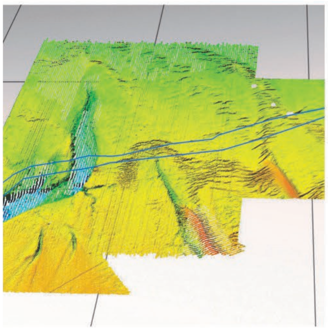
Severn Sands Ltd

North Middle Grounds and Bedwyn Sands

Coastal Impact Study

November 2023


Innovative Thinking - Sustainable Solutions

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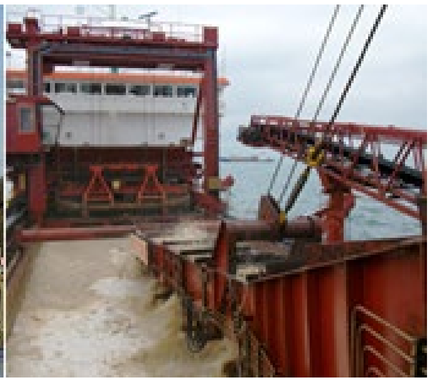

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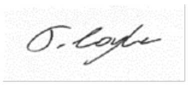		

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ABPmer
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ
T: +44 (0) 2380 711844 W: http://www.abpmer.co.uk/

Summary

The existing aggregate extraction areas of Bedwyn Sands and North Middle Ground (NMG) comprise two sites, situated in the lower Severn Estuary and licenced to Severn Sands (now owned by Breedon Aggregates). Continuous, licenced extraction has been undertaken from both areas since 2008 and 2011, respectively. NMG consists of two Crown Estate lease areas (Area 455 and Area 459) and is situated entirely within Welsh waters. Bedwyn Sands straddles the English/Welsh border, on land privately owned by the Swangrove Estate and, consequently, not subject to licencing by The Crown Estate (TCE).

Severn Sands are presently preparing supporting documents to accompany an application for renewal of the existing aggregate extraction Marine Licences (covering both sites) for a further 15-year period. As part of these investigations, it is necessary to consider how the proposed dredging might impact the local and regional hydrodynamic and/ or sediment transport regime, which could, in turn, adversely affect the adjacent coastlines. To this end, ABPmer has been commissioned to undertake a Coastal Impact Study (CIS) to investigate the potential effects of the proposed dredging on physical processes across the study area.

A combination of site-specific survey data, numerical modelling, desk-based analyses and expert knowledge has been used to consider the potential effects of the continuing extraction on patterns of currents, waves and sediment transport. These predicted changes have subsequently been applied to an assessment of potentially sensitive receptors within the study area.

This CIS has been supported by application of numerical modelling tools and demonstrates that the predicted effects on waves and tidal currents will be generally small in magnitude, in both relative and absolute terms, and will be largely confined to within a few hundred metres of the licence area boundaries. The predicted changes to tidal flows and waves are insufficient to measurably affect sediment movements across the far-field, based on the material present within the study area, and the transport pathways associated with cohesive and non-cohesive sediment material. Where potential changes are predicted, these are considered to be small in magnitude and limited in extent to within the deepened parts of the assessment area.

As a consequence of the limited changes predicted to physical processes, it is concluded that potentially sensitive receptors, including the English and Welsh coasts and the wider Severn Estuary SAC, would not be adversely affected by the continued aggregate extraction activity within NMG and Bedwyn Sands, over the proposed renewal period.

When considering the full range of scenarios assessed, the greatest predicted effects are associated with a conservative scenario of a 200-year storm event, from the southwest, occurring at the time of MHWS. The CIS assessment itself has also assumed a measure of conservatism in its approach, applying a 10% uplift on proposed renewal volumes, bed lowering assessed over the wider seabed feature (rather than within the extraction area alone) and upper estimates of sea level rise. Accordingly, the predicted effects can be considered a ‘conservative, worst-case impact’. Under less severe storm conditions, from other directions or with lower than simulated levels of extraction, the predicted effects on the local and regional physical processes will be lower.

Contents

Appendix

Tables

Figures

1 Introduction

The existing aggregate extraction Licence Areas 455 and 459 (North Middle Ground, NMG) and Bedwyn Sands (covering a combined area of 19.6 km^2 in total), are situated in the lower Severn Estuary, with NMG located 17 km northwest of Clevedon and Bedwyn Sands 3 km southwest of the Severn bridge (Figure 1). Both sites are licensed to Severn Sands (now owned by Breedon Aggregates) and are subject to existing seven-year extraction licences of 250,000 tonnes per annum (tpa). Breedon is seeking to renew the existing extraction licences for NMG and Bedwyn sands (which are due to expire during the first half of 2024) for a further 15-year licence period.

In order to support this renewal application, it is necessary to consider how the proposed dredging might impact the hydrodynamic or sediment transport regime that could, in turn, adversely affect the adjacent coastlines. To this end, ABPmer has been commissioned to carry out a Coastal Impact Study (CIS) to investigate the potential effects of the proposed dredging on physical processes as part of the wider EIA studies. The findings of this CIS can then be used in the Impact Assessment stage (for a range of related topics) and reported in the accompanying Environmental Statement (ES).

This CIS document is structured as follows:

Section 2: Provides a brief description of the Licence Areas;

Section 3: Describes the baseline physical environment;

Section 4: Details the methodology used to inform the CIS;

Section 5: Presents the results of the assessment; and

Section 6: Provides a summary of the conclusions drawn from the CIS.

The CIS has been carried out in accordance with the most recent BMAPA best practice guidance for the assessment of possible effects of marine aggregate extraction along the coast, developed in association with The Crown Estate, MMO, CEFAS and NRW (BMAPA, 2013). This involves implementing the assessments of potential changes to nearshore tidal, wave and sediment transport conditions, with a view to evaluating potential changes at the coast. Guidance recommends consideration of key physical processes, in order to carry out the necessary assessment.

2 Description of Licence Areas

The existing licence areas are located within the lower Severn estuary, with NMG consisting of two licence areas (455 and 459). Additionally, Bedwyn Sands spans English and Welsh waters, with consent provided by both Natural Resources Wales (NRW) and the Marine Management Organisation (MMO). As the site is wholly owned by the Swangrove Estate, Bedwyn Sands extraction area does not have a Crown Estate lease ID. The licence areas are shown in Figure 1, with coordinates presented in Table 1. Both areas have existing seven-year extraction licences for up to 250,000 tpa, subject to exclusion areas (Figure 1 and Table 2), with dredging (under the current licences) due to cease in the first half of 2024.

2.1 Proposed licence renewal

This CIS evaluates the potential impacts associated with the proposed license renewal at NMG and Bedwyn Sands. Specifically, it assesses the renewal applications for a 15-year license to extract up to 250,000 tpa from NMG (Area 459 and Area 455 combined), and up to 250,000 tonnes per annum from Bedwyn Sands. Consequently, over the proposed licence renewal period, a combined total (across both licence areas) of 7.5 million tonnes of aggregate is proposed for extraction.

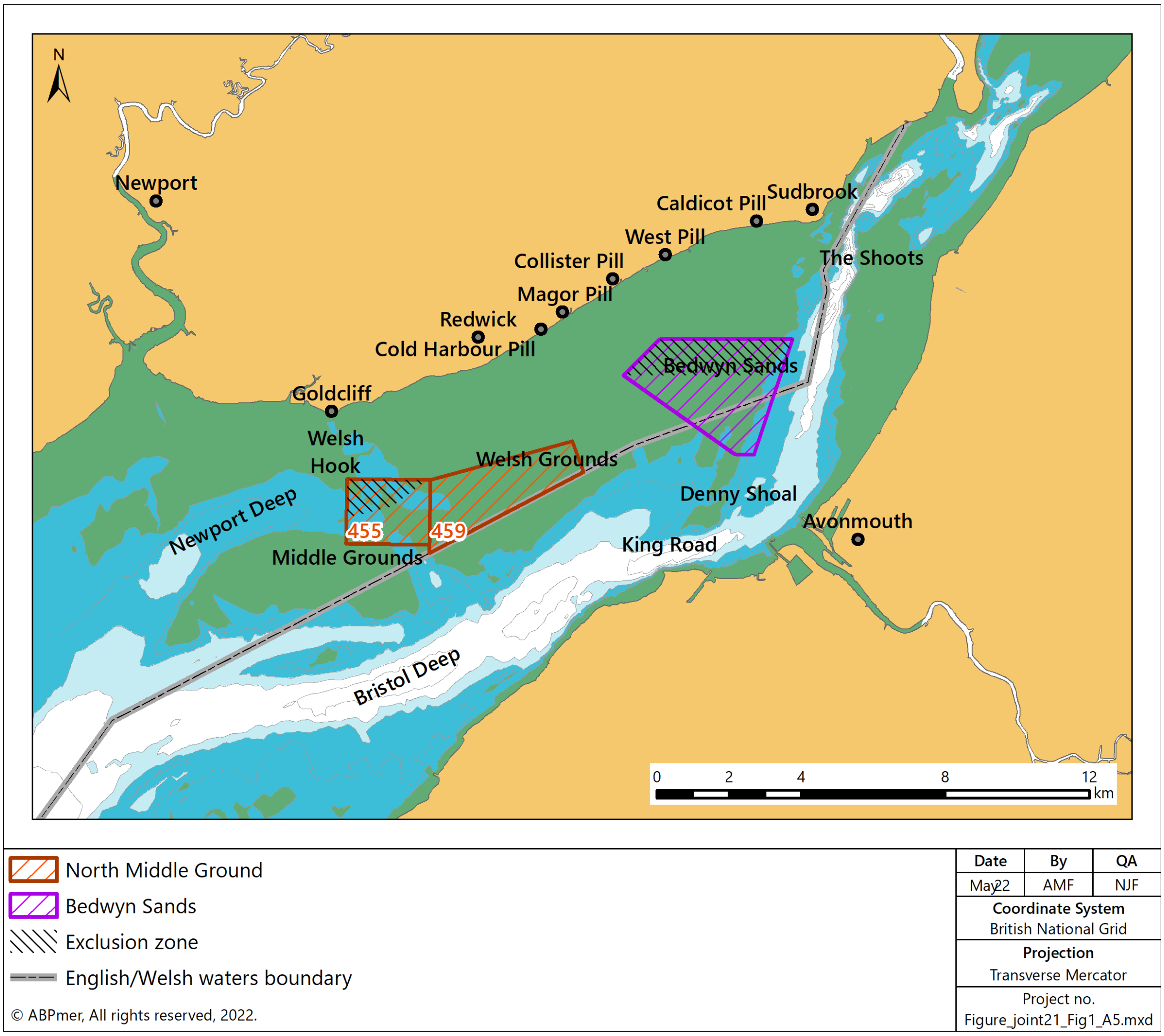


Figure 1. Breedon licensed extraction sites

Table 1. Coordinates of licenced areas

Area	Point	Latitude (°)	Longitude (°)
Bedwyn Sands Dredge zone in Welsh and English waters	A	51° 32.5938′ N	2° 47.3922′ W
	B	51° 33.1392′ N	2° 46.5366′ W
	C	51° 33.1596′ N	2° 43.3524′ W
	E	51° 32.3340′ N	2° 43.7802′ W
	H	51° 31.4274′ N	2° 44.2500′ W
	G	51° 31.4352′ N	2° 44.7084′ W
	F	51° 31.8786′ N	2° 45.7350′ W
Area 459: North Middle Ground	A	51º 31.0000′ N	2º 52.0000′ W
	B	51º 31.6000′ N	2º 48.6000′ W
	C	51º 31.1460′ N	2º 48.3282′ W
	D	51º 29.9040′ N	2º 52.0000′ W
Area 455: North Middle Ground	E	51º 30.0300′ N	2º 52.0000′ W
	F	51º 30.0300′ N	2º 54.0000′ W
	G	51º 31.0000′ N	2º 54.0000′ W
	A	51º 31.0000′ N	2º 52.0000′ W

Table 2. Coordinates of exclusion zones within licenced areas

Area	Point	Latitude (°)	Longitude (°)
Bedwyn Sands Dredge zone in Welsh and English waters – *Exclusion Zone*	A	51° 32.5938′ N	2° 47.3922′ W
	B	51° 33.1392′ N	2° 46.5366′ W
	C	51° 33.1596′ N	2° 43.3524′ W
	D	51° 32.6196′ N	2° 43.6320′ W
Area 455: North Middle Ground – *Exclusion Zone*	A	51° 31.0000′ N	2° 54.0000′ W
	B	51° 30.4200′ N	2° 540000′ W
	C	51° 30.6000′ N	2° 52.9200′ W
	D	51° 31.0000′ N	2° 52.0800′ W

2.2 Historic and contemporary aggregate dredging in the vicinity of NMG and Bedwyn Sands

The extraction of aggregates from both sites was initially authorized by the Welsh Assembly Government in 2008 (Bedwyn) and 2011 (NMG). Prior to the expiration of these original licenses, Natural Resources Wales (NRW) renewed them for both sites to cover an additional seven-year period. This extension allowed for the ongoing extraction of 250,000 tpa at each location, subject to specific exclusions and appropriate monitoring measures. Aggregate extraction under the current licences is due to cease during the first half of 2024. Breedon Aggregates is, consequently, seeking permissions to extend the dredging activities in these licensed areas for a further 15-year period.

Alongside the previous Licence applications for both areas, a series of supporting studies have been undertaken, which have been used to inform this assessment. These include (but are not limited to):

- Severn Estuary SMP2 (Atkins, 2009);
- Bedwyn Sands ES (ABPmer, 2015);

- North Middle Grounds ES (ABPmer 2016);
- Area 531 Coastal Impact Study (CIS) (ABPmer, 2019);
- Bedwyn Sands and North Middle Ground: Annual Compliance Report 2021-2022 (ABPmer 2022a);
- Bedwyn Sands and North Middle Ground: 5-year substantive review (ABPmer 2022b);
- Shoreline Surveys Ltd: Bathymetry survey (Shoreline Surveys Limited, 2022);

Down-estuary from the licenced site aggregate extraction sites, approximately 4 km east of NMG, is an additional extraction area: Area 531 (North Bristol Deep), with a licenced extraction rate of up to 300,000 tonnes per annum. A CIS was undertaken in 2019 in support of the licence application for this site, which included consideration of cumulative dredging across the combined licence areas (ABPmer, 2019).

Aggregate extraction in the vicinity of the two extraction areas has also been previously licenced from Area 385 (West Middle Ground) and Area 391 (Denny Shoal). These licences lapsed in 2014 and 2012, respectively, and have not been subsequently renewed. The relative locations of these current and historic licenced aggregate extraction sites are shown in Figure 2.

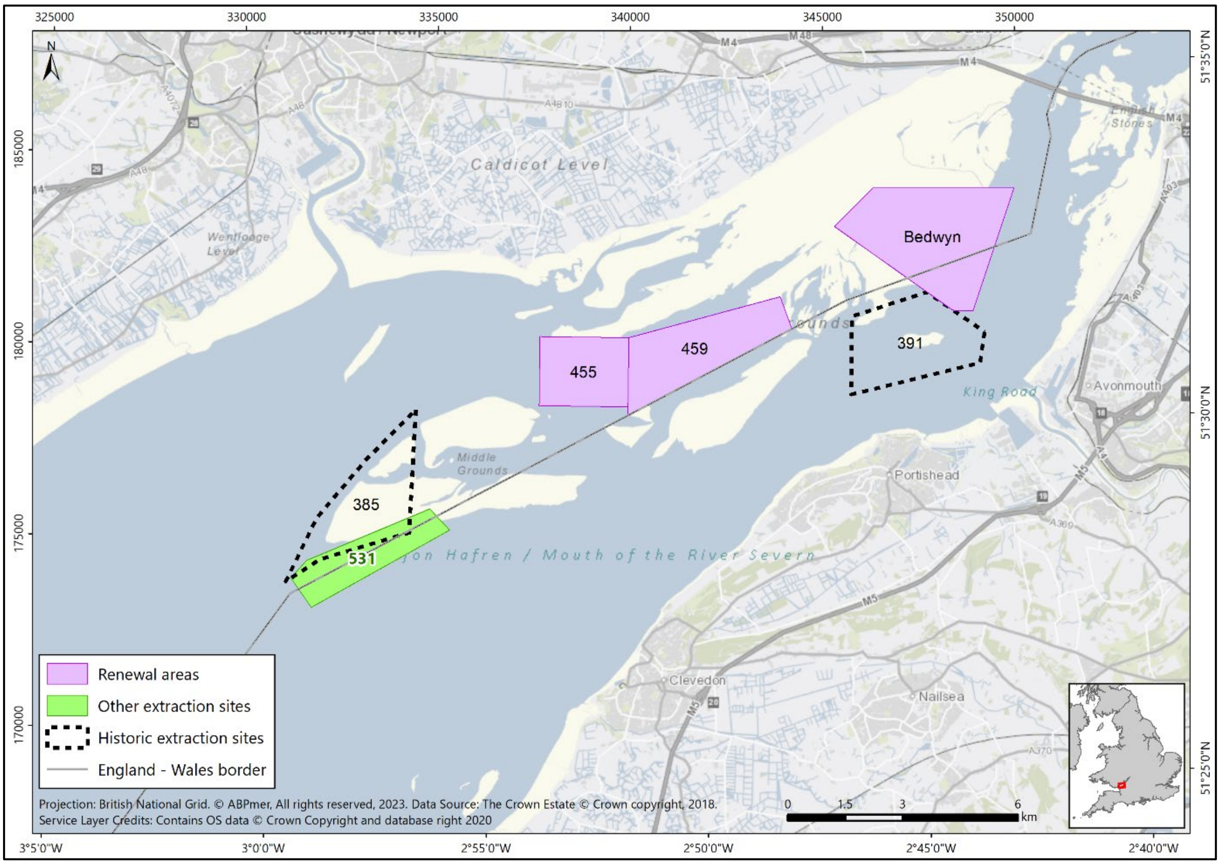


Figure 2. Existing and historic licenced aggregate extraction sites within the study area

3 Baseline Characterisation

The characterisation of the baseline physical environment presents an evidence-based understanding of the coastal morphology and physical processes within the study area. In line with the best practice guidance (BMAPA, 2013), this information has been drawn from field measured data, numerical modelling outputs (in relation to the combined NMG and Bedwyn Sands), and published literature from studies in the Bristol Channel and Severn Estuary. The baseline characterisation is used to determine the relative importance of the wave and tidal regimes in driving local sediment transport and coastal evolution. The report also identifies the potential effect pathways, which may exist between the dredge area and the physical process receptors; namely the coast, seabed and adjacent sandbank systems. In doing so, it addresses the key considerations of potential effects from the proposed marine aggregate dredging activities.

The baseline characterisation uses information presented in various documents prepared in support of the existing licence applications for NMG and Bedwyn Sands, supplemented with additional relevant information and data, where these have been obtained since these previous studies.

3.1 Study area

The Study Area is described as a combination of near-field and far-field regions. The near-field study area covers the NMG and Bedwyn Sands extraction and licence areas. The far-field study area is defined on the basis of the potential area of influence from the proposed dredge. This includes the Lower Severn Estuary, and the coastal frontage between Newport and the Prince of Wales Bridge (M4 road bridge), on the Welsh coast; and between Middle Hope and the Second Severn Crossing, on the English coast (Figure 3).

3.2 Coastal description

The Middle and Welsh Grounds (including Bedwyn Sands) can be considered predominantly inter-tidal sandflat features, located within the wider region of the Severn Estuary. The Severn Estuary is part of the wider Bristol Channel submarine valley system and is bounded by a series of embayments and cliffed coastlines at its landward edges.

Within the Severn Estuary, the coastline and channel have a general northeast / southwest alignment, expanding seaward of the islands of Flat Holm and Steep Holm, into the Bristol Channel, which has a more east / west orientation (Figure 3).

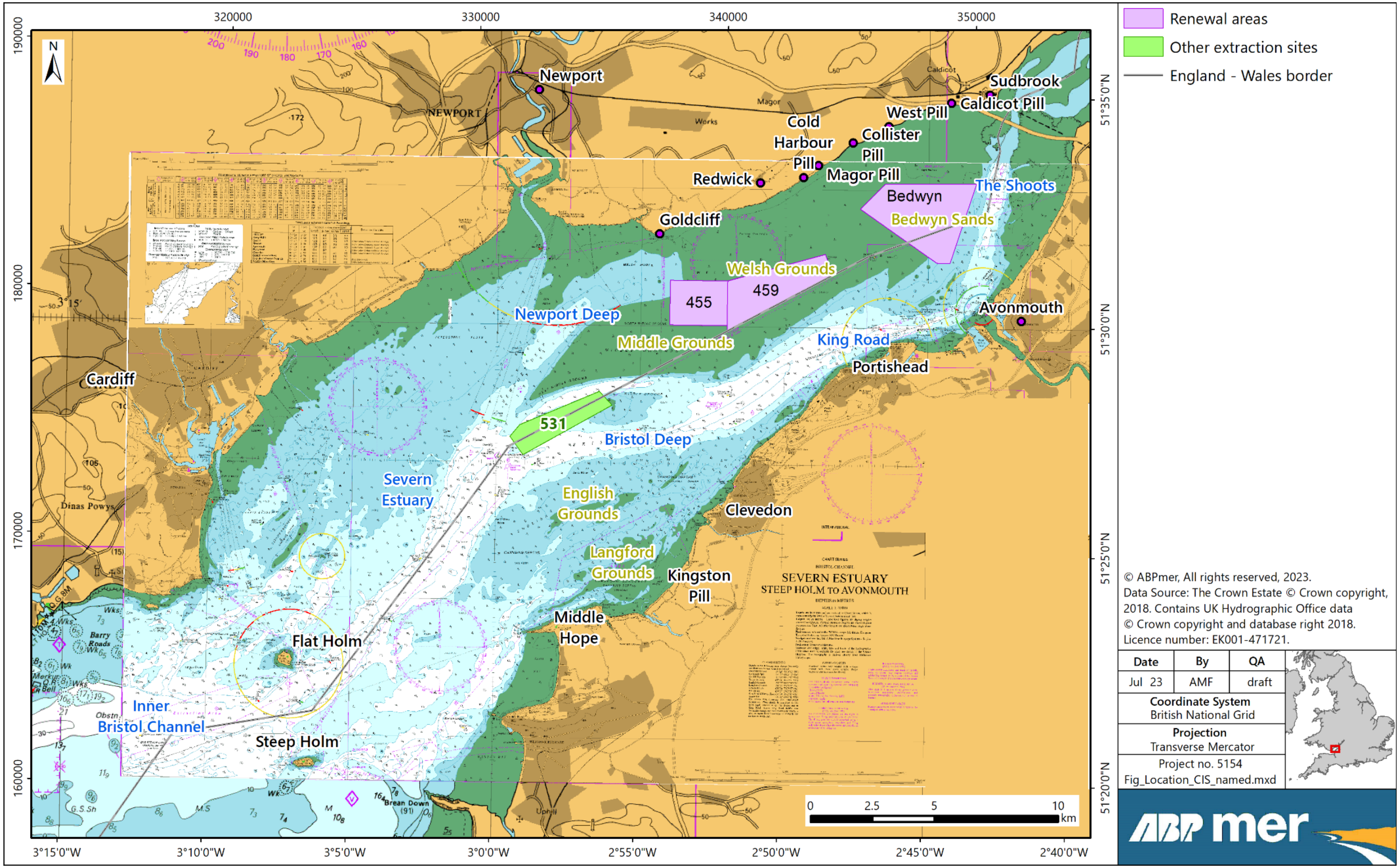


Figure 3. NMG and Bedwyn Sands CIS Study Area and local features

3.2.1 Severn Estuary and Approaches

The Severn Estuary is the largest coastal-plain type estuary in the UK, with the second largest tidal range in the world, at 10 to 12 m. The estuary extends from Haw Bridge to the north of Gloucester, to its downstream limit between the headlands at Lavernock Point (Welsh coast) and Brean Down, on the southern side of Weston Bay on the English coast. The area to seaward is commonly referred to as the Inner Bristol Channel.

It is at this location where the orientation of the coastline changes from a mainly east to west trend down-estuary, to a northeast alignment and the start of the funnel-shaped estuary. The estuary extends from 15 km wide in its outer reaches to <60 m wide in the River Severn, near Gloucester. In most places, it is less than 5 m deep, although maximum depths of up to 30 m are found in the main channel between the islands of Flat Holm and Steep Holm, at the seaward extent. The tidal limit of the Severn is normally taken to be at Maisemore and Llanthony weirs, near Gloucester. However, on high spring tides the weirs can be overtopped by the tidal bore and the limit of the tidal flood risk is often taken as Haw Bridge (Atkins, 2009).

The Severn Estuary is a high-energy environment and a dynamic system that responds to the influence of tides and storms. These episodic events can move large quantities of sediments and alter channel profiles and locations. The most significant influence (with the exception of major development), over future periods, is likely to be from climate change and the response of the estuary to increases in sea level and storminess. The net effect of these issues is to create coastal squeeze along the developed/defended margins of the estuary, with the potential for loss of intertidal features.

The hydrodynamic character of the Severn Estuary is partly due to its form and partly due to its geographic setting. The form is determined from geological evolution, human intervention and interaction with present-day physical processes, resulting in a funnel shaped estuary. The main estuary channel is the former river channel, which became drowned and infilled as sea levels increased in the post-glacial period. The geographical setting of the estuary produces the very high tidal range, which forms a major control on hydrodynamic processes.

The principal morphological components of the Severn Estuary, as defined in the SMP (Atkins, 2009) are:

- Rocky intertidal platforms covered with a thin veneer of sediment;
- Major sand deposits and sandbanks in the central parts of the estuary;
- Subtidal channels, with gravel and sand or mud deposits;
- Muddy tributary estuaries;
- Muddy intertidal foreshores with relatively limited saltmarsh; and
- Sand beaches and dunes on the Atlantic facing coast.

3.2.2 Welsh Coast - Newport to the Second Severn Crossing

The Welsh coastline, in the vicinity of the Severn Estuary aggregate extraction areas, extends approximately from Newport, in the west, to the Second Severn Crossing in the east (Figure 3). This coastline lies in the lee of the Middle and Welsh Grounds, when considering the dominant direction of wave approach from the southwest.

General description

This section of the Welsh coastline is described, with reference to a series of Process Units in the Severn Estuary Shoreline Management Plan SMP2 (Atkins, 2009). Along this frontage, descriptions are provided for Uskmouth (between Uskmouth Power Station and Gold Cliff), and the Caldicot Levels (between Gold Cliff and Sudbrook Point).

Uskmouth

The coastline between the Uskmouth Power Station, at the mouth of the River Usk, and Gold Cliff, marks the boundary between low-lying alluvium in the west, and the Jurassic Lias cliffs, to the east. The unit is at the western end of the Caldicot Levels and, therefore, has a low-lying backshore fronted by wide intertidal mudflats. The area consists of wet reedbeds, wet grasslands and shallow saline lagoons. The intertidal area here is effectively an extension of the muddy foreshore at the mouth of the River Usk.

The tidal dynamics of this frontage behave in a similar manner to that described in the Severn Estuary, with little tidal modulation. The tidal currents along the frontage are directed upstream. The physical properties of the study area are described further in subsequent sections of this report.

The line defining the mouth of the River Usk has changed little and, in the past, has been largely maintained by maintenance dredging. The western section of the Uskmouth frontage is eroding and the eastern is accreting. There are saltmarsh areas along much of the shoreline, particularly between the Nash Breakwater and Goldcliff Pill, which has suffered significant localised erosion and accretion over the last 100 years. The construction of the Cardiff Bay Barrage, and the loss of the SSSI, led to a mitigation scheme - the Gwent Wetlands Reserve - being constructed along the frontage of Uskmouth, Saltmarsh and Gold Cliff.

The Caldicot Levels

The Caldicot Levels extend from the rocky outcrop at the Gold Cliff promontory, in the southwest, to the southern side of Sudbrook Point, in the northeast. At this point, the coastline exhibits a transition from the low-lying alluvial plain of the Caldicot Levels, to the Old Red Sandstone headland at Sudbrook. The coastal frontage is south-easterly facing, with a low-lying foreshore composed of muddy Holocene marine and estuarine alluvium and fronted by a relatively wide expanse of intertidal saltmarsh and sandbanks (as shown in Figure 4). The backshore is almost entirely below the level of mean high-water springs (MHWS) and is, therefore, defended by a continuous clay embankment located on former marsh surfaces (and typically reinforced by a wall and revetment). Predicted tidal residuals show a downstream, onshore-directed current, although to the north of Gold Cliff, residuals are directed offshore (ABPmer, 2009).

There has been long-term retreat and erosion of saltmarsh in the past, although the rates have been shown to vary. The saltmarsh located north of Magor Pill, extending to Caldicot Pill, has been subject to a long-term erosional trend and retreat of the mean high-water mark by up to 140 m (between West Pill and Caldicot Pill) and up to 170 m adjacent to Rogiet Moor Pill/West Pill), since the 1880’s. However, to the southwest of Magor Pill, MHW has not changed significantly. There has also been erosion of the intertidal zone below that of the marsh. Some increase of saltmarsh area between 1946 and 1998 along this frontage can be explained by the planting of *Spartina* in the area (Atkins, 2009).

Source: HR Wallingford, 2003

Figure 4. **Narrow upper foreshore between Redwick and Goldcliff**

3.2.3 English Coast - Middle Hope to the Second Severn Crossing

The English coastline, in the vicinity of the Severn Estuary aggregate extraction areas, extends approximately from Middle Hope, in the west, to the Second Severn Crossing in the east (Figure 3).

General description

This section of the English coastline is described, with reference to a series of Process Units in the Severn Estuary Shoreline Management Plan SMP2 (Atkins, 2009). Along this frontage, descriptions are provided for the sections of coastline between Middle Hope and Clevedon, Clevedon and Portishead, and between Portishead and the Second Severn Crossing.

Middle Hope to Clevedon

The upstream and downstream extents of Middle Hope (Figure 3) are defined by the seaward limits of the Carboniferous Limestone headlands at each end (St. Thomas' Head and Sand Point). The frontage is characterised by steep cliffs, and a narrow rocky intertidal area, whilst the ridge at Middle Hope rises to a height of over 40 m. Behind this ridge is low lying estuarine alluvium. The hard rock cliffs experience only a low rate of erosion and there are no anthropogenic coastal defences along this frontage. There is some evidence of narrowing of the foreshore, especially of the muddy lower intertidal zone, which has been accompanied by steepening of the foreshore. This, however, does not appear to have resulted in an increased rate of cliff erosion, due to the presence of the wave cut platform.

Further up-estuary of Middle Hope, the coastline fronting Kingston Pill (Figure 3) defines a region of transition between the cliffed areas to the east and west. The frontage along Kingston Pill is characterised by resistant rock outcrops to the southwest and northeast, with a number of tributaries discharging into the Severn Estuary. These include the Blind Yeo (that discharges into Clevedon Pill); Kingston Pill; the Congresbury Yeo River; and the River Banwell.

The tides are ebb-dominant in this area, whilst some protection from wave and tide processes is afforded to the shoreline by the offshore sandbanks of the English and Langford Grounds (Figure 3). Between the cliffed coastline to the east and west, the low-lying land around Kingston Pill is defended along the entire frontage by a system of embankments, fronted by upper and lower saltmarsh (of varying width), and mudflats. Although foreshore accretion has been noted just south of Clevedon, where the intertidal has accreted by up to 200 m since the 1880's, the general trend over the past 100 years is for erosion, with a net loss of saltmarsh (Atkins, 2009).

Clevedon to Portishead

This coastline extends from Portbury Docks in the northeast, to Wains Hill in the southwest, and is characterised by cliffs, fronted by a rock platform. These features combine to form a narrow intertidal area, covered by intermittent mud and gravel deposits. The north-eastern boundary marks the transition from the cliffed coast to the low-lying estuarine alluvium shoreline to the north. The southwestern boundary marks the southern limit of the rocky cliffs and the wave cut platform at Wains Hill. The tidal residuals show ebb-dominance. The cliffed coast is largely undefended, although some local protection is in place, and the cliffs have a hard rock geology which is generally resistant to erosion. Where erosion has been observed, rates are shown to vary along the frontage (according to local geological and geomorphological factors), although they are generally low (Atkins, 2009).

Salthouse and Woodhill Bays are the only low-lying areas along this frontage: Salthouse Bay was a muddy depositional environment, and which has been enclosed by the construction of a seawall; and Kilkenny and Woodhill Bays are fronted by saltmarsh, which has accumulated to around 130 m wide, whilst the low water mark has moved seaward in this area.

Portishead to New Passage

This frontage extends from New Passage in the north to the Old Pier at Portishead in the south, on the south bank of the Severn. The north-eastern boundary marks the transition from the low-lying saltmarsh shoreline between the Severn Crossings, to the offshore rocky exposures of English Stones. The southwestern boundary marks a transition from the low-lying shoreline of Portbury Wharf to the cliffed coastline between Portishead and Clevedon (described above). The coastline is a northwest facing embayment, and is generally fronted by intertidal mud, sand or gravel banks, saltmarsh and rock outcrops at the northern end. Between Chittening Warth and Old Passage there is a large bank of gravel and sand at the mudflat edge. The River Avon enters the Severn Estuary along this frontage, between Avonmouth and Portishead.

There has been marked accretion along sections of this coastline. For example, at Chittening Warth historic survey data has indicated around 100 m of accretion, and at Chapel Pill between 100 and 160 m of accretion, and a slight seaward extension of MLW, over the last 100 years (Atkins, 2009). The channel of Avonmouth port is generally controlled by anthropogenic structures, although the wide intertidal area has reduced here from 0.8 km wide to 0.17 km. The area behind the East Breakwater, however, has continued to accrete.

3.3 Geological overview

The present configuration of the Bristol Channel and Seven Estuary, as seen today, has been formed during the Quaternary glacial and interglacial periods. The broad underlying geology in the outer estuary (i.e. to seaward of the Severn Crossings) is of folded and faulted lower Jurassic mudstones and limestones. Carboniferous limestone exposures occur at the headlands and the islands of Flat Holm and Steep Holm. Further into the estuary, at Sharpness, more resistant Silurian, Devonian and Cambrian strata transect the estuary, and upstream of this point Jurassic and Triassic marls and sandstones underlie recent alluvial deposits. Bordering much of the estuarine deposits are Devonian and Carboniferous lithologies of Old Red Sandstone and limestones. Bedrock is evident in the cliff sections, producing a rock-constrained system.

The Holocene started at the end of the last glaciation, at which time mean sea levels are believed to have been around 30 m below present-day levels. The estuarine environment would have been to the west (seaward) of its present location with a freshwater river valley where the inner estuary is today. Following deglaciation, available data indicates an initial rapid rise in sea level of 25 m, up to around 6,000 years BP, which displaced the estuary landward (into the river valley) and resulted in sections of palaeo-channels being infilled. Coastal plains were submerged, and rocky headlands such as Brean Down, were likely to have been islands. Since that time the size and shape of the Bristol Channel and Severn Estuary have varied with ongoing fluctuations in sea level. Subsequent rates of sea level rise, up to the present day, have been slower (approximately 1 mm/yr to 2,500 BP) (Atkins, 2009).

