastal Observatory (CCO); and
- Wind and wave frequency distributions from around the British Isles taken from the Marine Renewables Atlas (ABPmer *et al*, 2008).

3.1.3.1 WaveNet wave buoys

Data in the vicinity of EON02 was downloaded from the WaveNet website and reviewed. The only relevant wave data available was from the Hastings deployments, the positions of these wave buoys are shown in Figure 1 and a deployment summary is provided in Table 9.

Table 9. Summary of Hastings wave buoy deployments

Buoy Name	Dates of Deployments		Depth of Water (m)
	Start	Finish	
Hastings Box North	15 Jul 00	16 Sep 00	6
Hastings North	09 Oct 99	17 Nov 99	29
Hastings South	09 Oct 99	17 Nov 99	23

As Table 9 shows, the wave data available is of limited duration and therefore does not adequately represent the seasonal variation that could be expected in the wave climate. Because of this limitation the WaveNet data has not been used at this time to characterise the wave climate at EON02.

3.1.3.2 CCO wave buoys

Data in the vicinity of EON02 was also downloaded and reviewed from the CCO website (http://www.channelcoast.org). Relevant data deployments are at Hayling Island, Pevensey Bay and Rustington (Figure 1), all of these buoys had data available between 1st January 2003 and the 31st December 2007.

A frequency analysis of wave heights against wave direction using bin sizes of 30º sectors in direction and 0.5m in height is presented as a series of wave roses (Figure 7) to demonstrate the primary wave direction events throughout the study area. This figure shows that at Hayling Island the prevailing wave direction is from the southerly sector and wave heights can reach up to 3.5 m. At both Pevensey Bay and Rustington the prevailing wave direction is the south west and wave heights can reach 4.2 and 4.8 m respectively.

A similar frequency analysis was performed to define the relationship between average (zero crossing) wave period and significant wave height, using bin sizes of 1 seconds and 0.5m, respectively. This reveals that wave periods are generally small to moderate with no value exceeding 10.5 seconds at Hayling Island 10 seconds at Rustington, and 7.5 seconds at Pevensey Bay. This indicates a general decrease in maximum wave period in a west to east direction. The following observations are also made:

- At Hayling Island the most frequent wave period is in the range 3 to 4 seconds, accounting for 49% of the record and the most common wave height is in the range 0 to 0.5 m, accounting for 48% of all records.
- At Rustington the most frequent wave period is in the range 3 to 4 seconds, accounting for 45% of the record and the most common wave height is in the range 0 to 0.5 m, accounting for 37% of all records.
- At Pevensey Bay the most frequent wave period is in the range 3 to 4 seconds, accounting for 50% of the record and the most common wave height is in the range 0 to 0.5 m, accounting for 41% of all records.

3.1.3.3 Renewables Atlas

The EON02 wave climate can be adequately understood with data presented in the Marine Renewables Atlas (ABPmer *et al*, 2008). It should be noted that care should be taken in the interpretation of nearshore data due to the relatively coarse resolution of coastal and estuarine bathymetry within the model. Significant wave height data extracted from EON02 shows that annual significant wave height varies between 0.76 and 1.3 m/s.

Data from the Renewables Atlas has also been presented as a series of figures, with the data sourced from grid cells to the east, west, landward and seaward parts of EON02 (see Figure 10 for locations of grid cells). Figure 8a-d summarises wave directions as a series of annual wave roses and also shows that the primary wave direction is from the south-westerly sector accounting for between approximately 25% (west and landward grid cells) to 45% (within the seaward area of the zone) of the record. Figure 9a-d shows seasonal variation in significant wave height and indicates that the largest waves occur during the winter months.

The Renewables Atlas has also been used to provide information regarding the spatial variation of the wave climate across EON02. Figure 10 shows that mean annual significant wave heights are typically greater in the southern (seaward) parts of EON02 as opposed to the (landward) northern part.

3.1.4 Wind

The wind resource was also sourced from the Marine Renewables Atlas (ABPmer *et al*, 2008). Wind data extracted from the model cells within EON02 shows that the annual mean wind speed 100 m above sea level ranges between 6.25 and 9.54 m/s;

In addition, data has also been extracted from the Renewables Atlas (ABPmer *et al*, 2008) as a number of figures. These figures have been sourced from data cells situated in the east, west, landward and seaward parts of EON02 (see Figure 13 for locations of grid cells). Figure 11a-d shows the variation in wind direction in the form of an annual wind rose. These figures show that in common with the wave data, the predominant direction is from the south-westerly sector. Figure 12a-d shows seasonal wind speed and, as would be expected shows that winter experiences the strongest wind speeds.