Prior to the rise in sea level the estuary was divided into two zones, one of bedload transport towards the sea, and one of transport inland. The rise in sea level caused the divide between the two zones to move up the estuary, in a landward direction. Sandy sediments were transported into the estuary to form the extensive banks now found along the original river channel axis, but the rise also released sediment from the seaward margin of the estuary, into the Celtic Sea. The effect of rising sea levels has resulted in a wide expanse of exposed seabed without any major sediment cover, over an area extending from the Inner Bristol Channel into the lower reaches of the Severn Estuary. This results in little sediment availability in this area. The present position of the bedload parting zone is now considered to be approximately at the boundary between the Inner Bristol Channel and the Severn Estuary, just to the west of the islands of Steep Holm and Flat Holm (Figure 3).

Lying directly on the underlying bedrock or earlier Pleistocene sediments of the Severn Estuary, at least four discrete sediment formations have been identified. With a thickness of 10-15 m, these deposits consist of alluvial and estuarine sediments and comprise much of the existing shoreline of the estuary. The earliest of these is the Wentlooge Formation, which first began accumulating between 3,000-2,500 years ago, and ended at the start of the first Roman occupation about 2,000 years BP. Earth embankments were initially built during the Roman period, and the marshes were drained for agriculture. This reclamation had the effect of narrowing the estuary and separating it from the natural fine sediment sink area. Three further formations: the Rumney (early Mediaeval to the 19th Century), the Awre (19th Century) and the Northwick (20th Century), are seen as steps, or terraces, across the intertidal zone.

3.3.1 Solid geology

Solid geological formations provide a set of hard constraints on the further evolution of the estuary. The boundary of the estuary with the Inner Bristol Channel is essentially a geological divide, corresponding to a denuded spine of Carboniferous Limestone. This solid geology extends between the headland feature of Brean Down, to the islands of Steep Holm and Flat Holm, and across to Lavernock Point, which is a further headland formed of Lower Lias mudstones. The seabed at this location remains sediment starved, with large areas of exposed rocky seabed.

The location of the first (upstream) Severn Bridge also represents a geological constraint, bounded by Aust Cliff (Lower Lias) and Beachley Point (Keuper Marl), and with a series of rock platforms, which direct the passage of the water. The Shoots, at the location of the Second Severn Crossing, is a further geologically-constrained reach of the estuary, with an over-deepened channel. A similar over-deepening occurs between Flat Holm and Steep Holm, where the channel passes between these hard rock outcrops, and onward to the Inner Bristol Channel, and is frequently infilled with gravels.

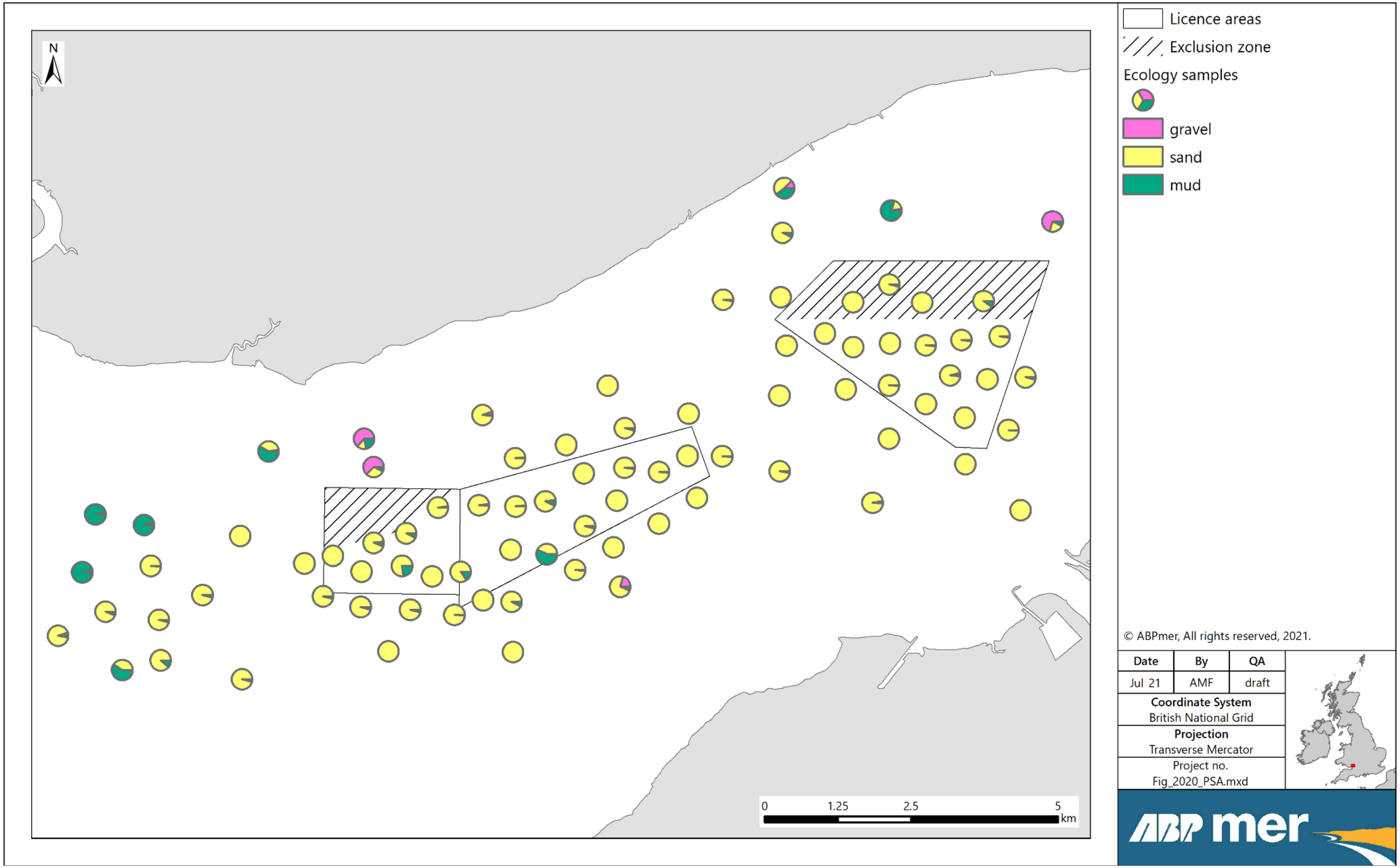
3.3.2 Surficial seabed sediment

Superficial sediments that rest on the top of the bedrock are glacial till, post-glacial valley infill, Flandrian accumulations and surface sediments, which subsequently interact with waves and tides. The largest sediment accumulation in the estuary is the infilled river valley (in the area occupied by the Middle and Welsh Grounds; Figure 3) with sediment thicknesses of up to 30 m. Elsewhere, however, unconsolidated sediment cover in the estuary is generally thin (typically less than 5 m), and the total quantity of coarse sediment is small when compared with the tidal volumes, making this area relatively starved of coarse sediment. Sediments are also highly divided, leading to distinct and separate deposits of gravels, sands and muds. Consequently, areas of mixed sediments are virtually absent.

The variation in surficial sediment cover, as informed by the analysis of surface grab samples (for monitoring purposes, ABPmer, 2021a), is shown in Figure 5. The sampling locations provided on this figure show grab sampling undertaken as part of the Regional Seabed Monitoring Plan (RSMP) (Cooper and Mason, 2019). These samples outline that the area around Bedwyn Sands and NMG is predominantly sand, with localised areas of sandy gravel and muddy sand located to the north and west.

Middle Grounds (including Bedwyn Sands)

A sediment budget for the Middle Grounds has been compiled through previous studies (HR Wallingford, 2003a; Velegrakis *et al*., 2001), by comparing the sediment base with historic bathymetric charts. The average volume of the Middle Grounds between 1832 and 1972 was calculated at 1.8 billion m^3, providing evidence of a massive sand store, several orders of magnitude greater than the presently permitted extraction volume. The same studies identified that, whilst there was some variation in the volumes between years, there was no overall significant change in the volume of the banks throughout the analysis period (spanning some 140 years).



Source: ABPmer, 2021a

Figure 5. Surface sediment classification

3.4 Bathymetry and seabed features

The bathymetry of the Severn Estuary varies greatly between deep channels and shallow intertidal features. The water depths, and the features observed, in and around the extraction areas are described in the following sections.

3.4.1 Bathymetry

Across the wider study area, natural deep channels exist along the boundaries of the Middle and Welsh Grounds and Bedwyn Sands (Figure 3). To the west of the Middle and Welsh Grounds, the Newport Deep extends to a depth of around 7 m below Chart Datum (CD). To the south, the Bristol Deep and King Road extend to depths of around 18 m and 20 m below CD, respectively; whilst to the east, The Shoots extends towards the Severn Crossings, with depths approaching 30 m below CD. The shape and form of the main channel results in relatively high flow speeds; this, in turn, maintains a natural flushing of these channels.

The Middle and Welsh Grounds and the Bedwyn Sands form an extensive expanse of linked intertidal sandbanks and sandflats. As a result of the hydrodynamic forcing, elevations across this area tend to vary both temporally and spatially. Across the Middle and Welsh Grounds, elevations reach approximately 8 m above CD; whilst, across the Bedwyn Sands area, elevations of around 6 m above CD are observed.

Figure 6 shows the collected bathymetry survey from the recent bathymetric survey campaign (Shoreline Surveys Limited, 2022).

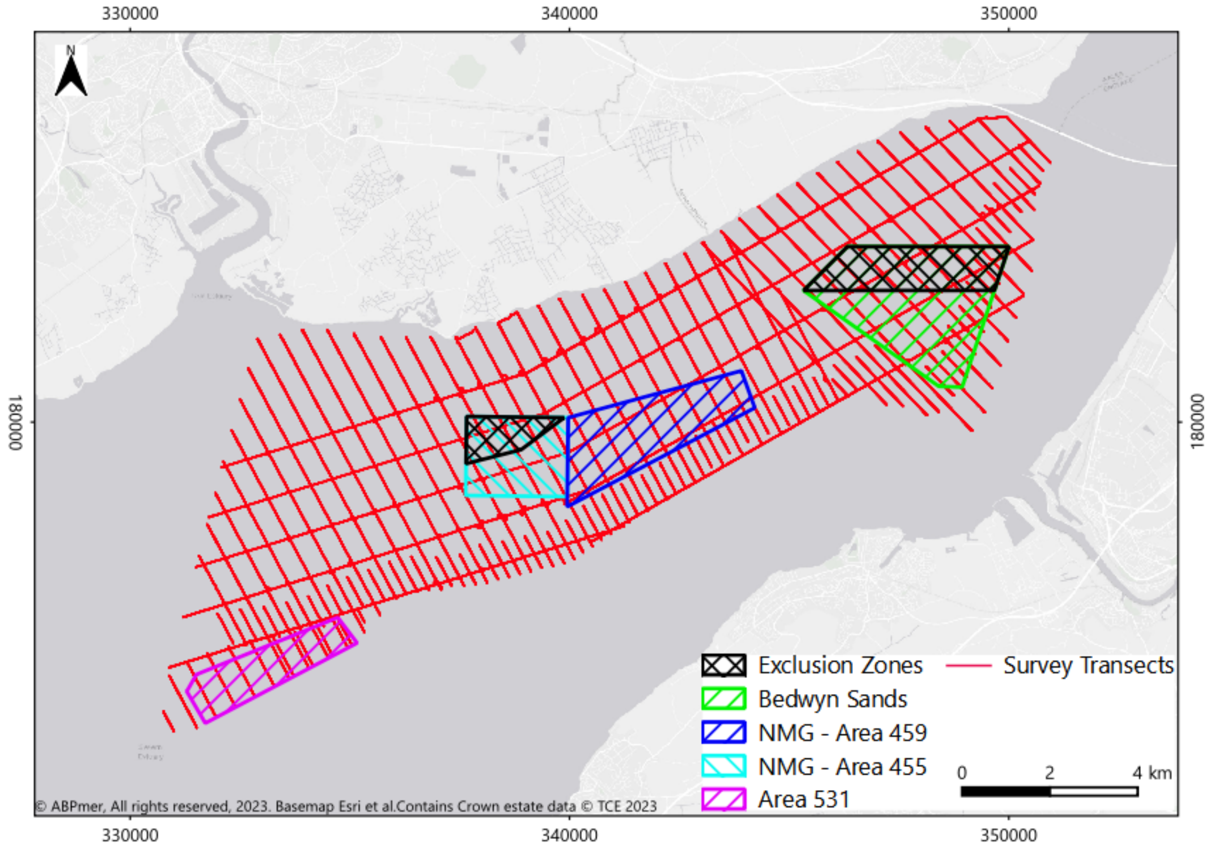


Figure 6. Bathymetric coverage of 2022 surveys

The data shows that elevations across the Application Area range from around 4.3 m AODN (~10.6 mCD), to the northeast of the sand resource, deepening to around -19.8 m AODN (~-26.1 mCD) in the southwest, close to The Prince of Wales Bridge (where the main channel splits into the Bristol Deep and the Newport Deep).

3.4.2 Seabed features

A series of seabed features have been identified, which are considered to be active under contemporary hydrodynamic conditions. Active seabed features within the wider study area are defined as:

- *Sandbanks/sandflats*. The connected sandbank/sandflat features of Middle Grounds, Welsh Grounds and Bedwyn Sands are approximately 22 km in length, extending offshore from the Caldicot Levels frontage for over 6 km at their widest point. Photographic evidence (Figure 7) indicates that the banks and flats are covered by sand wave and sand ribbon features; and
- *Sand waves/sand ribbons*. Smaller bedform features overlay the larger banks, with arrangements of mega-ripples indicating an active sand transport environment. The presence of these bedforms indicates that the dominant driver of sand transport across the banks and flats is under the action of tidal currents (HR Wallingford, 2003a).

Source: HR Wallingford, 2003b

Figure 7. Tidally induced bedforms over The Middle Grounds

Middle and Welsh Grounds including Bedwyn Sands

Offshore of the Caldicot Levels frontage, the wider study area encompasses the Middle and Welsh Grounds. These features form an extensive expanse of linked intertidal sandbanks and sandflats, which are constrained (in lateral extent) by a series of naturally deep channels - Newport Deep to the west, Bristol Deep and King Road to the south and The Shoots to the east (Figure 3). The region is located within the 'Severn Estuary' zone, as defined within the Bristol Channel Marine Aggregates (BCMA) study (Posford Duvivier and ABP Research & Consultancy, 2000), and is contained within 'Sediment Environment SE4', as previously defined in the Marine Aggregate dredging Protocol (MADP) (Welsh Government, 2004).

3.5 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 (e.g. winds, atmospheric pressure and storm events). The baseline hydrodynamic regime has been characterised in terms of:

- Water levels;
- Currents; and
- Waves.

The baseline scenario is defined not only by the present coastal process characteristics and inherent variability, but also the present, ongoing dredging activity within the study area and by any natural changes in key processes or morphological features that might be anticipated over the lifetime of the dredging activity. The locations of the hydrodynamic data sources, as referred to in the following sections, are shown in Figure 8.

3.5.1 Water levels

The Severn Estuary is subject to an exceptionally large semi-diurnal macro tidal regime with a mean spring range of 10 to 12 m. This significant range tidal range is due to the combination of the North Atlantic tidal wave approaching through the Bristol Channel and the further amplification and convergence of this tidal wave as it moves into the funnel-shape of the Severn Estuary and generates the renowned Severn Bore within the upper reaches. The tidal prism (i.e. the volume of water the enters and leaves the estuary on an average tide, calculated as the difference between the tidal volume at high water and that at low water) of the Severn Estuary has been calculated at approximately 96 x 10^8 m^3 (Atkins, 2009).

The tide enters the Severn Estuary from the Bristol Channel as a progressive tidal wave, with a fairly symmetrical sinusoidal shape. As the tide moves upstream it amplifies in range due to the funnel shape of the estuary, reaching a mean spring tidal range of 12.2 m at Avonmouth and a maximum of 12.3 m, at Beachley (Chepstow, Severn Bridge). Further upstream the estuary widens out slightly and shallows rapidly, leading to increased asymmetry of the shape of the tidal curve and, therefore, steepening of the curve due to the shallow water effects. In this way, the interaction of the tidal wave with the shallowing bed causes a slowing of the trough of the tidal wave, with respect to the crest, therefore creating asymmetry. Consequently, the flood tide becomes increasingly short and steep, whereas the ebb drops less steeply and more slowly (i.e. with a longer duration). For example, at Avonmouth the spring flood tide typically lasts about 5.5 hours compared to 7 hours of ebb flow. Eventually, this steepening can lead to the formation of a tidal bore from Awre to Avonmouth (on high spring tides), the size of which can reach 1.2 m.

Around low water there is a further feature of the tide: upstream of Oldbury Power Station, low water levels on neap tides fall to marginally lower levels (0.1 m, on average) than on spring tides. This is due to the longer times required to drain larger volumes of water on a spring tide, meaning that the system has not fully drained before the next flood tide commences.

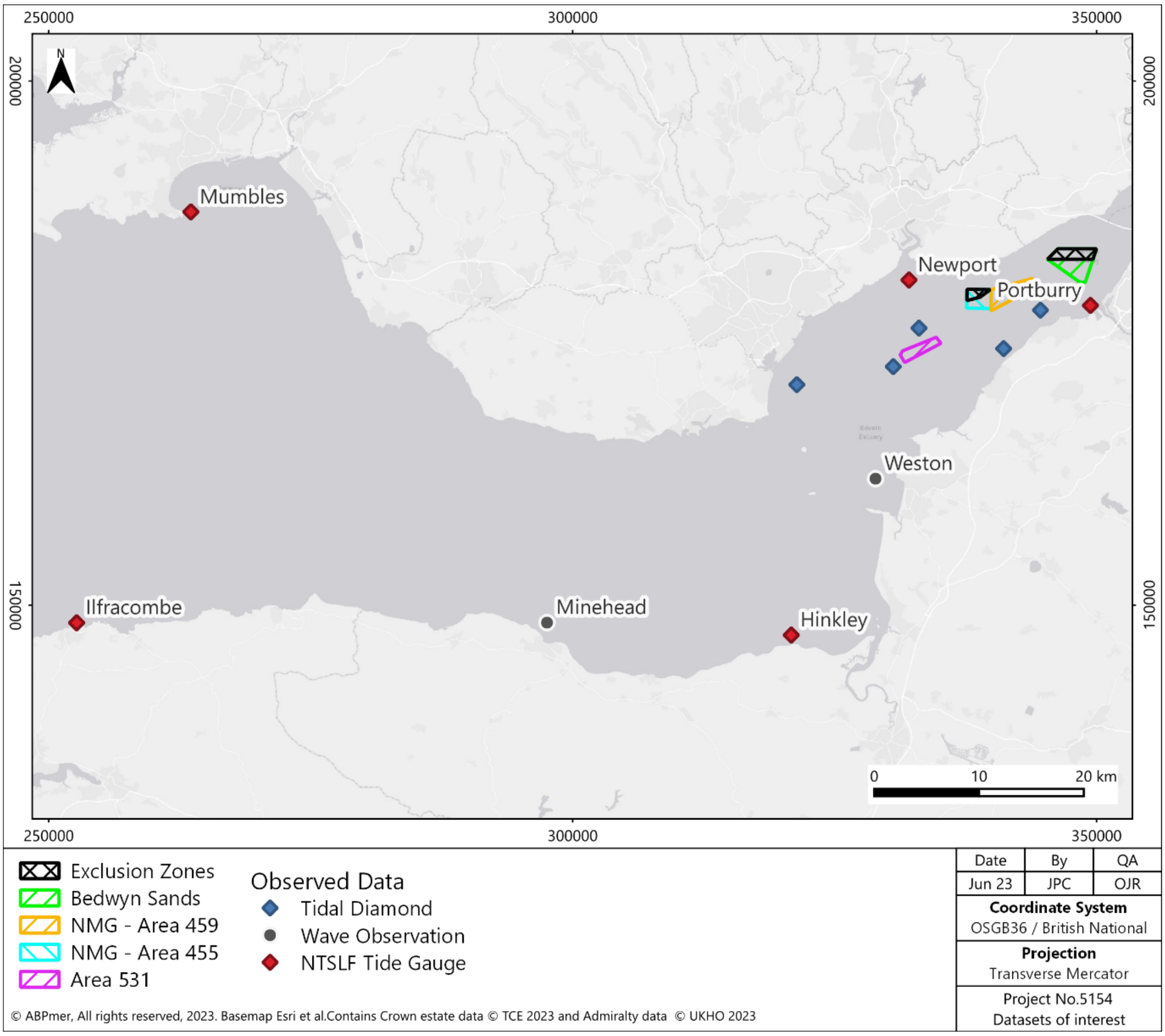


Figure 8. Locations of hydrographic data sources

Tidal water levels

Table 3 shows the tidal elevations for a range of locations across the primary study area (Figure 8).

Table 3. Astronomic tidal levels across the study area

Parameter	Astronomic Tidal Level (mCD)		
	Port Talbot (Downstream)	Newport (Adjacent)	Portburry (Avonmouth) (Upstream)
Highest Astronomic Tide (HAT)	10.7	13.6	14.7
Mean High Water Spring (MHWS)	9.7	12.3	13.2
Mean High Water Neap (MHWN)	7.3	8.9	9.8
Mean Sea Level (MSL)	5.41	6.26	6.96
Mean Low Water Neap (MLWN)	3.5	3.6	3.8
Mean Low Water Spring (MLWS)	1.1	0.8	1.0
Lowest Astronomic Tide (LAT)	0.2	-0.4	-0.1
Astronomic Tidal Range (HAT-LAT)	10.5	14.1	14.8
Spring Range (MHWS-MLWS)	8.6	11.5	12.2
Neap Range (MHWN-MLWN)	3.8	5.3	6.0

Source: UKHO, 2023

Surge

Variations in water levels in the estuary are primarily determined by tidal forces, with further short-term variations resulting from meteorological effects, such as surges, as well as long-term trends in mean sea level.

Surges within the Severn Estuary have been measured at Portburry, with the largest occurring on 16 March 1947 and measuring 3.5 m. The average of the seven largest surges at Portburry /Avonmouth, between 1930 and 1954, was 2.5 m (Atkins, 2009). The effects of surges increase up-estuary, in response to the funnel shape and the fetch distances available.

Relative sea level rise

It is now widely accepted that climate change will cause a continuing increase in mean sea level, although changes in sea level are a combination of climatic effects and changes in the elevation of the land due to post-glacial uplift (isostatic rebound) and tectonic effects. Information on the rate and magnitude of anticipated relative sea level change within the NMG and Bedwyn Sands licence areas, during the 21st Century, has been derived from the UK Climate Projections 2018 (UKCP18) (Palmer, *et al*., 2018).

These findings (provided in Table 4) suggest that by 2100, relative sea level will have risen by up to 0.98 m above 2023 levels (based on a high emissions scenario (RCP8.5), at 95% confidence limits), with the majority of this change being experienced in the second half of the century. These long-term changes to sea level may, for example, allow more wave energy to reach the coast, thereby potentially leading to future increases in coastal erosion across the wider study area.

Under the projected values given in Table 4, the conservative estimate of sea level rise (using the 95% confidence limit values), after the applied-for 15-year licence period, assuming issue in 2024, is calculated as 0.13 m (in 2039).

Table 4. Predicted relative sea level rise, across study area: RCP8.5 scenario

Year	Relative Predicted Mean Sea Level Rise (m Above 2023 Levels)		
	5% Confidence Limit	50% Confidence Limit	95% Confidence Limit
2030	0.03	0.04	0.04
2040	0.07	0.10	0.14
2060	0.17	0.25	0.36
2080	0.30	0.44	0.64
2100	0.43	0.65	0.98

Source: UKCP18 Marine Projections

3.5.2 Currents

The large and rapid rise and fall of the tide leads to very strong currents through the main body of the estuary. These strong currents maintain deep channels and high suspended sediment loads. Flows also increase in strength where they are forced through constrained narrows (e.g. The Shoots, just below the Second Severn Crossing, where the currents can exceed 6 m/s).

Where the tide becomes asymmetric then a dominance is established between ebb and flood currents: i.e. the flood tide becomes dominant in strength over the ebb (flood currents increasingly exceed those occurring on the ebb tide), but the duration of the ebb tide is longer. This effect also increases further up the estuary. These currents appear to be the primary mechanism for sorting seabed materials, so that the channels tend to contain gravels, with rocky patches, and the intertidal margins of the estuary have muddy deposits. Within the centre of the estuary there is also a large sand body called Middle Grounds, which extends to the northeast into the Welsh Grounds.

The estuary is considered to be ebb dominant towards the mouth, whilst further upstream the estuary is flood dominant. The location of the switch is just upstream of Avonmouth, which relates to a change in the bathymetry from deep water at the mouth, to the shallow water of the upper estuary. The exact location of this switch will likely vary as a function of factors, including tidal range, fluvial flows and topography.

The direction of the currents is strongly influenced by the morphology of the seabed, with currents generally aligned through the main channels and past shallow sandbanks. However, geological hard points extend out into the estuary and can influence the tidal flows to produce local modifications to the flow regime. For example, The Shoots directs the ebb tide over to the English shoreline upstream of Avonmouth.

At the confluences of the main tributaries there can also be impacts on the estuary flow as the tidal stream is influenced by the flooding or ebbing tide within the tributary. This can also lead to a dynamic local morphology in the tributary mouths. Typically, the influence of freshwater discharges into the estuary from tributaries is negligible, because under most conditions the tidal prism dominates. However, under high fluvial discharges, the relative significance of peak discharge is likely to become more locally significant, with the potential to introduce large amounts of sediment in suspension. The currents created by the incoming tide travel up the estuary until the opposing fluvial flow creates an area of slack flow, the location and timing of which varies with each tide. As the current is slowed, and then stops altogether, deposition of both incoming and fluvial sediment can be expected. The tidal asymmetry results in a division of the sediment transport pathways, between mud (as suspended load) and sand (as bedload) (see Section 4.3).

Tidal currents

Table 5 shows the tidal current speeds, in the vicinity of the extraction areas (see Figure 8 for location).

Table 5. Tidal stream information in the vicinity of extraction areas

Hours Relative to HW		Tidal Diamond SN053E (51°29.83′N, 02°57.88′W)		
		Direction (°N)	Mean Spring (m/s)	Mean Neap (m/s)
Before HW (Flood tide)	-6	232	0.72	0.41
	-5	056	0.87	0.46
	-4	053	1.65	0.87
	-3	054	2.06	1.08
	-2	056	1.75	0.93
	-1	059	0.98	0.51
HW	0	077	0.26	0.10
After HW (Ebb tide)	1	234	0.87	0.46
	2	241	1.49	0.77
	3	238	1.54	0.82
	4	233	1.44	0.77
	5	232	1.23	0.67
	6	232	0.98	0.51
		Maximum	**2.06**	**1.08**

Source: UKHO, 2023

Marine sands are pushed up the estuary during the fast-flowing flood tide, where they are deposited at the point where slack water is reached. The slower flowing ebb tide is generally unable to remobilise all the material for a seaward return and, therefore, sand is transported up the estuary by a process called 'tidal pumping'. The landward direction of net sand transport has been confirmed by sediment trends analysis (see Section 3.6 for further detail on the sediment regime). Muds tend to remain in suspension for most tides (particularly on springs) and tend to be introduced into the estuary primarily from fluvial sources.

3.5.3 Waves and winds

The wave climate within the Severn Estuary mainly consists of local, wind-generated, frictional waves with exposure to Atlantic swell waves limited by the change in orientation of the estuary around Flat Holm and Steep Holm (ABPmer, 2005). The wave conditions are linked to exposure to the direction of prevailing winds and fetch distances. At high water, wave fetches can extend over long distances, whereas at low water the intertidal banks dramatically reduce fetches. Sand Bay and Weston Bay are the limit of the Atlantic facing beaches exposed to swell waves.

Swell waves enter the Bristol Channel from the Atlantic Ocean, their height tending to decline with their passage up the estuary. As the alignment changes to the northeast, at the boundary with the Severn Estuary, the coast becomes increasingly protected from the incoming swell, and wind generated waves become more important. Because of the large tidal range, the Severn Estuary constantly changes as intertidal banks and wide intertidal flats become inundated and exposed, thereby changing the fetch distances over which waves can be generated. Correspondingly, upstream of Avonmouth, as the estuary narrows and fetches distances decrease, the size of waves also declines.

The presence of various banks in the estuary influences the wave climate, since they act as natural breakwaters through shallow water diffraction and limit the fetch distance (at certain tidal stages) across which waves can be generated. As described below, the main wind direction is from southwest and northeast, with the maximum wind speeds related to southwesterly winds. However, storms tend to approach from one direction; the southwest. Wind waves can be generated anywhere within the estuary, but their size is dependent on the fetch distance across which the wind blows to enable wave generation.

Wave climate

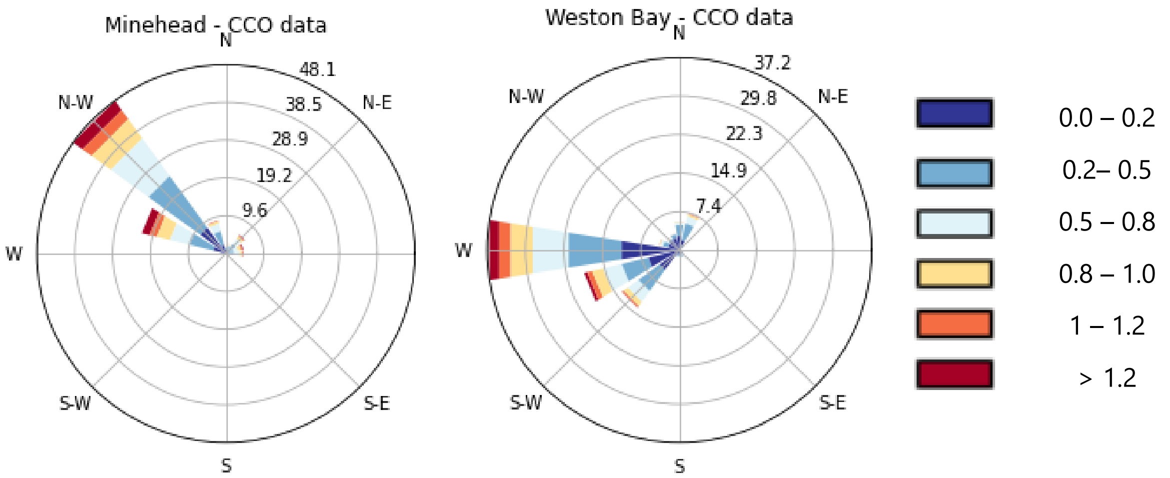
A number of sources of wave data are available within the wider study area. The Channel Coastal Observatory (CCO) provides access to two wave buoy datasets - one close to Minehead and the other in the vicinity of Weston-Super-Mare (Figure 8). In addition, data is available, through CCO, from a WaveRadar station mounted on the underside of the Second Severn Crossing (approximately 3 km upstream of Bedwyn Sands). Summary information of significant wave height (Hs), zero-crossing wave period (Tz) and peak wave direction (noting this information is not available for the WaveRadar station, which does not resolve direction in the wave climate), from each of these data sources, is provided in Table 6, with wave roses also presented in Figure 9.

Table 6. Summary of measured wave data

Location	Data Start	Observed Mean Wave Parameters				
		Hs (m)	H_{max} (m)	Tp (s)	Tz (s)	Modal Peak Direction (°N)
Minehead	01/12/2006	0.56	0.90	6.9	4.0	315
Weston-Super-Mare	10/09/2009	0.42	0.66	4.9	3.2	270
Second Severn Crossing	29/06/2011	0.11	0.20	6.0	2.3	Not resolved

Source: CCO 2023

The sites at Minehead and Weston are located in parts of the system which remain exposed to swell waves progressing throughout the wider Bristol Channel; the WaveRadar station on the Second Severn Crossing, by contrast, is within the Severn Estuary and in an area, which is expected to be more sheltered, with a climate dominated by wind-waves. The locations of these observed datasets are presented in Figure 8.



Source: CCO 2023

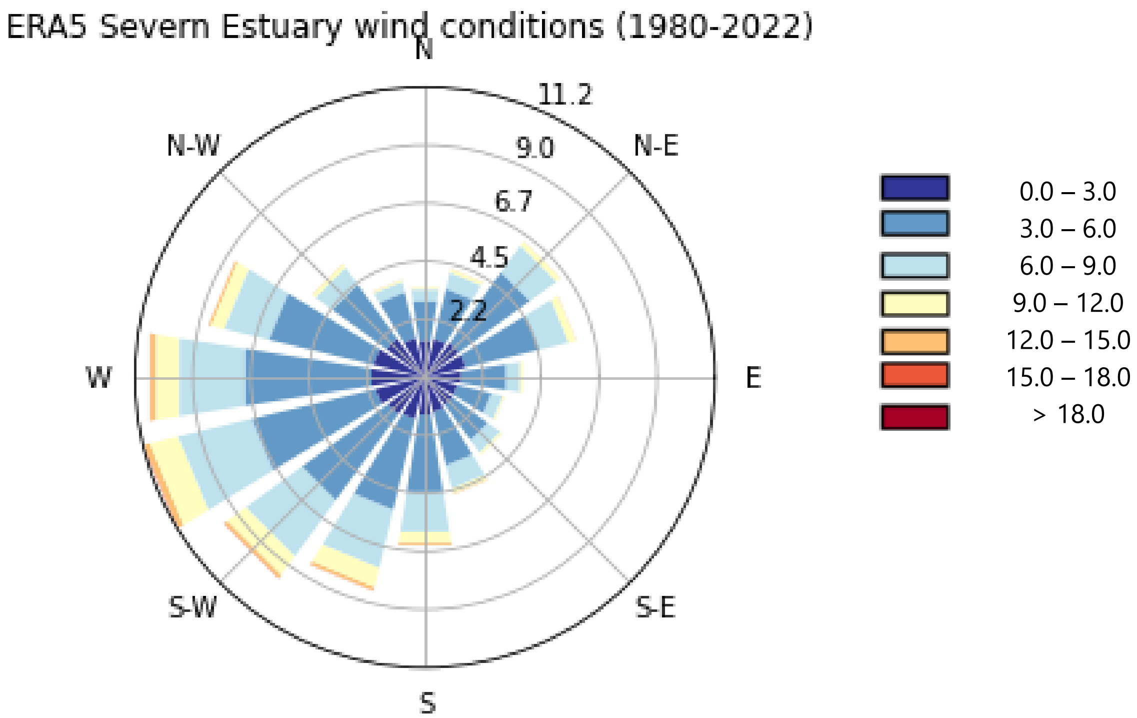
Figure 9. Wave roses for Minehead (left) and Weston-Super-Mare (right)

With regard to extreme wave conditions, a previous study (SEAWG, 2008), carried out numerical modelling of a series of extreme wave events throughout the Severn Estuary. Across the western extent of the Middle Grounds, modelled Hs values of a 10 in 1-year extreme wave event (expected to be experienced, on average, ten times in a year), approaching on a MHWS tide, and from the dominant wave direction (225°N), were found to be up to approximately 2.3 m (SEAWG, 2008). By contrast, a higher magnitude, lower frequency 1 in 100-year extreme event (expected to occur, on average, once in a 100-year period), with the same water level and approach direction, predicted Hs values of approximately 3 to 3.5 m.

Wind climate

Long-term wind statistics, derived from 40-years of hindcast data (1979 to 2022) available from the National Oceanographic and Atmospheric Administration (NOAA) National Centres for Environmental Prediction (NCEP) hindcast databases, are presented in Figure 10, in the form of a wind rose. Wind is taken from the hindcast model grid cell geographically representative of the dredge areas assessed. The wind data are referenced to 10 m above surface and represent the hourly mean value, illustrating that both the prevailing and strongest winds approach the region from the west and southwest.

The wind hindcast dataset has a spatial resolution of 0.2° (latitude and longitude), equivalent to approximately 8 by 12 km at UK latitudes. These meteorological hindcast data benefit from an assimilation of historical observed data (a method of optimising model predictions at each time-step using the observed conditions at that time). Assimilation data typically include satellite, terrestrial weather stations and discrete observations from ships of opportunity.



Source: NCEP hindcast data between 1979 and 2022

Figure 10. Wind rose derived from 45-year hindcast data

Climate change

The effect of future sea level rise upon locally generated wind waves in generally expected to increase the wave-generating capacity of the fetches. As a consequence, the heights of locally generated waves will likely increase at inshore sites as a result of increased sea level. The amount by which wave heights might increase is subject to considerable uncertainty. However, joint probability studies along the Gwent Levels (ABP Research, 2000) concluded that an exaggerated increase in wave height of 0.5 m had a limited impact on the morphological response of intertidal profiles, when compared against the effect of an associated predicted increase in sea level.

UKCP18 climate change projections are also considered with high levels of uncertainty. The general guidance is for a potential reduction in long-term mean Hs by around 10%, whilst annual maximum Hs could increase by around 8% (depending on scenario and reference period). To consider this, an additional test has been simulated to review the impact of changes in wave height and wind speed by applying a 10% uplift to each parameter.

3.6 Sediment regime

The sediment regime consists of two components:

- **Bedload**: refers to all sedimentary grains that move, roll or bounce (saltation) along the seabed as they are transported by currents. This mode of transport is principally related to coarser material (sands and gravels); and
- **Suspended load**: refers to particles of sediment that are carried above the seabed by currents and are supported in the water without recourse to saltation.

The following sections describe the characteristics of the sediment regime across the wider study area.

3.6.1 Sediment transport pathways

Two sediment transport pathways have been identified, related to coarse and fine material.

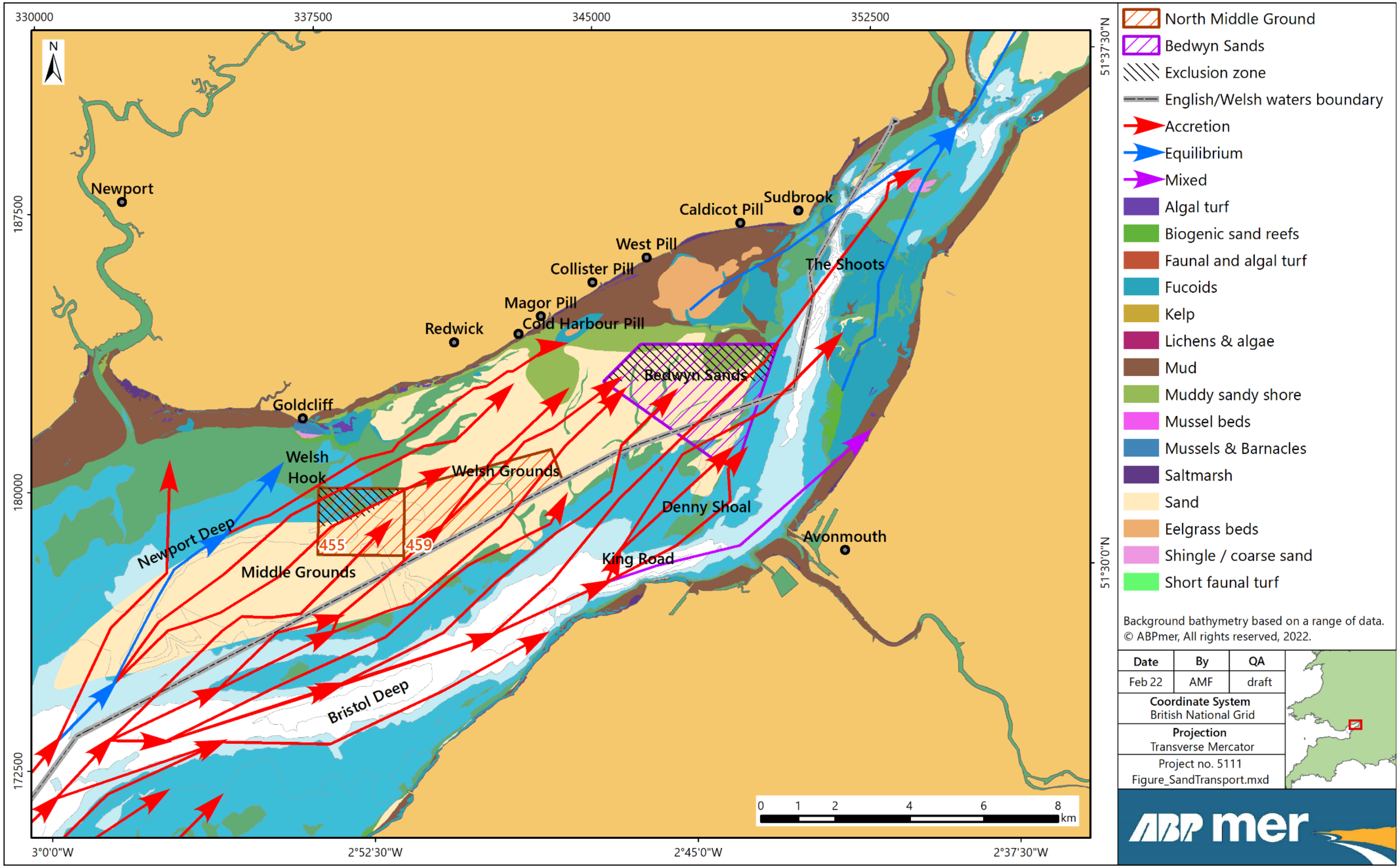
Bedload

The bedload sediment regime within the Severn Estuary is primarily controlled by the strong tidal currents. In general, there is a net up-estuary transport of sands driven by the asymmetry in tidal currents (faster flood tide current speeds).

The general consensus is that Bedwyn Sands is towards the down-drift end of an active sand transport pathway through the Severn Estuary, a process which is driven by the flood dominant tide and, at times, enhanced by prevailing south-westerly winds and waves (McLaren & Collins, 1989).

Evidence of the net sediment pathways has been derived as part of the set of field investigations provided for the Severn Tidal Barrage Project and using a technique of 'sediment trends analysis' (STA). This work is reported in McLaren & Collins (1989) with a summary of the findings presented in Figure 11. The up-estuary pathway is consistent through this part of the estuary and with a signature of 'accretion' (red lines and arrows on Figure 11), i.e. material is depositing along this pathway. Pathways continue upstream of Bedwyn Sands but are classified at this point as 'equilibrium' (blue lines and arrows), with neither erosion nor deposition taking place. This is explained by the stronger currents along The Shoots quickly taking this material upstream to further areas of deposition (e.g. Dun, Charston and Oldbury Sands).

Of particular note is the apparent line of transport for sediments reaching the Middle and Welsh Grounds, which suggests that material moving along Bristol Deep and Newport Deep during the dominant flood tide is the primary source, with some onward transport of sands from West Middle Ground. There is no apparent linkage in sediment transport to the muddier areas on the leeward side of Middle Ground.



Source: McLaren & Collins, 1989

Figure 11. Sand transport pathways derived from Sediment Trends Analysis

Suspended sediment transport pathways

The Severn Estuary is a relatively high suspended sediment environment. Primary sources of material in suspension are from the main tributaries to the estuary - namely the Rivers Severn, Wye, Usk, Avon and Parrett - and from intertidal erosion of mudflats, due to wave action.

Within an estuary, the concentration of suspended sediments often develops a maximum where fluxes from rivers and the action of tides and density driven currents converge. This maximum is known as the Estuarine Turbidity Maximum (ETM). For the Severn Estuary, the ETM extends from around Watchet, upstream to above The Shoots - a spatial range that incorporates the Middle and Welsh Grounds, NMG, Bedwyn Sands and Area 531. The ETM demonstrates marked variations between spring and neap tides, and also laterally across the estuary (predominantly governed by the passage of tidal flows along the main channel).

The most comprehensive survey of suspended sediment loads across the estuary was undertaken between 1974 and 1978, consisting of multiple cross-estuary transects, which were sampled throughout the tidal cycle. Close to 2,500 profiles were assessed in total. The main findings were of an estuary with high regional turbidity, and a cycling of suspended material over semi-diurnal (ebb and flood) and semi-lunar (spring-neap) timescales, between the water column and the seabed. Sampling indicated an estuary-wide suspended sediment load of around 30 million tonnes on high spring tides, reducing to around 2 million tonnes on low neap tides (when sediments have sufficient time to settle into fluid mud pools in the main estuary channels, e.g. Newport Deep).

Sediment sinks

Sinks can be coarsely defined as areas where sediment is transported to, and then deposited, on a relatively permanent basis. There are a number of sediment sinks within the Severn Estuary and wider Bristol Channel area. For example, a large part of the nearshore subtidal in Bridgwater Bay (south of Steep Holm), acts as a sink for muds. Similarly, considerable volumes of fine material are stored in the expansive intertidal mudflats of the Inner Bristol Channel and the Severn Estuary. These areas provide a contemporary sink for fine material and also act as an intermittent sediment source during periods of extreme wave action (i.e. under large storm conditions).

Within the study area, and as described in Section 3.3, there are wide intertidal mudflats along the Welsh foreshore, in the lee of the Middle and Welsh Grounds, along with smaller areas of mud upstream and downstream of Avonmouth. These tidal flats comprise predominantly of fine material (silts and muds), which is of a different composition to the sediment found within NMG and Bedwyn Sands. As a result, it is considered that there is no direct transport pathway between these areas (this is discussed further in Section 3.6.2).

Some material also accumulates within the lower reaches of the main river tributaries, due to limited exposure to the active hydrodynamic regime. The main tributaries flowing into the Severn Estuary, in the vicinity of the study area, include the Usk (at Newport) and the Avon (at Avonmouth). The estuary floodplain would also be expected to act as a major sink if this were available. However, anthropogenic flood embankments isolate this potential sink from the estuary, keeping the material within the estuarine environment.

3.6.2 Local sediment transport regime

Local-scale variability in seabed topography and hydrodynamic characteristics bring about a variation in the sediment transport patterns in and around the proposed extraction areas. Toward the southwest, adjacent to the primary channel, tides are considered to be the dominant process on the sediment transport regime, including the sediment sorting. This is a result of the strong tidal currents within the estuary, along with some intermittent influence from waves, particularly under storm conditions. The relative importance of waves and tides, on sediment transport in and around the NMG and Bedwyn Sands, is considered in more detail below.

Tidal controls

The threshold of mobility for medium sand grains (0.35 mm) in approximately 5 m water depth, (considered as a representative depth within dredge areas), was calculated as 0.89 m/s (Soulsby, 1997). Tidal flows, within and around the extraction areas, exceed this threshold velocity for the majority of the tidal cycle. Empirical sediment mobility calculations completed for this study, confirm that sediments up to coarse sand would therefore be mobile during the majority of the spring-neap tidal cycle, with coarser gravel sized material (3 mm) being mobilised mainly during the peak of the spring tidal cycle. This highlights the dynamic environment within the study area, with tides strongly influencing the potential sediment transport.

Wave controls

In view of the available evidence, tidal currents provide the principal control on sediment transport within the study area. The additional effect of wave stirring of the seabed during occasional storm events can also further mobilise sediment, thereby altering the magnitude of sediment transport along the defined pathways. Additionally, the dominant south westerly wind/ wave climate will exacerbate the north-westerly movement of sediments through longshore transport processes. It is therefore necessary to consider the implications of changes to storm waves, as a result of the proposed aggregate extraction, in the context of sediment mobility potential.

Across the intertidal and subtidal flats at the coastlines within the study area, particularly along the Caldicot foreshore, waves are the primary controlling factor on nearshore sediment movement and, in particular, the re-suspension of the finer material that can accrete there. It is, therefore, also important to consider the potential effects of changes to the wave climate at the coast and on coastal sediment transport.

Potential sediment transport linkages between the licence areas and the coast

Previous numerical modelling and desk-based analyses consistently indicate that there are no apparent sediment transport pathways between the existing aggregate extraction areas and the wider Middle and Welsh Grounds, with either the English or Welsh coastlines (McLaren *et al*., 1993; Posford Duvivier & ABP Research & Consultancy, 2000; HR Wallingford, 2003a & b; SEAWG, 2008). By association, this would further indicate that there is also no pathway between the NMG or Bedwyn Sands licence areas and either the English or Welsh coasts.

Furthermore, analysis of sediment grain sizes and mineralogy concluded that the sediments within the nearshore region, along both the English and Welsh coasts, were of a different composition to those found offshore over the intertidal sandbank features (Harris & Collins, 1991). The coastal sediments are interpreted to be derived from local sources, such as cliff erosion, riverine inputs, and longshore transport. The sediment transport along the coast, therefore, may be considered as a separate sediment transport regime than that which occurs over the offshore sandbanks, and within the aggregate extraction areas. This is due to the mineralogical differences between the coastal and offshore locations, coupled with the fact that longshore transport is primarily driven by wave action rather than tidal currents.

3.7 Annual monitoring of regional bathymetry

The description of the baseline environment provided in Sections 3.1 to 3.6, provide an overview of the system, and the primary drivers that control the form and evolution of the identified features. Annual regional monitoring is carried out, in discharge of conditions within the existing licences, across the Middle and Welsh Grounds sandbank feature.

This monitoring, which is carried out in compliance with the Marine Licence requirements of the respective areas, assesses the changes observed across the wider region, in response to a set of defined metrics looking at height, area and volume of the sandbank above a series of given elevation planes. The latest annual monitoring report for NMG and Bedwyn Sands is given in ABPmer (2022), which provides a substantive review of the preceding 5 years of dredge activity.

Full detail of the monitoring analyses, and the associated results, is provided in the 5-year substantive review report; in providing a general summary, the ongoing analysis against the monitoring metrics reveals information on the range of natural variability across the wider system. This analysis includes consideration of pre-dredge datasets and historic baseline survey data. Such variability often results in slight changes in the values calculated against the performance metrics on an inter-annual basis, with further detail provided in the following Sections.

3.7.1 North Middle Ground

A long-term analysis of monitoring metrics, including height, area, and volume at NMG, reveals a slight downward trend in the average bank height, drying area extent, and bank volume above MLWS since the baseline conditions in 2005 (prior to dredge activities). However, it is important to note that all these metrics still remain significantly higher than what was observed in the 1920 surveys (the trigger in the monitoring conditions). Therefore, the variation is considered to be well within the natural variability of the system and does not indicate a significant depletion of available sediment.

3.7.2 Bedwyn Sands

The most recent monitoring analysis at Bedwyn Sands outlines that the area above 4 mCD is lower in 2021 than 2020 but remains within (or above) the envelope of natural variability established by prior surveys. The observed changes are largely attributed to the extension of the central sandbank feature toward the south of the extraction area in 2012, peaking in 2017. Additionally, this area is greater than the surveyed extent of the 2006 baseline conditions (prior to commencement of dredge activities), and significantly greater than 1920 extents (ABPmer, 2022).

3.8 Summary of baseline understanding

The Severn Estuary and Bristol Channel is a submarine valley system that was originally formed during the Quaternary glacial and interglacial periods (e.g. the Ipswichian interglacial around 130,000 to 115,000 years BP, and the subsequent Devensian glaciation around 115,000 to 10,000 years BP); and has been subject to ongoing modification to reach its present form (Jacobs, 2007). The primary geological units are overlain by thin veneers of glacial till and discrete areas of channel infill deposits. The largest sediment accumulations in the estuary are in the infilled river valley (in the area occupied by the Middle and Welsh Grounds) with sediment thicknesses of up to 30 m. Elsewhere, unconsolidated sediment cover in the estuary is generally thin (typically less than 5 m). Sediments are also generally well-sorted by the high energy tidal regime, leading to distinct and separate deposits of gravels, sands and muds.

The Welsh coastline, in the vicinity of the Severn Estuary aggregate extraction areas, extends approximately from Newport, in the west, to the Second Severn Crossing in the east (Figure 3). This coastline lies in the lee of the Middle and Welsh Grounds, when considering the dominant direction of wave approach, from the southwest. The coastline here consists of wet reedbeds, wet grasslands and shallow saline lagoons, fronted by a muddy foreshore. The frontage along the Caldicot Levels is south-easterly facing and fronted by a relatively wide expanse of intertidal saltmarsh and sandbanks. The backshore along much of this stretch is almost entirely below the level of mean high-water springs and is defended by a continuous clay embankment.

The English coastline within the study area, extends approximately from Middle Hope, in the west, to the Second Severn Crossing in the east (Figure 3). This coastline is a mixture of high cliffs (around Middle Hope, and between Portishead and Clevedon), along with a narrow rocky intertidal area. The coastline fronting Kingston Pill is characterised by resistant rock outcrops to the southwest and northeast, with a number of tributaries discharging into the Severn Estuary. Further upstream, the frontage between New Passage and the Old Pier at Portishead is a northwest facing embayment, and is generally fronted by intertidal mud, sand or gravel banks, saltmarsh and rock outcrops at the northern end. The docks at Avonmouth and Portishead influence the local conditions along this frontage. Sediment sizes within both extraction areas are predominantly Sand with localised gravel and mud fractions, particularly within the NMG.

The Middle and Welsh Grounds form an extensive expanse of linked intertidal sandbanks and sandflats, which are laterally constrained by a series of naturally deep channels. To the west, the Newport Deep extends to a depth of around 7 m below Chart Datum (CD). To the south, the Bristol Deep and King Road extend to depths of around 18 m and 20 m below CD, respectively; whilst to the east, The Shoots extends towards the Severn Crossings, with depths approaching 30 m below CD. The shape and form of the main channel results in relatively high flow speeds, maintaining a natural flushing of these channels.

The Severn Estuary is subject to a very large semi-diurnal tide, of 10 to 12 m mean spring range. This high tidal range is due to the combination of the North Atlantic tidal wave approaching through the Bristol Channel and the further amplification and convergence of this tidal wave as it moves into the funnel-shape of the Severn Estuary. This large and rapid rise and fall of the tide leads to very strong currents through the main body of the estuary. These strong currents maintain deep channels and high suspended sediment loads. Flows also increase in strength where they are forced through constrained narrows (e.g. The Shoots, just below the Second Severn Crossing, where the currents can exceed 6 m/s).

The wave climate within the Severn Estuary is considered to be mainly wind-generated, with exposure to Atlantic swell waves limited by the change in orientation of the estuary around the islands of Flat Holm and Steep Holm. The wave conditions are linked to exposure to the direction of prevailing winds and fetch distances. At high water, wave fetches can extend over long distances, whereas at low water the intertidal banks dramatically reduce fetches. Sand Bay and Weston Bay, at the seaward extent of the estuary, are the upstream limit of the Atlantic-facing beaches, exposed to swell waves.

The bedload sediment regime within the Severn Estuary is primarily controlled by the strong tidal currents. In general, there is a net upstream transport of sands driven by the flood tide. It is considered Bedwyn Sands extraction area is towards the down-drift end of an active sand transport pathway through the Severn Estuary, a process primarily driven by the flood dominant tide, and enhanced by prevailing southwesterly winds and waves during storm conditions.

The Severn Estuary is a relatively high suspended sediment environment. Primary sources of material in suspension are from the main tributaries to the estuary - namely the Rivers Severn, Wye, Usk, Avon and Parrett - and from intertidal erosion of mudflats, due to wave action. An estuary-wide suspended sediment load of around 30 million tonnes has been defined on high spring tides, reducing to around 2 million tonnes on low neap tides. Under low-energy conditions, sediments have sufficient time to settle into fluid mud pools in the main estuary channels (e.g. Newport Deep). Primary sinks for suspended material are the sub-tidal areas fronting Bridgwater Bay (in the Inner Bristol Channel) and Newport Deep. The floodplain would also be expected to act as a major sink if this were available. However, the flood embankments (which extend along the low-lying coastlines), isolate this sink from the estuary, keeping the material within the estuarine environment and causing high concentrations.

There are no apparent sediment transport pathways for coarse material (i.e. sand and larger) between the North and Welsh Middle Grounds and the adjacent English or Welsh coastlines. Although the wide expanses of muddy foreshore (particularly along the Welsh coastline), act as a sink for fine sediments, available evidence suggests that coarser sediments across the Middle and Welsh Grounds are distinct from these. It is considered, therefore, that no pathway exists between the onshore and offshore locations, and *vice versa*.

4 Coastal Impact Assessment Methodology

This CIS has been undertaken in accordance with the most recent guidance published by BMAPA, in association with The Crown Estate, MMO, CEFAS and NRW (BMAPA, 2013), which relates to the assessment of physical processes for marine aggregate licence applications. This includes characterising the coastal frontage and baseline hydrodynamic and sediment transport conditions for the study area, with a view to assessing the potential changes to these properties as a result of marine aggregate dredging in NMG and Bedwyn Sands.

4.1 CIS objectives

The primary objective of the assessment is to determine whether the renewed aggregate extraction within NMG and Bedwyn Sands licenced extraction areas would adversely affect the English or Welsh coasts. These so called 'receptors' can only be exposed to a change if a pathway exists, through which an effect can be transmitted between the source activity and the receptor. Furthermore, an effect can only be defined if a 'receptor' is deemed sensitive to the predicted change in the associated 'pathway'. Physical processes, namely waves, tides and sediment transport are the forcing mechanisms, which control the coastal and seabed receptors and therefore constitute the primary effect pathways. To ensure that all the potential effects of dredging are considered, the CIS has been carried out on the basis of a conceptual 'Source > Pathway > Receptor' model whereby:

- The **source** is the initiator event - in this case the seabed lowering caused by aggregate extraction;
- The **pathway** is the link between the source and the receptor impacted by the effect - for example waves, tides and sediment transport; and
- The **receptors** are the receiving entities - for example, the coastline and the wider Middle and Welsh Grounds sandbank system.

4.1.1 Key considerations for assessment

Based on the best practice guidance applied to this CIS, a number of potential assessment pathways have been identified between the proposed aggregate extraction renewal within NMG and Bedwyn Sands and the physical process receptors. These draw on the properties and sensitivities that exist within the study area, and are summarised below:

- Effects at the English and Welsh coasts due to changes in:
  - south-westerly waves;
  - westerly waves;
  - north-westerly waves; and
  - north-easterly waves.
- Effects at the English and Welsh coasts due to:
  - beach draw-down; and
  - changes in bedload sediment transport;
- Effects on the wider system of sandbanks within the Severn Estuary Special Area of Conservation (SAC), due to changes in bedload sediment transport and wave and tidal induced seabed mobility; and
- Cumulative effects on the coast with ongoing dredging within Licence Areas 531, NMG and Bedwyn Sands.

Specific effect pathways have been identified within the baseline characterisation (above), in line with present guidance (BMAPA, 2013). The magnitude of changes to these pathways and the consequential effects on the coastline and seabed has been assessed using a range of analytical techniques including:

- GIS based applications to create pre- and post-dredge bathymetries;
- Numerical modelling;
- Empirical calculations; and
- Expert judgement.

Details of these various analytical approaches are provided in the following sections.

4.1.2 Creation of bathymetric datasets

To determine the effects of ongoing and future aggregate dredging on the hydrodynamic and sedimentary regime it is necessary to develop an appropriate representation of the pre- and post-dredging bathymetry. This CIS assumes removal of a combined 500,000 tpa, over a 15-year licence period, equating to a total volume of 7.5 million tonnes to be removed across the two areas. The maximum permitted (licensed) tonnage remaining on the existing licences (from the collection of the most recent bathymetry data in 2022) is also accounted for in the modelling assessment.

The aggregate removal has been represented in the modelling study, applying a level of conservatism to the assessment. This conservatism is represented by an uplift of 10% on the calculated extraction volumes (from each site), and by an averaged bed lowering over the wider bathymetric feature that each extraction area sits within (rather than a lowering of the extraction area only). These wider features are generally defined as being bounded by aspects of the bathymetry, separating them from other parts of the wider Middle and Welsh Grounds feature. These include the Bristol Deep and the Newport Deep, and the boundary tends to associate with the switch between the primarily sandy character of the Middle and Welsh Grounds, the coarser material in the main channel and the finer material along the Porton Grounds and the Caldicot foreshore.

This approach to the assessment follows that which was previously undertaken in earlier modelling studies (e.g. SEAWG, 2008 and ABPmer 2021). The assessment is also representative of the conceptual understanding that dredging tracks, from aggregate extraction on the Middle and Welsh Grounds, are rapidly smoothed by the dynamic flow conditions. This smoothing potentially results in surface material being reworked over a wider area; hence the assessment including these wider bed features, as described above. Figure 12 shows the equivalent bed lowering across the renewal area, noting (as described above) the modelling assessment has applied the combined bed lowering volume across the wider bathymetric features.

This approach provides a conservative simulation of dredging patterns within the area of interest, which can be represented and assessed within the numerical models, by allowing for changes in bed levels across the extraction areas. For this investigation, separate bathymetric datasets have been produced:

- **Present day** - which informs the contemporary bed levels within the NMG and Bedwyn Sands extraction areas (along with the nearby Licence Area 531). This includes the seabed as surveyed during the 2022 bathymetric survey (Shoreline Surveys Limited, 2022), reflecting the dredging that has also been carried out, within existing licence areas, up to the 2022 survey date;
- **NMG and Bedwyn Sands: Post - dredging** - which shows the total bed level changes, applied over the wider bathymetric features of the estuary, assuming removal of the renewed licenced tonnage from both NMG and Bedwyn Sands; and

- **In-combination Post - dredging** - which includes the NMG and Bedwyn Sands Post-dredge, and also provides for the current total licenced extraction from the adjacent Licence Area 531.

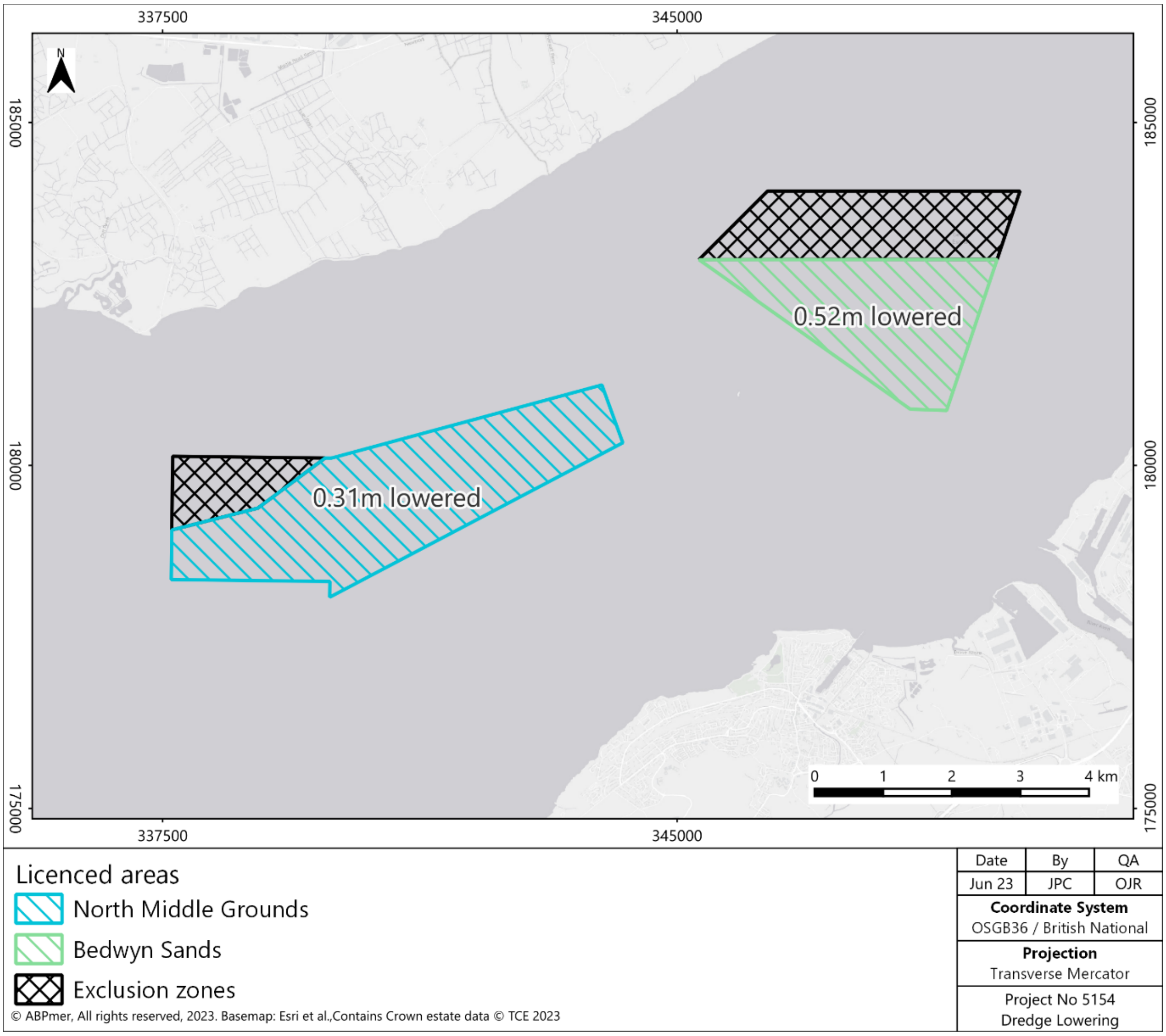


Figure 12. Equivalent bed lowering (by area) associated with renewed licenced abstraction

The present-day bathymetry has been created using the most recent survey data, including data collected in September 2022 (regional survey of the Middle and Welsh Grounds, including Bedwyn Sands – Shoreline Surveys Limited, 2022), which provides an up-to-date representation of the seabed. The post-dredging bathymetry was created by lowering the 2022 bathymetry surface by an amount equating to the combined licenced (undredged) and future renewal tonnages. The assessment volumes, and equivalent bed lowering for each Licence Area, are summarised in Table 7.

These assessed volumes have been considered, using the numerical modelling tools (as described in the following Section), by assuming the complete removal of the entire licenced volume, for the remaining licence and future renewal duration at each site. In this way, an assessment of the potential effects (alone and in-combination) of the whole licenced volume (should it be taken) has been undertaken. Step-wise assessment of extraction over smaller spatial and/or temporal scales is not considered necessary, due to the observed variability in the characteristics of the wider system (ABPmer 2021a). These analyses show no evidence of consistent bed lowering over the active dredge zones, further supporting the understanding that the Middle and Welsh Grounds are an active region for sand transport, with the strong tidal flows redistributing material into any dredge tracks within a few tides.

Table 7. Summary of assessed dredge volumes

Licence Area	Licence/Application Rate (tpa)	Duration (yr)*	Total Volume (Mm^3)**	Average Lowering Over Feature (m)***
531	300,000	15	5	1.58
North Middle grounds	250,000	15	2.5	0.31
Bedwyn Sands	250,000	15	2.5	0.52

* Between baseline survey and end of present licence / application, to assess the total possible extraction volume
** Conversion from tonnage to volume achieved using a sediment density conversion of 1.5
*** Equivalent average bed lowering over feature includes a 10% uplift on total extraction volumes for added conservatism

As a result, a conservative worst-case assessment has been undertaken of the full licenced dredge volume, over the full licenced dredge area, using the September 2022 bathymetric survey. Consequently, predicted impacts from extracting a smaller volume, or from extraction over a smaller area, or from extraction during periods where the natural variability of the wider system provides a higher, more protective, sandbank system, can be expected to be less than those described herein.

4.2 Modelling methodology

The best practice guidance for assessing the potential effects on aggregate dredging on the coast calls for the use of modelling information to supplement available field data. This project has, therefore, applied a numerical modelling study to investigate the range of potential effects. This study has benefitted from ABPmer's existing hydrodynamic and spectral wave numerical models of the Bristol Channel and Severn Estuary region, which have previously been used for a number of projects, including the Area 472 dredging impact assessment (ABPmer, 2013 and 2014), Area 526 Coastal Impact Study (ABPmer, 2016) and Area 531 Coastal Impact Study (ABPmer 2019). These same models, with necessary refinements, have been used to inform this Coastal Impact Study for the proposed licence renewal of extraction licences for NMG and Bedwyn Sands.

4.2.1 Hydrodynamic (tidal) modelling

The tidal model has been configured using the MIKE21FM-HD module. The model has been designed in 2D, depth-averaged mode applying a flexible mesh (FM) element grid. The use of a flexible mesh enables the necessary detail of the Severn Estuary, including NMG and Bedwyn Sands (and Area 531), to be sufficiently resolved within the model, whilst maintaining a coarser resolution away from the site of interest to maximise computational efficiency.

The model has been updated to include the more recently collected bathymetry from the 2022 site geophysical survey (Shoreline Surveys Limited, 2022), covering the extraction sites and the surrounding area. The model has previously been subject to robust calibration for locations throughout the estuary (ABPmer, 2010), and has been revalidated since the most recent updates applied for this study. Full details of this validation process can be found in Appendix A of this report.

Overall, the model was set up and run to represent the following scenarios:

- Existing baseline;
- NMG and Bedwyn sands post-dredge; and
- Cumulative post-dredge (NMG, Bedwyn, and Area 531).

Bed lowering was applied in the model across the licenced areas within the model domain: NMG and Bedwyn Sands (the study sites) and additionally Area 531, for the cumulative assessment. Two post dredge variations were produced:

- The first of which removed material only from the study sites, NMG and Bedwyn Sands
- The second of which removed material from all three licenced dredge areas (Area 531, NMG and Bedwyn Sands), assessing the cumulative effect of aggregate extraction within the wider Severn Estuary.

The tidal model was run for a mean spring-neap cycle, for each of the present day and post-dredge scenarios. The outputs from the modelling assessment have been compared (post-dredge vs. baseline) in order to assess the effects of the dredging on the hydrodynamics of the study area.