The Renewables Atlas has also been used to provide information regarding the spatial variation of the wind climate across EON02. Figure 13 shows that the mean annual wind speed is typically greater in the southern (seaward) part as opposed to the northern (landward) part.

3.2 Sediment Regime

3.2.1 Seabed Deposits

Within the English Channel, gravel sized sediment populations dominate in greater water depths with the smaller, sand sized material dominating in shallower water depths, particularly in the coastal zone and within the Dover Straits. Fine muds are typically found within the estuaries (ABP Research, 2001). Exposed bedrock is located immediately to the west of Beachy Head, at the shoreline between Hastings and Pett Level and further offshore to the south Rye Harbour (ABP Research, 2001). Within EON02, the predominant sediment populations are composed of sand, gravel and mud sized material. In more detail, the sediment distribution is 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).

These sediment types are to be expected in an area which has a high concentration of marine aggregate developers as this material has the highest commercial value; the exact locations of these deposits are discussed in Section 3.3 and are illustrated in Figure 14. The predominance of the coarser sediments, in addition to the absence of fines, suggests a strong tidal regime.

3.2.2 Seabed Features

3.2.2.1 Shoreline character

The English coast immediately shoreward of EON02 can be characterised as headland – bay compartments (ABP Research, 2001). Within these embayments, estuaries and inlets are present. The first embayment is between Selsey Bill and Beachy Head and can be described as:

- Composed of cliff, beach and estuary features (Pagham Harbour; Arun, Adur, Ouse and Cuckmore estuaries);
- Accreting at the harbour mouths (Brand *et al*., 1995); and
- Eroding along the shingle beaches. This coastline has undergone severe erosion in places, particularly to the west of Pagham Harbour, despite the introduction of major sea defences (Evans *et al*, 1998).

The coastal stretch between Beachy Head and Dungeness is characterised by:

- Composed of cliff and beach with one estuarine feature (Rye Harbour);
- Accreting at Rye, and in the lee of Dungeness; and
- Beach and cliff erosion dominate elsewhere. Beachy Head is documented to be in an area of retreating coastline, with chalk cliffs that are unresisting to prolonged wave attack (EMU, 1999). Further, the sandstone cliffs located to the east of Bulverhythe are exhibiting erosion. Many of the coastal stretches can be characterised by the presence of coastal defences, particularly between Shoreham and Brighton (Evans *et al*, 1998).

3.2.2.2 Offshore character

The English Channel has both negative and positive morphodynamic features. The larger scale features present located outside EON02 are:

- St. Catherine's Deep, located south of the Isle of Wight. This feature is a narrow linear feature with a maximum depth of 60m (James *et al*., 2007); and
- Sand banks, concentrated within the Dover Straits. These extensive linear features, of which there are at least eleven, may have dimensions of 30m high and 40m high (James *et al*., 2007). These also typically have sand waves present on their flanks. One of these features is located slightly seaward of EON02's seaward boundary offshore from Dungeness.

Within EON02, the main sea bed features, as reported in the Eastern English Channel Marine Habitat Map (EECMHM; James *et al*., 2007) are:

1 The Northern Palaeovalley, which represents the most prominent open, relatively shallow channel system, extending along most of the coastal limit of the south coast. The main channel of this feature is present towards the seaward extent of EON02, forming a relatively steep boundary to the coastal platform. Depths are less than 30m. Numerous channels join this valley, of which some are open and others sediment infilled, and typically extend over much of EON02. Unfilled sections are greatest towards the south of EON02;

2 Sand streaks, patches and megaripple trains. These features are present towards the seaward extent of the zone. However, their apparent absence over the remaining sea bed is due to lack of data coverage and does not mean they do not occur ; and

3 Sand wave fields, which tend to be localised, are interspersed to the east of the zone. Again, their absence from the remaining sea bed is due to lack of data coverage and does not mean they do not occur. An image of a sand wave collected during the EECMHM survey is shown in Figure 15.

The location of these bedforms is illustrated in Figure 16, in relation to the location of EON02.