4.2.2 Wave modelling

Previous wave modelling (SEAWG, 2008)

In support of the aggregate extraction at the existing licenced areas, the Severn Estuary Aggregate Working Group (SEAWG) commissioned a wave modelling study (SEAWG, 2008) to investigate the combined effect of aggregate dredging activity on the wave climate throughout the Severn Estuary. This study assessed all the existing and proposed future dredging activity throughout the Severn Estuary, upstream of a line between Brean Down and Lavernock Point. The purpose of the assessment was to provide a collaborative approach to assessing the in-combination effects, on waves, of aggregate extraction undertaken and proposed by CEMEX UK Marine Ltd, Hanson Aggregates Marine Ltd, Severn Sands (now owned by Breedon) and Tarmac Marine Ltd. (formerly United Marine Dredging - UMD), who together form SEAWG.

Existing and proposed licenced tonnages within the Severn Estuary were supplied to the study by The Crown Estate, totalling a maximum licenced annual extraction rate of 925,000 tonnes, over a 5-year period (and amounting to a maximum combined extraction of 4,625,000 tonnes over the period). By contrast, with the subsequent surrender of Areas 385 and 391 (by other dredging companies), the present combined maximum annual extraction rate from the existing licences within the Severn Estuary totals 800,000 tonnes per year.

The SEAWG wave modelling study applied a range of bathymetric data across the model domain. Over the specific region of the Middle and Welsh Grounds, the data within the modelling were provided by a bathymetric survey carried out in 2005 (Aquatech, 2005). The wave study investigated the effect of dredging on wave transformation, linking through to an assessment of effects on coastal processes, morphology and flood risk. The findings of the study identified that the maximum combined aggregate extraction throughout the Severn Estuary would not have any marked effect on wave conditions along any part of the Severn Estuary coastline. The changes in wave height that were predicted were for a localised increase in Hs over the extraction areas of less than 0.08 m. These changes did not, however, result in any change to the predicted wave height along either the English or Welsh coastlines.

With the present renewal areas for continued aggregate extraction in NMG and Bedwyn Sands, this CIS is now carrying out an updated wave modelling study, informed by the approaches used in the SEAWG report (and, more recently, for the assessment of the Area 531 licence application (ABPmer, 2021)), to consider the combined effect of aggregate extraction across the Severn Estuary. The updated modelling study is described further in Section 4, with the results then informing the Impact Assessment, detailed in Section 5.

Wave modelling in support of NMG and Bedwyn Sands renewal

In order to simulate the propagation of waves through the Bristol Channel and Severn Estuary, to the renewal sites, and beyond, a spectral wave model has been developed using the MIKE21 Spectral Wave (SW) module. This model has built upon ABPmer's existing spectral wave model of the region, which was previously utilised for the Areas 472, 526 and 531 dredging studies and calibrated and validated across the estuary (ABPmer 2010). Full details of the model setup for the present scenarios can be found in Appendix A of this report. As with the hydrodynamic modelling, the model bathymetry was also revised to include the existing (baseline) bathymetry and post-dredge scenarios.

Offshore boundary conditions

Wave parameters are input at a single offshore wave boundary where significant wave height, peak wave period, wave direction and directional spreading have been defined. The offshore wave boundary conditions are derived from the ABPmer SEASTATES[1] wave hindcast database, extracted for a central location along the western wave boundary. A constant wind field, based on the individual wave event being assessed (see below), is applied across the whole domain. The model is run to reach a stable-state solution, in order to establish wave conditions for fixed return period events. The effects of dredging on a 1 in 200-year event at Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) water levels have been modelled. This is to investigate the influence of water depth on predicted wave behaviour. Additionally, a more typically occurring wave scenario, with a 10 in 1-year return period, has also been simulated. A summary of the range of modelled wave conditions is provided in the following section.

Selection of input conditions

Modelling of the 1 in 200-year and 10 in 1-year wave events (in conjunction with MHWS and MLWS water levels) has been completed from four directional sectors; namely the southwest, west, northwest and northeast. The resulting wave heights have undergone extensive validation against available estimates of extreme wave heights throughout the estuary and based upon measured data and previous modelling studies. Full details of this process are provided in Appendix A.

Table 8 to Table 9 present the selected wave boundary and wind field forcing conditions for the final return period wave simulations.

Table 8. Model inputs for 10 in 1-year return period events

Scenario	Hs (m)	Tp (s)	Wave Dir (°N)	Wind Speed (m/s)	Wind Dir (°N)
NE 10 in 1*				12.2	045
SW 10 in 1	5.5	11.4	225	16.0	225
W 10 in 1	5.5	11.4	270	16.0	270
NW 10 in 1	3.5	9.1	315	14.3	315
* Assessment of north-easterly wave considers wind-generated waves only					

Table 9. Model inputs for 1 in 200-year return period events

Scenario	Hs (m)	Tp (s)	Wave Dir (°N)	Wind Speed (m/s)	Wind Dir (°N)
NE 1 in 200*				23.6	45
SW 1 in 200	12.6	17.2	225	31.0	225
W 1 in 200	12.6	17.2	270	31.0	270
NW 1 in 200	8.1	13.7	315	27.8	315
* Assessment of north-easterly wave considers wind-generated waves only					

[1] ABPmer: www.seastates.net

To provide some context to the range of wave events included in the assessment, the larger of the 10 in 1-year events (Table 8; west and southwesterly), are generally equivalent to Beaufort scale Force 6 and Force 7 winds - described as ‘strong breeze’, to ‘high wind’.

The more extreme 1 in 200-year events (Table 9; west and southwesterly) represent Force 11 ‘violent storm’ conditions, with offshore wave heights of around 12 to 16 m. For reference, the widely publicised Valentine’s Day storm of 2014, which impacted much of the west coast of the UK, recorded maximum wind gust speeds of around 30 m/s (60 knots), in and around the Bristol Channel and Severn Estuary (MetOffice 2023); these speeds are equivalent to Force 11 ‘violent storm’ conditions on the Beaufort scale.

The eight scenarios detailed in Table 8 and Table 9 were each run for a MHWS water level condition (+6.04 mMSL) and for a MLWS water level condition (-5.46 mMSL). The 1 in 200-year event from the predominant southwesterly approach direction (Table 9) was also run for a MHWN water level condition; this was undertaken to assess the potential impact of extraction where the majority of the Middle and Welsh Grounds are not exposed, but where water depths are sufficiently limited to potentially affect wave energy dissipation.

Additional tests were also carried out for a climate change scenario, whereby water level, wind and wave conditions were increased in accordance with the UKCP projections described in Section 3.5.

4.3 Sediment transport

In order to assess the potential impacts to sediment transport characteristics across the study area, desk based empirical approaches were applied. This included calculating the potential for sediment mobility under currents and waves based on a standard approach, using established relationships defined by Soulsby (1997).

These methods do not provide a direct estimation of changes in sediment transport rates. Instead they quantify changes to the sediment mobility potential, which, in turn, demonstrate if, and where, changes to the hydrodynamic regime are likely to have an effect on sediment movements (and patterns of erosion and accretion) in and around the dredging areas.

4.3.1 Bed shear stress

In order to assess the seabed mobility potential, the modelled bed shear stress, as a result of the modelled currents and waves, was analysed at key locations within the study area, for both the baseline and post-dredge scenarios. This information is then compared with calculated theoretical sediment mobility thresholds, for the different sized fractions at each site. This allows mobilisation events to be identified and demonstrates the extent to which changes in waves or tidal currents may affect sediment mobility and, hence, potential sediment transport.

5 Impact Assessment

The following sections present the results of the hydrodynamic (Section 5.1) and wave modelling (Sections 0 to 5.3), removing the full 15-year NMG and Bedwyn Sands renewal application tonnage from the present-day bathymetry (and inclusive of a 10% uplift for conservatism). The resultant implications on sediment transport pathways are considered in Section 5.4, whilst the assessment of effects on key receptors is described in Section 5.5. An additional set of model scenarios are also provided, assessing the cumulative effects of dredging across multiple Licence Areas within the Severn Estuary (Section 5.6).

In accordance with the 'source > pathway > receptor' model described in Section 4, the assessment has determined the magnitude of changes to physical processes (pathways), and the likely consequential effects on the identified receptors.

5.1 Predicted changes to the hydrodynamic regime

The assessed changes to the present-day baseline peak flood and ebb tidal flows, within and around the Bedwyn and NMG aggregate extraction sites, are shown in Figure 13. In both cases, the following information is presented:

i. Baseline flow regime
ii. Absolute change in peak flow speed (whereby a positive change equates to an increase and *vice versa*); and
iii. Change in flow direction (displayed as overlaid vectors).

The pattern of change within the extraction areas is variable with areas of increasing and decreasing peak tidal currents on both the flood and ebb. The overall magnitude of change is, however, relatively small, with maximum changes of < ±0.1 m/s. The reductions in flow within the extraction areas occur in isolated locations, close to the edges of the dredge sites, with changes in speed generally within ±0.04 m/s (Figure 13). Beyond the immediate vicinity of the extraction areas, predicted changes are typically less than 0.01 m/s. The changes in flow speeds within the Bedwyn Sands extraction area, equate to approximately 2-3% change in speeds from the peak baseline flow (up to 1 m/s), on both the flood and ebb tide. Conversely at NMG, slightly higher baseline current speeds (up to 1.3 m/s) results in a slightly lower percentage decrease (~1-2%), as a result of the proposed extraction.

At Bedwyn Sands, the biggest difference in velocity is along the south-western edge of the extraction site, adjacent to the channel, where the extraction of sediments yields current speed reductions of up to 0.06 m/s (~6% of baseline flow) on both flood and ebb tides (Figure 13). On a flooding tide, the bed lowering generates decreases of around 0.05 m/s within the footprint. Beyond the extraction footprint, reductions in flow of up to 0.01 m/s are simulated to extend northwest and northeast toward the Welsh and English shorelines. This change in flow is however predicted to be typically less than 1% of the existing (baseline) flow speed in these areas and is considered negligible. This is discussed in greater detail in Section 5.4.1. Increases in flow velocity are simulated downdrift of the dredge, extending around 2 km northeast (for flood tide) and southwest (for ebb tide) of the extraction footprint.

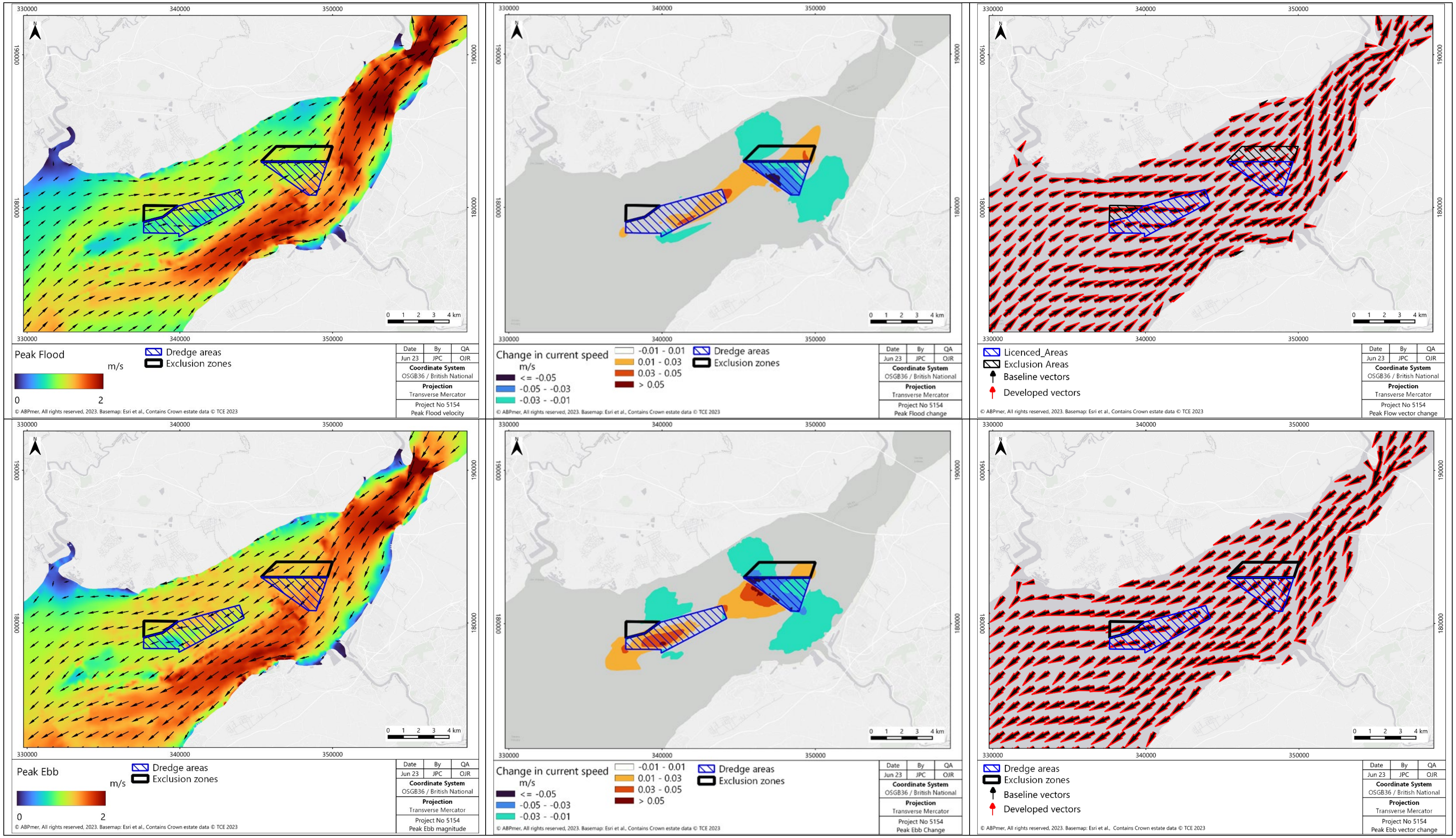


Figure 13. Predicted changes to flow regime: Baseline flow speed (left), post-dredge difference to baseline (middle) and flow vectors (right) for peak flood tide (top) and peak ebb tide (bottom)

The peak flow direction is predicted to alter by less than ±2°, as a result of the proposed dredging, and on both the flood and ebb tides (as demonstrated in Figure 13). To the northeast of the wider assessment area, tidal currents are predicted to rotate anticlockwise by up to 2°. Conversely, to the northwest and southeast, a clockwise shift of around 1° is predicted. A similar magnitude and extent of change is shown for both the flood and ebb flows. The changes predicted are, however, relatively small in magnitude and confined to within a distance of 1-2 km of the extraction area boundaries. The implications of the predicted changes to tidal flows will be considered further in Section 5.4, in relation to sediment transport and coastal processes.

Predicted changes to current speeds, as a result of the conservative extraction scenario assessed, are generally constrained to within the extraction areas and are of small magnitude in both relative and absolute terms. Given the dynamic nature of the Severn Estuary (Section 3.5), it is considered that the changes predicted would not be measurable within the range of natural variability. In addition, no change is predicted to the existing (baseline) tidal asymmetry (the relative or absolute duration that currents flow, in the ebb and flood directions, on a given tide), following the proposed extraction of the renewal volumes.

5.2 Predicted changes to the extreme (1 in 200 year) wave conditions

The 1:200-year return period wave conditions for each directional sector were derived as described in Section 4.2.2. The MIKE21-SW model was used to simulate these waves at both high and low water on a mean spring tide (MHWS and MLWS). Results are presented for each directional sector (southwest, west, northwest and northeast) in Figure 14 to Figure 18, with larger magnitude waves considered to approach from the westerly sectors and much smaller wind-generated waves from the northerly and easterly sectors.

In each case, the following information is presented.

- Baseline significant wave height;
- Absolute change in significant wave height (whereby a positive change equates to an increase and *vice versa*; and
- Percentage change in significant wave height.

Most notably, for all directional sectors, different patterns of change are predicted between the MHWS and MLWS states. Although the magnitude and extent of change varies between the different wave approach directions, an increase in wave height is generally predicted across the shallow subtidal parts of the assessment area at MLWS. Conversely, a patchier pattern of change is predicted at MHWS, dependent on wave approach direction, and with an overall smaller predicted relative change in wave height. Away from the dredged areas, changes to existing (baseline) wave heights are typically negligible.

Specific effects for each wave direction are detailed in the following sections; Sections 5.2.1 to 5.2.4 describe the different magnitude and extent of change for each directional sector, highlighting the difference in predicted change between the waves approaching over MHWS and MLWS.

5.2.1 Effects of dredging on extreme westerly waves

The predicted changes to a 1:200-year, westerly wave at MHWS and MLWS are shown in Figure 14, which demonstrates a similar overall extent of change at both tidal states. There is, however, variation in the predicted magnitude of change between MLWS and MHWS, with larger relative changes to wave heights occurring on MLWS.

Under MHWS conditions, wave height increases of up to 0.03 m are predicted, however these are limited to the dredge footprint, extending around 0.5 km east and southeast of NMG. Limited decreases in wave height are also predicted within and around the Bedwyn Sands site.

Changes in the baseline wave heights at MLWS differ from that described for MHWS only within the extraction areas and in relation to the wider feature. Within the assessment area, increases in wave height of up to 0.3 m are predicted within Bedwyn Sands, coinciding with the lowering of the shallow subtidal areas of the site. Outside of the assessment area, changes to wave height are limited by the lower water levels, meaning much of the wider sandbank feature is exposed. The relative (percentage) changes in wave height are similarly limited in extent, with changes of up to 8% predicted within the extraction areas and changes of up to 1% extending around 0.5 km up-estuary of the Bedwyn site. Outside of these areas, there is no predicted change to the baseline wave climate.

Predicted changes in mean wave direction are less than 2° and result from subtle changes in refraction patterns as the waves pass over the deepened areas. Along the northern edges of the extraction areas, the wave direction is shifted slightly anticlockwise, whilst to the south the waves are rotated slightly clockwise, compared to baseline conditions.

For a westerly wave, the overall predicted effects of dredging on both wave height and direction are generally limited to within a few hundred metres of the extraction areas. Furthermore, there are no changes predicted along either the English or Welsh coastlines.

The potential implications of the predicted changes to waves are considered in Section 5.5, in relation to the key receptors.

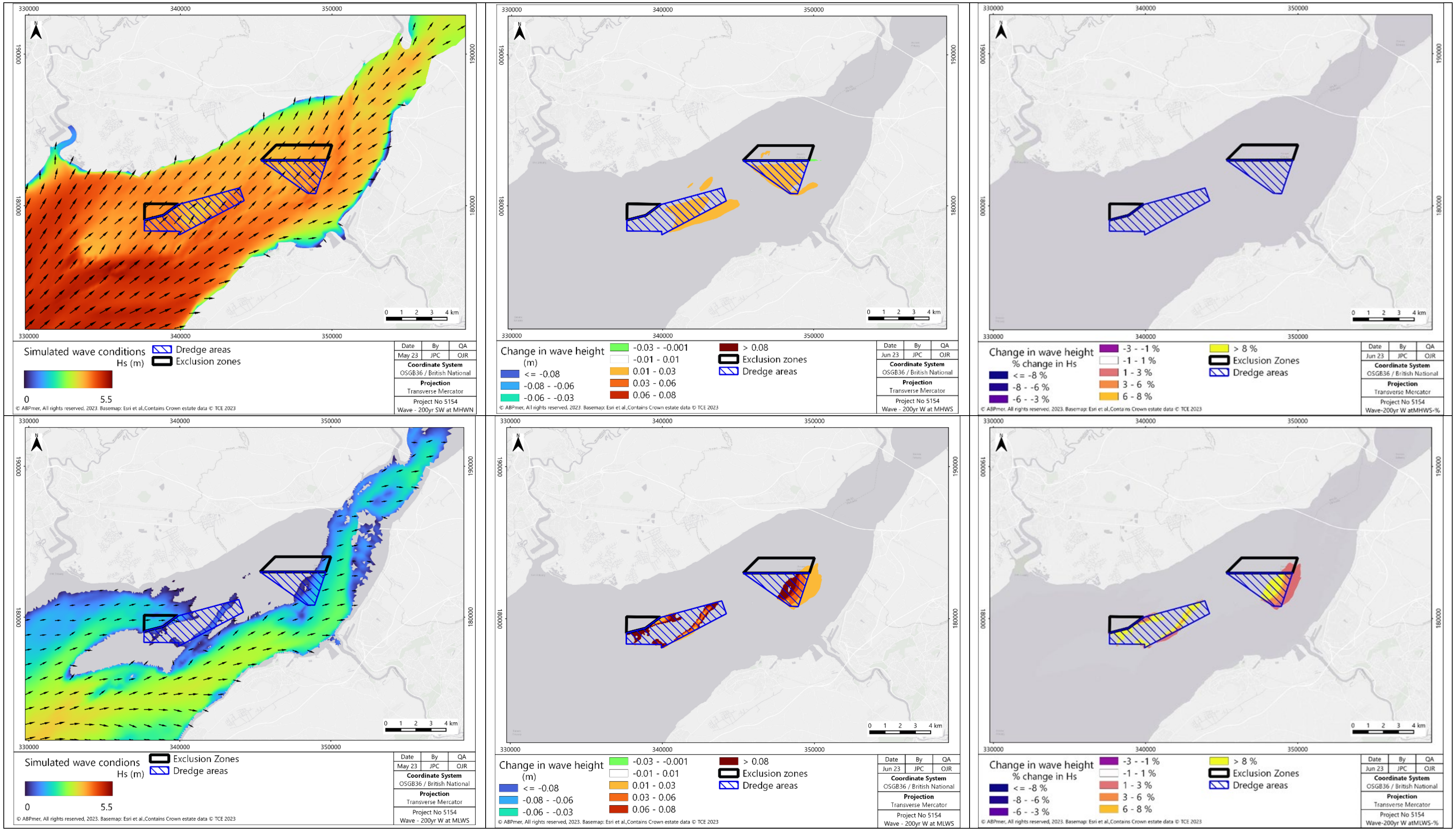


Figure 14. Predicted changes to 1 in 200-year westerly wave regime: Baseline wave height (left), post-dredge absolute difference to baseline (middle) and post-dredge relative (%) difference to baseline (right) for MHWS (top) and MLWS (bottom) tide elevations

5.2.2 Effects of dredging on extreme southwesterly waves

The predicted changes to a 1:200-year, southwesterly wave at MHWS and MLWS are presented in Figure 15, with results from an addition run on a MHWN tidal elevation also provided in Figure 16. In a similar way to that described for the westerly waves (Section 5.2.1), varying changes are predicted between the MHWS and MLWS conditions (Figure 15). Within the extraction areas at MHWS, wave heights are predicted to increase by up to 0.12 m, particularly within NMG, with smaller increases observed over the Bedwyn Sands site (Figure 15). This equates to changes of approximately 3% (Figure 15) from the baseline wave heights.

Within the NMG area increases in wave height are predicted over the crest of the sandbank at MHWS as bed lowering reduces breaking over this feature. These changes extend up to 1.5 km northeast from the dredge area. The model predicts that this wider impact of NMG is low (<0.03 m), less than 1% of baseline Hs, and is considered to be negligible and well within the margin of uncertainty in the underlying estimate of the assessed extreme wave conditions. At Bedwyn Sands, increases in wave heights are predicted within the extraction area, however this is less than that simulated at NMG and almost entirely confined within the Licence area. These changes in Hs are less than 1% of the baseline wave heights. The associated impact of these changes (in relation to bed shear stresses) is discussed in greater detail in Section 5.4.2. It is noted that these predicted changes result from the assessment of an extreme southwesterly wave approaching on MHWS tidal conditions. Predicted effects from less extreme wave conditions (Section 5.3), from other wave directions (Section 5.2.1, 5.2.3 and 5.2.4), and for lower tidal levels (below), result in a substantially smaller extent and magnitude of predicted effect.

Subsequent implications for wave-induced sediment transport in this area are considered further in Section 5.4.2; in summary, however, the small, predicted increase in wave height is not considered to affect the sediment mobility potential along the Middle and Welsh Grounds. Additionally, no significant changes in present-day wave conditions are predicted to reach either the English or Welsh coastlines.

Under MHWN conditions, a similar pattern of change is predicted, although the extent of predicted change is slightly greater than under MHWS conditions (Figure 16). This is largely attributed to the influence of the sandbank decreasing wave breaking. Here, lowering is predicted to generate increased wave heights of up to 0.14 m, in NMG and of up to 0.05 m in Bedwyn Sands. The pattern of impact is similar to that simulated at MHWS, however the influence of extraction at Bedwyn Sands generates a slightly larger extent of predicted change than at MLWS (discussed below). The relative change in wave heights is up to 6% within NMG and around 1-2% at Bedwyn. No associated changes to wave heights are predicted along either the Welsh or English coastlines. Overall, as with the predicted changes under MHWS conditions, this predicted magnitude of change is generally considered to be negligible and well within the margin of uncertainty in the underlying estimate of extreme wave conditions.

At MLWS, increases of up to 0.1 m are predicted, which mainly occur within the shallower subtidal parts of the assessment area. These changes equate to approximately 8% of baseline wave heights at low water. Outside of the assessment area, the exposure of the intertidal at low water limits the spatial extent of the predicted changes (Figure 15).

Changes in direction of less than 2° are predicted for waves approaching from the southwest, which occur in relation to changes in refraction patterns. The largest changes occur within the extraction areas and immediately adjacent to the boundaries. In the northern part of the extraction areas, and adjacent to this boundary, an anticlockwise shift is predicted; whilst within the southern half of the extraction areas, a slight clockwise shift is predicted. No changes in wave direction, however, are predicted at either the English or Welsh coastlines.

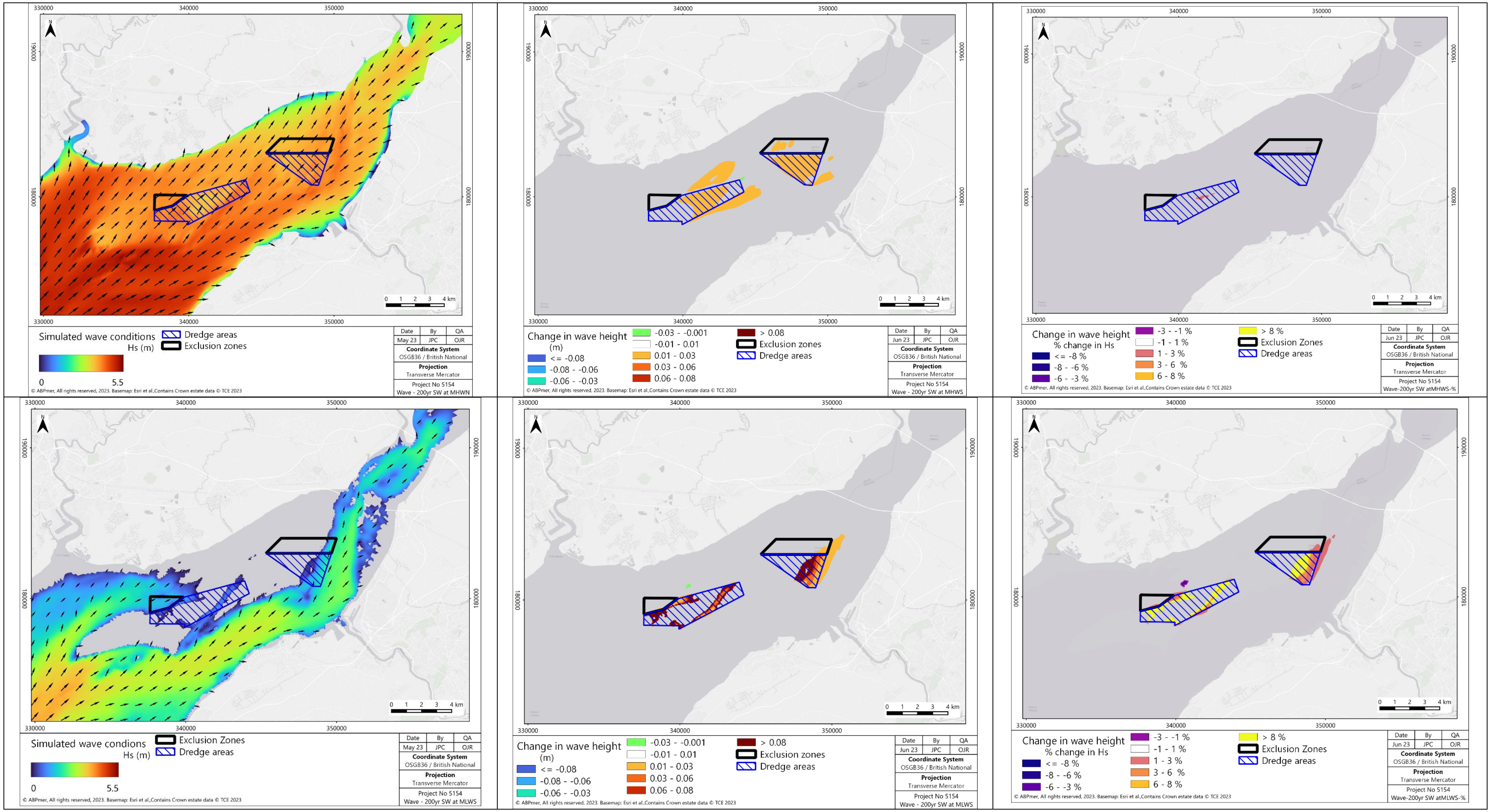
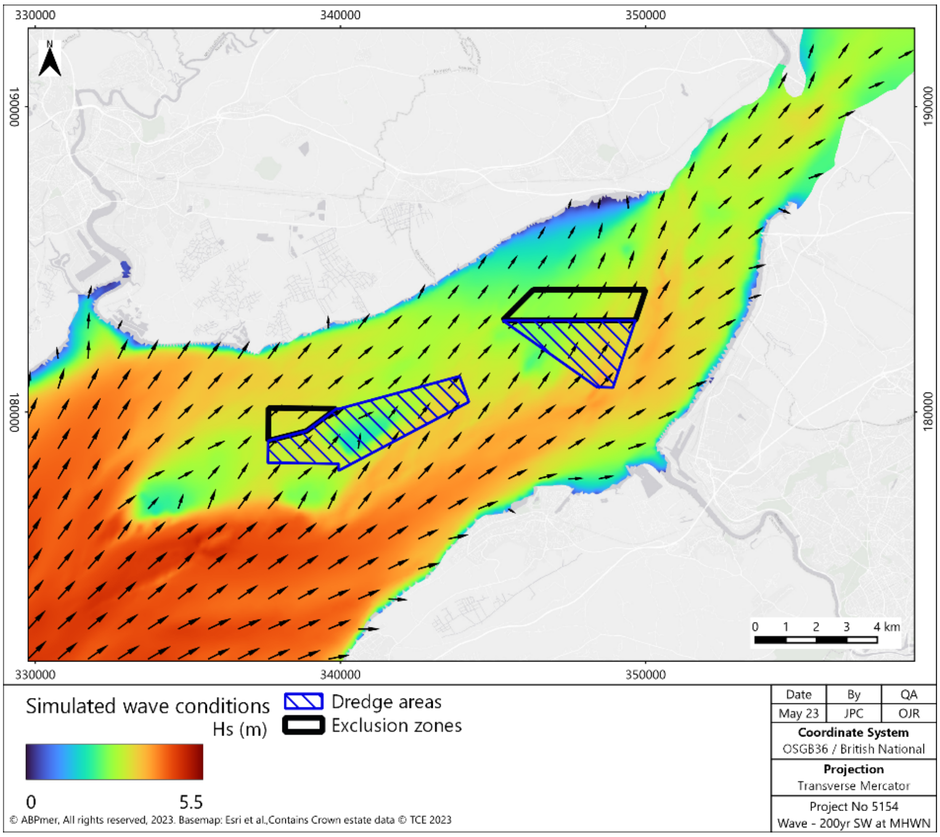


Figure 15. Predicted changes to 1 in 200-year south-westerly wave regime: Baseline wave height (left), post-dredge absolute difference to baseline (middle) and post-dredge relative (%) difference to baseline (right) for MHWS (top) and MLWS (bottom) tide elevations

Baseline Hs



Percentage change in Hs

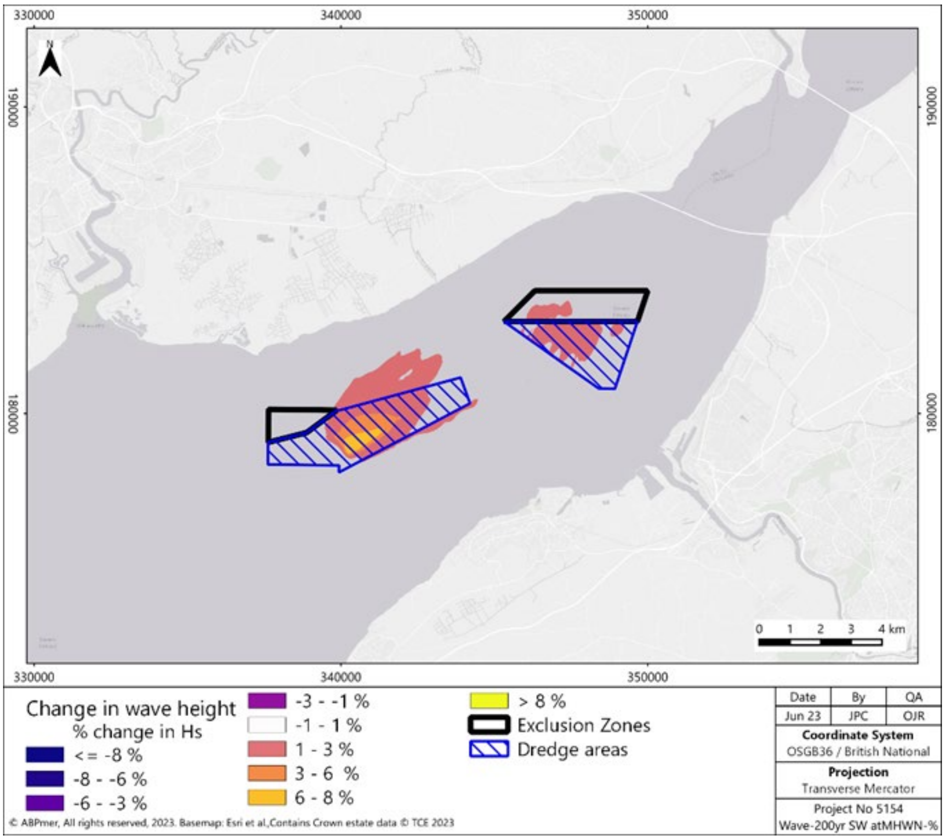


Figure 16. Predicted relative change in Hs for 1 in 200-year south-westerly wave at MHWN

5.2.3 Effects of dredging on extreme north-westerly waves

The predicted changes to a 1:200 year, north-westerly wave at MHWS and MLWS are presented in Figure 17. As identified for the waves from the west and southwest (Section 5.2.1 and 5.2.2, above), varying changes are predicted between the MHWS and MLWS conditions (Figure 17).

Within the dredge area at MHWS, no increases in wave height of over 0.01 m are predicted (Figure 17), with no associated changes in relative wave height greater than ±1%. In contrast, at MLWS, increases of up to 0.1 m are predicted, equivalent to around 8% of baseline wave heights, in both dredge areas. These predicted changes are mainly limited in extent to within the shallowest subtidal parts of the assessment area (Figure 17). At Bedwyn Sands, increases in wave height of up to 0.03 m are predicted to extend towards the southeast for up to 0.5 km and are largely attributed to increases associated with increased wave growth over a slightly longer effective fetch (as a result of the extraction). Relative increases over this are around 1-3% of baseline wave heights.

5.2.4 Effects of dredging on extreme north-easterly waves

The predicted changes to a 1:200 year north-easterly wave at MHWS and MLWS are presented in Figure 18. As identified for each directional sector, varying patterns of change are predicted between MLWS and MHWS conditions (Figure 18).

At MHWS, as with waves from north-westerly directions, no changes to the baseline wave height above ±0.01 m (±1%) are predicted (Figure 18).

In contrast. at MLWS, increases in wave height of up to 0.1 m are predicted locally, mostly constrained to the shallow subtidal parts of the dredge areas (Figure 18). These changes equate to around 10% of baseline wave heights at low water. Outside of the assessment area, small increases in wave height (around 1-3%) are predicted to extend around 0.5 km to the southwest. As with other assessment directions, no predicted changes to wave height are predicted to extend to either the Welsh or English coastlines.

The predicted changes in wave direction for this sector predominantly occur within the extraction areas and adjacent to the northern boundary. Directional shifts of less than 2° are predicted, shifting to the south and north in the northern and southern part of the extraction areas, respectively. Changes are limited in extent to the assessment area, and do not extend towards either the Welsh or English coastline.

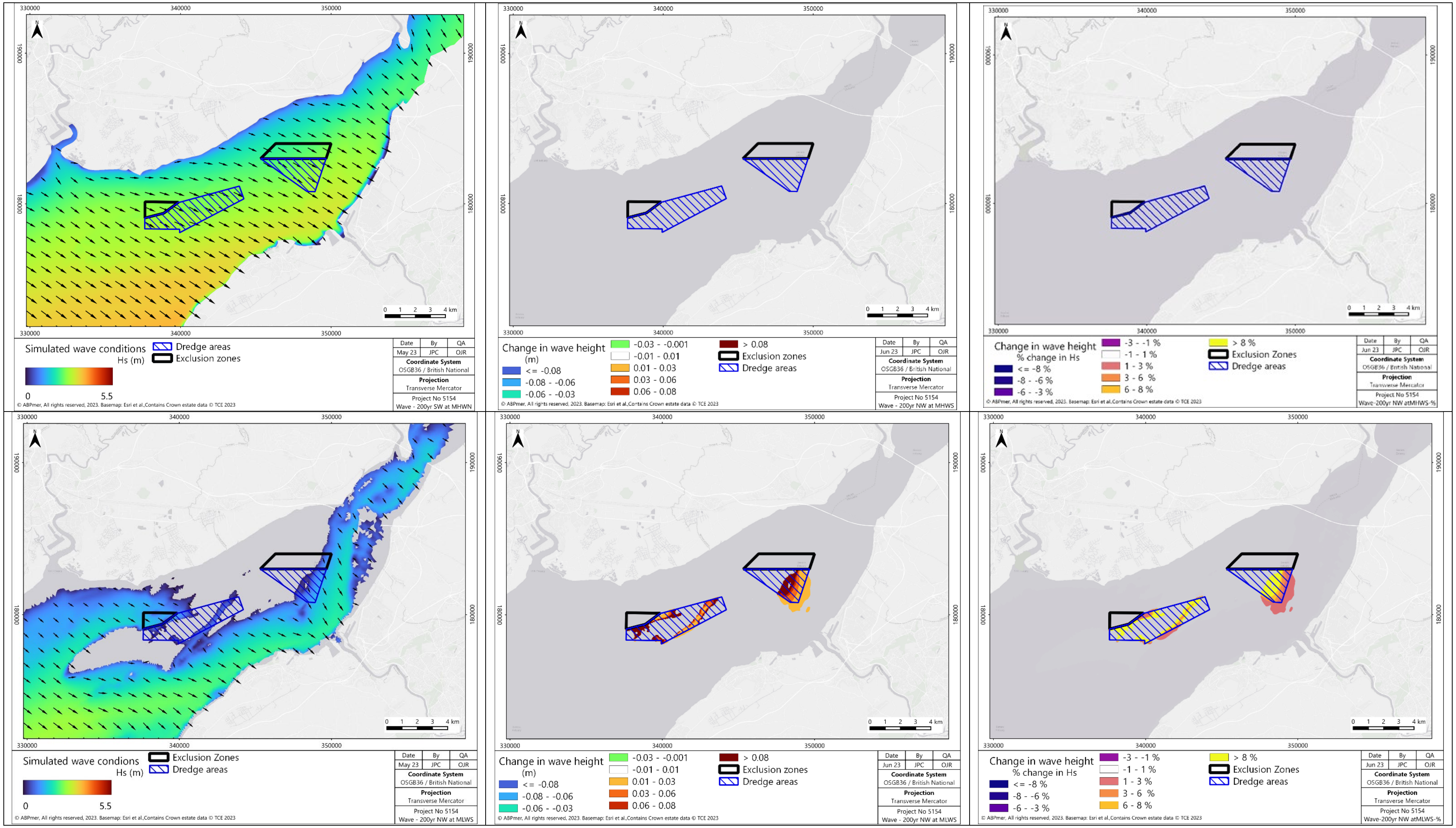


Figure 17. Predicted changes to 1 in 200-year north-westerly wave regime: Baseline wave height (left), post-dredge absolute difference to baseline (middle) and post-dredge relative (%) difference to baseline (right) for MHWS (top) and MLWS (bottom) tide elevations

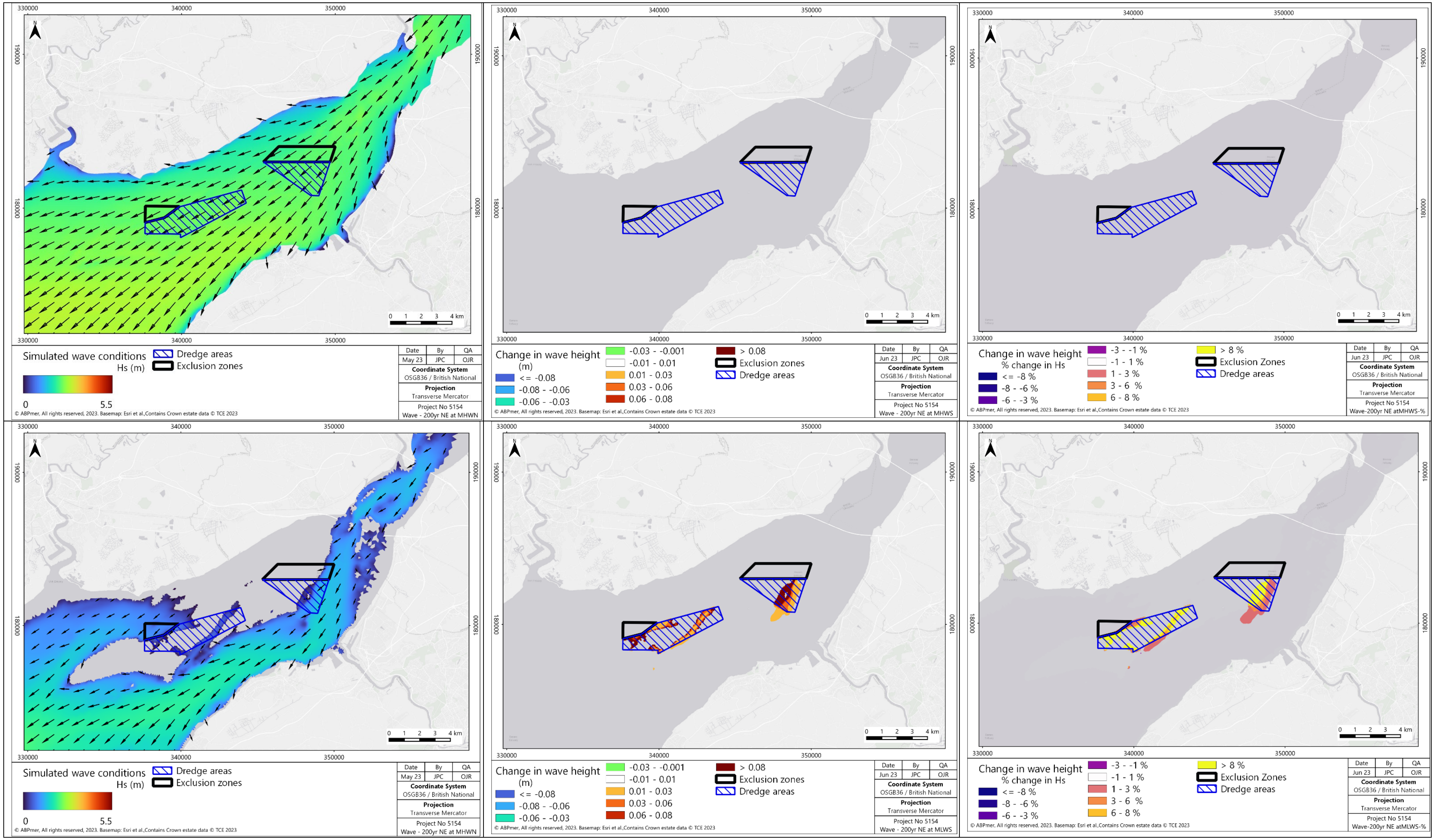


Figure 18. Predicted changes to 1 in 200-year north-easterly wave regime: Baseline wave height (left), post-dredge absolute difference to baseline (middle) and post-dredge relative (%) difference to baseline (right) for MHWS (top) and MLWS (bottom) tide elevations

5.2.5 Summary of effects on 1:200-year wave conditions

As detailed in Sections 5.2.1 to 5.2.4, for each of the four wave approach directions, the general effects of the proposed dredge on extreme (1:200 year) waves can be summarised as follows:

- Absolute effects are greatest within the assessment footprint of both extraction areas (NMG and Bedwyn Sands). Across the wider region, absolute effects are small and rarely result in predicted changes to existing (baseline) wave heights greater than ±0.03 m. Relative effects are also small, typically up to 3% change in wave heights, against baseline;
- Such small changes are not considered to be measurable in practice, and are well within the range of natural variability across the region, and also within the range of uncertainty with respect to estimates of extreme storm conditions;
- Predicted effects on the wave climate (wave height, period and direction), as a result of the proposed renewal extraction, do not extend to either the English or Welsh coastlines; and
- Additional model scenarios have been undertaken with increased sea levels, in response to projected climate change over the proposed 15-year licence period. The results of these sensitivity tests, which are discussed in greater detail in Section 5.7, reveal a very similar pattern of predicted change (in magnitude and extent of effect), to the results presented above.

5.3 Predicted changes to the morphological (10 in 1 year) wave

In order to assess the potential effects on wave induced sediment mobility and the local morphology, it is necessary to consider a more typical wave condition, for which the 10 in 1-year return period has been selected (as described in Section 4.2.2). The MIKE21-SW model was again used to simulate these waves at both MHWS and MLWS states, and for each of the four directional sectors.

Changes are predicted for each directional sector, with similar patterns of variation between the MLWS and MHWS tidal states. As with the more severe (1:200) wave condition, the largest changes are predicted for the westerly and southwesterly waves. The predicted changes, in relation to these directions, are discussed in Sections 5.3.1 and 5.3.2, respectively (and for both the MLWS and MHWS states), as the directions which capture the upper limit of predicted effect. Results for the two directional sectors are also illustrated in Figure 19 and Figure 20, for which the following information is presented.

- Baseline wave regime;
- Absolute change in significant wave height (whereby a positive change equates to an increase and *vice versa*; and
- Percentage change in wave height.

Overall, changes to the 10:1-year wave are generally of very low magnitude and limited spatial extent, particularly when compared against the 1:200-year waves (above). The implications of the predicted changes to this wave condition on sediment transport are considered further in Section 5.4.

5.3.1 Effects of dredging on typical westerly waves

The predicted changes at MHWS and MLWS are shown in Figure 19.

Overall, 10 in 1-year wave events at MHWS exhibit minimal predicted change to baseline conditions (Figure 19). Wave heights at MLWS are predicted to increase over limited parts of the dredge area, predominantly within the shallow subtidal areas (Figure 19). Increases of up to 0.1 m occur locally, with changes elsewhere generally less than 0.03 m. This equates to a maximum change of less than 8% of existing (baseline) heights. Smaller predicted increases (less than 3%) are predicted to extend approximately 0.5 km from the eastern site boundary of Bedwyn Sands, toward the Prince of Wales bridge. Outside of these areas, including along the adjacent English and Welsh coastlines, there are no predicted changes to the 10 in 1-year wave condition.

The predicted change to the wave direction (at MLWS), as a result of the proposed dredging is for a shift of less than 1°, constrained mainly within the extraction areas.

5.3.2 Effects of dredging on typical south-westerly waves

The predicted changes at MHWS and MLWS for a 10 in 1-year south-westerly wave are shown in Figure 20.

As with typical westerly waves (above), there are minimal predicted changes to wave height (in both absolute and relative terms) under MHWS conditions (Figure 20). At MLWS, small increases to wave height are predicted to occur mainly within shallow subtidal parts of the assessment area. Beyond the dredge footprint, change in wave height are typically less than ±1%, and no change is predicted along either the Welsh or English coastlines.

The predicted change to the wave direction indicates very little effect of from the deepened area. A shift of less than 1° is predicted and constrained to within the boundaries of the assessment area.

5.3.3 Summary effects on 10 in 1-year wave conditions

As detailed above, for each of the wave approach directions, the general effects of the proposed dredge on morphological (10:1-year) waves can be summarised as follows:

- Absolute effects are greatest within NMG and Bedwyn Sands extraction footprints. Across the wider region, absolute effects are small (<0.03 m change in wave height), whilst relative effects across the whole area are also small (typically < ±3% change in wave heights, against baseline);
- Such small changes are not measurable in practice, and are within the range of natural variability;
- Predicted effects on the wave climate (wave height, period and direction) do not extend to either the English or Welsh coastlines; and
- Additional model scenarios have been undertaken with increased sea levels, in response to projected climate change over the proposed 15-year licence period. The results of these sensitivity tests reveal no predicted change in magnitude or extent of effect, compared to the results presented above.

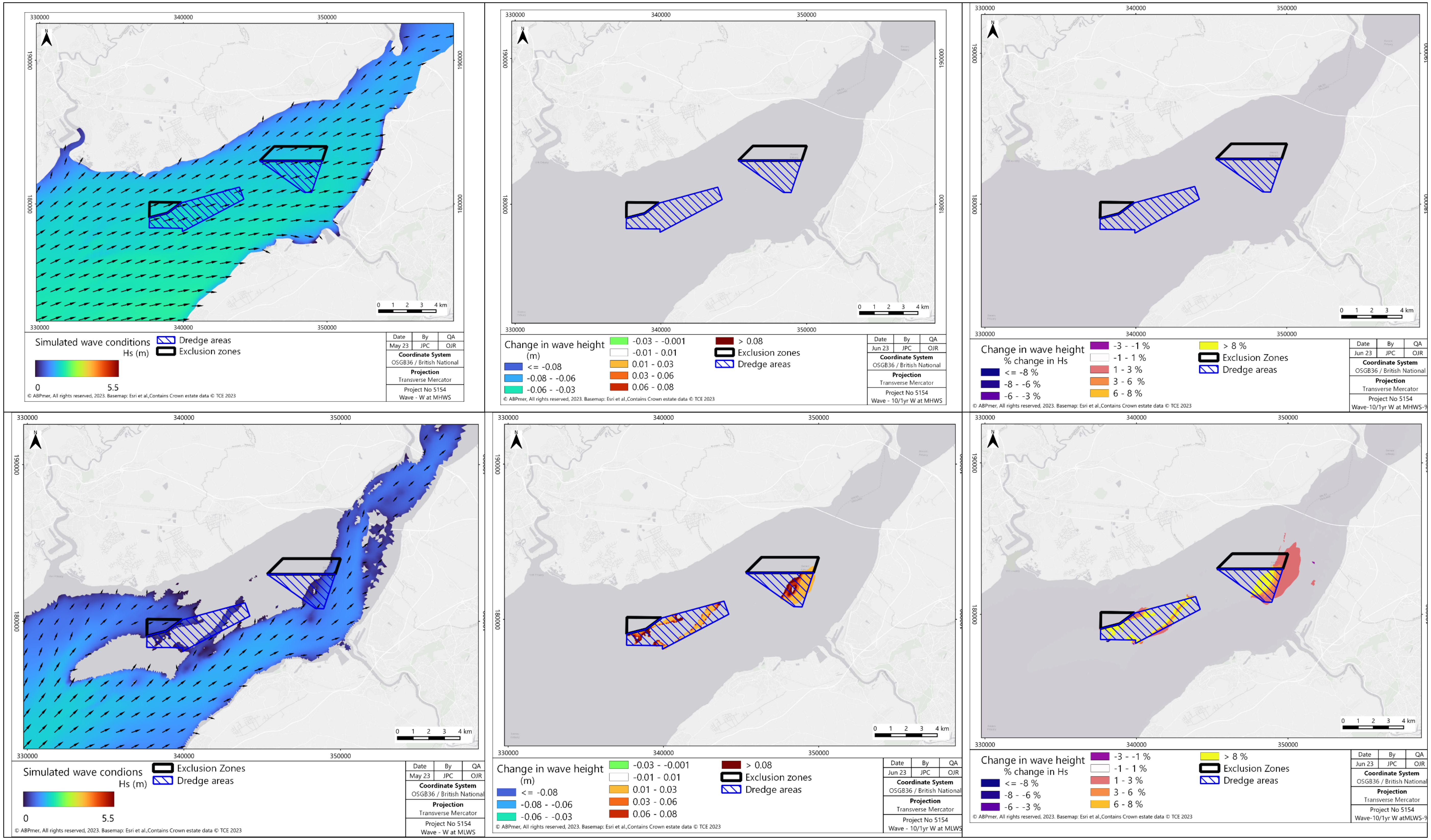


Figure 19. Predicted changes to 10 in 1-year westerly wave regime: Baseline wave height (left), post-dredge absolute difference to baseline (middle) and post-dredge relative (%) difference to baseline (right) for MHWS (top) and MLWS (bottom) tide elevations

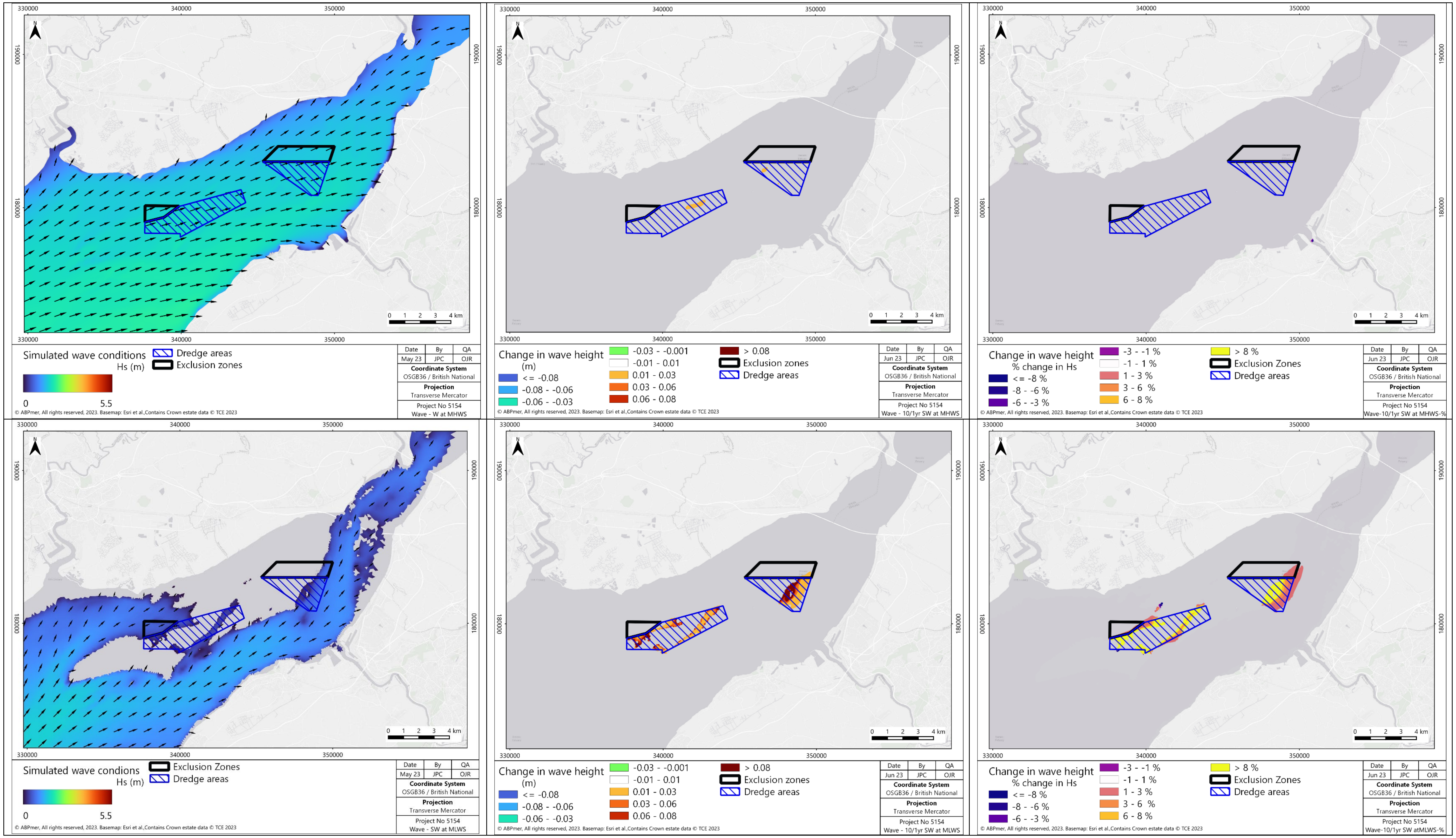


Figure 20. Predicted changes to 10 in 1-year south-westerly wave regime: Baseline wave height (left), post-dredge absolute difference to baseline (middle) and post-dredge relative (%) difference to baseline (right) for MHWS (top) and MLWS (bottom) tide elevations

5.4 Predicted changes to sediment transport

Predicted change to bed shear stress have been assessed to inform the sediment mobility potential and consider any potential changes, within and around the extraction areas, as a result of the proposed aggregate extraction. The analysis has been carried out at the 23 hydrodynamic (HD) assessment points (HD1 to HD23), and the 26 wave assessment points (W1 to W26), selected from around the study area (see Figure 21 for locations). These assessment locations have been selected to coincide with the areas of greatest predicted change in current flow and wave heights, as described in the above sections, as well as the locations of key receptors.

The bed shear stress calculations have applied available sediment information, along with the modelled spring-neap cycle tidal flow data and the wave events described above. The bed shear stress for both the present day and post dredging scenarios have been compared to determine the extent and magnitude of change.

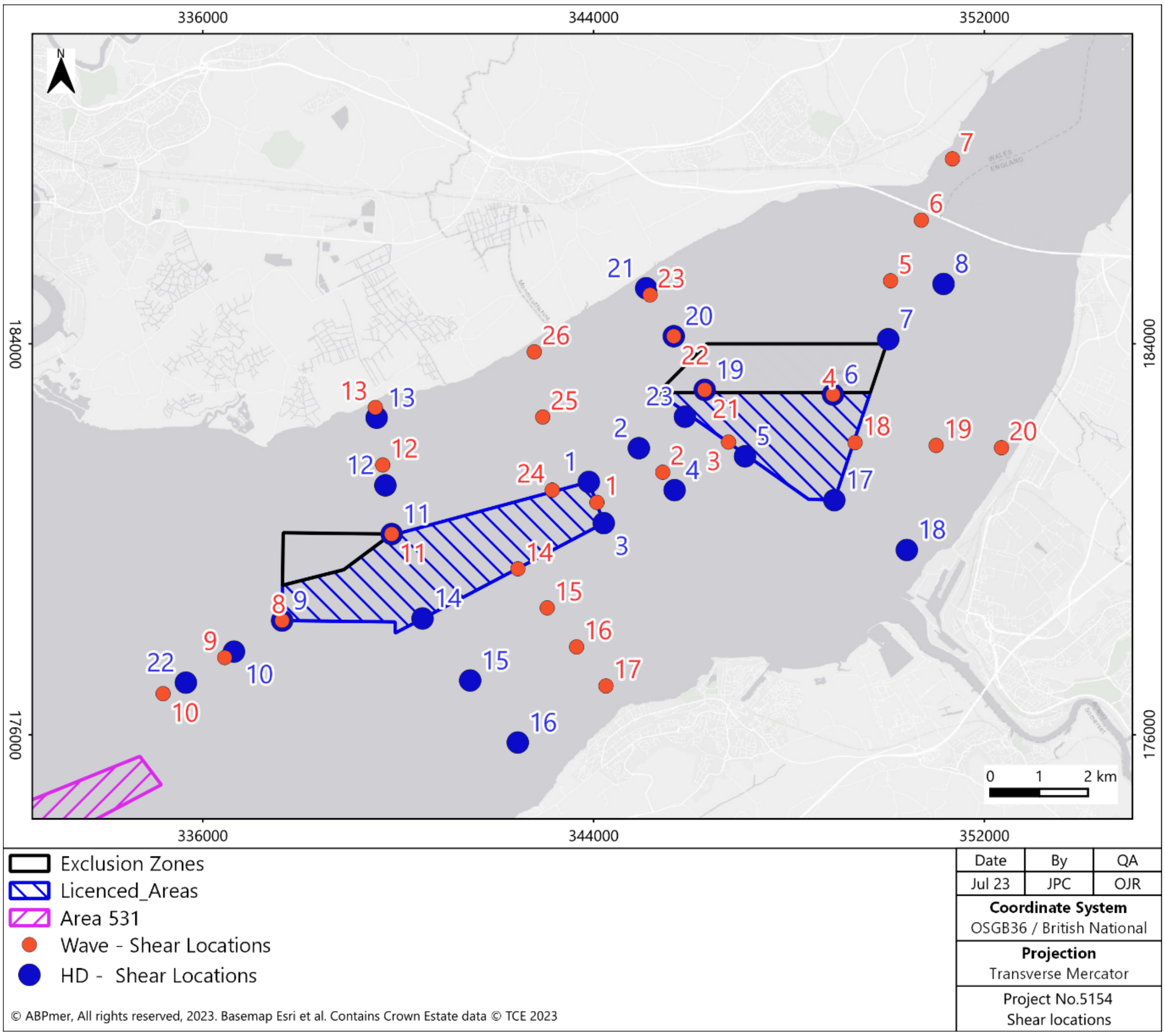


Figure 21. Bed shear stress assessment locations from model output

5.4.1 Tidal current-induced seabed mobility

Figure 22 shows the baseline and predicted changes to bed shear stress at a selection of the 23 analysis sites, within approximately 1.5 km of the edge of the licence boundaries, as a result of the proposed extraction. These sites have been selected to provide the range of predicted impacts in all directions.

The plots presented in Figure 22 indicate the critical bed shear stress required to mobilise the different grain size fractions found on the bed within and around the dredge areas and display bed shear stresses simulated under baseline and dredged conditions. Results for all sites are summarised in Table 10 and the impact of these variations in bed shear stresses are discussed below.

Table 10. Summary effects on calculated tidal-induced seabed mobility

Site	Change in max bed shear (N/m^2)	% change at timestep	Site	Change in max bed shear (N/m^2)	% change at timestep
HD1 *	-0.78	-32.3%	HD13	0.08	-4.4%
HD2	-0.21	-7.9%	HD14*	0.39	45.7%
HD3 *	0.73	10.3%	HD15	-0.09	-2.3%
HD4	0.39	1.2%	HD16	-0.10	-2.4%
HD5 *	0.61	16.5%	HD17*	0.55	8.3%
HD6 *	0.27	9.9%	HD18	0.14	5.1%
HD7	-0.09	-1.3%	HD19*	1.25	9.3%
HD8	-0.10	-0.2%	HD20	-0.15	-0.1%
HD9 *	-0.16	-5.2%	HD21	0.07	2.5%
HD10	-0.10	-4.8%	HD22	-0.06	-2.3%
HD11 *	0.12	2.8%	HD23*	-0.78	-3.4%
HD12	0.08	1.9%			
*	Point locations are within the near-field impact area, at the edge of the dredge areas				

The selected points can be generally divided into two categories: near-field and far-field, depending on their location. Among these points, nine are highlighted in Table 10 as they are situated at the edges of the dredge areas. At these locations, the side slopes resulting from material removal tend to result in the greatest predicted changes in peak flow speed and associated bed shear stress.

Across the wider study area, maximum predicted changes to bed shear stress are generally below ±0.2 N/m^2. This change in bed shear stress equates to a relative change of less than ±10% of baseline values for the majority of points reviewed. The greatest predicted effects are defined in areas with the greatest predicted change in the far field assessment area:

The effect of these predicted changes to bed shear stress, on seabed mobility are illustrated in the timeseries plots in Figure 22. These plots compare the calculated bed shear stresses under pre- and post-dredge conditions and plot them relative to the threshold of mobility for a range of sediment particles (from coarse silt (0.05 mm) up to pebble gravel (6 mm)). The plots shown in Figure 22 provide results at a representative selection of the assessment locations, as described above.

The results of the assessment generally show that, while change in bed shear stress is predicted within and around the edges of the proposed dredge locations, locations across the wider region typically exhibit a negligible effect on the exceedance of the defined thresholds. Consequently, material that is presently mobile (under existing conditions) will continue to be mobile under post-dredge conditions. Equally, material that is not presently mobile at a given site across the study area, will continue to be so following the proposed extraction.

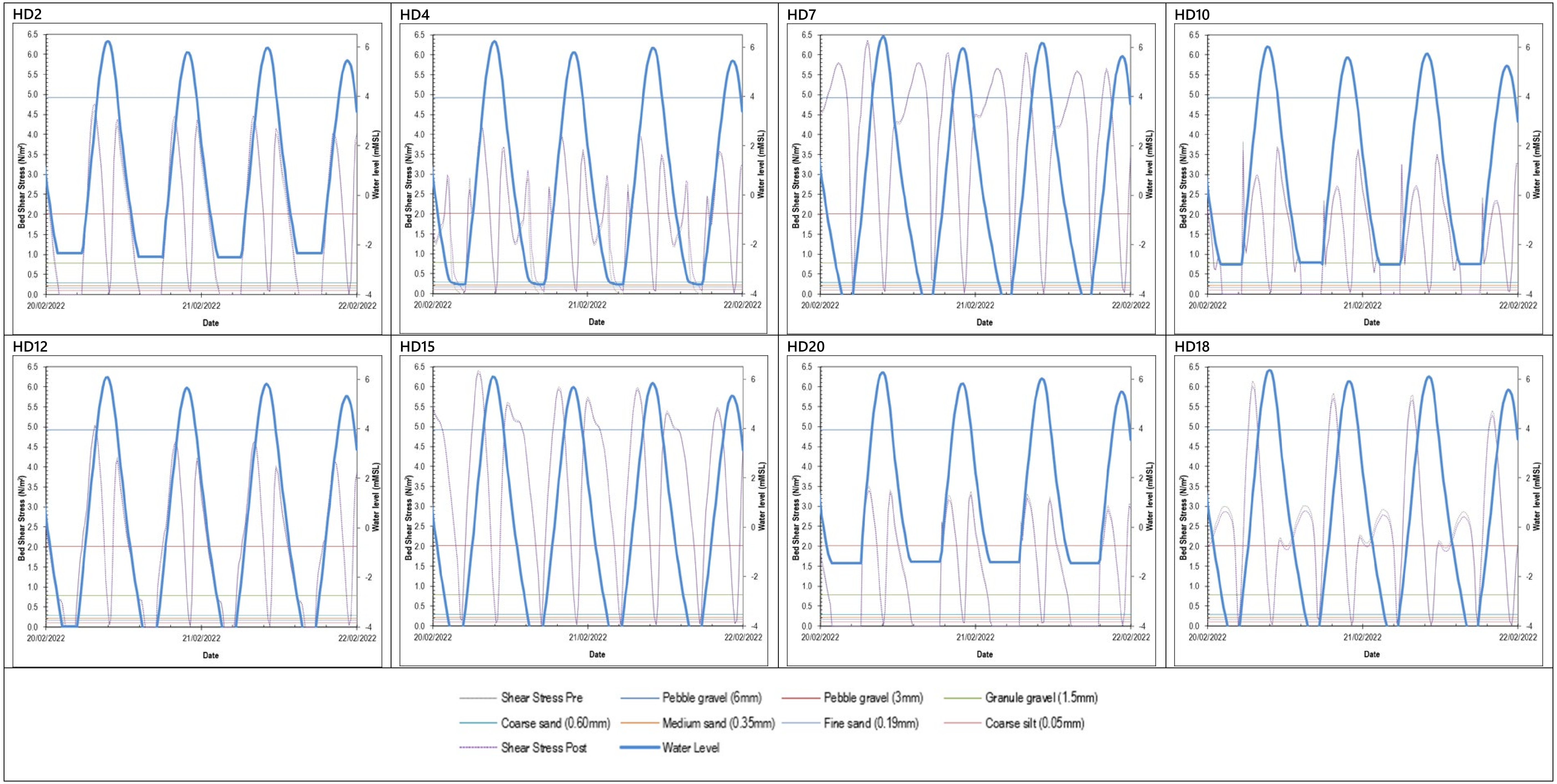


Figure 22. Comparison of changes to bed shear stress (pre- and post-dredge) at selected locations under peak spring tidal conditions

5.4.2 Wave-induced seabed mobility

In a similar way to that described above for tidal flows, the wave-induced bed shear stress has also been calculated for the present and future dredging scenarios at 26 wave assessment sites across the study area (Figure 21).

The analysis of wave induced bed shear stress was carried out for all the scenarios. The focus of the results presented here is on the typical (10 in 1-year) and extreme (1 in 200-year) south-westerly wave events, assessed over a MHWS condition (see Figure 23, which also includes mobility thresholds for a range of grain sizes). These wave events are selected as the assessment results (described in Sections 5.2 and 5.3) reveal these wave scenarios to generally exhibit the greatest change. Under low water conditions, the drying sandbanks of the Middle and Welsh Grounds limit the wave climate to the subtidal parts of the Severn Estuary. Wave heights from other assessment directions are more fetch limited, thus tend to be smaller (and the associated effect of the proposed dredging is also smaller in absolute and relative magnitude).

Under all wave conditions, the results show that within the dredge areas of NMG and Bedwyn Sands, there are small variations in the predicted changes to the existing (baseline) bed shear stress, as a result of the proposed extraction. The largest changes are predicted at the edges of the extraction areas (Locations W1, W3, W4, W8, W11, W21 and W24) where reductions of approximately 0.1 to 0.2 N/m^2 are predicted. These reductions in bed shear are largely attributed to the locally increased water depth within the assessment areas, as a result of the bed lowering, and mean that waves exert less of an influence on the bed. As shown in Figure 23, the mobility potential of medium sand (between 0.25 and 0.5 mm), which is the predominant sediment type across much of this area, is not affected by this predicted reduction in wave-induced bed shear stress.