3.2.3 Seabed Mobility

Sediment transport within EON02, and indeed the majority of the English Channel is under the dominant control of the tidal regime. As reported in Grochowski *et al* (1993), the tidal currents control the long-term net sediment transport within the Eastern English Channel due to the infrequency of sufficient wave events over this temporal period. As is typical of shallower water environments, the controls exerted by the wave climate become more important in the coastal fringes.

The documented sediment transport pathways for the study area are shown in Figure 17. These include both nearshore and offshore pathways and it can be seen that:

- Littoral, or longshore, sediment transport is predominantly to the east (Bray *et al*., 1995);
- Sediment input from coastal erosion sources is low;
- A bedload parting, or divergence, zone is located, approximately, south of the Isle of Wight extending across the Channel to the Cotentin Peninsula. This zone coincides with the location of the highest tidal velocities within the central Channel; >2.5m/s (Grochowski *et al*.,1993). Further, the location of the M2 amphidromic region is also present here (Pingree and Griffiths, 1979) (Section 3);
- Material is dominantly transported from the bedload parting zone to the east;

- A bedload convergence zone is located, approximately, from Hythe/Dungeness across the channel to Boulogne. This zone results from the net effect of the flood and ebb tidal current directions and maximum tidal currents have been recorded to be in excess of 1.7m/s (Velegrakis *et al*., 1997). Whilst outside the immediate study area, it is noted that a bypass is present along the French coast, with a sediment transport pathway present into the North Sea (Grochowski *et al*.,1993) ; and
- Sediment enters the Dover Straits from the Southern North Sea towards the bedload convergence zone.

Within the main sediment transport pathways listed above, localised convergence, divergence, deposition and erosional zones occur, typically at the entrance to estuaries and inlets. Those documented, and of immediate interest to EON02, are listed below:

- A convergence zone is located in the mouth of Pagham Harbour, with anti-clockwise sediment circulation located slightly offshore; and
- Fine-grained sediment sinks have occurred at the Arun, Adur, Ouse and Cuckmore estuaries throughout the late Holocene;

It has been shown that, for the English Channel between the Isle of Wight and Shoreham, sand is likely to be mobile during part of each tide whilst gravel is only likely to be mobile in shallower water depths where storm energy significantly enhances the tidal current effects (HR Wallingford, 1993).

3.2.4 Suspended Sediment Concentrations

The majority of the suspended sediment concentration (ssc) is derived from fluvial inputs originating from the French coast. The bulk of material derived from the English coast is transported offshore. However this represents a relatively small proportion of the total. Avoine (1997) estimated the total mean fluvial input from the Eastern English Channel at 4.5 x 104 ty/r and the discharge from the River Seine, France in the range 5 to 10 x 105 t/yr.

The net ssc transport pathway follows that of the bedload sediment transport, and is therefore to the east within the area of interest to EON02. Calculations show that, between the Isle of Wight and Dungeness, the suspended sediment flux is in the range 2 to 71 x 106 t/yr (Velegrakis *et al*., 1997, 1999). For reference, a flux in the range 2.5 to 44 x 106 t/yr into the North Sea has also been calculated (Velegrakis *et al*., 1997, 1999).

Investigations into the effects of dredging on ssc and in particular changes to the background concentrations and sediment dispersion form an integral part of EAs for marine aggregate activities. Whilst the published results of such analyses are valid for an area much smaller than that of EON02, nevertheless these provide useful background information for wind farm developers. The effects of a wind farm upon suspended sediment concentrations and dispersions are potentially greatest during turbine installation and cable laying activities.

Numerical simulations of sediment plumes have been undertaken at Hastings Shingle Bank (Area 460; Section 3.3) (EMU, 1999). This site is located to the south-east of Beachy Head in 15 to 23 m water depth. Within the dredge site, typical ssc increases beyond the background concentrations were 5mg/l, during the spring tide, with peak short-term increases of 25 to 30mg/l. Outside the dredge site, peak increases were less than 15mg/l. Of interest, is that numerical simulations of the effects of wind action upon the released sediment plumes indicated no significant increase in dispersion extent.

3.3 Cumulative and In-combination Effects

As introduced during the Round 2 offshore wind process, there exists a requirement to assess the potential for in-combination and cumulative effects of a proposed wind farm with other projects 'progressed (or to be progressed) in the past, present or foreseeable future'. It is important to note that the number of other projects which may need consideration for cumulative and in-combination effects may change if the zone were to be progressed beyond the scoping stage. Here:

- Cumulative refers to all other wind farm projects; and
- In-combination refers to other marine projects, for example marine aggregate extraction.

To provide assistance, Cefas have stated that only those projects located within one tidal ellipse / excursion of the proposed site require consideration.

Presently, there are no known offshore wind farms within one tidal excursion of EON02, and therefore there is no requirement to consider cumulative effects. It is noted that the Crown Estate map of areas of indicative economic potential for offshore wind (Crown Estate, September 2008) includes an area of sea bed within EON02.

In-combination developments have the potential to include:

- Marine extraction activities;
- Marine disposal activities;
- Capital/maintenance dredging operations;
- Port development activities; and
- Sub-sea cables and pipelines.

All activities listed above with relevance to EON02 are listed in Table 10 and shown in relation to the zone in Figure 18. It is noted that fifteen marine aggregate sites are located within EON02, in addition to two submarine cables which cross the site, from north to south. Further details on the aggregate sites are provided in Table 11.

Table 10. Sea bed users for consideration of cumulative and in-combination effects of relevance to EON02

Effect of Relevance	User/Use
Aggregate Site	453 460 369 123 A -G 488 122/1 370 396 122/1 A -G 396/1-2 435 366 367 124 A -G 368 351 395/1 - 2 451 N - S
Sub-Sea Cables and Pipelines	Offshore from Brighton Offshore from Pevensey Bay
Port Development	N/a
Dredging (Capital and Maintenance)	Pagham Harbour Rye Harbour Littlehampton Harbour Brighton Marina Newhaven Marina
Spoil Disposal Site	N/a
Offshore Wind Farms	N/a

Table 11. Marine aggregate site details

Company	License Code	Status (as of July 2008)	Distance from Zone (km)
CEMEX UK Marine Ltd	453	Application area	inside zone
	460	Application area	inside zone
	369	Licensed area	inside zone
	407	Licensed area	>10
	340	Licensed area	>10
	123 A - G	Licensed area	inside zone
United Marine Dredging Ltd	488	Application area	inside zone
	370	Licensed area	inside zone
	396 / 1 - 2	Licensed area	inside zone
	122/1 A - G	Licensed area	inside zone
Hanson Aggregates Marine Ltd	435/1-2	Licensed area	inside zone
	366	Licensed area	inside zone
	367	Licensed area	inside zone
	124 A - G	Licensed area	inside zone
British Dredging Ltd	368	Licensed area	inside zone
Northwood (Farham) Ltd Volker Dredging Ltd	351	Licensed area	inside zone
Kendall Brothers (Portsmouth) Ltd	395/1 - 2	Licensed area	1.8 (395/1) and 3.5 (395/2)
Westminster Gravels	451 N - S	Licensed area	4.5 (451 N) and 1 (451 S)

4. Risk Review

The proposed zone, EON02, located in the Eastern English Channel, approximately, 7.5 km from the South Coast of England at its closest point. The zone is within a macro-tidal regime, with spring tidal ranges between 3.8m to 6.4m, from west to east. Tidal currents are energetic, with spring speeds recorded at adjacent tidal diamonds ranging from 1.3m/s to 1.6m/s, from west to east, respectively. Near-bed spring tidal currents over the proposed zone have been reported to range from 0.48m/s to 1.33m/s for the spring tidal period. Due to its position in the eastern extent of the English Channel, exposure to extreme waves originating from the North Atlantic is limited; measurements of annual significant wave height at three wave buoys in the area of interest indicate a typical height of 0 to 0.5m. At these same locations over a five year period, the maximum wave height recorded was 4.8m. It is typically the tidal regime which dominates sediment mobility and thus sediment transport pathways.

Surface sea bed deposits are typically coarse, being composed of sands and gravels. Bedforms indicative of a mobile regime occur, with sand streaks, patches and megaripples present. Sand waves, which indicate the presence of higher tidal currents than the pre-mentioned features, are not widespread and occur only in localised zones within the study area. Whilst the sea bed features are indicative of a mobile regime, it is considered that the mobility within EON02 is not as great as that of the other zones pre-selected by E.On. Consequently, solutions to mitigate against, for example, scour and exposure, may not be as technically demanding at this zone. However, it is important to note that this is based upon regional-scale information and would require confirmation through project specific campaigns.

Unlike the other zones selected for a preliminary assessment, it is key to note that EON02 has the greatest number of cumulative users. In particular, there are a large number of marine aggregate sites in close proximity to the zone. The main potential effect between an OWF and dredging activities is that of overlapping sediment plumes (for example the combination of plumes arising due to OWF construction impacts and aggregate dredging overspill).