Elsewhere, predicted changes to wave induced bed shear stress are typically < ±2%. The predicted changes across the wider study area are considered negligible and do not impact the mobility potential of the range of material found across the study area. In addition, any changes to wave-induced bed shear stress are considered likely to be dwarfed by the influence of the overriding hydrodynamic forcings across the wider Severn Estuary.

With specific reference to the adjacent Welsh and English coastlines, assessment Locations W13, W23 and W26 (Welsh) and W17 and W20 (English) indicate no change in predicted wave-induced bed shear stress for either the more extreme (1 in 200) or more frequent (10 in 1) return period event. Consequently, the proposed renewal of extraction from Bedwyn and NMG sites is not anticipated to impact the mobility potential of bed material along either of the adjacent coastlines.

5.4.3 Summary of effect on seabed mobility

Based on the analyses of the modelled data presented above, any effects on sediment transport are principally localised to the assessment area associated with the removal of aggregates at NMG and Bedwyn Sands. It is, therefore, considered that the proposed future dredging (even at the conservative maximum offtake rate currently licensed) within these areas will not result in any associated change in sediment transport patterns or seabed morphology across the wider study area, or along either the English or Welsh coasts.

At the same time, there is unlikely to be any substantial change to the easterly directed sediment transport pathway through the study area (Figure 11). This is due to the negligible predicted changes to the bed shear stress thresholds and the minimal change in predicted tidal current direction, within and around the extraction areas.

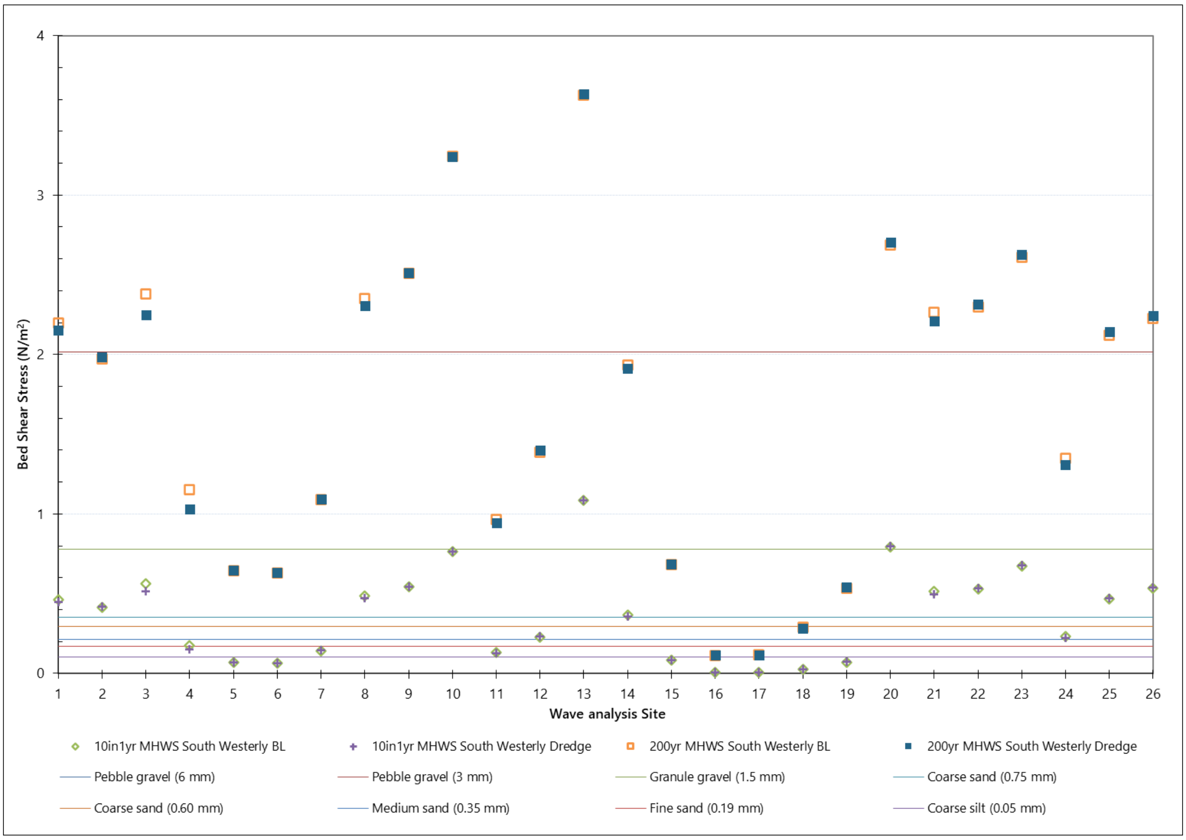


Figure 23. Comparison of changes to bed shear stress under southwesterly wave conditions

5.5 Assessment of effects on key receptors

The analyses and discussion presented in Sections 5.1 to 5.4, above, provide the evidence against which the key issues described in Section 4.1.1 are evaluated. The findings of the assessment for each of the identified receptors are described below.

5.5.1 English and Welsh coastlines: potential changes in wave height, tidal currents, beach 'draw-down' and sediment transport

Wave height and tidal currents

The predicted changes to flood and ebb tidal currents are small in magnitude and are principally confined to the vicinity of the extraction area boundaries, generally extending less than 2 km from the edges of the assessment area. Across the study area, the predicted magnitude of change is largely less than ±0.1 m/s in peak current speed and less than 2° shift in current direction, which is well within the range of natural variability and would not be considered measurable in practice. No effects are predicted along any of the coastal frontages within the study area.

The predicted changes to the extreme wave heights (i.e. 1:200-year) are also small in magnitude and, although they extend slightly beyond the boundaries of the licence areas (notably under MLWS conditions), they do not impact either the English or Welsh coastlines. Small increases in wave height of generally less than 0.03 m (< 3%) locally are predicted in relation to the southwesterly waves under high water conditions, which extend around 0.5 km from the assessment area. In addition, subsequent assessment of potential implications on sediment mobility across the wider study area reveal that any predicted changes to bed shear stress do not affect the mobility potential of the bed material. Under low water conditions, the drying sandbank of the Middle and Welsh Grounds limits the extent of predicted effect on the wave climate.

On this basis, it is concluded that there is no risk from the predicted changes to the 1:200-year wave height, or from energy focussing along sensitive coastlines (notably along the Caldicot Levels frontage). The extreme wave is also an infrequent event that is unlikely to affect the net long-term transport pathways. As a result, it is considered that both littoral transport (along the English and Welsh coasts), and sand transport within, and upstream of, the Middle and Welsh Grounds, would not be affected by the proposed renewal of the ongoing extraction activity.

Beach draw-down

If dredging is carried out too close to the shoreline there is potential for some beach material to be drawn down into the dredged depressions under wave action, where it may become trapped (permanently or temporarily). Natural beach draw-down during storms is normally followed by recovery during periods of calmer weather. The seaward limit of offshore movement during this process, and the depth from which sediment can subsequently return to the beach, depends on a number of factors such as the severity of the wave climate, the nature of the beach material itself, as well as the nearshore seabed topography.

This type of seasonal behaviour is exhibited by non-cohesive sediments, which are generally carried offshore in suspension and returned to the beach as bed load. No such process for movement exists for cohesive sediments, which can be transported very large distances, and indeed, which may remain in suspension for a long time. The seasonal limit of shoreward beach profile variation (or beach closure depth) within the Severn Estuary depends very much on the nature of sediments found along the coastal margins and the degree of exposure to wave action.

The coastlines of the Severn Estuary are situated around 2.3 km, across the tidal axis, from the edge of the Bedwyn Sands extraction site assessment area boundary with a similar distance to the English coastline (across the tidal Bristol Deep channel). The Welsh frontage is predominantly exposed to locally generated waves from the southwest, whilst the English coastline is limited in exposure to waves approaching from the northwest and west (and over shorter fetch distances). Throughout this central part of the Severn Estuary there is a clear delineation between the upper foreshore, which is characterised by fine sediments, and the lower foreshore and shallow subtidal, which is largely composed of sand across the Middle and Welsh Grounds sandbank features (Figure 5). Fine material is very rarely drawn down onto the offshore sandbanks (which is one of the reasons why it is such a sought-after aggregate resource), and hence the closure depth in this case is located towards the coastline.

With specific reference to NMG and Bedwyn Sands, the dredge locations are separated from the English shoreline by the primary Bristol Deep navigation channel. NMG can similarly be considered separated from the Welsh coastline by the Newport Deep channel. As such, the fine material contained within the muddy foreshore regions is not directly linked to either of the extraction areas, nor is there a possibility of movement under gravity, since the presence of the channels would require upwards flow onto the sandbank. No significant channel exists between the Bedwyn Sands extraction site and the Welsh shoreline, however previous studies on sediment transport pathways (for example, that summarised in Figure 11 from McLaren & Collins, 1989), conclude that there is no sediment transfer between Bedwyn Sands and the shoreline along the Caldicot Levels, meaning the removal of aggregates at Bedwyn sands is not considered likely to have any impact on beach levels along the Welsh coastline. Furthermore, ongoing annual monitoring of both offshore bathymetry and foreshore topography, associated with the existing extraction activities from both sites reveals no impact on the Welsh foreshore as a result of current aggregate extraction activities.

Changes in bedload sediment transport

The assessment of wave- and tidal-induced sediment mobility clearly demonstrates that any changes to sediment movement will be of negligible magnitude and will be confined to the extraction areas and the immediate vicinity. The baseline characterisation in Section 3 identified that the offshore sandbank/ sand flat features are not a contemporary source of material and that there are no sediment transport linkages between the wider Middle and Welsh Grounds and the adjacent coastlines.

In view of the evidence presented above, it is concluded that the receptor coastlines (and the general bedload sediment transport pathways across the study area) would not be affected by the proposed renewal of aggregate extraction within NMG and Bedwyn Sands.

5.5.2 Effects on bedforms within the Severn Estuary SAC due to changes in tidal currents or sediment transport

The proposed renewal of extraction within NMG and Bedwyn Sands, along with the existing Licence at Area 531, is located within the designated Severn Estuary SAC. Noting there will be a continuation of direct effects on the sand resources from the renewal of the currently licenced activities, this CIS has also assessed the potential wider, indirect effects on sand transport pathways linking the seabed features throughout the study area.

As described in Section 3, the Severn Estuary is characterised by a number of intertidal sandbank and sand flat features, bounded by relatively deep channels. The seabed features include the English and Langford Grounds, fronting the English coastline at Middle Hope (Figure 3); the Middle and Welsh Grounds, extending to Bedwyn Sands, fronting the Welsh coastline upstream of Newport (and the location of the existing aggregate extraction areas); and features upstream of the Second Severn Crossing, which include Dun, Oldbury and Charston Sands.

The understanding of the existing sediment transport pathways has been described in Section 3.6.1. Evidence from Sediment Trends Analysis (McLaren & Collins, 1989) is provided in Figure 11, illustrating the sand transport pathways across the study area. The available evidence-base indicates that sand material is transported up-estuary, driven by the dominant flood tide, and enhanced by intermittent south-westerly storm activity. The defined transport pathways extend over the wider Middle and Welsh Grounds, across to the English coastline, and then onwards, past the Severn crossings, to the upper estuary.

The pathways extend across the full width of the Middle and Welsh Grounds, with material transported through, and to both the north and south of, the existing extraction areas (Figure 11). The assessment of effects on flows, waves and resultant sediment transport (as described above), indicates negligible change in the existing sediment transport potential, or in the direction of the primary drivers of bedload transport (Sections 5.1 to 5.4). In summary, the findings show that:

- Changes to tidal currents and waves will be small in magnitude and localised to the deepened assessment areas within NMG and Bedwyn Sands;
- The associated effects on sediment transport are also small in magnitude and similarly localised to the deepened assessment areas of NMG and Bedwyn Sands;
- The proposed renewal of dredging in the NMG and Bedwyn Sands extraction areas is considered unlikely to result in a measurable change in sediment transport patterns or seabed morphology across the wider study area; and
- There is unlikely to be any change to the general easterly-directed sediment transport pathways, through the wider study area (Figure 11).

As part of the licence conditions for both sites, monitoring of the aggregate resource has been ongoing since extraction began at Bedwyn (2008), (ABPmer 2021b). This monitoring has identified a variable pattern of change with some years showing increases against baseline metrics and others showing reductions. Overall, none of the assessment metrics have flagged any issues of concern and none of the triggers for further monitoring (or, indeed, adjustments to extraction) have been met. Throughout the monitoring period, no changes outside of the natural variability of the wider system have been observed.

In light of the evidence presented above, it is concluded that the proposed renewal of the existing extraction licences from the NMG and Bedwyn Sands areas will continue to have limited effect on the sand transport pathways across the wider region. The defined sand transport to the Middle and Welsh Grounds will be maintained, as will the onward transport of material into up-estuary areas, and to the associated bed features therein. Any changes will be highly localised to the assessment area around the existing extraction locations and, given the baseline characterisation regarding the dynamic nature of these sandbank features (Section 3.3), any such change is likely to be within the range of natural variability. Overall, there is not considered to be any significant effect on the sandbank features within the SAC.

5.5.3 Monitored impacts

The large-scale abstraction of sediments has been ongoing at the sites assessed since 2005 and has been accompanied with ongoing monitoring of sensitive features including the monitoring of resource thickness (bathymetric survey) and benthic ecology (day grab sampling) (ABPmer 2022). This monitoring has not identified a significant impact on the resource thickness or the benthic ecology (including key species - *S. alveolata*). Additionally, no reports of wider impacts have been identified in the 17 years of annual reviews.

5.6 Cumulative effects of dredging in multiple licence areas

As described previously, there are a number of existing marine aggregate licences within the Severn Estuary (Figure 2). It is necessary to ensure that the combined effects of these and the proposed renewal of extraction from NMG and Bedwyn Sands would not result in adverse cumulative effects on either the physical processes or the coastline receptors.

The numerical modelling approach (as described in Section 4), includes assessment of a set of cumulative scenarios, which consider the combined effects of renewed aggregate extraction from NMG and Bedwyn Sands in addition to the continued extraction from the licensed Area 531. The results of this cumulative assessment are provided below.

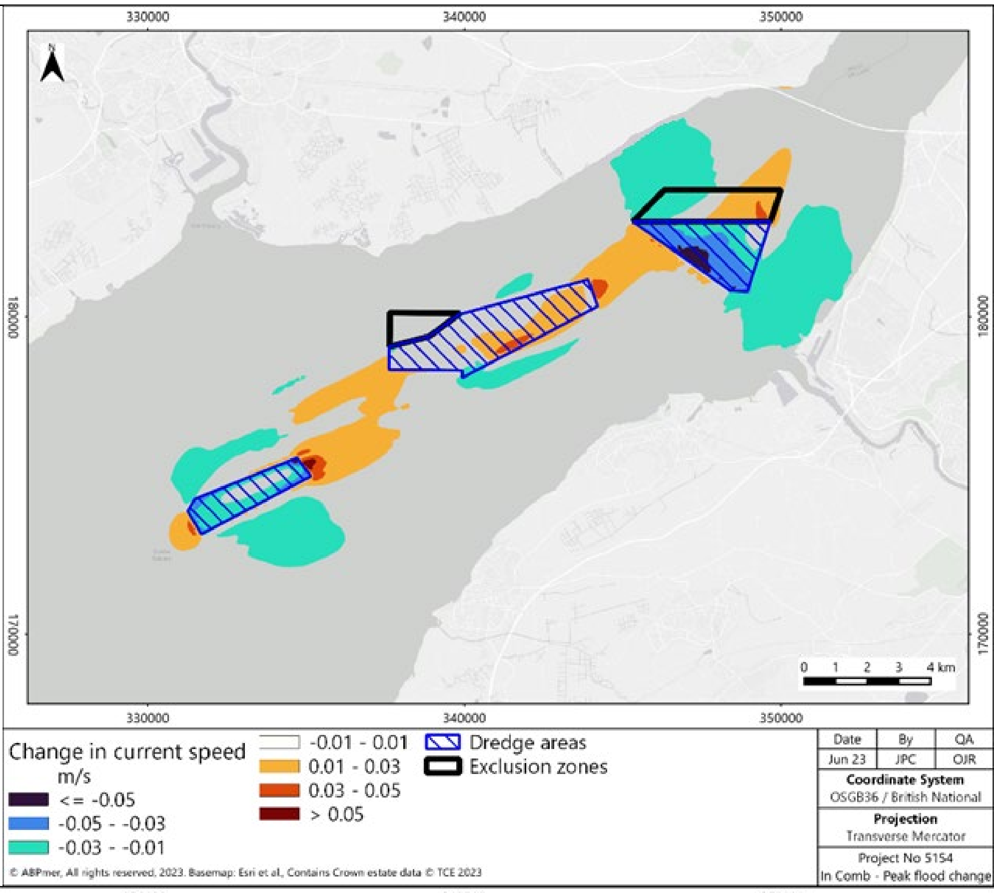
5.6.1 Cumulative effects on tidal flows and waves

The assessment has repeated the model runs described above for aggregate extraction from NMG and Bedwyn Sands, but also including the bathymetric variation representing the cumulative dredging from the other licenced extraction area (Area 531) within the Severn Estuary (Figure 12).

Tidal flows

From the cumulative assessment of multiple aggregate extraction areas, the predicted changes to peak ebb and flood tidal flow speeds are shown in Figure 24.

Absolute change in peak flood current speed



Absolute change in peak ebb current speed

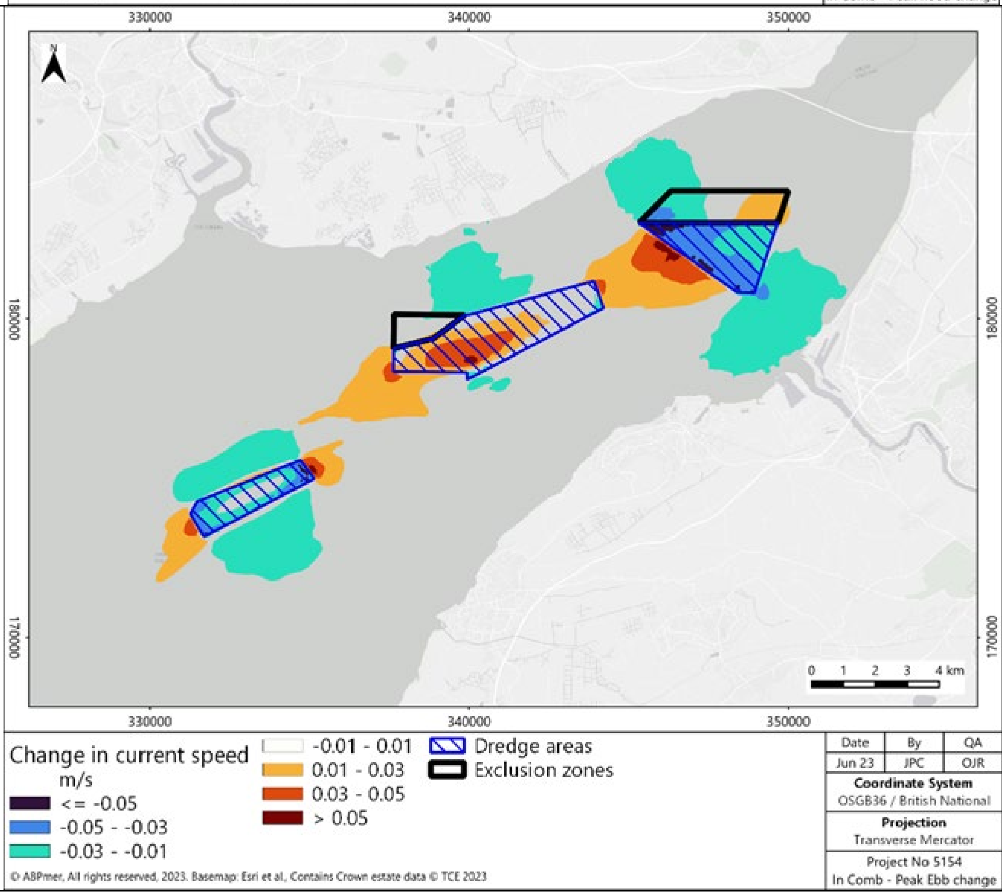


Figure 24. Predicted changes to peak flood and ebb flow regime - cumulative scenario

The assessment outputs demonstrate that, in general, the effects from aggregate extraction at each dredge area, tend to be limited in extent, in close proximity to the deepened areas. In and around NMG and Bedwyn Sands, the pattern and magnitudes of changes to flow speeds are very similar to those predicted for extraction from these sites in isolation (Section 5.1). Here, the predicted changes to peak flow speed are less than ±0.1 m/s. The magnitude of predicted change is greatest, in closest proximity to the deepened, areas, and reduces with distance. Predicted effects typically expire within 2 km of the assessment area boundaries.

Overall, the predicted cumulative effects on tidal flows are consistent with that identified from dredging within the proposed individual licence areas only. A larger extent of effect is exhibited as a result of extending the assessment to include the licensed down-estuary dredging at Area 531; however, there is no evidence of effects from the different extraction areas combining to cause increased impacts on peak flow speeds.

Typical and extreme wave events

The results of the cumulative assessment on the extreme wave conditions (the 1 in 200-year return period condition, representative of winds up to Force 11, and offshore wave heights in excess of 12 m), remain consistent with those derived from consideration of extraction in NMG and Bedwyn Sands only (Section 5.2).

Under MHWS tidal elevations, the greatest predicted effects are shown under westerly and south-westerly wave approach directions, with the largest magnitude of effect (up to 0.03 m increase in southwesterly wave height) limited to the deepened dredge areas (Figure 25). Further up-estuary, smaller magnitude effects are predicted (around ±0.01 m) extending slightly beyond the licenced areas.

Westerly wave directions also produce comparable results to assessments without extraction in Area 531 modelled. Area 531 is simulated to generate a localised reduction in wave heights in the northern end by up to 0.04 m. It is likely that this is generated by steeper shoaling of waves and increased breaking, associated with bed slope. For north-westerly and north-easterly wave events at MHWS, the influence of extraction from Area 531 has a minor impact, and the simulated changes in wave height from both NMG and Bedwyn Sands are similar to that predicted when these areas are assessed in isolation.

The equivalent set of predicted effects, under MLWS conditions, are provided in Figure 26. In keeping with the previous assessment, the predicted effects on low water wave conditions are greatly limited in extent by the drying intertidal sandbanks, with the greatest predicted effect under westerly wave conditions. Here, the predicted increase in wave height resulting from dredge of Area 531 of up to 0.03 m extends eastwards the English coastline, although it does not overlap with the predicted extent of effect from either the NMG or Bedwyn sites. A similar pattern is observed under south-westerly wave conditions with a more limited extent of change. To the north of Area 531, shallow water prevents the propagation of this change further north. Under northwest and northeast wave conditions, the licenced extraction from Area 531 also produces small increases in wave height, with increases over 0.01 m extending around 5 km east under north-westerly wave conditions and 4 km east under north-easterly conditions. Again, no overlap (and no cumulative effect) is predicted with either of the renewal sites.

Overall, the assessment of extraction from multiple sites predicts changes to wave conditions which are consistent with those described for the assessment of NMG and Bedwyn Sands alone. Predicted changes associated with extraction of sediments from Area 531 results in a small, predicted increase (up to 0.03 m) in significant wave height, which extends eastwards from the site. The impact of this dredge, however, does not interact with the predicted changes associated with NMG and Bedwyn Sands, indicating that the combined extractions from all sites do not interact.

As with the cumulative assessment of tidal flows, the results described above provide no evidence of wave effects from different extraction areas combining to cause an overall accumulation of effects. In addition, the predicted cumulative effects on a more typical (10 in 1-year) wave, under both MHWS and MLWS elevations, are reduced in extent and magnitude, hence only the results from the extreme wave conditions are presented.

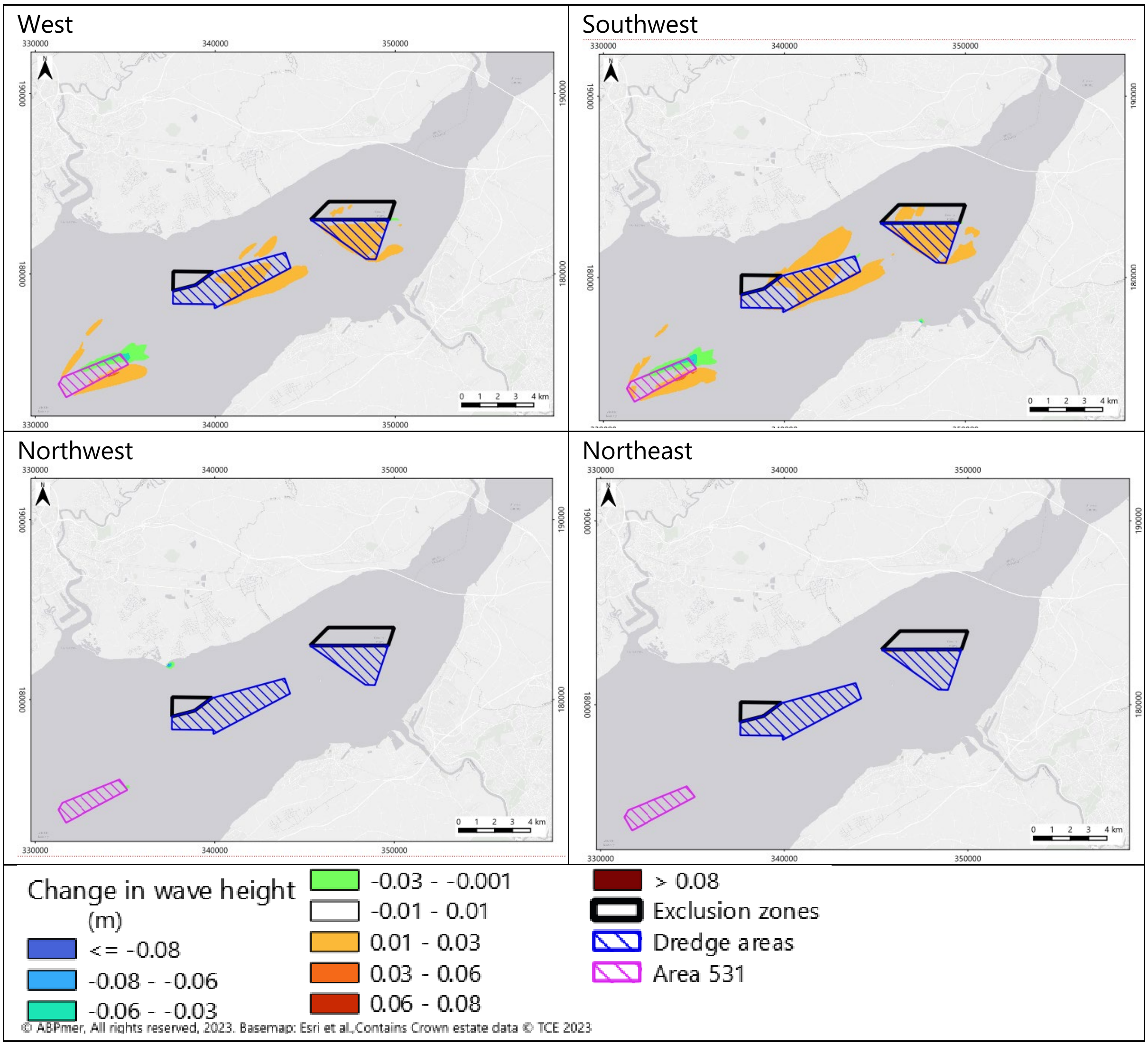


Figure 25. Predicted changes to extreme (1:200-yr) wave at MHWS - cumulative scenario

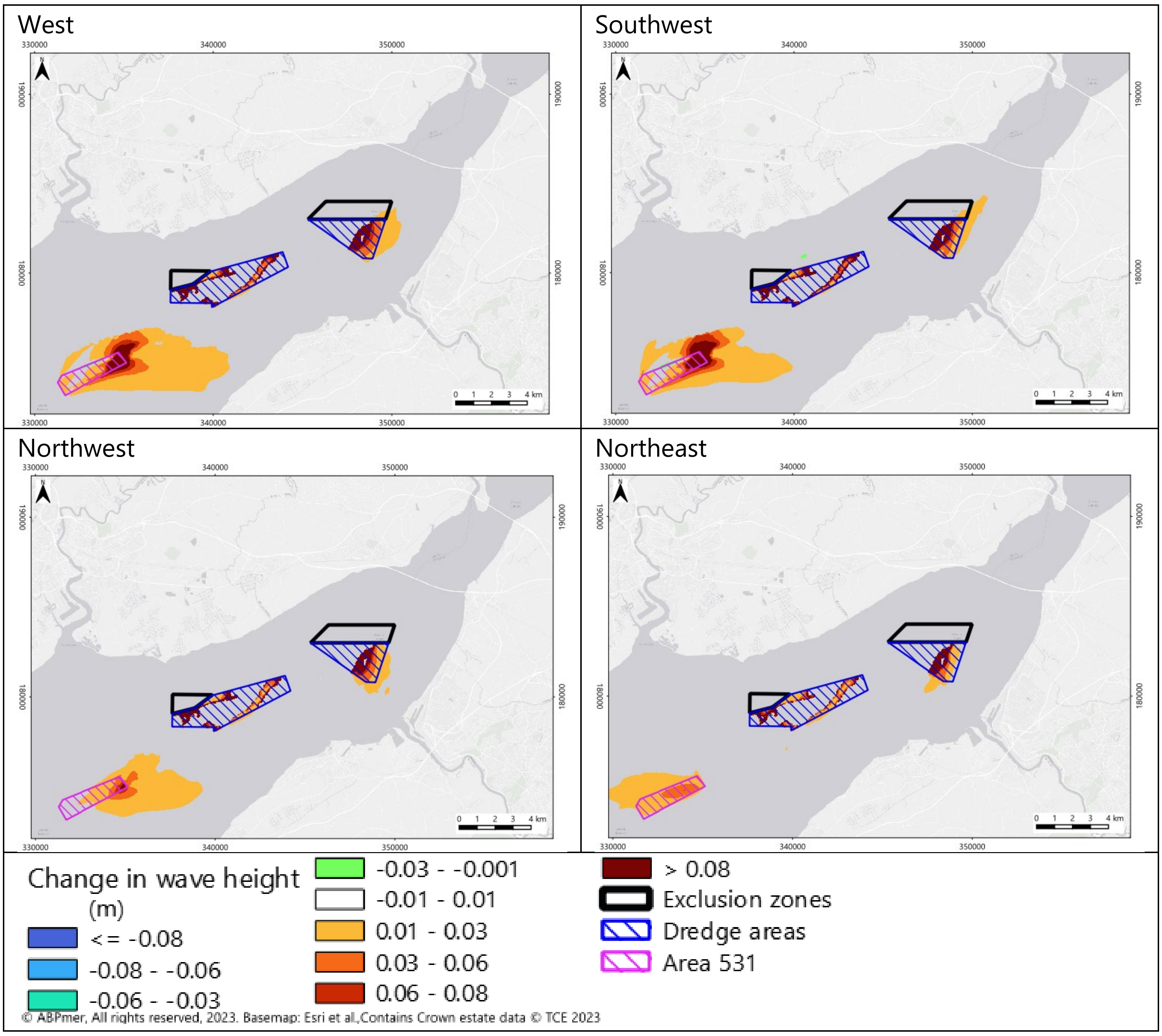


Figure 26. Predicted changes to extreme (1:200-yr) wave at MLWS - cumulative scenario

5.6.2 Cumulative effects on sediment mobility

The predicted cumulative effects on the tidal and wave conditions are similar in magnitude to those predicted for the assessment of NMG and Bedwyn Sands in isolation. Accordingly, the associated changes to bed shear stress, and resultant seabed mobility, also remain similar. Where changes to flow speeds or wave heights are predicted, small changes to local bed shear stress can be expected. Given the seabed composition and water depths across the wider Middle and Welsh Grounds, changes to bed shear stress are considered to be similar in magnitude and extent to those described in Section 5.4. In summary:

- Predicted changes to flow speeds and wave heights are greatest within the licence boundaries for NMG, Bedwyn Sands and Area 531. Effects across the wider study area are much lower in magnitude;
- Across Area 531, associated changes to bed shear stresses, associated with flow, of ±0.2 N/m^2 are predicted. These changes represent a relative change of around ±5% of existing (baseline) values, similar in magnitude and extent to impacts predicted for NMG and Bedwyn Sands alone;

- The extraction of aggregates from Area 531 increases wave height over a limited extent under MLWS scenarios. The predicted changes are not anticipated to impact any sensitive receptors and is considered independent of extraction activities at NMG and Bedwyn Sands;
- The lack of evidence to suggest effects from different extraction sites are combining to cause greater overall effects on flows or waves, indicates that changes in bed shear stress across the wider region will be similar to those described in Section 5.4; and
- As a result, the predicted effect on sediment mobility (and the wider sand transport pathways), is likely to be small in magnitude and limited in extent to the individual extraction areas.

Considering these predicted effects in the context of the wider sediment regime, the large tidal range and strong flows are the dominant drivers of sand transport within the Severn Estuary (Section 3.6). Intermittent storm wave activity also has the potential to help mobilise material for onward transport by the tidal flows.

Additionally, Section 3.7 provides a brief summary of the latest analysis of offshore bathymetry, as undertaken for the annual operational monitoring, comparing changes against baseline, using a range of descriptive metrics.

The results of this ongoing monitoring reveal the range of variability in the elevation and area of the wider Middle and Welsh Grounds sandbank system, both prior to and since the commencement of dredging at NMG and Bedwyn Sands. During this time, aggregate extraction has also been carried out at the downstream licence area of Area 531 (formerly Area 470). As a result, the observed changes in the sandbank system, over this monitoring period, can be reasonably assumed to reflect any impacts arising from the cumulative extraction activity at each of the presently licenced Severn Estuary extraction sites.

Inter-annual variability in the sandbank features, as described in Section 3.7, reveals periods where large parts of the system have accreted, and other periods where some elevations have lowered. The magnitude of these changes is within the bounds of natural variability and so, no net (negative or positive) effect (that can be attributed to the extraction of sand volume from the open licence areas) is observed. Given the period of monitoring (that now spans over 15 years), it could be concluded that the combined extraction volume is more than compensated for by any supply of material (however limited) to the Middle and Welsh Grounds. Such supply is understood to be driven primarily by littoral transport of material, along the Welsh coast, from the Bristol Channel (Otto, 1998; Parsons Brinckerhoff, 2010) under winter storm events. This provides material to the Severn Estuary, which is then distributed according to the conceptual sand transport pathways described in Section 3.6, and as summarised in Figure 11.

Given the projected future climate change impacts, a natural, unconstrained estuary system might respond to sea level rise in a number of ways (ABPmer and HR Wallingford, 2007). The method of response is determined by a range of factors, including sediment availability, changes in exposure, rate of sea level rise, and the constraints placed on the system (e.g. flood defences, coastal infrastructure, SMP policy definitions etc.). The ability of The Severn Estuary to respond morphologically to sea level rise is limited by the constrained nature of the system. Furthermore, over the proposed 15-year licence renewal period for NMG and Bedwyn Sands, the rate of sea level rise (Table 4) is conservatively estimated at 0.13 m and is considered small, particularly in comparison to the natural variation in tidal levels and the magnitude of meteorological surge events (Section 3.5.1) and storm conditions (Section 3.5.3). Thus, it is anticipated that the presently observed inter-annual variability in the character of the Middle and Welsh Grounds will likely continue, even with the 15-year renewal of the current extraction licences for NMG and Bedwyn Sands.

Overall, the proposed extraction from NMG and Bedwyn Sands (combined with that from Area 531) is not predicted to significantly change the existing regional sand transport pathways, carrying material around the wider Middle and Welsh Grounds, and up-estuary beyond the Severn crossings. Ongoing annual monitoring is also aimed at providing an early-warning of adverse changes to the sandbank system, allowing mitigation to be put in place before any significant effect is observed.

5.7 Impacts of climate change

To review the impacts of the dredge within a changing climate, the assessment performed above was repeated, assessing the extraction of aggregate sediments from NMG and Bedwyn Sands with water levels uplifted to 2039 levels (assumed end of a renewed 15-year licence period) along with a conservative 10% increase on wave heights and windspeeds.

5.7.1 Climate change influence on tidal flows

The predicted change in flow speeds associated the dredge conditions under an increased water level scenario has been assessed. The spatial distribution and pattern of change is comparable to that discussed in Section 5.1, with similar lateral extents and magnitudes on both peak ebb and peak flood cycles. The impact assessment presented in Section 5.1 is therefore considered representative throughout the licence period.

5.7.2 Climate change influence on waves

The increased water levels and uplifted wave and wind conditions have been assessed. The results indicate a maximum increases in 'baseline' wave heights of up to 0.07 m predicted with 2039 water levels and an associated 10% uplift applied to wave heights and wind speeds. The overall impact of aggregate removal from NMG and Bedwyn Sands in 2039 is, however, comparable with the present-day impacts discussed in Sections 5.2 and 5.3, with the predicted change to the larger waves similar in magnitude and extent. The impact of the extraction under the conservative estimation of 2039 conditions for a 200-year south-westerly wave/wind condition occurring at MHWN is shown in Figure 27 (and can be compared against the equivalent – present-day – assessment shown in Figure 16).

It is shown that the results from this assessment (Figure 27) are similar (in magnitude and extent) to those under present-day conditions (shown in Figure 16). Consequently, no significant change in the predicted impact from dredging is identified as a result of future uplifted water levels, wave heights and wind speed. Subsequently, the impact of climate change has not been assessed further.

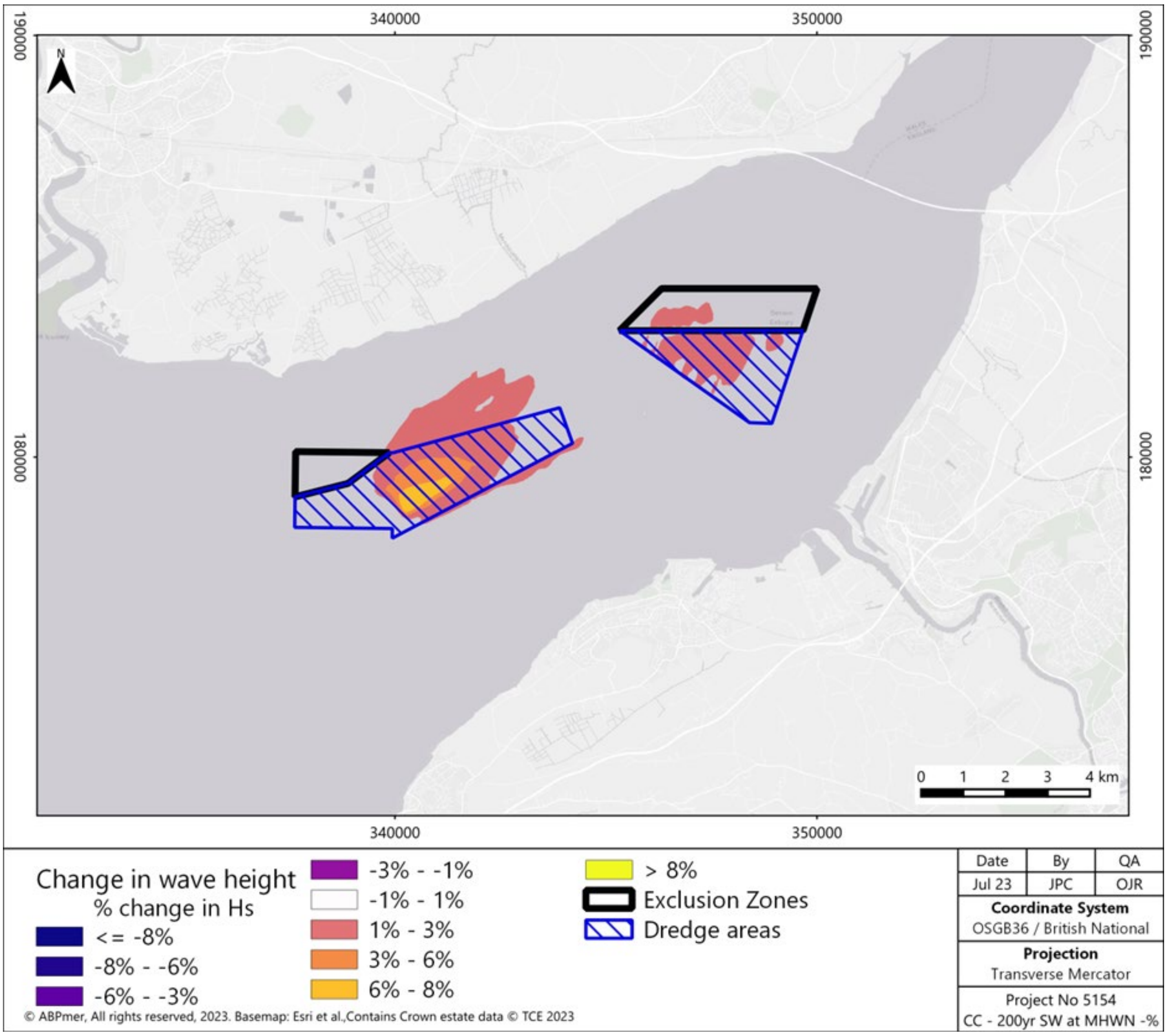


Figure 27: **Change in wave height for a 1 in 200 year south-westerly wave event at MHWN under a 15-year climate change scenario**

6 Conclusions

A combination of site-specific survey data, numerical modelling, desk-based analyses and expert knowledge has been used to determine the potential effects of removing the renewal application tonnage from within the NMG and Bedwyn Sands licence areas. These predicted changes have subsequently been applied to an assessment of potentially sensitive receptors within the study area.

The CIS has demonstrated that the predicted effects on waves and tidal currents will be small in magnitude, in both relative and absolute terms, and will be largely confined to within a few hundred metres of the licenced extraction areas. The predicted changes to tidal flows and waves are insufficient to measurably affect sediment movements across the far-field, based on the material present within the study area, and the transport pathways associated with cohesive and non-cohesive sediment material. Where potential changes are predicted, these are considered to be small in magnitude and limited in extent to within the dredge footprints. Additional model scenarios were undertaken with increased sea levels in response to projected climate change over the proposed 15-year licence renewal period. The results of these tests reveal no significant change in magnitude or extent of effect, compared to the results of the present-day modelling scenarios.

The assessment has also been extended to include the cumulative effects of combined aggregate extraction from Licence Areas across the wider Severn Estuary. The results from this assessment remain consistent with the 'Bedwyn Sands and NMG' scenario, with a generally small magnitude of predicted change, which is primarily constrained to within the deepened assessment areas. No effects are predicted along either the Welsh or English coastlines. The results also indicate that the effects from each extraction area act in isolation, and do not combine with each other to cause accumulated effects on flows or waves. Accordingly, the predicted cumulative effects do not substantially affect the sediment mobility potential (and the wider sediment transport pathways) across the wider study area.

As a consequence of the limited changes predicted to physical processes, it is concluded that potentially sensitive receptors, including the English and Welsh coasts and the wider Severn Estuary SAC, would not be adversely affected by the proposed renewal of aggregate extraction activity within NMG and Bedwyn Sands.

The greatest predicted effects are based on the conservative scenario of a 200-year storm event, from the southwest, at the time of MHWS. The CIS assessment itself also assumes a measure of conservatism in its approach (Section 4), with a 10% uplift on calculated extraction volumes, and bed lowering assessed over the wider seabed feature (rather than within the extraction areas alone). Accordingly, the predicted effects can be considered a 'conservative, worst-case impact'. Under less severe storm conditions, from other directions, at other states of the tide or with a decreased extraction volume, the effects will be lower than those described above.

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8 Abbreviations/Acronyms

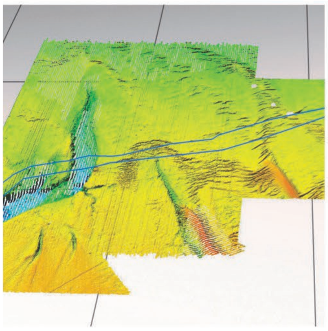
2D	Two Dimension(al)
3D	Three Dimension(al)
ABP	Associated British Ports
abs	Absolute
AODN	Above Ordinance Datum Newlyn (datum)
BCMA	Bristol Channel Marine Aggregates
BMAPA	British Marine Aggregate Producers Association
BP	Before Present
CCO	Channel Coastal Observatory
CD	Chart Datum
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CFSR	Climate Forecast System Reanalysis
CIS	Coastal Impact Study
DHI	Danish Hydraulics Institute
diff	Difference
Dir	Direction
DOE	Department of Energy
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data network
ES	Environmental Statement
ETM	Estuarine Turbidity Maximum
EVA	Extreme Value Analysis
FM	Flexible Mesh
GIS	Geographic Information System
HAT	Highest Astronomical Tide
HD	Hydrodynamic
Hmax	Maximum wave height
Hs	Significant Wave Height
HW	High Water
LAT	Lowest Astronomical Tide
MADP	Marine Aggregate Dredging Policy
MHW	Mean High Water
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
mins	Minutes
MLW	Mean Low Water
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MMO	Marine Management Organisation
MSL	Mean Sea Level (Datum)
N/m^2	Newton per square metre
NCEP	National Centers for Environmental Prediction (US)
NMG	North Middle Ground
NOAA	National Oceanographic and Atmospheric Administration
NRW	Natural Resources Wales
NTSLF	National Tidal and Sea Level Facility
OS	Ordnance Survey

POT	Peaks Over Threshold
RCP	Representative Concentration Pathway
RMSE	Root Mean Square Error
RoI	Republic of Ireland
RSMP	Regional Seabed Monitoring Programme
SAC	Special Area of Conservation
SEA	Strategic Environmental Assessment
SEASTATES	ABPmer forecast service: www.seastates.net
SEAWG	Severn Estuary Aggregates Working Group
SMP	Shoreline Management Plan
SSSI	Site of Special Scientific Interest
STA	Sediment Trends Analysis
SW	Spectral Wave
TCE	The Crown Estate
Tp	Peak Wave Period
tpa	Tonnes Per Annum
Tz	Mean Zero Crossing Period
UK	United Kingdom
UKCP	UK Climate Projections
UKCP18	UK Climate Projections 2018
UKHO	United Kingdom Hydrographic Office
US	United States
WL	Water Level

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendix


Innovative Thinking - Sustainable Solutions

A North Middle Grounds and Bedwyn Sands: Model verification

A.1 Introduction

ABPmer has been commissioned by Severn Sands (now owned by Breedon Aggregates) to undertake a Coastal Impact Study (CIS) to assess the effects of removing the resource from two extraction areas within the wider Severn estuary at Bedwyn Sands and Licence Areas 455 and 459 (collectively referred to as North Middle Ground, NMG).

To assist in the assessment, numerical models have been built using the Danish Hydraulic Institute (DHI) software package MIKE21 FM (Flexible Mesh). The modelling system was developed by MIKE DHI for complex applications within oceanographic, coastal and estuarine environments. MIKE21 FLOW model simulates the water level variation and two-dimensional flows in the area of interest. The wave module, MIKE21 SW (Spectral Wave), is a new generation spectral model based on unstructured mesh which simulates the growth, decay and propagation of the swell and wind generated waves in offshore and coastal areas.

This report provides a description of the tidal and wave models applied in this assessment and details the calibration and validation process undertaken to demonstrate that the flow and wave models produce a representative simulation of the natural processes. The model outputs are used to support CIS of the removal of resource from Bedwyn sands and NMG.

The derivation of the model scenario setup is also documented within this report. This includes the assessment of the mean tidal range for the tidal model and the derivation of fixed return period (10 in 1, 1 in 5 and 1 in 200-year) directional waves and associated wind speeds for the spectral wave model setup.

A.2 Model Configuration

A.2.1 Grid design

Hydrodynamic model

This project has benefitted from ABPmer's existing hydrodynamic numerical model of the Severn Estuary and Bristol Channel region which has previously been used for a number of projects including the Culver Sand dredging impact assessment and Culver extension Coastal Impact Assessment (ABPmer, 2013 and ABPmer 2016) and the extension of Area 531: North Bristol Deep (ABPmer 2021). This same model, with necessary edits and refinements has been used in the present study.

The tidal model has been configured using the MIKE21FM-HD module. The model has been designed in 2D, depth-averaged mode applying a flexible mesh (FM) element grid. The implementation of flexible mesh enables the necessary detail of the Severn Estuary, including the dredge extraction areas, to be sufficiently resolved (75 m node spacing) within the model, while maintaining a coarser resolution away from the site of interest to maximise computational efficiency.

The grid configuration of the hydrodynamic model is shown in Figure A1,

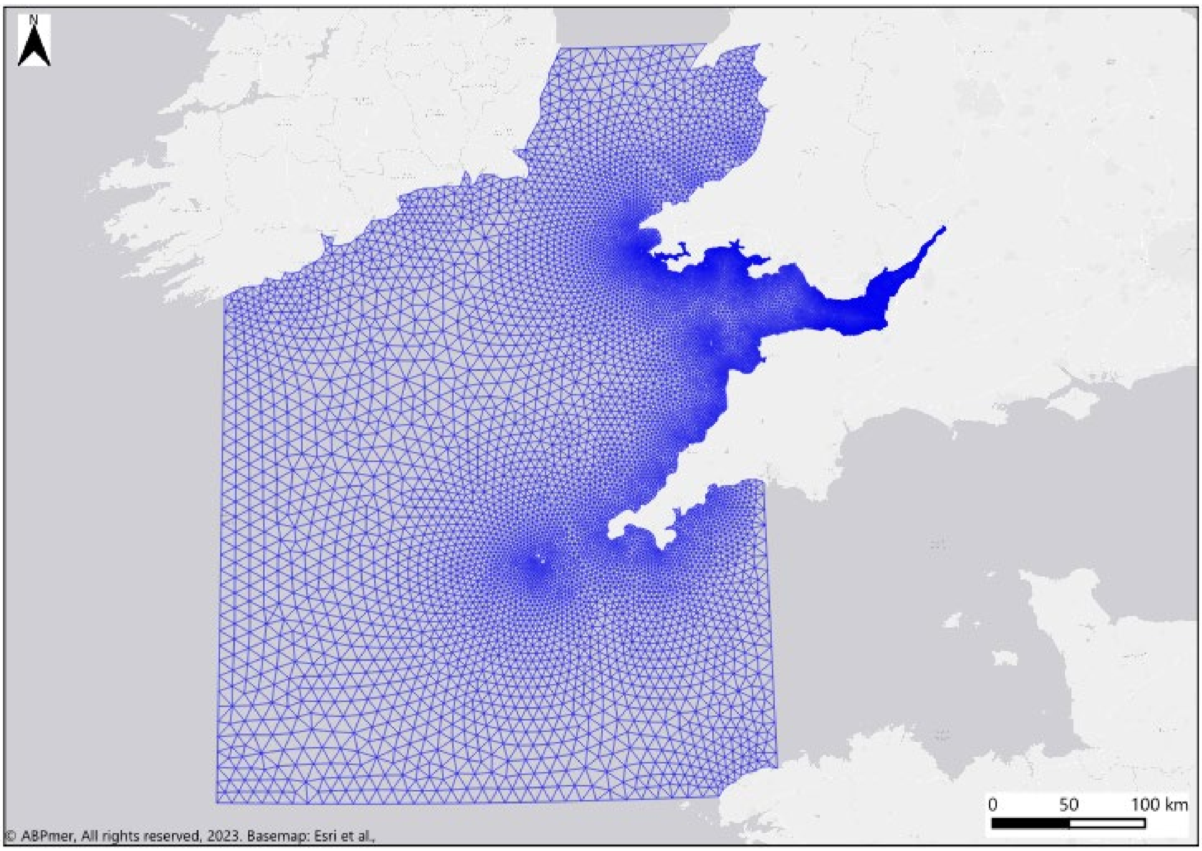


Figure A1. Hydrodynamic Model grid

The extent of which is defined by the following boundaries:

- Northern boundary: Across Caernarfon Bay from the Lleyn Peninsula (Wales) to Wicklow (RoI);
- Eastern inshore boundary: Upper Severn Estuary;
- Southern offshore boundary: Offshore, parallel to the southern Cornish coast; and
- Western offshore boundary: Perpendicular to Baltimore on the southern Irish coast.

The offshore boundary extents are designed to adequately capture the tidal approaches to the Bristol Channel. The horizontal resolution across the proposed dredge extension is an element side length of approximately 75 m.

Wave model

In order to simulate the propagation of wave events through the Severn Estuary to North Middle Grounds and Bedwyn Sands a spectral wave model has also been developed. Once again, this model is built upon ABPmer's existing spectral wave model of the Severn, previously utilised for the 2013 and 2016 Culver and Area 531 dredge and extension studies, with the model previously calibrated and validated across the estuary. The extent of this model is smaller in comparison to the hydrodynamic model grid as the requirement for wave modelling is to transport waves from a defined offshore location into the estuary to the site of the proposed dredge, there is no need to have the wider boundary extents required to capture the tidal dynamics. The reduction of the model domain allows a faster model run time increasing the efficiency of the calibration and cutting out unnecessary processing time. The wave model domain is shown in Figure A2. The grid resolution across the dredge extraction areas is once again ~75 m node spacing.

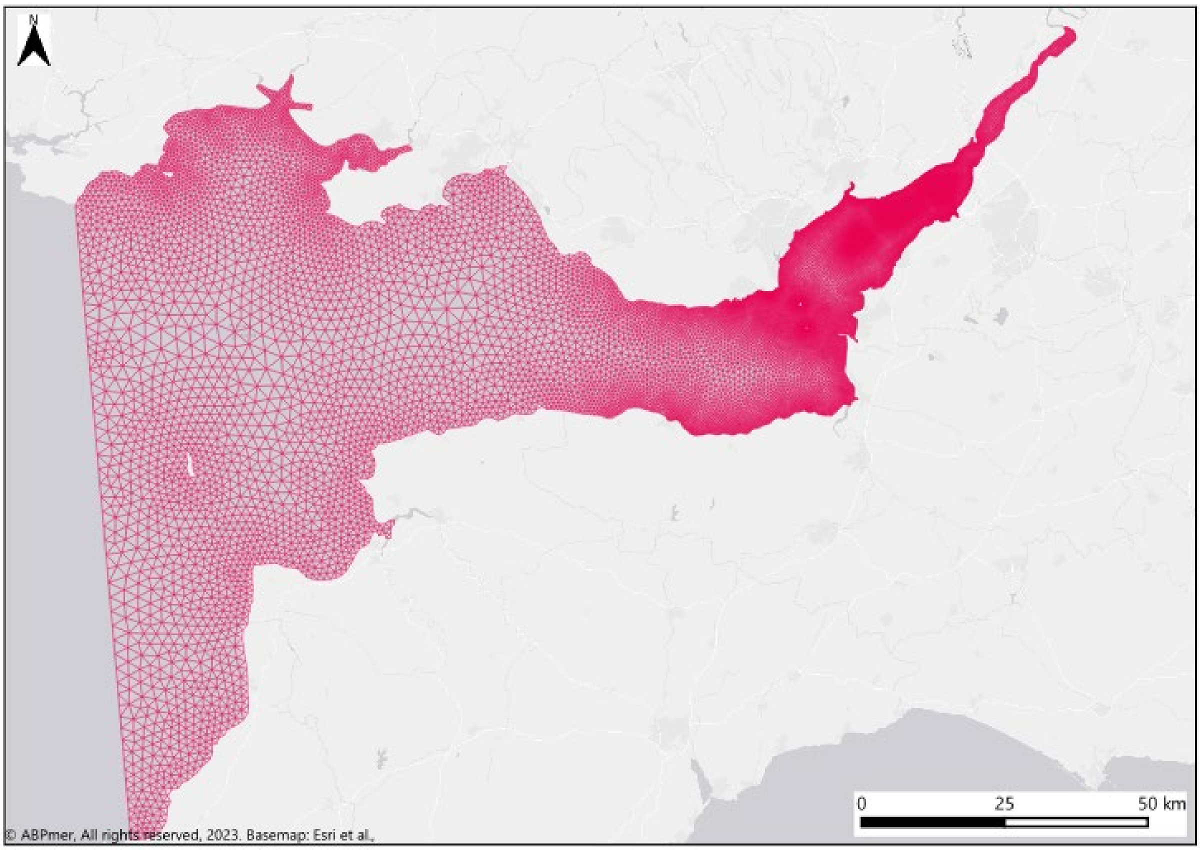


Figure A2. Wave Model grid

Both the hydrodynamic and wave models use the same bathymetry dataset interpolated across the model grids. This dataset is described in Section A.2.2 below.

A.2.2 Bathymetry

Bathymetry data across the model domain is provided from a number of sources, listed below:

- Shoreline Surveys Limited: Survey of Welsh grounds-Severn estuary (2022);
- UKHO (Admiralty Surveys);
- OS High water delineation;
- EMODnet DTM (The General Bathymetric Chart of the Oceans).

These datasets are described more fully in the following paragraphs:

Shoreline Surveys Limited 2022: During four days in September 2022 Shoreline Surveys Limited carried out a bathymetric survey of NMG, Bedwyn sands and the surrounding area), covering an identical area and transects to prior annual surveys from 2005. Sounding spacing along the transects was between 0.4 and 0.45 m) and the survey area is shown in Figure A3. Full details of the survey specification can be found in Shoreline Surveys Limited (2022).

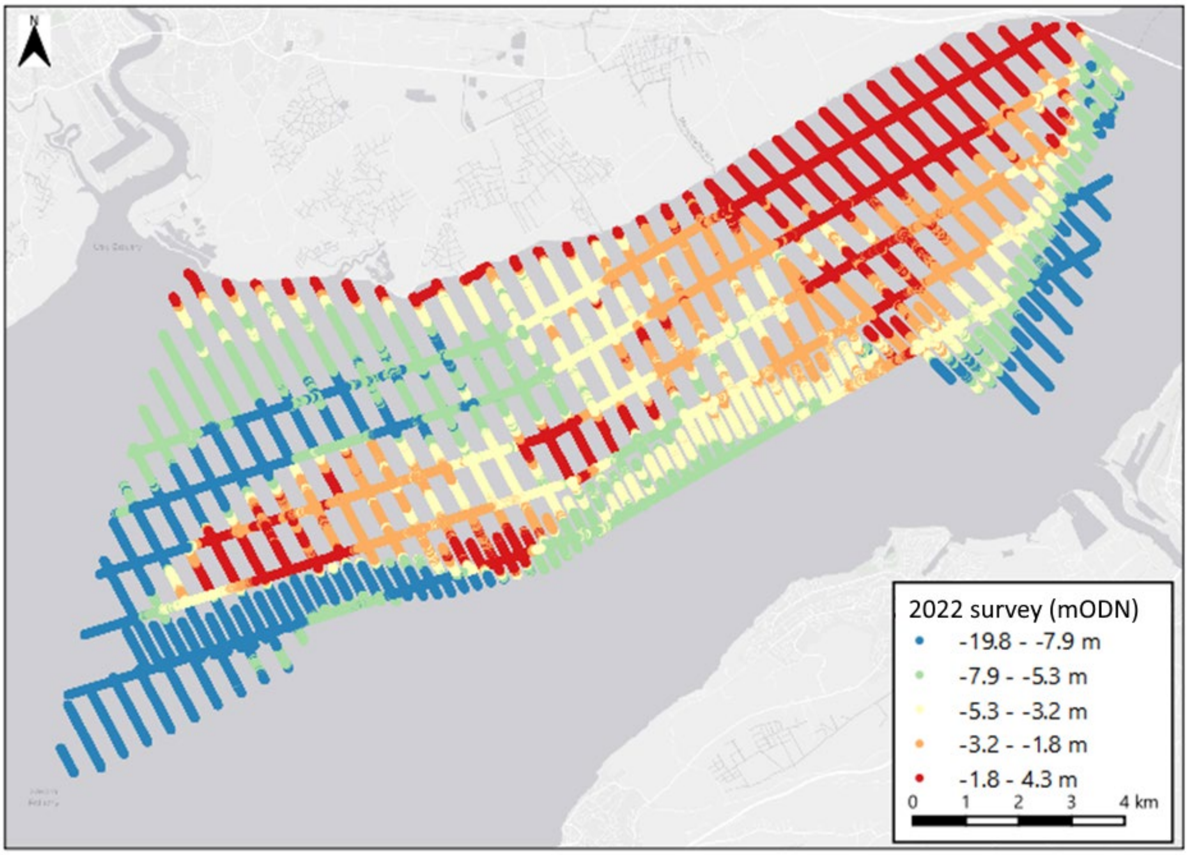


Figure A3. North Middle Grounds and Bedwyn Sands Survey Area

UKHO: Surveyed bathymetry data from around the UK coastline are available via the UK Hydrographic Office. The UKHO database was searched for DTM datasets covering the mid and outer Severn Estuary from 2015 or later for inclusion in the model mesh. 50 bathymetric survey DTM were identified, with the coverage visible in Figure A4. DTM data within the upper estuary was not readily available. to resolve this, two additional point depth surveys of the Upper Severn Estuary from 2006 and 2015 were also identified and interpolated to the model mesh.

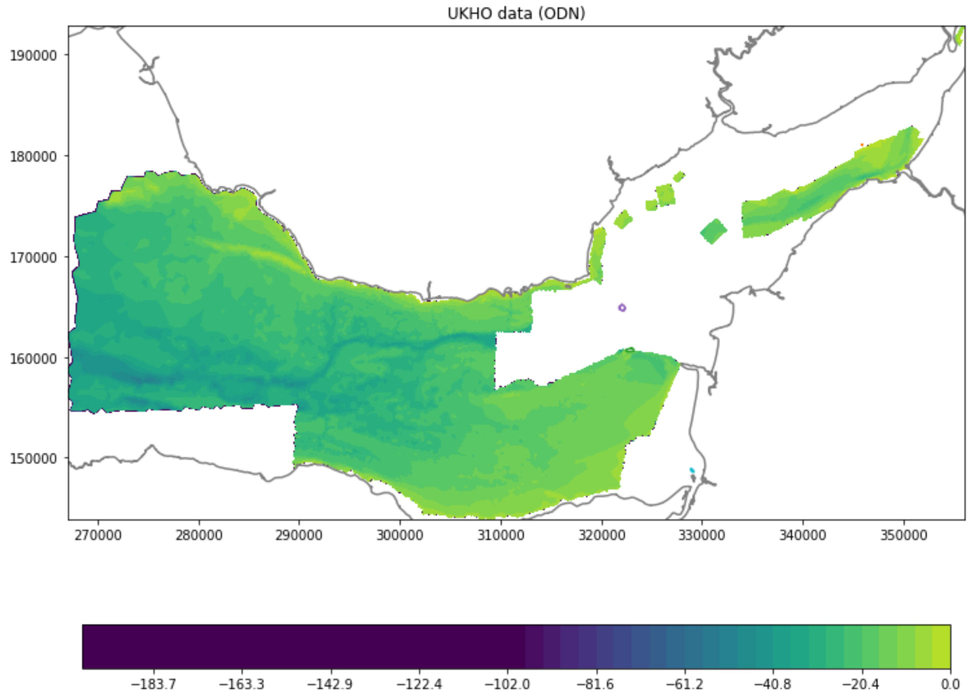


Figure A4. Combined UKHO survey data in the Severn Estuary

EMODnet (2020): The EMODnet DTM is an elevation model created by combining data from a wide range of European bathymetry repositories (including the UKHO) sources. Datasets come from a selection of remote sensing techniques including multibeam and single-beam echo soundings, satellite altimetry, and airborne lidar. This dataset was available at approximately 75 m resolution in the vicinity of the dredge areas and was utilised where no other survey data are available.

Each bathymetry dataset was referenced to the same vertical datum, taken as MSL. This datum was selected as it was the most relevant to model boundary conditions. Having concatenated the datasets, the bathymetry data were interpolated across the model grid for the hydrodynamic and wave model meshes.

A.3 Hydrodynamic Model

A.3.1 Flooding and drying

Flooding and drying was included within the model setup as this is an important consideration within the Severn estuary due to the large tidal range and large intertidal areas. The following settings were used:

The values for the parameters specified within Table A1 were set to ensure that flooding and drying was sufficiently replicated within the Severn. When the water depth is less than the wetting depth the model makes a further calculation. If the water depth is less than the drying depth the element is removed from the calculation for that timestep within the model simulation.

The flooding depth is used to determine when an element is flooded (i.e. re-entered into the calculation). Consequently, any element within the model grid with a water depth less than 0.005 m at any point during the model simulation period will be considered as dry.

Table A1. Flooding and drying depths

Parameter	Depth (m)
Drying depth	0.005
Flooding depth	0.05
Wetting depth	0.1

A.3.2 Bed friction/ Bed resistance

Manning's m was selected as the bed resistance type. A spatially varying Manning's M value was applied directly from ABPmer's in house, validated SEASTATES model, varying bed roughness based on the classification of bed substrate and depth.

A.3.3 Boundaries

The open boundary conditions in the hydrodynamic model are specified as spatially and temporally varying water levels and velocities, covering a 16-day period in February 2022 selected to approximate the time of bathy survey and available validation data as well as covering a period of mean range spring -neap cycle at the dredge sites.

Boundary conditions were generated directly from ABPmer's SEASTATES model, applying tide only predictions of water movement.

A.3.4 Verification

The Severn Estuary hydrodynamic model has previously been calibrated and validated for locations throughout the Severn Estuary (ABPmer, 2010). The existing model has been updated to include the most up to date bathymetry and the grid has been refined across the areas of interest as described in Sections A.2.1 and A.2.2. The performance of the updated model has been compared against the previous model outputs by assessing simulated conditions against observed conditions and ensuring that the same level of performance has been maintained. Details of the previous model calibration can be provided upon request if required.

Following this quality check the model was run for a 16-day period in February 2022 (with two days model spin-up. Model performance plots and statistics were produced for the model outputs of this time period to validate the model performance. These are presented and discussed in the following report sections.

NTSLF

The National Tidal and Sea Level Facility holds archived tide gauge records from 45 standard ports around the UK. The data are collected, processed and archived centrally to provide long time series of reliable and accurate sea levels. Data are related through the national levelling network to Ordnance Datum Newlyn. Five port locations exist within the model domain, which provide suitable water level data for calibration purposes for the period of the model calibration run. The selected port calibration locations are listed below (Table A2 and shown in Figure A5).

Table A2. NTSLF water level calibration data

Port	NTSLF Reference	Lat	Lon	Duration
Hinkley*	HIN	51.22	-3.13	1990-2022
Ilfracombe	ILF	51.21	-4.11	1968-2022
Newport	NPO	51.55	-2.99	1993-2022
Mumbles	MUM	51.57	3.98	1988-2022
Portbury*	PTB	51.50	-2.73	2008-2022
* Data collection issues meant that distinction between observed and harmonic water levels was not possible				

The level data from the National Tidal and Sea Level Facility are provided as a measured gauge level and residual signal. Residual signals have been resolved by the NTSLF through harmonic analysis of the very long duration available datasets. A simple subtraction of the residual signal from the measured gauge level provides the tidal level components required for comparison with the tidal model outputs. This assessment however was not available for Hinkley and Portbury at the time of writing and the assessment below has been performed for total water level at both locations.

A.3.5 Hydrodynamic model validation

Water levels

A graphical comparison of the model water level performance at calibrations sites is shown in Figure A5. The statistical description of the model performance is detailed in Table A3.

The comparison of time series data shows a good agreement between the modelled water levels and those derived from the NTSLF gauge data. Differenced in mean high water levels and the observed time series are less than 10% at all locations over a spring and neap tide - meeting the guideline criteria for calibration standard.