The objective of this report has been to refine the site selection process through the description of coastal processes within each zone to (i) develop an understanding of each site; and (ii) identify any risks which may result in the zone being unsuitable for development, in terms of coastal processes. Further to the above discussion of the notable coastal processes which preside within EON02, it has been possible to provide a first order indication of the potential risk that these may pose to activities which occur within the lifetime of an offshore wind farm development. These are presented qualitatively in Table 12, and draw upon the lessons learnt from earlier Round 1 and Round 2 OWF developments. When considering the risks presented in Table 12, it is important to understand what the different risk levels represent at the broad scale of this scoping phase of this study:

- **Low**: there is a small potential for this risk to be present at the site;
- **Medium**: the risk has the potential to be present and requires further studies to determine the extent spatial, temporal and magnitude of the risk;
- **High**: there is a large potential for the risk to be present. However, this does not represent a showstopper, instead indicating that in addition to the site requiring further studies, it may also provide more technical challenges to the developer; and
- **Showstopper**: the risk is considerable and it is considered, from a coastal processes, that this site is not suitable for wind farm development.

However, it is key to note that the application of these risk levels is based upon presently available generic, broad-scale information regarding the coastal process regime within the wider area and also EON02. It is therefore advisable that, in order to understand and / or reduce these potential risks, the level of uncertainty associated with the coastal process assessment needs to be reduced, for example, through site specific monitoring programmes.

Table 12. Potential risks to offshore wind farm development within EON02 as a consequence of coastal processes

Topic	Issue	Risk Rating			Discussion of Issue
		West[1]	Centre	East	
Migration of seabed features resulting in net lowering of seabed profile	Undermining of foundations	Medium (*open sections of the Northern Paleovalley dominant this sub-zone*)	Low	Medium (*sand waves occur in localised parts in this sub-zone*)	Technical difficulties may exist where sediment mobility means the sea bed is unstable for foundations. Also, sea bed may be unstable due to geological formations.
	Rapid changes to bathymetry leading to access problems	Nature of sea bed forms means that this is not an issue			Rapid changes to bathymetry and un-navigable areas could lead to access problems for maintenance
	Exposure of cables (including export cable)	Low	Low	Medium	Rapid migration of seabed features could lead to exposure of buried cables
	Construction problems	Medium (*open sections of the Northern Paleovalley dominant this sub-zone)*	Low	Medium *(sand waves occur in localised parts in this sub-zone)*	Technical difficulties may exist where sediment mobility means the sea bed is unstable for equipment which rests on the sea bed, as observed at Robin Rigg. Also, sea bed may be unstable due to geological formations.
Sediment mobility	Scour around foundations and cables	Medium	Medium	Medium	Rapid currents and mobile sediments lead to local scour and the potential undermining of foundations and the exposure of cables. Changes more likely in areas where high sediment mobility, as observed at Scroby Sands and Robin Rigg
	Plumes of high suspended sediment concentration occurring during the construction process	Low	Low	Medium	Changes more likely in those areas where finer sediment population. Risk enhanced if seabed disturbance occurs during periods of higher exposure, i.e. spring tidal cycle. It should be noted that this risk is dependant on the location of sensitivity receptors (sites of environmental importance).
Waves	Excessive forces on structures	Medium	Medium	Medium	Where stronger wave regimes exist, design costs could be higher.
	Interruptions to maintenance	Low	Low	Low	Limited available windows for access in areas where higher wave exposure, as observed at Scroby.
	Interruptions to construction	Low	Low	Low	Limited available windows for construction in areas where higher wave exposure, as observed at Scarweather.
In-combination / cumulative	Cumulative effects from other wind farms nearby	Low	Low	Low	Effects of the wind farm could be extended spatially and in magnitude due to the presence of other wind farms located within one tidal excursion Does not account for development within Crown Estate Round 3 zones.
	In-combination effects due to other sea bed users	High	High	High	Effects of the wind farm could be extended spatially and in magnitude due to the presence of other sea bed users located within one tidal excursion, for example the creation of sediment plumes due to activities of foundation installation and aggregate dredging.

- The risk rating here is qualitative
- **It is important to refer to the explanation of the different risk levels as given in the main text of Section 4. Of key note is that 'High' means only that the site may be more technically challenging due to the possibility of, for example, scour and does not mean represent a 'Showstopper'.**

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Figures

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