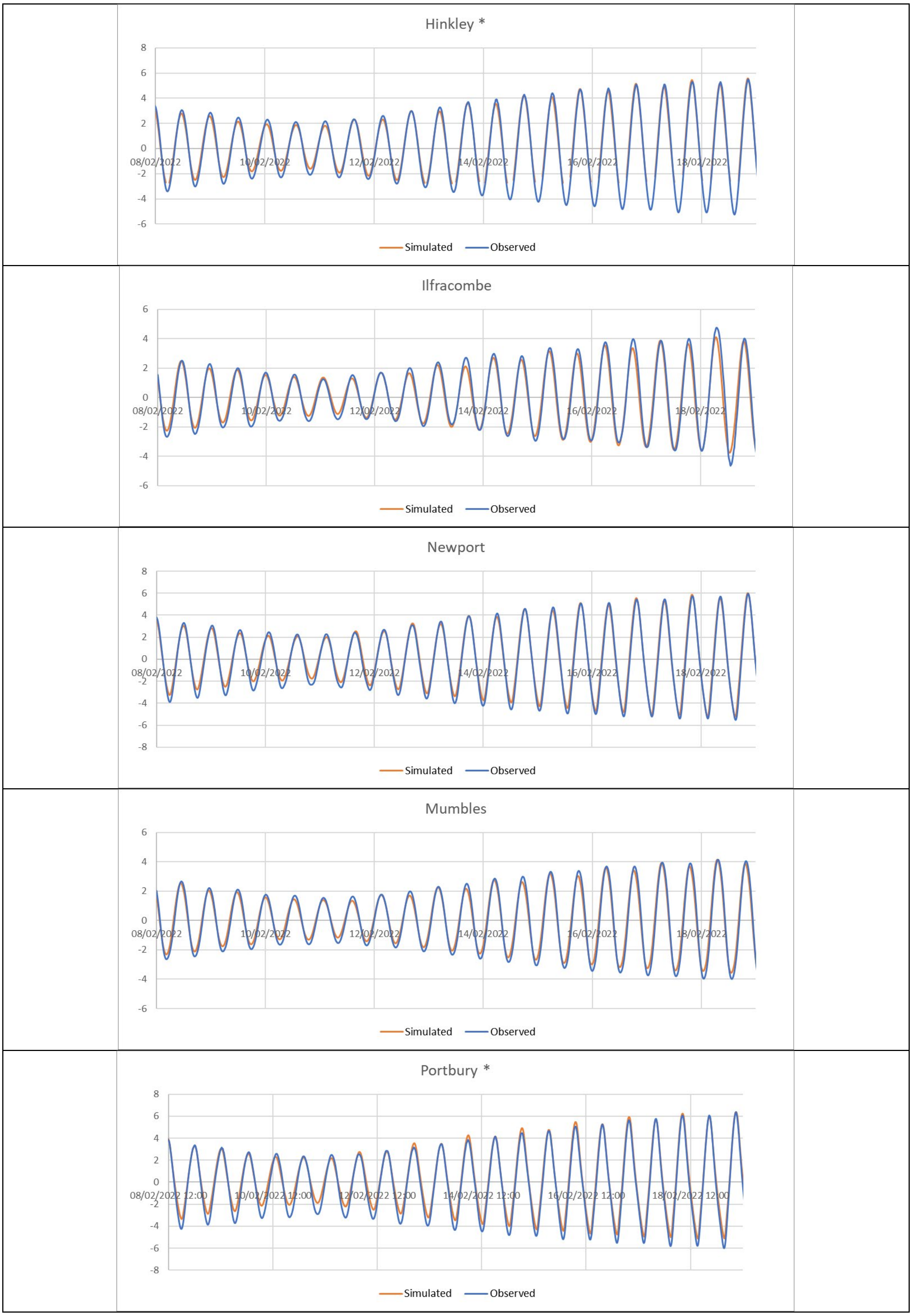


Figure A5. Water level calibration - all NTSLF locations

Table A3. Water level calibration statistics

Parameter	Hinkley	Ilfracombe	Newport	Mumbles	Portbury
Mean high water WL difference (modelled - observed)	*	-0.05	-0.05	-0.6	*
Mean low water WL difference (modelled - observed)	*	0.10	0.16	0.16	*
Mean high water phase difference in mins	*	0	0	0	*
High water percentage difference relative to tidal range (%)	*	1.30	1.79	1.06	*
Average Bias throughout validation period (m)	0.08	-0.02	0.20	0.10	0.42
Average Mean absolute Error throughout validation period (m)	0.26	0.34	0.30	0.31	0.46
Average Mean absolute Error throughout validation period as a percentage of tidal range(m)	2.1%	4.3%	3.3%	3.3%	3.8%
Average RMSE throughout validation period	0.27	0.44	0.36	0.36	0.54

A.4 Wave Model

A.4.1 Model calibration

The spectral wave model has previously been calibrated using available measured wave data within the Severn Estuary. The existing model has been updated to include the most up to date bathymetry and the grid has been refined across the areas of interest as described in Sections A.2.1 and A.2.2. As with the hydrodynamic model, the performance of the updated spectral wave model has been compared against the previous model outputs by running a coincident time period and ensuring that the same level of performance has been maintained.

A.4.2 Model parameters

The model is driven by wave parameters defined at a single offshore wave boundary at the western extent of the model grid (see Figure A2), and a wind field applied across the model domain. As waves propagate, they can change height, period, shape and direction due to the influence of gradients in the underlying seabed, bottom friction and wave breaking. At this stage, no current-wave interaction is considered, and a fixed tidal level is defined based on the spring tidal range. Table A4 presents the list of modelled scenarios required by the client for the coastal impact assessment modelling: 18 model runs each of the bathymetries constructed for impact assessment (see Section A.5). two alternative bathymetries were created resulting in a total of 54 model runs. The derivation of the parameters to generate these scenarios is described in the following sections.

Table A4. Modelled scenarios required for baseline and post dredge conditions

Wave Direction (from)	10 in 1 year	1 in 5-year	1 in 200-year	1 in 200-year
Northeast	MHWS and MLWS (total of 8 runs)	MHWS Southwest wave only	MHWS and MLWS (total of 8 runs)	MHWN Southwest wave only
Southwest				
West				
Northwest				

Wave boundaries

Wave parameters are defined at a single offshore wave boundary where significant wave height, peak wave period, wave direction and directional spreading have been defined. The offshore wave boundary conditions are derived from the ABPmer wave hindcast service SEASTATES, extracted for a central location along the western wave boundary.

SEASTATES (www.seastates.net/) is a service provided by ABPmer to supply metocean information to support site characterisation, project design or operational planning around the UK. SEASTATES includes a long-term 37 year) wave hindcast database driven by wind fields derived from the NCEP 'Reanalysis II' hindcast datasets of spatially and temporally varying winds. This allows a long-term hourly dataset of wave parameters, including significant wave height, maximum wave height, wave period and wave direction to be created for a specific location.

Hindcast significant wave height data were extracted from the SEASTATES wave hindcast for a location central to the Western wave boundary. The wave height data were processed to select a subset of storm events from the 37 year hindcast to which an extreme value distribution could then be fitted. Storms were selected with the following criteria:

Storm Hs threshold:	4.5 m
Minimum storm duration:	3 hours
Gap between storm events:	12 hours

The storm threshold was iteratively adjusted to achieve a storm rate of approximately 10 storms per year, a suitable representation of extreme events to which to fit a theoretical probability distribution. This approach is known as a Peaks Over Threshold (POT) analysis.

Having selected a storm subset, the statistical analysis program R was used to fit a theoretical probability distribution to the storm events. A generalised Pareto distribution was used to fit to data. A number of storm thresholds were processed in order to achieve the best fit to data (assessed visually) while maintaining a good representation of storm events - based on the storm rate. The best fit to data was selected (shown in Figure A6) and the resulting extreme return period wave heights are presented in Table A5.

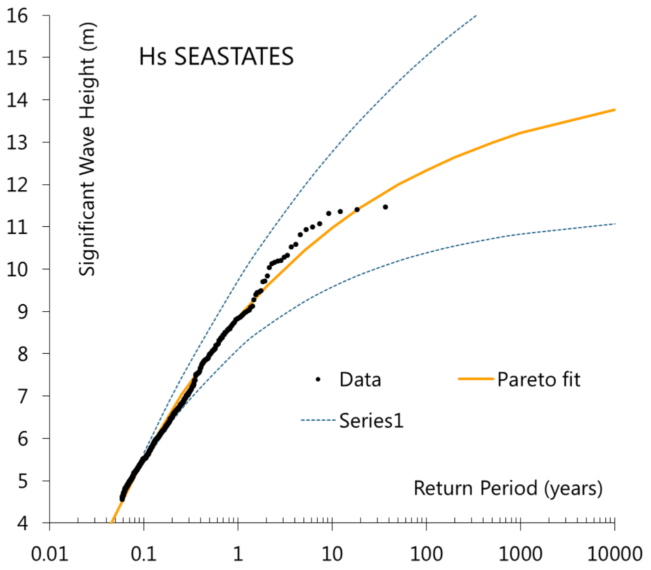


Figure A6. Selected Extreme Value Analysis (EVA) fit to boundary data

Table A5. Extrapolated Omnidirectional Hs at the model boundary

Significant Wave Height (m)				
10 in 1 year	1-year	5-year	100-year	200-year
5.5	8.9	10.4	12.3	12.6

Wave direction

Wave simulations are required for four directional sectors, these being: northeast, southwest, west and northwest. Model wind and wave input parameters therefore need to be generated for these directional sectors.

Wave boundary conditions have been produced based on directional assessment of the SEASTATES data at the boundary location: Extreme return period Hs for 8 x 45° directional sectors have been determined by considering the relative magnitude of events occurring in each directional sector.

For this analysis, the SEASTATES data extracted at the model boundary was used. The approach taken is summarised below:

- Wave hindcast data are split by direction into 8 x 45° sectors.
- The 99th percentile wave height (i.e. the 1% exceedance value) in each sector is identified. The 99th percentile is used in preference to other statistical descriptors to define the extreme wave height; by contrast, simply taking the largest value (for example) risks providing an outlier to the distribution of the extreme tail of the hindcast data.
- The ratio between the largest directional 99th percentile value and all other directional values is calculated.
- Directional extreme return period values of Hs are found as the omnidirectional value (Table A5) multiplied by the associated directional ratio.

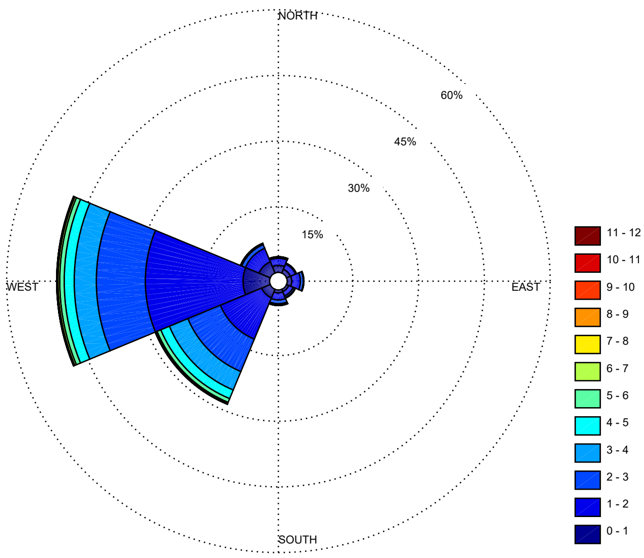


Figure A7. Wave rose for offshore wave boundary based on SEASTATES hindcast

The results of the SEASTATES directional analysis are shown in Table A6, sectors of interest are shown in bold.

Table A6. Directional assessment of boundary waves

	N	NE	E	SE	S	SW	W	NW
99 percentile Hs	3.29	**2.95**	3.76	3.98	4.88	**6.40**	**6.39**	**4.08**
Relative Magnitude	0.51	**0.46**	0.59	0.62	0.76	**1.00**	**1.00**	**0.64**

This assessment shows that at the model boundary location the most severe waves occur from a westerly to southwesterly direction. The most extreme waves from the northwest are less severe, approximately 64% of the omnidirectional magnitude. While waves from the northeast are the least severe at approximately 46% of the worst-case direction.

These relative magnitude scaling factors were applied to the omnidirectional waves calculated previously and are presented in Table A7. The north-easterly waves have not been included since a wave travelling towards the northeast at the model boundary will not propagate towards the site but will travel out of the model domain.

Table A7. Return period boundary waves

Direction (from)	SW	W	NW
10 in 1-year Hs (m)	5.5	5.5	3.5
1 in 5-year Hs (m)	10.4		
1 in 200-year Hs (m)	12.6	12.6	8.1

The boundary wave heights produced in Table A7 were sense checked against the previous boundary conditions used in the culver dredge study of 2013 (ABPmer, 2013) and are similar to that used in the assessment of Area 531 (ABPmer 2021).

The SEASTATES hindcast data can be used to sense check the output without the need for extrapolation: Since the 10 in 1 year wave height predicted should be exceeded approximately 370 times within the 37-year dataset. The storm picking Matlab script was applied to the data set using a storm threshold of 5.5 m (based on Table A5) which resulted in the expected 10 events per year. The storm duration and gap between storms were adjusted to see the range of values achieved with the selected threshold. This quality check supports the use of the 10 in 1 year Hs values calculated in Table A7.

Associated wave periods

As well as the significant wave height, the peak wave period (Tp) is also defined at the wave model boundary. This has been calculated with reference to the SEASTATES hindcast wave periods as well as available measured data from the Minehead and Scarweather Buoys. Ideally associated periods would be determined based on measured datasets of long duration (several years or tens of years) local to the site of interest, in this case the model boundary location. For this study, we have available a long duration local hindcast data set as well as measured data from the Scarweather and Minehead buoys which are of shorter duration and less local to the site but are still of value to for comparison and assessment of the final wave period calculation. Measured data from the Weston buoy have not been included as this is considered too remote from the boundary.

Using these three datasets wave periods associated with the derived return period wave heights have been calculated using the following approach:

Mean zero crossing period (Tz) is first calculated before progressing to Tp. The derivation of these associated periods has been based upon an assessment of wave steepnesses from the available data sets. This is based on the following formulation:

$$Steepness = \frac{1}{\left(\frac{2\pi . Hs}{gT^2}\right)}$$

Where:

Hs = significant wave height (m)
g = acceleration due to gravity (9.81 m/s2); and
T = wave period (Tz) (s)

For each data series:

- The wave steepness has been calculated for each individual time step.
- The data have been evaluated with greater weight given to larger wave heights. In order to do this all data have been 'binned' and sorted by Hs.
- The 2.5, 50 and 97.5 percentile steepness in each Hs bin have been calculated, to provide a range of likely steepnesses from which to subsequently assess associated wave period; this

range of values has subsequently been compared against existing data sources to help define the final model setup conditions (as described below).

- It is expected in a wind sea dominated environment that as wave heights increase the variation in the steepness will decrease.
- It should therefore be possible to identify a suitable range of steepnesses associated with extreme waves by considering the ratios derived in the upper Hs bins and selecting an appropriate representative value for the 2.5, 50 and 97.5 percentiles.
- The calculated lower and upper values encompass what we believe to be 95% of the entire range of associated periods that could occur with the extreme return period Hs.

The resulting ratios from the steepness analysis are presented in Table A8 below.

Table A8. Estimates of Wave Steepness from Available Data

Dataset	Lower Steepness	Mid Steepness	Upper Steepness
SEASTATES	13	17	21
Minehead	14	21	37
Scarweather	15	18	27

Battjes (1970) found that scatter diagrams of waves recorded at sites around the British Isles suggested a limiting steepness of between 1:16 and 1:20 for large waves, with most values near to 1:18. Table A8 shows the mid steepness ranges calculated from SEASTATES and the Scarweather buoy agree closely and are close to the values suggested by Battjes (1970). The values from Minehead are more variable - as may be expected from a more coastal location further into the estuary. Using these steepnesses the associated Tz can be calculated from significant wave height. Tz values associated with extreme return period Hs were calculated using the mid-steepness ratios calculated form the SEASTATES hindcast data.

Peak spectral period (Tp)

The derivation of peak wave period (Tp) associated with extreme wave heights follows a similar approach to the Tz assessment described above. The ratio between Tp and Tz is assessed in terms of wave height, and suitable lower, central and upper ratios between Tp/Tz are identified as follows:

- The Tp/Tz ratio has been calculated for each individual time step.
- The data have been evaluated with greater weight given to larger wave heights. In order to do this all data have been 'binned' and sorted by Hs.
- The 2.5, 50 and 97.5 percentile Tp/Tz ratios in each Hs bin have been calculated.
- Suitable Tp/Tz ratios associated with extreme waves have been identified through a visual assessment of the binned data.
- The calculated lower and upper values encompass what we believe to be 95% of the entire range of associated periods that could occur with the extreme return period Hs.

The resulting ratios from the Tp/Tz ratio analysis are presented in Table A9 below.

Table A9. Estimates of Tp/Tz ratio from Available Data

Dataset	Lower Tp/Tz	Mid Tp/Tz	Upper Tp/Tz
SEASTATES	1.35	1.46	1.98
Minehead	1.07	1.35	2.24
Scarweather	1.18	1.46	2.11

Once again, the SEASTATES and Scarweather statistics agree closely - particularly in the central range of data. While the values from Minehead differ more. Carter (1982) reported Tp/Tz relationship of Tp = 1.41.Tz, which agrees very closely with the central values from Scarweather and SEASTATES.

Final associated periods have been selected based upon the mid ratios produced from the SEASTATES data. This selection is supported by the good agreement with the Scarweather data which has the advantage of being a measured dataset although is not as site specific or as long duration. These selected return periods are presented in Table A10 below:

Table A10. Selected associated boundary wave periods

Parameter	Hs			Tp		
	0.1 yr	5 yr	200 yr	0.1 yr	5 yr	200 yr
Southwest	5.5	10.4	12.6	11.4	15.6	17.2
West	5.5		12.6	11.4		17.2
Northwest	3.5		8.1	9.1		13.7

Wind forcing

The Severn Estuary spectral wave model applies a spatially constant wind field consisting of wind speed and direction across the whole model domain. Due to the solution formularisation of the model (quasi-stationary) this means that the solution is effectively time independent (i.e. the wind field is blown across the model domain until a steady state is reached). This is an efficient way to simulate fixed return period events but relies on careful calculation of the appropriate wind speed for the return period being modelled. Preferably a known wave height will exist within the model domain which can be used as a reference height and a solution can be reached iteratively through modification of the wind field in combination with the fixed boundary conditions derived above. A number of wind data sets exist for consideration in this study to inform the selection of appropriate model wind fields, these are:

NCEP II

The US National Centers for Environmental Prediction (NCEP) 'Reanalysis II' hindcast data set (NCEP2, Saha *et al*., 2010). The hindcast data have a spatial resolution of approximately 0.31° (latitude and longitude) and are derived at hourly intervals from the NCEP operational data for a 31-year period between January 1979 and December 2009.

CFSR

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) was completed over the 31-year period of 1979 to 2009 in January 2010 and was subsequently extended to March 2011. The CFSR was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over this period. The CFSR model was upgraded to version 2 in 2011 and this model update currently covers the period from 2011 to 2018.

Flat Holm measured wind speeds

There is a met station on Flat Holm island recording wind speed and direction data operated by the Cardiff Harbour Authority. Historically the station was operated by the Met Office. Historic data are available for years 1990 to 1997 from the Met Office archives and then from the Cardiff Harbour Authority for the period 2009 to 2016. Wind speeds and wind gust speeds are recorded in miles per hour to the nearest whole unit. Directions are recorded in 16 directional sectors.

As a starting point for the assessment of wind forcing conditions, the hourly wind speeds associated with fixed return periods were calculated using the available datasets. This was undertaken using the same peaks over threshold approach described above for the extrapolation of significant wave heights.

The forcing wind speeds applied in the model to achieve the representative omnidirectional extreme wave heights in the Severn Estuary were derived through an iterative process described in the wave validation section of this Appendix. These were applied for both the westerly and southwesterly model simulations. In order to derive the appropriate wind speeds for the additional wave direction runs (NE and NW) the NCEP wind hindcast dataset was assessed.

For each directional sector, the 99%ile wind speed was calculated from the NCEP data – this being an appropriate percentile to be representative of an extreme weather condition, while disregarding potentially anomalous events in the top 1% of the data which might fall outside the normal distribution of wind speeds.

The 99%ile wind speeds for each directional sector were converted to a relative magnitude –relative to the 99%ile omnidirectional wind speed. These directional relative magnitudes were then used to scale the omnidirectional 10 in 1 and 1 in 200-year extreme wind speeds to derive the appropriate directional speeds to apply within the model. These are presented in Table A18 and A19.

Having extrapolated alternative estimates of hourly wind speeds from each of the data sets the associated wind speeds at longer averaging periods can be calculated using the guidance in Department of Energy (DOE) Guidelines (1990). Offshore Installations: Guidance on Design, Construction and Certification. These estimates are shown in Table A11 and Table A12.

Table A11. Estimates of 10 in 1-year wind speeds

Averaging Period (h)	Scaling Factor	10 in 1 Year Resulting Speed		
		Flat Holm	NCEP	CFSR
24	0.8	15.7	14.6	12.9
12	0.87	17.0	15.8	14.0
3	0.97	19.0	17.7	15.6
1	1.00	19.6	18.2	16.1

Table A12. Estimates of 1 in 200-year wind speeds

Averaging Period (h)	Scaling Factor	1 in 200 Year Resulting Speed		
		Flat Holm	NCEP	CFSR
24	0.8	24.4	23.1	21.5
12	0.87	26.6	25.1	23.4
3	0.97	29.6	28.0	26.1
1	1.00	30.5	28.9	26.9

In order to determine final wind speeds for the model simulations an iterative approach was adopted adjusting the wind field until target wind speeds were reached. This process is documented in Section A.4.3. The final westerly wind speed for the 10 in 1 year event was selected to be 16 m/s, and for the 200-year event 31 m/s. The wind speeds were calculated using the same approach for the 1 in 5-year event, resulting in a final Southwesterly wind speed of 26 m/s.

The available wind hindcast data were firstly assessed via comparison with the Flat Holm measurements. This was done using a subsampled dataset containing only records coincident between the measurements and hindcasts to allow a fair comparison. Hindcast data were extracted from a site ~51.41N 4.35W within the boundary of the wave model before the curve of the estuary at Flat Holm. The CFSR resolution is finer & the grid point was very close to this location - the NCEP data is a larger grid - so the representative location is less certain.

Comparisons showed much better agreement between Flat Holm and NCEP than CFSR, particularly in terms of speeds (Figure A8.).

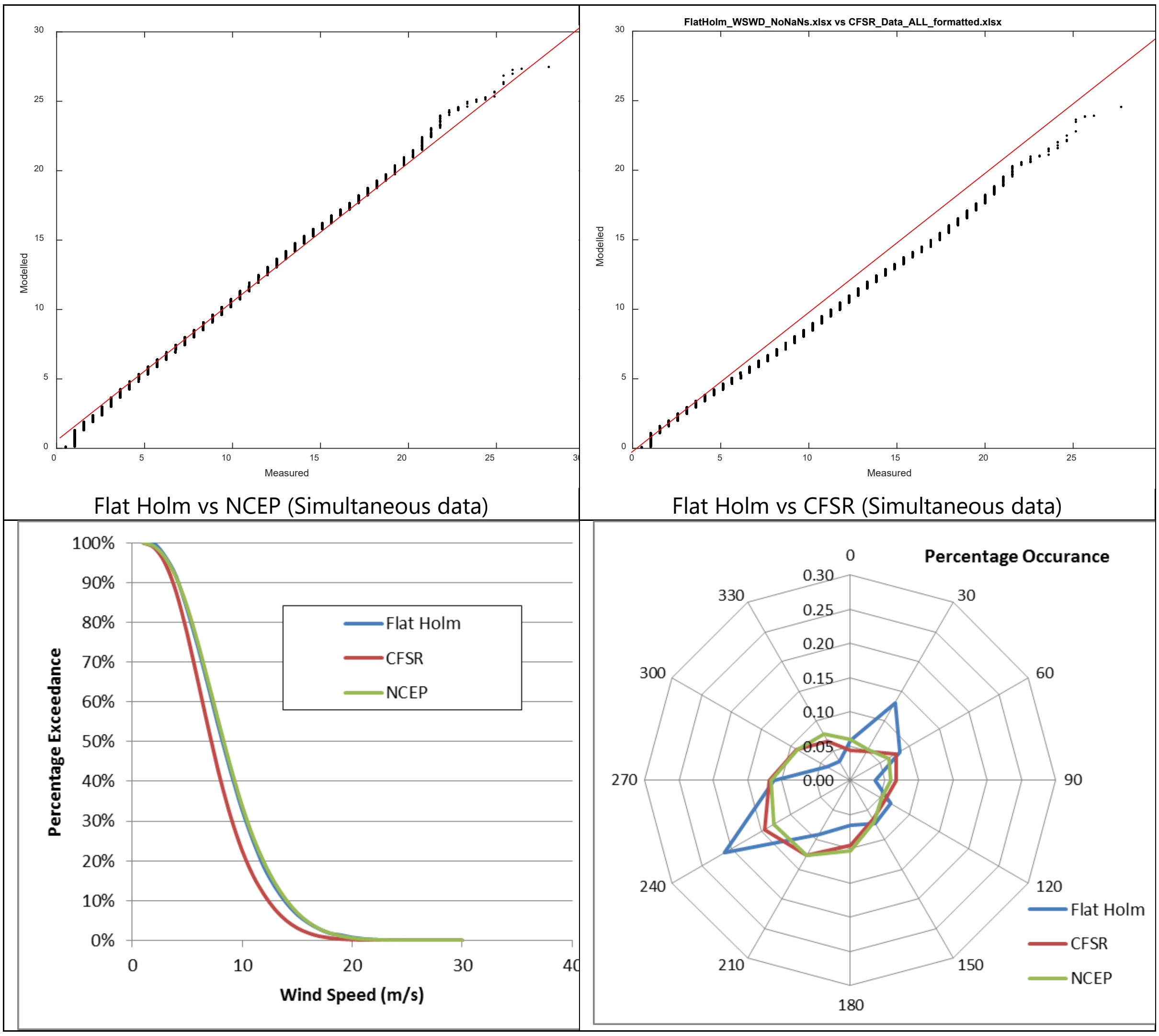


Figure A8. Comparison of available hindcast wind data with Flat Holm measurements

Water level

The model domain bathymetry is relative to AODN. No variable water level is applied to the wave simulations since the solution is time independent. However, a constant water level offset can be applied across the domain to simulate specific states of the tide.

Modelled waves have been simulated on a water level representative of a mean high-water spring and mean low water spring tide. Tidal ranges at the nearest available tidal ports were calculated from the gauge measurements and available Admiralty tide tables. Final selected spring water levels were based on the Newport gauge. A water level of +6.04 mMSL was applied to simulate mean high-water springs, and -5.46 mMSL for mean low water springs.

A.4.3 Validation of wave events

Wave conditions at the model boundary have been established through analysis of the SEASTATES hindcast data. For previous iterations of the model, hindcast wave conditions at Scarweather Minehead and Hinkley were used to validate the model against a previous significant event. The wave model was found to closely follow the distribution suggested by the measurements and demonstrate generally good agreement in the comparisons increases confidence in the model outputs. (ABPmer 2019).

As the updates to the model performed in this assessment focus on updating of bathymetry datasets and increasing mesh resolution in the vicinity of the extraction sites, this validation is considered sufficient for the application of the updated wave model.

A.4.4 Final Wave model setup

Table A13 to Table A14 present the final wave boundary and wind field forcing conditions for the final return period wave simulations.

Table A13. Model inputs for 10 in 1-year simulations

	Hs (m)	Tp (s)	Wave Dir (°from)	Wind Speed (m/s)	Wind Direction (°from)
NE 10 in 1				12.2	45
SW 10 in 1	5.5	11.4	225	16.0	225
W 10 in 1	5.5	11.4	270	16.0	270
NW 10 in 1	3.5	9.1	315	14.3	315

Table A14. Model inputs for 1 in 200-year simulations

	Hs (m)	Tp (s)	Wave Dir (°from)	Wind Speed (m/s)	Wind Direction (°from)
NE 1 in 200				23.6	45
SW 1 in 200	12.6	17.2	225	31.0	225
W 1 in 200	12.6	17.2	270	31.0	270
NW 1 in 200	8.1	13.7	315	27.8	315

The eight scenarios detailed in Table A13 and Table A14 were run for a MHWS condition (+6.04 mMSL) and for a MLWS condition (-5.46 mMSL).

The different bathymetry options modelled for these scenarios are described in Section A.5.

A.5 Post-dredge Model Setup

The wave and hydrodynamic models were configured to simulate 5 different bathymetry options. These are:

- Present day baseline
- North Middle Grounds and Bedwyn Sands Post Dredge
- Cumulative dredge

The construction of the present-day baseline condition for the hydrodynamic and spectral wave model has been described in the previous report sections along with the model validation that has been undertaken to demonstrate model performance. The following report sections provide details of the model setup - specifically the model bathymetry - which has been altered in order to assess the impact of dredging on the oceanographic conditions in the estuary as well as consideration of historic conditions.

The model bathymetry was updated as described in Section A.2.2 and Section A.5.1. All other model settings such as boundary conditions, meteorological forcing and solution technique remained unchanged.

A.5.1 Post dredge bathymetry

Bed lowering was applied in the model across the wider features associated with the three licenced areas within the model domain: North Middle Grounds and Bedwyn Sands (the study sites) and additionally Area 531 (for cumulative assessment). Two post dredge variations were produced:

- The first of which removed material only from the study sites; North Middle Ground and Bedwyn Sands; and
- The second of which removed material from all three locations in order to assess the cumulative effect of dredging at all three sites.

The average equivalent bed lowering for the three application areas was calculated based on the licenced/ renewal application tonnages provided by Breedon. A 10% uplift was applied for conservatism resulting in the following values of bed lowering:

- Area 531 = 1.58 m
- North Middle Ground = 0.31 m
- Bedwyn Sands = 0.51 m

For each resource area, the appropriate bed thickness was subtracted from the existing baseline bed level to create the new post dredge bathymetry.

The geographical definition of these areas is shown in Figure A9 below.

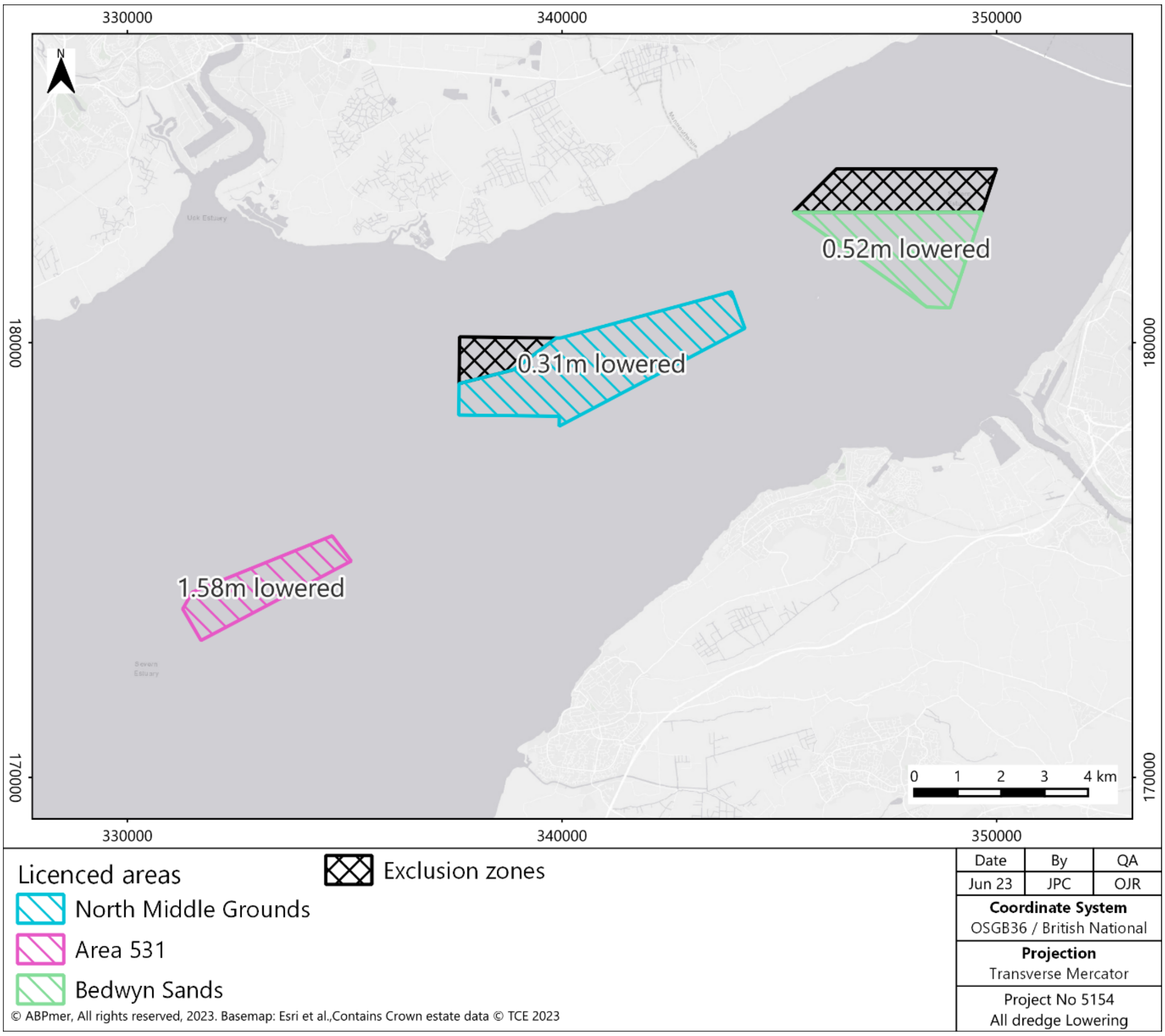


Figure A9. Equivalent areas of bed lowering for cumulative dredge scenario

A.6 Climate Change

The impact of climate change on the change in wave heights were reviewed for the assessment at the end of the licence period (2039). To assess this, baseline and dredged wave conditions were re-simulated with the below modifications to forcing conditions:

- Water levels uplifted from 2019 to 2039 (+0.156 m)
- 10% increase in Hs and Tp
- 10% increase in Wind speed.

Climate change scenarios were assessed for extreme wave conditions only.

A.7 Summary

The hydrodynamic and spectral wave models of the Severn Estuary and Bristol Channel Approach have been updated using the most recently available bathymetric datasets and by refining the mesh size across the NMG and Bedwyn Sands assessment sites, with mesh resolution also increased over Area 531. The model validation has been assessed for hydrodynamic conditions, with the validation of the wave model inherited from previous iterations of the model mesh.

Suitable model setups have been constructed to support the coastal impact assessment of the removal of material from North Middle Grounds and Bedwyn Sands as well as the cumulative effect of removing material from Area 531, North Middle Grounds and Bedwyn Sands. The full list of modelled scenarios is listed in Table A15 and Table A16. A total number of 54 scenarios (3 hydrodynamic and 51 wave) has been run.

Table A15. Hydrodynamic model scenarios

Name	Description
Baseline Present Day	Bathymetry based on most recent measured data. Run for a period of 14-day period in February 2022, covering a period of mean range spring-neap cycle at the dredge extraction areas.
Post Dredge Present Day	Bathymetry updated to simulate removal of dredge material in NMG and Bedwyn sands.
Cumulative Post Dredge Present Day	Bathymetry updated to simulate removal of dredge material in Area 531, North Middle Ground and Bedwyn sands to show the cumulative effect of dredging all three areas.

Table A16. Spectral wave model scenarios

Wave Direction	Tide	Present Day Baseline	Present Day NMG and Bedwyn Sands Dredge	Present Day Cumulative Dredge
Westerly wave	MHWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
	MLWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
North-westerly wave	MHWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
	MLWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
South-westerly wave	MHWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
	MHWN	200-year	200-year	200-year
	MLWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
North-easterly wave	MHWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year
	MLWS	10 in 1	10 in 1	10 in 1
		200-year	200-year	200-year

Table A17. Future spectral wave model scenarios

Wave Direction	Water level	2039 Baseline	2039 NMG and Bedwyn Sands Dredge
Westerly wave	MHWS	200-year +10%	200-year + 10%
	MLWS	200-year +10%	200-year + 10%
North-westerly wave	MHWS	200-year + 10%	200-year + 10%
	MHWS	200-year + 10%	200-year + 10%
South-westerly wave	MHWS	200-year + 10%	200-year + 10%
	MHWN	200-year + 10%	200-year + 10%
	MLWS	200-year + 10%	200-year + 10%
North-easterly wave	MHWS	200-year + 10%	200-year + 10%
	MLWS	200-year + 10%	200-year + 10%

Contact Us

ABPmer

Quayside Suite,
Medina Chambers
Town Quay, Southampton
SO14 2AQ

T +44 (0) 23 8071 1840
F +44 (0) 23 8071 1841
E enquiries@abpmer.co.uk

www.abpmer.co.uk